United States Government Accountability Office

Report to Congressional Committees

March 2021

EARTHQUAKES

Progress Made to Implement Early Warning System, but Actions Needed to Improve Program Management

A Century of Non-Partisan Fact-Based Work

GAO-21-129

GAO@100 Highlights

Highlights of GAO-21-129, a report to congressional committees

March 2021

EARTHQUAKES

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Why GAO Did This Study

Earthquakes and related hazards are a significant threat to people and infrastructure in the U.S. For instance, magnitude 6.4 and 7.1 earthquakes centered west of Searles Valley in California, struck in July 2019, causing over $5 billion in damage. USGS is the lead federal agency for providing earthquake monitoring and notification. USGS began implementing ShakeAlert, its earthquake early warning system, in California, Oregon, and Washington State in 2012.

GAO was asked to assess, among other things, USGS efforts to identify earthquake hazards. This report addresses, among other things, (1) USGS actions to identify earthquake hazards, (2) the extent USGS actions to achieve its earthquake hazard mission meet leading practices; and (3) what progress USGS and its partners have made implementing ShakeAlert. GAO evaluated agency guidance and other planning documents, such as USGS's ShakeAlert implementation plans; assessed its ShakeAlert cost estimate; conducted site visits to selected cities; and interviewed federal and state officials, among others.

What GAO Recommends

GAO is making 7 recommendations, including that USGS develop a strategic plan, including measures, and conduct a staffing gap analysis for the EHP that identifies the resources needed to achieve its mission and goals; follow best practices for a comprehensive ShakeAlert cost estimate; and complete the stakeholder outreach plan for its earthquake early warning system. USGS generally concurred with GAO's recommendations

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What GAO Found

The U.S. Geological Survey (USGS), through its Earthquake Hazards Program (EHP), has made several efforts to identify the dangers from earthquakes, such as tsunamis and landslides, to inform the public and help decision-makers ensure public safety and mitigate losses. For example, USGS publishes national seismic hazard maps, which are used to strengthen building codes throughout the nation. USGS officials, state geologists, and other stakeholders GAO interviewed stated that the program's capacity to meet its mission has been impeded by flat discretionary resources for its core capabilities, such as conducting applied science research or urban hazard assessments.

In response, USGS implemented cost-cutting and cost-saving actions to meet EHP's mission that are consistent with some but not all leading practices for strategic planning, performance measurement, and human capital planning identified in past GAO work. For example, USGS lacks a strategic plan that, among other things, identifies the resources needed to achieve the EHP's mission and goals for all major functions of the EHP, such as conducting applied earthquake science research or urban hazard assessments. Further, USGS has not conducted an analysis of staffing needs consistent with leading practices for effective strategic workforce planning principles, such an analysis could include succession planning and a data-driven assessment of its needs for critical skills and competencies. By developing a strategic plan that identifies the strategies, priorities, and resources needed to reach these goals and conducting a staffing gap analysis, USGS can better ensure it has well-thought-out strategies to achieve results-oriented goals with Congress understanding the tradeoffs USGS made in applying its resources toward its goals.

USGS has made progress implementing seismic stations; however, some challenges remain to fully implement the ShakeAlert system. GAO found that USGS had not followed best practices in establishing schedules, milestones, and timeframes for its ShakeAlert implementation, and has not completed its plan for coordinating outreach with stakeholders. By developing schedules and milestones, USGS will be able to track completion of key activities that impact the overall cost of ShakeAlert. By updating and completing its ShakeAlert outreach plan, USGS can better ensure all stakeholders have a shared understanding of how to communicate and educate the public on the ShakeAlert system.

Engineers Installing an Earthquake Early Warning Seismic Station on Mt. St. Helens

Source: Marc Barc Biundo / University of Washington. | GAO-21-129

Contents

Letter		1
	Background	7
	USGS Has Several Efforts to Identify Earthquake Hazards that Stakeholders Report Are Impeded by Resource Challenges	15
	USGS Has Taken Actions to Ensure the Earthquake Hazards Program Meets Its Mission but Has Not Followed Leading Practices for Strategic Planning, Performance Measurement, and Human Capital	30
	USGS and Its Partners Have Implemented Seismic Stations for the Early Warning System, but Several Challenges Remain	39
	USGS and NOAA Have Established But Not Fully Implemented a Memorandum of Understanding for Coordinating and Sharing Tsunami Related Information	59
	Conclusions	62
	Recommendations for Executive Action	63
	Agency Comments	65
Appendix I	Objectives, Scope, and Methodology	71
Appendix II	Examples of U.S. Geological Survey Products on Earthquake Severity and Damage	79
Appendix III	Efforts to Expedite the Permitting Process for Installing Seismic Stations	84
Appendix IV	Comments from the Department of the Interior	86
Appendix V	GAO Contact and Staff Acknowledgments	90
Tables		
	Table 1: Actions Related to Using Data Analytics to Guide Decision-Making Reported by U.S. Geological Survey (USGS)	32

Table 2: Actions Related to Using Data Analytics to Guide Decision-Making Reported by U.S. Geological Survey (USGS) 33
Table 3: Short and Long-term Cost Cutting and Cost Avoidance Actions Reported by U.S. Geological Survey (USGS) 34
Table 4: Summary of Our Assessment of U.S. Geological Survey Cost Estimate for ShakeAlert Compared to Best Practices of a Comprehensive Cost Characteristic 44
Table 5: Summary of Challenges Identified by the Organizations Adopting Earthquake Early Warning (EEW) Application Systems 50
Table 6: Number of Seismic Stations and Systems Needing Permits on Federal, State, and Private-owned Lands as of August 2020 84

Figures

Figure 1: Earthquake Hazards and Their Effects 8
Figure 2: Modified Mercalli Intensity Scale 9
Figure 3: ShakeAlert Issuance of Earthquake Early Warning Alerts 15
Figure 4: Advanced National Seismic System (ANSS) stations across the U.S. 18
Figure 5: Example of a U.S. Geological Survey National Seismic Hazard Map for the Probability of a Modified Mercalli Intensity 6 Earthquake in 100 Years, Expressed as a Percentage 21
Figure 6: Overview of GAO’s Framework for Examining Agencies’ Efforts to Manage Declining Resources 31
Figure 7: Percent of ShakeAlert Seismic Stations Operating in the California Integrated Seismic Network and the Pacific Northwest Seismic Network as of August 31, 2020 41
Figure 8: Alerting Capabilities through the Integrated Public Alert and Warning System 51
Figure 9: Prompt Assessment of Global Earthquakes for Response Issued for 2018 Earthquake in Anchorage, Alaska 80
Figure 10: ShakeMap for 2019 Earthquake in Ridgecrest, California 81
Figure 11: Aftershock Forecast for 2020 Earthquake in Indios, Puerto Rico 82
Figure 12: Ground Failure Product Issued for 2020 Néon Karlovásion, Greece Earthquake 83

Abbreviations

ANSS	Advanced National Seismic System
EHP	Earthquake Hazards Program
EEW	Earthquake Early Warning
FEMA	Federal Emergency Management Agency
IPAWS	Integrated Public Alert and Warnings System
MOU	Memorandum of Understanding
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
USGS	U.S. Geological Survey
WBS	Work Breakdown Schedule
WEA	Wireless Emergency Alert

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Congressional Committees

Earthquakes and related seismic activity pose a significant threat to people and infrastructure. Recent major earthquakes are examples of the power of such threats. For instance, a magnitude 6.4 earthquake centered west of the Searles Valley in California, struck on July 4, 2019, followed by a magnitude 7.1 earthquake the next day.[1] The U.S. Navy estimated the damage from these earthquakes to its China Lake Naval Air Weapons Station to be over $5 billion. In addition, the southwestern part of Puerto Rico has been struck by a swarm of earthquakes that began on December 28, 2019, and continued into 2020. As of February 2021, the southwestern part of the island experienced 15 magnitude 5.0 or greater earthquakes with an estimated $1 billion in damages.[2] USGS, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, and state geological surveys share responsibility for identifying and studying earthquake hazards, including tsunamis, liquefaction, and landslides.[3]

In 1977, the National Earthquake Hazards Reduction Program was established, and includes four federal agencies that coordinate their work together: 1) USGS, 2) the National Science Foundation, 3) the Federal Emergency Management Agency (FEMA), and 4) the National Institute of Standards and Technology.[4] Under the program, the federal government supports efforts to assess and monitor earthquake hazards in the U.S., and thereby mitigate the risks associated with these hazards and reduce the risks of life and property from future earthquakes. In particular, USGS,

[1]Magnitude characterizes the relative size of an earthquake and is a measurement of the maximum motion recorded by a seismograph. The severity of an earthquake can be expressed in terms of both intensity and magnitude. Intensity is based on the observed effects of ground shaking on people, buildings, and natural features and varies from place to place within the disturbed region. Magnitude is related to the amount of seismic energy released at the center of the earthquake.

[2]According to USGS, the mainshock occurred on January 7, 2020, and was a magnitude 6.4 earthquake. As of February 2021, the latest earthquake of magnitude 5.0 or higher occurred on July 3, 2020.

[3]According to USGS liquefaction occurs when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong ground shaking.

[4]42 U.S.C. § 7704.

through its Earthquake Hazards Program (EHP), is the federal entity responsible for identifying earthquake hazards including earthquake monitoring and notification, assessing national and regional seismic hazards, conducting applied scientific research to improve these functions, and coordinating post-earthquake investigation under the program.[5] USGS also began implementing an earthquake early warning (EEW) system, known as ShakeAlert, in California, Oregon, and Washington in 2011. In addition, NOAA's National Weather Service (NWS) is responsible for federal tsunami detection and warning activities.[6] State geological surveys also produce hazard maps of earthquake faults, and ground rupture, liquefaction, landslide and tsunami inundation zones, among other efforts, to identify earthquake hazards in their states.[7]

We have previously reported about the nation's preparedness for such events and various response and recovery challenges that could ensue. In 2016, we reviewed earthquake risks to federal buildings, finding that additional actions were needed to identify and mitigate those risks.[8] We also identified early implementation challenges with ShakeAlert. Among other things, we recommended that USGS establish a program management plan that addresses the known challenges for implementing ShakeAlert, which USGS fully implemented in November 2017. In addition, in 2010, we reported that NOAA's strategic plans for the National Tsunami Hazard Mitigation Program included most of the components of effective strategic plans, but other necessary components were missing or incomplete.[9] We recommended NOAA revise the plans

[5]42 U.S.C. § 7704(b)(3).

[6]33 U.S.C. § 3204. The National Weather Service (NWS) is an agency within the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA),

[7]The responsibilities of the various state surveys differ from state to state, depending upon the enabling legislation and the states' traditions. Almost all serve as a source of basic geological information for their state governments' executive, legislative, and judicial branches. For example, the California Geological Survey is charged with providing scientific products and services about a state's geology, seismology and mineral resources that affect the health, safety, and business interests.

[8]GAO, *Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System,* GAO-16-680*, (Washington, D.C.: Aug 31, 2016).*

[9]GAO, *U.S. Preparedness: NOAA Has Expanded Its Tsunami Programs, but Improved Planning Could Enhance Effectiveness*, GAO-10-490 (Washington, D.C.: Apr 28, 2010).

to ensure that they include effective strategies and performance measures for all goals, which NOAA fully implemented in 2014.

We were asked to review USGS's efforts to identify earthquake hazards and implement its earthquake early warning system.[10] This report addresses the following questions:

(1) what efforts has USGS taken to identify earthquake hazards, and what challenges have stakeholders reported to such efforts?

(2) what actions has USGS taken to ensure the EHP can meet its mission, and what additional actions could be taken?

(3) what progress have USGS and its partners made in implementing its EEW system, and what challenges have they reported?

(4) to what extent have USGS and NOAA coordinated and shared data when identifying the source and magnitude of an earthquake that may result in a tsunami?

To address our first objective, we reviewed USGS guidance, such as Circular 1429: ANSS Current Status, Development Opportunities, and Priorities for 2017-2027 (referring to the Advanced National Seismic System), and reports and planning documents relevant to USGS's efforts to identify and assess seismic hazards, including developing and updating earthquake hazard products, such as the National Seismic Hazard Maps.[11] Further, we interviewed officials from USGS's EHP regarding the agency's efforts to identify earthquakes hazards, and challenges to doing so. To obtain the perspectives of state officials, we conducted semi-structured interviews with officials from 16 state geological surveys to discuss the extent that earthquakes hazards are identified in their states and the challenges to identifying these hazards, among other things.[12] While the information gathered during these

[10]See Pub. L. No. 115-307, § 4, 132 Stat. 4408, 4414.

[11]USGS, *ANSS Current Status, Development Opportunities, and Priorities for 2017-2027,* Circular 1429 (Reston, VA: July 2017) and USGS, *Reducing Risk Where Tectonic Plates collide—U.S. Geological Survey subduction zone science plan,* Circular 1428 (Reston, VA: June19, 2017).

[12]To interview these officials, we conducted two site visits in Seattle, WA, Moffitt Field and Menlo Park, California prior to the Coronavirus Disease 2019 (COVID-19) pandemic. After the onset of the pandemic, we interviewed USGS and NOAA officials, as well as state geological survey officials, via telephone interview or virtual roundtable.

interviews cannot be generalized to all states or other stakeholders, it provides a range of perspectives on a variety of topics relevant to earthquake hazards and efforts to identify them. Our selection criteria and other additional details about how we analyzed these responses is presented in more detail in appendix I.

To determine the trends in the EHP's resources and their effects on the program, we reviewed USGS budget requests from fiscal years 2014 through 2021. We also reviewed federal laws and accompanying Congressional appropriations committee explanatory statements and reports directing appropriations to the program during this period of time.[13]

To address our second objective, we reviewed USGS guidance and other documents that detail USGS efforts to manage the program and compared them to the framework we developed for examining agencies' efforts to effectively manage in an environment of declining resources (framework).[14] Examples of the documents reviewed include annual budget guidance, implementation and performance plans for the Advanced National Seismic System (ANSS), and compared them to EHP officials' testimonial evidence.[15] We interviewed these officials to discuss the extent that USGS management lead efforts to manage declining resources.[16]

To address our third objective, we reviewed USGS's 2018 Revised Technical Implementation Plan and other documents, including the National Earthquake Hazards Reduction Program Reauthorization Act of 2018.[17] We also conducted interviews with USGS officials and other

[13]We reviewed these documents during this period of time because appropriations committees directed appropriations be set aside for the EHP within appropriations made to USGS, but had not in prior years. For example, see House of Representatives; Congressional Record, Vol. 165, H11288, Dec. 17, 2019, excerpt from Committee report.

[14]GAO, *Declining Resources: Selected Agencies Took Steps to Minimize Effects on Mission but Opportunities Exist for Additional Action*, GAO-17-79 (Washington, D.C: Dec. 20, 2016).

[15]ANSS collects and analyzes seismic and geodetic data on earthquakes, issues notifications of their occurrence and impacts, and provides data for earthquake research and the hazard and risk assessments.

[16]GAO-17-79.

[17]Pub. L. No. 115-307,132 Stat. 4408.

stakeholders of the ShakeAlert system, including the Northern California Seismic Network, Pacific Northwest Seismic Network, and academia. We also conducted semi-structured interviews with seven of the 46 organizations that are operating EEW systems in California, Washington, and Oregon, and four of the seven licensed technical operators to obtain their perspectives on the guidance provided by USGS.[18] While the information gathered during these interviews cannot be generalized to all 46 organizations operating EEW application systems and licensed technical operators, it provides a range of perspectives on a variety of topics relevant to earthquake early warning systems and applications. Our selection criteria and details about how we analyzed these responses is presented in more detail in appendix I. Further, to determine the extent USGS experienced challenges using FEMA's Integrated Public Alert and Warning System in the delivery of EEW alerts, we reviewed documentation of two controlled tests and discussed the challenges identified in the tests with senior USGS officials to determine what steps USGS is taking to address them.

In addition, to assess the extent USGS followed best practices for comprehensively estimating the cost for ShakeAlert implementation, we compared USGS practices from their 2018 cost estimate against the four best practices for a comprehensive cost estimate identified in our Cost Estimating and Assessment Guide (Guide).[19] We focused on the "comprehensive" cost characteristic because, according to our cost guide, a cost estimate that is not comprehensive cannot fully meet the other best practice characteristics because it is not complete.[20] Further, to assess the extent that USGS followed best practices in establishing schedules and milestones, we reviewed USGS's 2018 ShakeAlert Technical Implementation Plan and other relevant documents and interviewed

[18]The 46 organizations use EEW application systems to alert employees and activate systems to take protective actions.

[19]GAO's cost guide is a compilation of cost estimating best practices drawn from across industry and government. *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: March 2020).

[20]The four best practices defined under the comprehensive cost characteristic (1) includes all life cycle cost, (2) is based on a technical baseline description, (3) documents all ground rules and assumptions and, (4) is based on a work breakdown structure. The four characteristics for establishing a reliable cost estimate are that it is comprehensive, well-documented, accurate, and credible.

relevant USGS officials, and compared the information we gathered to the best practices from our Schedule Assessment Guide (schedule guide).[21]

To assess USGS's communication, education, and outreach efforts related to ShakeAlert, we compared USGS's draft Communication, Education, and Outreach Plan against collaboration mechanisms to coordinate program administration.[22] We also reviewed states' relevant planning documents such as the Cascadia Region Earthquake Workgroup's 2018 Pacific Northwest Strategy for Earthquake Early Warning Outreach, Education.[23] Additionally, we interviewed USGS officials and officials from the state emergency management agencies in California, Oregon, and Washington to discuss USGS efforts and how USGS and the states collaborate in such efforts. We compared these documents and information obtained from these interviews against collaboration mechanisms identified in our prior work for enhancing and sustaining collaboration among federal agencies, and other stakeholders.[24]

To address our fourth objective, we reviewed the 2016 memorandum of understanding between USGS and NOAA and interviewed officials from USGS, NOAA's National Weather Service, and officials from the state emergency management offices in California, Oregon, and Washington.[25] We compared the information contained in these documents to the actions taken by USGS and NOAA as of January 2021 to coordinate and share information.

[21]GAO's schedule guide is a compilation of best practices associated with developing and maintaining a reliable, high-quality schedule. GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

[22]See "Draft" *ShakeAlert Joint Committee for Communication, Education, and Outreach, Communication, Education, & Outreach (CEO) Plan: 2018 ShakeAlert – Phased Alerting* (July 2018).

[23]*See Pacific Northwest Strategy for Earthquake Early Warning (EEW) Outreach, Education, and Training*, (March 2018) and *Implementing Earthquake Early Warning in California* (May 2018).

[24]GAO-12-1022.

[25]*Memorandum of Understanding between the U.S. Geological Survey of the Department of the Interior and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce*, (October 2016).

Additional details on our scope and methodology are contained in Appendix I.

We conducted this performance audit from June 2019 to March 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Types of Earthquake Hazards

Earthquake hazards include any natural physical phenomenon associated with an earthquake that may produce adverse effects on human activities.[26] Earthquakes and their effects proceed as cascades, in which their primary effects (faulting and ground shaking) induce secondary effects including surface rupture, landslides, liquefaction, and tsunamis.[27] Figure 1 describes each of these earthquake hazards. These may result in other destructive effects such as fires and building and critical infrastructure failures.

[26]We have previously reported that earthquake hazards and risks are not synonymous. Earthquake hazards are defined as naturally-occurring phenomena capable of causing loss or damage. Risk is the potential that exposure to the hazard will lead to a negative consequence such as loss of life or economic loss. These risks are usually measured in terms of expected casualties (fatalities and injuries), direct economic losses (repair and replacement costs), and indirect economic losses (income lost during downtime resulting from damage to private property or public infrastructure). In any geographic area, three main factors determine earthquake risks: (1) the level of earthquake hazard, (2) the number of people and amount of property that are exposed to earthquake hazards, and (3) how vulnerable these people and property are to the hazards. In contrast, hazard is generally measured in physical units: energy, shaking strength, or depth of water inundation. See GAO-16-680.

[27]Other hazards caused by earthquakes may include fire, flooding, and seiches. A seiche (pronounced: saysh), is a tsunami-like wave that occurs in an enclosed or partially enclosed body of water. Seiches have been observed on lakes, reservoirs, swimming pools, bays, harbors and seas.

Figure 1: Earthquake Hazards and Their Effects

Ground rupture

Surface rupture is an offset of the ground surface when a fault ruptures to the Earth's surface. Any structure built across the fault is at risk of being torn apart as the two sides of the fault slip past each other. For example, the 1999 Chi Chi, Taiwan earthquake raised the upper stream 15 to 20 feet creating a new waterfall.

Ground shaking

Most earthquake hazards result from the shaking, or ground motions, caused by seismic waves that radiate out from a fault as it ruptures. Seismic waves transmit the energy released by the earthquake, and bigger quakes generate larger and longer lasting waves. For example, the Cypress Viaduct in Oakland, California collapsed, in part, because of ground shaking during the 1989 Loma Prieta earthquake.

Landslide

Landslides are frequently triggered by strong ground motions. Earthquakes of magnitude 4.0 and greater have been known to trigger landslides. For example, the 1964 magnitude 9.2 Great Alaska Earthquake caused parts of the bluff the Turnagain Heights neighborhood in Anchorage was located on to move as much as 2,000 feet into the bay. 75 homes were destroyed.

Liquefaction

According to USGS, loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong ground shaking. Liquefaction occurring beneath buildings and other structures can cause major damage during earthquakes because the soil cannot support buildings or other structures. For example, the 1964 Niigata earthquake caused widespread liquefaction in Niigata, Japan which destroyed many buildings.

Tsunami

A tsunami is caused by a large and sudden displacement of the ocean. Large earthquakes below or near the ocean floor are the most common cause, but landslides, volcanic activity, certain types of weather, and near earth objects (e.g., asteroids, comets) can also cause a tsunami. For example, the tsunami waves that followed the 1964 Anchorage Alaska earthquake reached as high as 27 feet in some areas. The tsunami caused a total of 128 deaths, including 16 in California and 4 children in Oregon.

Source: GAO analysis of U.S. Geological Survey (USGS) and Pacific Northwest Seismic Network documents; photos (clockwise from top left) Pacific Northwest Seismic Network, USGS, National Oceanic and Atmospheric Administration (NOAA), NOAA, NOAA. | GAO-21-129

An earthquake's severity can be measured both in magnitude and intensity. Magnitude is a quantitative measurement of the size of an earthquake. However, intensity is a descriptive measurement of the effect of an earthquake at a given location. Therefore, an earthquake will have a single magnitude, but locations may have different intensity levels depending on their distance from its epicenter. The intensity scale used in the U.S. is the Modified Mercalli Intensity Scale composed of increasing levels of intensity that range from unnoticeable shaking to buildings being destroyed (see fig. 2).[28]

Figure 2: Modified Mercalli Intensity Scale

Intensity	Shaking	Description/damage
I	Not felt	Not felt except by a very few.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.

Source: U.S. Geological Survey. | GAO-21-129

[28]The lower Roman numerals of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher Roman numerals of the scale are based on observed structural damage.

While major earthquakes do not occur as frequently as other natural disasters, such as hurricanes or floods, they can claim many lives and cause unprecedented damage and social and economic upheaval to affected communities such that, according to FEMA, full recovery may not be achievable. The cost of recovering from a major earthquake is estimated to be very high. For example, the 1994 magnitude 6.7 Northridge, California earthquake remains the third costliest disaster in U.S. history the most costly earthquake in U.S. history, and one of the most expensive disasters for the federal government. Moreover, FEMA estimates that the average annualized loss from earthquakes to be $6.1 billion per year with California alone making up 73 percent of such losses ($3.7 billion).[29]

Variation in Earthquake Hazards Across the U.S. and its Territories

Portions of all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and territories in the Pacific are vulnerable to earthquake hazards.[30] However, risks vary greatly across the U.S. and within individual states. Further, in 2015, USGS reported that its estimate of the number of people in the U.S. who live or work in areas with some risk of damaging ground shaking nearly doubled from 75 million to 143 million since 2006. USGS attributed the estimated increase, in part, because of significant population growth in areas vulnerable to earthquakes.

Earthquake hazards are greatest in the western part of the U.S., particularly in California, Alaska, Washington, Oregon, and Hawaii. However, according to USGS, 16 states have the highest earthquake hazard.[31] For example, according to USGS, California has a 99 percent chance of experiencing a magnitude 6.7 or greater earthquake in the next

[29]See Federal Emergency Management Agency, *Hazus® Estimated Annualized Earthquake Losses for the United States,* FEMA P-366, (Washington, D.C: April, 2017).

[30]According to USGS, the 10 states with highest populations exposed to very strong ground shaking levels are California, Washington, Utah, Tennessee, Oregon, South Carolina, Nevada, Arkansas, Missouri, and Illinois. The Pacific territories that are vulnerable to seismic hazards include Guam, Marianas Islands, American Samoa and neighboring islands.

[31]According to USGS, the states with the highest earthquake hazard are Alaska, Arkansas, California, Hawaii, Idaho, Illinois, Kentucky, Missouri, Montana, Nevada, Oregon, South Carolina, Tennessee, Utah, Washington, and Wyoming. The states with the lowest ground shaking hazard are Florida, Iowa, Minnesota, North Dakota, and Wisconsin.

30 years. However, areas believed to have low earthquake risk may still experience a damaging earthquake.[32]

Since the establishment of the National Earthquake Hazards Reduction Program in 1977, scientific understanding of earthquakes and the technology used to measure and monitor them has improved. Officials are concerned that more areas of the nation may be under greater threat than previously understood. For example, earthquake hazards are now known also to be prominent in the Rocky Mountain region and the New Madrid Seismic Zone, as well as in portions of the eastern seaboard, particularly South Carolina.[33] Further, since the 1990s, research has found that subduction zones, such as the Cascadia Subduction Zone, have historically produced very strong offshore earthquakes (i.e. magnitude 8.0 or higher).[34] According to USGS, there is a higher probability that a major earthquake will occur in these areas. Research has also found that strong earthquakes in these areas produce tsunamis and landslides that cause widespread damage.[35] In addition, the Central

[32]USGS, *UCERF3: A new earthquake forecast for California's complex fault system,* Fact Sheet 2015-3009 (Washington, D.C.: Mar. 2015). On August 23, 2011, a magnitude 5.8 earthquake near Mineral, Virginia occurred. It was felt across more than a dozen U.S. states and Southeastern Canada—an area inhabiting one-third of the U.S. population. Minor and moderate damage to buildings was widespread and estimated to be $200 million to $300 million.

[33]The New Madrid Seismic Zone includes parts of eight states: Illinois, Indiana, Missouri, Arkansas, Kentucky, Tennessee, Oklahoma, and Mississippi.

[34]A subduction zone is where two tectonic plates come together, one riding over the other. According to USGS, Alaska, Washington, Oregon, and northern California, the commonwealths of Puerto Rico and the Northern Mariana Islands, US Virgin Islands, Guam, and American Samoa all lie within a subduction zone. The Cascadia Subduction Zone stretches from mid-Vancouver Island in southern British Columbia, Canada to Cape Mendocino in northern California.

[35]The 1964 magnitude 9.0 earthquake in Anchorage, Alaska, and more recent events in Indonesia, Chile, and Japan provide powerful examples of the potential destructiveness of a subduction zone event Shaking during the 1964 Alaska earthquake was felt as far away as Seattle, Washington, and the tsunamis generated caused about $2.3 billion in damage (2013 dollars).The 2004 Sumatra–Andaman earthquake and ensuing Indian Ocean tsunami killed more than 200,000 people in 14 countries, damaged fisheries in Japan, and triggered earthquakes as far away as Alaska. The tsunami generated by the 2010 Chilean earthquake damaged coastal towns and affected ports as far away as San Diego, California. Nearly 525 people died, and the estimated economic losses range from $15 billion to $30 billion. The 2011 magnitude 9.0 Tohoku, Japan earthquake shook the ground for 5 minutes and generated a tsunami over 100 feet, flung boats atop houses, flooded rural farms with seawater, and caused a meltdown at the Fukushima Daiichi Nuclear Power Plant. Approximately 16,000 people died and damage was estimated to be more than $220 billion.

and Eastern U.S. has undergone a significant rise in seismicity over the past 6 years.[36] The USGS reported that the growth in seismicity is largely in areas near oil and gas operations, and has been shown to be due to deep injection of fluids.

Federal Agencies' Roles and Responsibilities for the National Earthquake Hazards Reduction Program

Since the establishment of the National Earthquake Hazards Reduction Program, the federal government has provided support for efforts related to, among other things, assessing and monitoring earthquake hazards and risk.[37]

The National Institute of Standards and Technology is the lead agency and, as such, has the primary responsibility for program planning and coordination of the National Earthquake Hazards Reduction Program. The Institute is also responsible for conducting earthquake engineering research to provide the technical basis for building codes, standards, and practices, and is responsible for working with FEMA and others to implement improved earthquake resistant design guidance for building codes and standards for new and existing buildings. FEMA is responsible for, among other things, promoting better building practices and providing assistance to enable states to improve earthquake preparedness. The National Science Foundation supports basic research to understand geophysical processes of the earth, including the nature and occurrence of geophysical hazards such as seismology.[38] It also supports research to improve safety and performance of buildings, structures, and lifelines. The National Science Foundation also supports social and behavioral research to support more effective risk communication, public

[36]According to USGS, the total number of earthquakes magnitude 3.0 or greater was 867 from 1973 to 2008. However, the rate of seismicity in this area increased sharply in 2009. USGS reported there were 3,804 magnitude 3 or greater earthquakes in this area 2009 to 2020. Further, there were 1010 such earthquakes in 2015 alone. Multiple damaging earthquakes have occurred during this time period, including a magnitude 5.6 earthquake near Prague, Oklahoma, a magnitude 5.3 earthquake near Trinidad, Colorado; and a magnitude 5.0 near Cushing, Oklahoma.

[37]Pub. L. No. 95-124, 91 Stat. 1098 (1978) (codified as amended at 42 U.S.C. §§ 7701-7709). The program promotes the development of standards, guidelines, and voluntary building codes, improved design and construction methods, coordinated emergency preparedness plans, and public education and involvement programs

[38]Under federal law, the National Science Foundation is to also work closely with USGS to support applied science in the production of a systematic series of earthquake-related geologic hazard maps, and to identify geographic regions of national concern that should be the focus of targeted solicitations for earthquake-related research proposals. 42 U.S.C. § 7704(b)(4)(iii).

preparedness, and mitigation policies. USGS is responsible for providing earthquake monitoring and notification, delivering regional and national seismic hazard assessments, conducting applied scientific research to improve these functions, and coordinating post-earthquake investigation. The National Earthquake Hazards Reduction Program Reauthorization Act of 2018 also requires USGS to issue earthquake warnings and alerts to FEMA, the National Institute of Standards and Technology, and state and local officials when necessary and feasible.[39] USGS's Earthquake Hazards Program (EHP) is charged with carrying out these functions. Identifying and monitoring earthquake hazards are also the responsibility of state and local government agencies. However, the federal government is also to provide support through coordinated activities of the National Earthquake Hazards Reduction Program and the National Tsunami Hazard Mitigation Program to state agencies.[40]

Regarding the National Tsunami Hazard Mitigation Program, NOAA assists states in emergency planning and in developing maps of potential coastal inundation for a tsunami.[41] In particular, NOAA's NWS is responsible for federal tsunami detection and warning activities.[42] Specifically, NWS operates two tsunami warning centers, which monitor data from seismic networks operated by NOAA, USGS, the Incorporated Research Institutions for Seismology, states, and universities, and issue tsunami warnings.[43]

Implementation of ShakeAlert Earthquake Early Warning System

USGS is the lead federal agency responsible for developing and operating ShakeAlert, which is an earthquake early warning system being implemented in California, Oregon, and Washington. Since 2006, USGS has been working with California, Oregon, and Washington state governments, as well as academic institutions to leverage existing

[39]See 42 U.S.C. §§ 7704(b)(3)(D).

[40]See 42 U.S.C. § 7704; NTHMP – 33 U.S.C. § 3204.

[41]NOAA, FEMA, USGS and 28 U.S. coastal states and territories participate in the National Hazard

[42]See 33 U.S.C. § 3204.

[43]The Incorporated Research Institutions for Seismology is a National Science Foundation supported consortium of over 100 U.S. universities that operates science facilities for the acquisition, management, and distribution of seismological data.

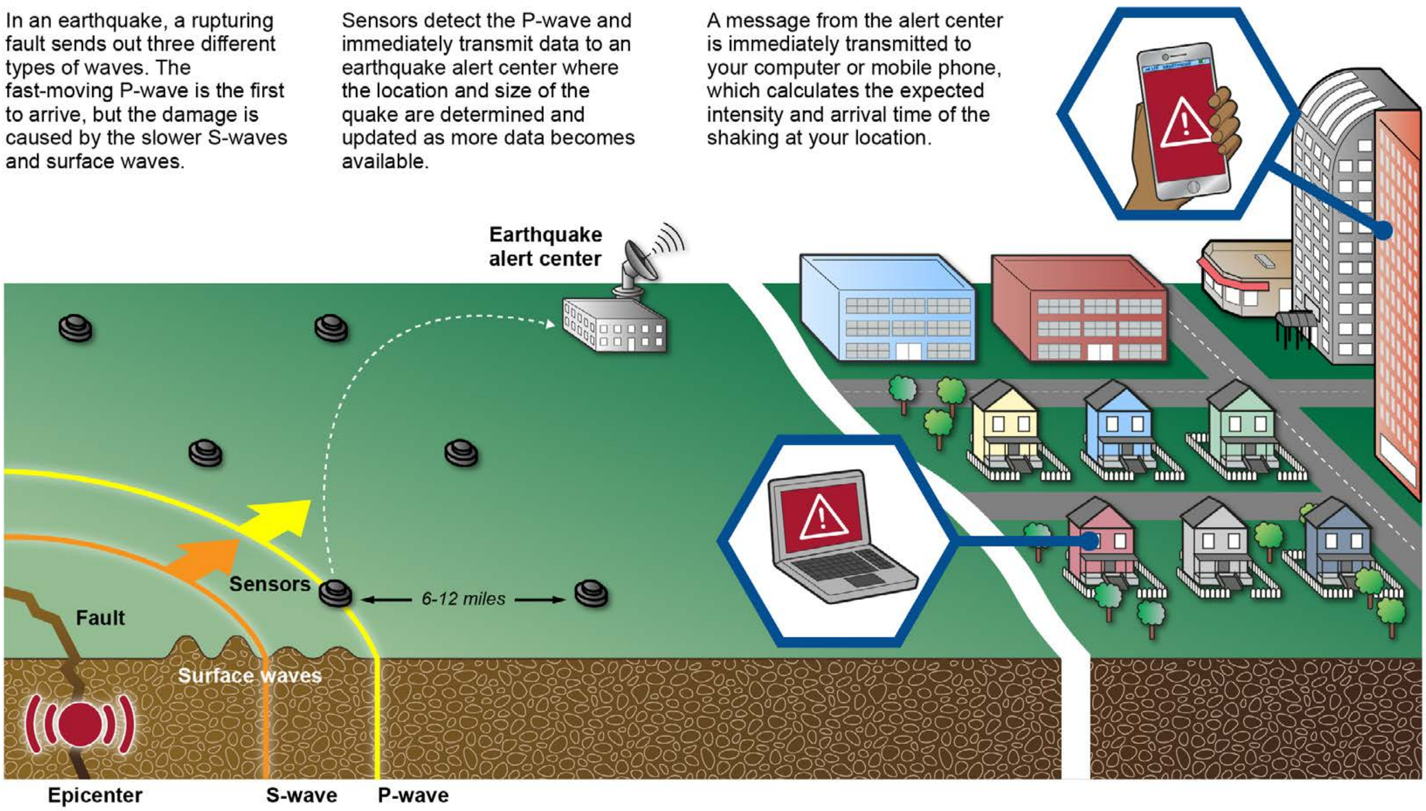
infrastructure while developing the ShakeAlert system.[44] The purpose of ShakeAlert is to automatically identify and characterize an earthquake rapidly after it begins, estimate the intensity of ground shaking that will result. If ShakeAlert detects an earthquake that is estimated to cause damaging ground shaking, the system issues an alert that may be delivered to the public via the Wireless Emergency Alerting system, public announcement systems, cell phone applications that consumers have downloaded.[45] These alerts warn the public to take protective actions, such as drop, cover, and hold, before strong shaking is expected to arrive at their location. In addition, ShakeAlert delivers data or alerts to automated systems that trigger automated actions, such as shutting down wastewater systems, stopping elevators, slowing down trains, or opening emergency exit doors. Unlike weather forecasts or tsunami warnings, ShakeAlert system can only provide seconds to tens of seconds of warning that shaking is imminent.[46] Figure 3 depicts how ShakeAlert detects and issues earthquake early warning alerts.

[44]The ShakeAlert system has been sending live alerts to "beta" users in California since January 2012 and in the Pacific Northwest since February 2015.

[45]The Wireless Emergency Alerting system allows authorized federal, state, territorial, tribal, and local government agencies to send text-like messages to mobile devices in geographically selected areas as one-way cellular broadcasts.

[46]ShakeAlert cannot deliver alerts before shaking arrives to areas near or at an earthquake's epicenter. This is because the system needs time to detect the earthquake, issue an alert, and for USGS partners to distribute the alert.

Figure 3: ShakeAlert Issuance of Earthquake Early Warning Alerts



Source: GAO analysis of U.S. Geological Survey information. | GAO-21-129

USGS Has Several Efforts to Identify Earthquake Hazards that Stakeholders Report Are Impeded by Resource Challenges

USGS Efforts to Identify Earthquake Hazards

To meet its mission, USGS, through the EHP, monitors and studies hazards and uses this information to create assessments, provide warnings, or generate products for anticipating and responding to hazardous seismic events. According to USGS, these efforts are to inform the public and decision-makers to ensure public safety, mitigate losses, and improve resilience to earthquake hazards. USGS's efforts fall into four interrelated categories: (1) monitoring earthquakes; (2) issuing notifications and products on ground shaking severity and damage after an earthquake has occurred, (3) assessing future earthquake risks and hazards, and (4) conducting and supporting scientific research of earthquakes occurrence and the effects of earthquakes.

Each type of effort relies on the others. Specifically, scientific assessments of earthquake hazards are necessary to assess vulnerability and risk, which must be determined to effectively prepare and mitigate the effects of these hazards. Decision-makers also need warnings and other information to effectively respond to an earthquake or tsunami. To create assessments and warnings, scientists require a fundamental understanding of the natural processes and observations of the natural events, which are gained through gathering and analyzing data. Data on earthquake hazards and their effects are obtained through seismic monitoring systems and scientific research. The following section includes more detail on the program's four categories.

Monitoring Earthquakes. According to USGS, monitoring provides awareness of the current state of earthquake hazards, and is the basis for short-term forecasts. Specifically, the EHP monitors ground shaking in the U.S. through the ANSS.[47] ANSS is composed of national and regional seismic networks and their associated data centers.[48] The system also includes national components, including the National Earthquake Information Center, National Strong Motion Project, and ShakeAlert (see

[47]USGS monitors all earthquakes outside the United States through the Global Seismographic Network This network is a partnership between USGS and the National Science Foundation. It provides worldwide monitoring of the Earth, with over 150 seismic stations distributed globally.

[48]A seismic network consists of a group of stations sending data to a data analysis center. A seismic station consists of a sensor to measure ground motion—a seismometer—and an instrument to convert the analog electrical signal to digital format. Because of the broad range of motions generated by earthquakes, there are usually two types of sensors included in seismic networks: broadband and strong motion. Broadband seismometers can record ground motions (velocity or acceleration) over a wide range of frequencies. Strong-motion seismometers record the shaking near large earthquakes, both on the ground and in buildings and lifelines.

sidebar for more information).[49] ANSS and its regional seismic networks issue notifications of earthquake occurrence, provide data used to assist emergency response efforts, and issue products on earthquake severity and damage, which are further discussed below.

The data collected by ANSS also supports hazard assessments, such as the National Seismic Hazard Model, and supports targeted research of natural hazards assessments and scientific research. The program supports national facilities, such as the National Earthquake Information Center and partially supports regional seismic networks (see sidebar for more information).[50] Figure 4 depicts the location of the stations that compose the seismic network of ANSS.

Elements of the Advanced National Seismic System (ANSS)

ANSS is composed of regional networks and three national components.

Regional seismic networks. ANSS is a cooperative effort between USGS and regional networks. Regional seismic networks provide critical station coverage in moderate- to high-hazard regions, analyze and distribute seismic data and information on earthquakes, and provide local expertise for a region's engineering and emergency management communities and for the public. Most networks monitor a unique geographic region where their earthquake locations and magnitudes are considered the authoritative ANSS result.

National components. The USGS operates the three national elements of the ANSS: the National Earthquake Information Center, the National Seismic Network, and the National Strong Motion Project.

The National Earthquake Information Center monitors domestic and international earthquakes, and disseminates earthquake information to national and international agencies, scientists, critical facilities, and the public within 20 minutes. The center also receives data from about 3,000 seismic stations across the planet, and reports on about 25,000 earthquakes per year. It is staffed 24/7 and serves as a backup for regional networks.

The National Seismic Network consists of 100 broadband stations providing a national backbone for the ANSS earthquake monitoring.

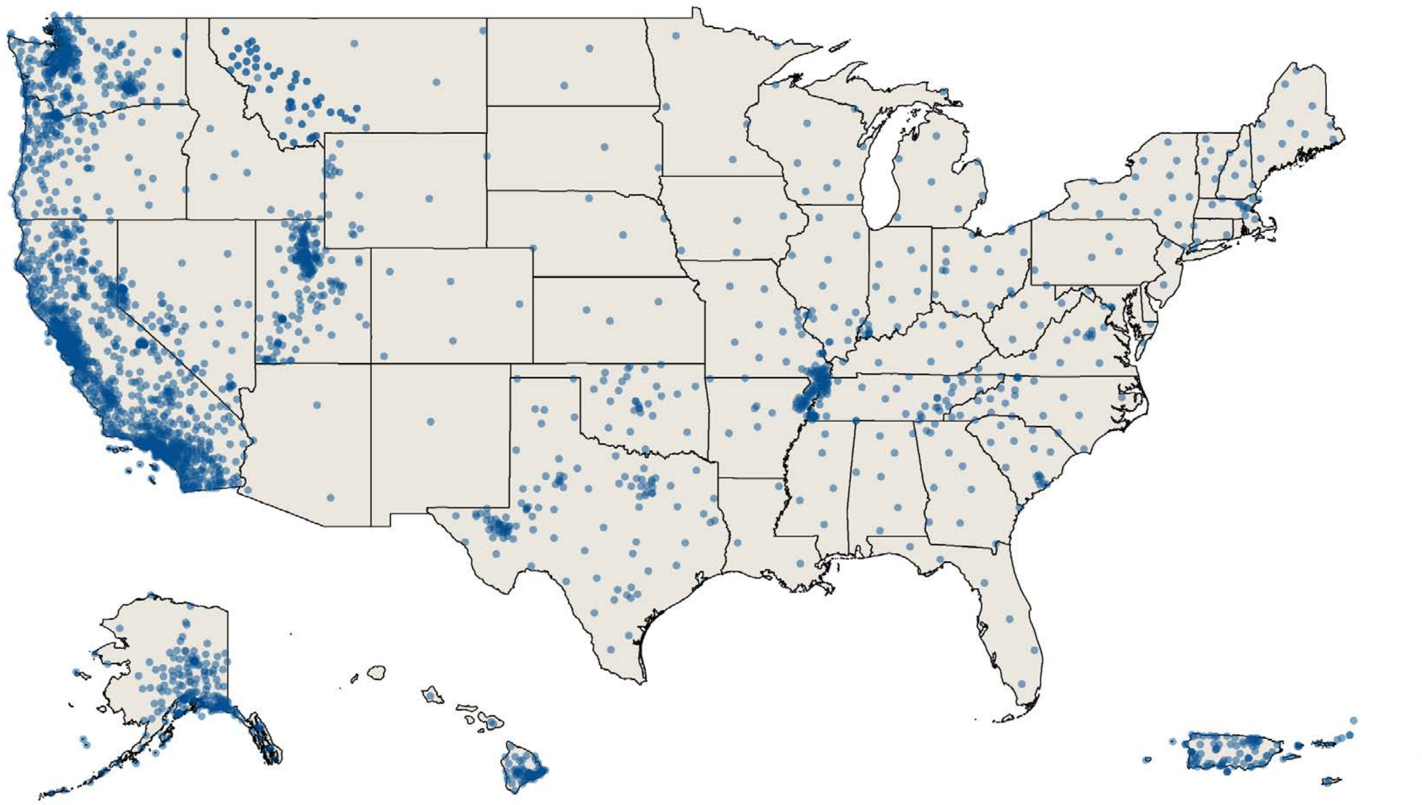
The National Strong Motion Project maintains stations designed to record strong shaking near earthquakes, with more than 400 stations and more than 150 instrumented structures with telemetry.

Source: U.S. Geological Survey Documents. | GAO-21-129

[49]The EHP supports national facilities, such as the National Earthquake Information Center, and partially supports regional seismic networks. There were 10 networks participating in the ANSS in 2020—10 were financially supported by USGS and 2 were not. Those supported by USGS included the Alaska Earthquake Center of the Geophysical Institute, (University of Alaska Fairbanks), California Integrated Seismic Network (California Institute of Technology, the University of California, Berkeley, the USGS Earthquake Science Center at Menlo Park, and the California Geological Survey), Center for Earthquake Research and Information; Nevada Seismological Laboratory (University of Nevada, Reno), Pacific Northwest Seismic Network (University of Washington and University of Oregon), Puerto Rico Seismic Network (University of Puerto Rico, Mayaguez), South Carolina Seismic Network, (University of South Carolina), University of Utah Seismograph Stations, USGS Hawaiian Volcano Observatory. The Montana Regional Seismic Network and Oklahoma Geological Survey Seismic Network participate in ANSS but are supported by state funding.

[50]Regional networks can receive additional support from their states, host universities, or other federal agencies.

Figure 4: Advanced National Seismic System (ANSS) stations across the U.S.



Source: GAO presentation of U.S. Geological Survey data. | GAO-21-129

Issuing Notifications and Products on Earthquake Severity and Damage. ANSS issues notifications and products on the severity and scope of earthquake damage after an earthquake has occurred. ANSS issues notifications once an earthquake is detected to assist federal and state emergency response efforts. Other ANSS products are used by federal and state emergency responders, public and private infrastructure owners, and the media to understand the severity and scope of damage and inform response efforts. For example, ANSS provides immediate earthquake notifications to governments and emergency managers after a potentially damaging earthquake has occurred, such as the earthquake sequence in Puerto Rico that began in 2019 (see appendix II for examples of earthquake information products USGS issues, including the aftershock forecast for the Puerto Rico sequence).[51] EHP officials reported that since January 2020, the program has issued earthquake situational awareness products for each of the 15 damaging earthquakes that have occurred, deployed staff to assist FEMA emergency management operations and the government of Puerto Rico, deployed six temporary seismic stations to monitor aftershocks, and frequently updated aftershock forecasts for the affected region in English and Spanish. Additional details of these products are described below and examples are provided in appendix II.

- **ShakeMaps**. Using ANSS data, USGS generates a ShakeMap after a significant earthquake has occurred. A ShakeMap is a map of the severity and spatial distribution of earthquake ground shaking and provides a rapid assessment of the scale of an earthquake's potential impact. ShakeMaps are intended to inform, among others, response officials and personnel, and transportation and lifeline managers response and recovery efforts by estimating damage levels and the scope of the needed response.
- **Prompt Assessment of Global Earthquakes for Response**. This assessment estimates dollar losses and fatalities immediately after significant earthquakes nationally and worldwide. To do this, ShakeMap results along with data on population density, inventories of buildings and construction types, and historical loss data, are used to rapidly estimate the scope and impact of domestic and international earthquakes. These estimates are generally available on USGS's website within 30 minutes of the earthquake and are updated as more information becomes available. The estimates include the number of people and names of cities exposed to each shaking intensity level, as well as the likely ranges of fatalities and economic losses. However, the assessment does not consider secondary effects such as landslides, liquefaction, and tsunami in loss estimates.
- **Ground failure products.** The EHP issues near-real-time spatial estimates of earthquake-triggered landslide and liquefaction (i.e. ground failures) following significant earthquakes worldwide. This includes maps that show areas that USGS models estimate may be

[51]The ANSS reports potentially damaging earthquakes to the White House; the Departments of Defense, Homeland Security (e.g., FEMA), Transportation, Energy, Commerce (e.g., NOAA and the National Institute of Standards and Technology), Veterans Affairs, State, and Interior; state emergency management and response agencies; and, the news media.

affected by ground failures, and includes estimates of the population potentially impacted by these earthquake hazards.[52]

- **Aftershock forecasts.** ANSS posts aftershock forecasts for earthquakes over magnitude 5 in the U.S. and U.S. territories on its website. It also computes forecasts for some smaller earthquakes that are of particular public interest, such as those in densely-populated areas. These forecasts include the expected number of smaller aftershocks that may be felt over future time intervals of a day, a week, a month, and a year; the probability of aftershocks large enough to potentially do damage; and the probability of future moderate to large earthquakes.

Assessing Earthquake Hazards and Risks. USGS publishes a suite of earthquake hazard assessment products, including the National Seismic Hazard Model and Urban Seismic Hazard Maps. Regarding the hazard model, USGS quantifies earthquake hazards across the nation by compiling all known earthquake sources (and proxies for unknown sources), their distance from the site in question, and other seismological and geological information. The model then projects peak ground motions that have a specific probability (e.g., 2 percent) of being exceeded over a particular period of time (e.g., 100 years) and produces national seismic hazard maps.[53] National seismic hazard maps are the basis for seismic provisions in model building codes adopted throughout the U.S. and inform $1 trillion of infrastructure construction per year. Government officials, emergency management, and policy makers also use the hazard models to address local efforts and to understand and reduce seismic risk. For example, FEMA incorporates the USGS hazard models directly in their computer programs, such as its Hazus tool, to assess earthquake risk to the nation and help communities prepare for earthquake shaking.[54] Figure 5 depicts the probability of a Modified Mercalli Intensity 6 earthquake occurring in 100 years as shown in the 2018 National Seismic Hazard Map for the 48 contiguous states in combination with the 2007,

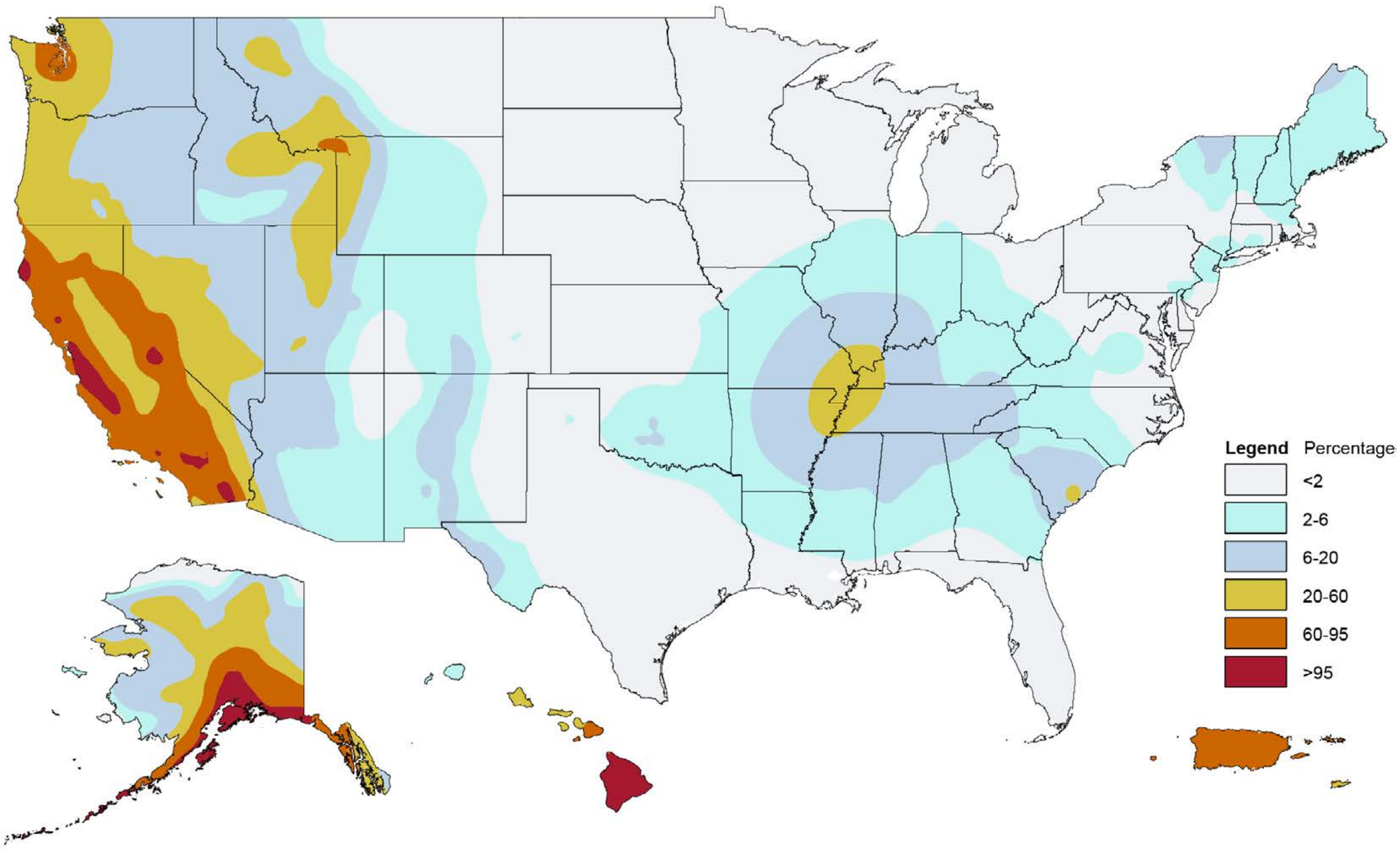
[52]According to USGS, its models provide regional estimates of landslide and liquefaction hazard triggered by this earthquake, but do not predict specific occurrences.

[53]USGS also occasionally issues short-term seismic hazard maps. For example, USGS also issued one-year seismic maps for the Central and Eastern United States from 2016 through 2018 to forecast potential shaking from both induced and natural earthquakes.

[54]Hazus is used for mitigation and recovery, as well as preparedness and response. Government planners, GIS specialists, and emergency managers use Hazus to determine losses and the most beneficial mitigation approaches to take to minimize them

2003, and 1998 seismic hazard maps for Alaska, Puerto Rico, and Hawaii, respectively.

Figure 5: Example of a U.S. Geological Survey National Seismic Hazard Map for the Probability of a Modified Mercalli Intensity 6 Earthquake in 100 Years, Expressed as a Percentage



Source: GAO presentation of U.S. Geological Survey data. | GAO-21-129

The National Earthquake Hazards Reduction Program Reauthorization Act of 2018 mandates the creation of a systematic set of maps of active faults and folds, liquefaction susceptibility, susceptibility for earthquake induced landslides, and other seismically induced hazards.[55] As of February 2021, USGS reported it is in the initial planning stages to develop a strategy to deliver national-scale assessments such as those

[55]Pub. L. No. 115-307, §3, 132 Stat. 4408, 4409.

for seismically induced liquefaction or landslides. In addition, USGS has partnered with state and local experts to produce more detailed urban seismic hazard maps. Some of these include additional hazard models and maps that estimate the likelihood and severity of secondary hazards such as earthquake-induced landslides and liquefaction. For example, to date, USGS has conducted urban hazards studies for the San Francisco Bay Area in California; Memphis and Shelby County in Tennessee; St. Louis, Missouri; Evansville, Indiana, and Seattle, Washington. USGS officials also reported ongoing seismic hazard studies for Salt Lake City, Utah and Los Angeles, California.

Conducting and Supporting Scientific Research. The EHP conducts targeted and broad research on the causes, characteristics, and effects of earthquakes. The program also provides grants to support external research on earthquake hazards. Finally, USGS, in coordination with NOAA and the relevant states, conducts tsunami-related research such as identifying offshore earthquake source zones that have the potential to generate tsunamis. For example, beginning in 2018, USGS's Coastal and Marine Hazards and Resources Program, NOAA and the Department of Interior's Bureau of Ocean Energy Management are working with academic and private partners to conduct geologic sampling research and geophysical offshore mapping to better assess earthquake, landslide, and tsunami hazards along the Pacific Northwest coastline.[56]

Stakeholders Report that Resource Challenges Have Impeded USGS's Efforts to Identify Earthquake Hazards

USGS officials, state geologists, and other stakeholders we interviewed stated that USGS's efforts to identify earthquake hazards have been impeded by limited discretionary resources for its core capabilities, such as conducting assessments and applied scientific research. For example, the administration requested a reduction in appropriations to the EHP in fiscal years 2016, and 2018 through 2021 ranging from almost $13 million dollars for fiscal year 2018 to over $25 million dollars for fiscal year 2021.[57] In contrast, the administration requested increases in appropriations to the program's budget for fiscal years 2014, 2015, and

[56]This work began in 2018 and is expected to be completed in 2022. Academic partners include the University of Washington, University of Hawaii, Humboldt State University, Scripps Institution of Oceanography, and Oregon State University.

[57]The administration proposed cutting the EHP's budget by about $34.4 million for fiscal year 2019 and $20.2 million in fiscal year 2020. The administration also proposed cutting the EHP budget by about $1.5 million in fiscal year 2016.

2017.[58] However, federal law and accompanying committee reports have sought to increase funding for the EHP through a combination of committee direction and supplemental appropriations from fiscal years 2014 through 2021.[59] Specifically, appropriations committees have directed increases to the program's overall funding from about $53.8 million in fiscal year 2014 to $85.4 million in fiscal year 2021. During this period, the Congressional committees have also directed increased spending toward implementation and maintenance of ANSS and its components. In particular, over this time period, the committees directed about $151.6 million toward ANSS or ShakeAlert implementation and maintenance and to provide support for ANSS regional networks. Of this amount, almost $119 million has been directed for ShakeAlert implementation and maintenance since fiscal year 2014.

According to USGS officials, the proportion of EHP funding dedicated for monitoring efforts, especially ShakeAlert, has increased rapidly relative to other aspects of the program. For example, USGS officials estimated that funding for all earthquake monitoring efforts comprised about 40 percent of EHP's total funding in fiscal year 2014; but comprised about 67 percent of EHP funding in 2020. However, the remainder of the program's funding, such as earthquake hazard assessment and research, has remained relatively flat since fiscal year 2014. We will discuss USGS efforts to manage its resources later in this report.

USGS officials also report that flat discretionary resources for the majority of the EHP's programs has resulted in increased staffing vacancies and reduced capabilities across the program's monitoring— except ShakeAlert—assessment, and research efforts. For example, EHP officials reported that staffing shortages result in capabilities that need multiple staff to be effective are now carried out by single person, or are held by staff who are eligible to retire. For instance, the retirement of the National Earthquake Information Center's operational manager after 30 years of service forced USGS to reorganize its operations because it could not backfill the position. USGS officials also stated that the agency's inability to fill strategically necessary positions has had a long-term impact on the scientific vitality of the program, and its ability to

[58] The administration proposed an increase of almost $3.5 million for fiscal year 2014, about $314,000 in fiscal year 2015, and almost $1.7 million for fiscal year 2017.

[59] In 2018, EHP received $8.1 million to repair and replace seismic stations damaged by Hurricanes Harvey, Irma, and Maria and the 2018 California Wildfires. See Pub. L. No. 115-123, 132 Stat. 64, 89

create and maintain state-of-the-art earthquake hazards products. Specifically, USGS officials stated that geology, earthquake, and paleotsunami work in the Caribbean, including Puerto Rico, has been greatly reduced.[60] Further, USGS's Scientific Earthquake Studies Advisory Committee expressed concern that USGS may permanently lose capabilities through retirements and unfilled vacancies in 2018, and new requirements, such as ShakeAlert, divert staff from previous work in 2019.[61] The committee also emphasized that a sufficient level of scientists and technicians is necessary to ensure ShakeAlert's success. USGS officials, state geologists, and other stakeholders we interviewed noted that USGS capacity may be affected in three areas: 1) research, 2) monitoring, 3) notification and product issuance, and 4) hazard assessments.

Earthquake Research

USGS officials reported that insufficient resources have left important positions unstaffed. For example, staffing vacancies have affected the maintenance and oversight of critical fault information, such as the Quaternary Faults and Folds Database, which is necessary to update the National Seismic Hazard Model.[62] In addition, USGS officials stated that staffing shortages have not allowed the program to accelerate the investigation of hazardous faults within Alaska, the Intermountain West, and the central and eastern U.S., or to develop improved ground motion models for the hazardous regions of the nation.

Further, USGS officials, state geologists, and other stakeholders we interviewed reported that the closure of regional USGS offices has

[60]Paleotsunami research seeks to determine the frequency and effects of tsunamis that occurred prior to the historical record or for which there are no written observations to better estimate the probability of the hazard. Paleotsunami research is based primarily on the identification, mapping, and dating of tsunami deposits found in coastal areas, and their correlation with similar sediments found elsewhere locally, regionally, or across ocean basins.

[61]Scientific Earthquake Studies Advisory Committee, 2018 Annual Report (Reston, VA: May 14, 2018) and 2019 Annual Report (Reston, VA: Oct 11, 2018). The Scientific Earthquake Studies Advisory Committee was created in 2000 by legislation reauthorizing National Earthquake Hazard Reduction Program and provides advice and direction to the USGS Director. See 42 U.S.C. § 7709.

[62]The Quaternary Fault and Fold Database contains information on faults and associated folds in the United States that are believed to be sources of earthquakes magnitude 6 or higher during the past 1,600,000 years.

reduced the effectiveness of USGS.[63] For example, USGS closed its regional office in Memphis in 2013 to reduce costs. USGS officials and state geologists in the New Madrid Seismic Zone we interviewed stated and USGS's Scientific Earthquake Studies Advisory Committee reported that since the closure of the Memphis office, public engagement and USGS effectiveness and responsiveness in the region have been reduced.[64] For example, a state geologist reported that they and their neighboring states were less active in studying or mapping seismic hazards without USGS presence to coordinate with states and other stakeholders in the region and to provide financial support for these projects. USGS officials stated that, despite a lack of on-site staff, a Central and Eastern U.S. coordinator works with stakeholders throughout this region, and annual EHP external grants solicitation provides external partners the opportunity to submit proposals to receive funding for projects. However, stakeholders in the region we interviewed generally reported that USGS external grant program funding levels, and coordination between USGS and the states had significantly decreased since the agency closed its Memphis office.

Further, 12 of the 16 state geologists we interviewed stated that USGS's reduced capacity has negatively affected state efforts to monitor or assess earthquake hazards. This is, in part, because USGS helps to support state efforts to study hazards including mapping faults or other liquefaction zones. For example, representatives from a state geological survey told us that portions of their state lack published hazard maps because USGS scientists did not complete their work before retiring, and their position remains vacant. In addition, representatives we interviewed from three state geological surveys and an earthquake consortia reported they were concerned that the loss of USGS support could result in uneven identification of earthquake hazards that cross state borders. State geologists also expressed concern regarding the loss of support of earthquake research given the scope of work that remains to identify hazards in their respective states. For example, only one of 16 state geologists we interviewed reported that earthquake hazards related to

[63]The four earthquake consortia are the Western States Seismic Policy Council, Central United States Earthquake Consortium, Northeast States Emergency Consortium, and Cascadia Region Earthquake Workgroup. These consortia are multi-state regional and multidisciplinary organizations. These consortia coordinate multi-State response and recovery planning and public awareness, education, and outreach efforts.

[64]See Scientific Earthquake Studies Advisory Committee, 2019 Report.

shaking and ground rupture were very well mapped in their state.[65] In addition, 9 of the 16 state geologists we interviewed also reported that 20 percent or less of their faults had been well studied, which they said is a necessary step to identifying earthquake hazards. Eleven of the 16 state geologists we interviewed also reported that less than one-third of their known faults had been mapped at a scale adequate to identify earthquake hazards.[66] Further, 10 of 16 of these state geologists stated that liquefaction hazards had been slightly mapped or had not been mapped at all in their state.[67] Similarly, 13 of 16 state geologists also said that landslide hazards in their states had been slightly mapped or not been mapped at all.[68]

Monitoring Earthquakes

Although funding has increased for ShakeAlert maintenance and implementation, USGS officials and other stakeholders report that current funding levels are insufficient to complete full ANSS implementation, and to maintain and support existing ANSS seismic networks. The 2017 ANSS strategic plan and the 2008 National Earthquake Hazard Reduction Program Strategic Plan called for the installation of 7,100 seismic stations.[69] However, according to USGS, 3,421 stations (48.2 percent of the original design goal) have been installed as of September 2020.

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[65]We asked 16 state geologists to rate the extent that seismic hazards related to ground shaking and rupture were mapped in their state using the following scale: 1= Not at all; 2= slightly mapped; 3= moderately mapped; 4= very well mapped; 5= completely mapped). Of the remaining 15 state geologists, 8 indicated that these hazards were slightly mapped, 5 indicated the hazards were moderately mapped, 1 indicated the hazards were not at all mapped, and 1 did not provide a response.

[66]The state geologists we interviewed generally stated that mapping efforts must be done at least at 1:24,000 scale to sufficiently identify seismic faults, liquefaction zones, and other seismic hazards.

[67]We asked 16 state geologists to rate the extent that liquefaction hazards were mapped in their state using the following scale: 1= Not at all; 2= slightly mapped; 3= moderately mapped; 4= very well mapped; 5= completely mapped). Of the remaining 6 state geologists, 4 indicated liquefaction hazard was moderately mapped, 1 indicated that it was very well mapped, and 1 did not provide a response.

[68]We asked 16 state geologists to rate the extent that seismically induced landslides were mapped in their state using the following scale: 1= Not at all; 2= slightly mapped; 3= moderately mapped; 4= very well mapped; 5= completely mapped). Of the remaining 3 state geologists, 2 indicated that seismically induced landslides were moderately mapped, and 1 did not provide a response.

[69]See USGS, Circular 1429 and National Earthquake Hazards Reduction Program Interagency Coordinating Committee, *Strategic Plan for the National Earthquake Hazards Reduction Program 2009-2013* (Washington, D.C.: Oct. 2008).

Furthermore, USGS noted in its plan that many regions with high earthquake hazards need expanded ANSS instrumentation, including Alaska, the Intermountain West (i.e., Idaho, Montana, Nevada, and Utah), and the Central and Eastern U.S.. In 2019, the Scientific Earthquake Studies Advisory Committee also noted in that existing earthquake monitoring hardware is aging and is difficult to maintain with no clear path to equipment upgrades.[70] Moreover, USGS has defunded nine regional networks since 2007 to reduce costs. We discuss USGS efforts to reduce costs later in this report.

The committee also noted that withdrawal of USGS support has diminished earthquake monitoring capability in seven states (Virginia, Kentucky, Massachusetts, Rhode Island, Maine, California, and Montana). According to USGS officials, ANSS advancements, such as assuming long-term support for 145 stations in the Central and Eastern U.S. Seismic Network (also known as the N4 Network) in 2017, ensure USGS effectively monitors earthquakes and deliver a broad suite of situational awareness products to these regions, despite the defunding of these networks. However, six of the 16 state geologists we interviewed stated that too having few ANSS stations negatively affected their ability to identify or monitor earthquake hazards in their states. For example, according to a state geologist from the Intermountain West we interviewed, their state geological survey has poor understanding of seismicity and behavior of their state's faults, and cannot monitor aftershocks. As a result, they rely on neighboring states to map and detect smaller earthquakes because of the sparse number of ANSS stations located in their state.

Issuing Notifications and Products on Earthquake Severity and Damage

EHP officials described demand for the program's earthquake information and products as very high from users across the world. A 2020 study found that USGS receives millions of requests for earthquake information for event-associated webpages and earthquake catalog downloads, as well as over a billion requests for automated data feed.[71] For example, USGS servers received a total of nearly 3.6 billion data requests including 29 million page views from 7.1 million users, and 606 million data feed

[70]Scientific Earthquake Studies Advisory Committee, Report (Reston, VA: Oct.11, 2019).

[71]The study counted number of page views as requests. See Leith, W. S., J. M. Fee, E. M. Martinez, and L. A. Lastowka "Now Trending … Earthquake Information", *Electronic Seismologist Letters.,* vol. 91, (2020): pp. 2900–2903.

requests in the month following the 2019 Ridgecrest, California earthquakes.

Further, in its 2019 annual report, the Scientific Earthquake Studies Advisory Committee described the products the EHP issued in response to the Ridgecrest earthquakes as successful. The state geologists and other stakeholders we interviewed, such as representatives from earthquake consortia and academia, also generally stated that the program's products and services were highly valuable, useful, and timely. However, the committee also expressed concern that demand for information following the earthquakes has stretched the EHP's capabilities to the limit and exposed the extent that EHP's core capabilities had eroded. Specifically, the council questioned whether the program could effectively respond to a similar-sized earthquake in an urban environment, where public demand for products and services would be much greater. In addition, USGS officials reported that the number of EHP software developers, network administrators and scientific programmers were insufficient to meet current demands.

Hazard Assessment

USGS updates the National Seismic Hazard Model and associated maps for the contiguous 48 states about every 6 years in alignment with federal statute and national building code development procedures.[72] USGS last updated these maps in 2018. However, USGS has not updated its models for Alaska since 2007, Hawaii since 1998, Puerto Rico and the Virgin Islands since 2003, and the remaining territories since 2012. USGS officials stated this because of insufficient funding and staff to update all 50 states and the territories at the same time. USGS officials reported that the appropriations committees directed $2 million in funding for fiscal year 2020 for the National Seismic Hazard Model, which the EHP is using to complete updates for Hawaii and Alaska in 2023.[73] USGS officials reported this and additional funding received in fiscal year 2021 are being directed toward to aligning model updates for Hawaii and Alaska with those for the contiguous 48 states that are planned in 2023. USGS officials also stated that, assuming current funding levels, the EHP could update the combined seismic hazard model for Puerto Rico and the Virgin Islands after updating the seismic hazard model for all 50 states in 2023.

[72]42 U.S.C. § 7704(a)(2).

[73]See House of Representatives; Congressional Record, Vol. 165, H11288, Dec. 17, 2019, excerpt from Committee report.

However, they also stated that additional funding would be necessary to include Puerto Rico and the territories in regular updates.

USGS officials report that, given the need to maintain its ongoing core National Earthquake Hazard Reduction Program functions, EHP does not have capacity to collect the data and perform large-scale assessments necessary to develop the federally mandated systematic set of national maps of seismically induced liquefaction or landslide hazards, and funding would be needed to support such an effort.[74] They also noted that such a set of national maps for landslides would fall under the purview of USGS's Landslide Hazards Program and its responsibilities under the recently authorized National Landslide Preparedness Act.[75] In addition, USGS officials stated that the program lacks sufficient resources to invest in any major urban seismic hazard study at this time—an activity that is specifically designated as one of USGS's responsibilities under federal law.[76] The Scientific Earthquake Studies Advisory Committee reported that insufficient resources forced USGS to slow existing work on urban seismic hazard maps for Salt Lake City, Utah and Reno and Carson City, Nevada.[77] The committee also stated that similar work for the San Francisco Bay, Seattle-Tacoma, Washington and Charleston, South Carolina areas is understaffed.

[74] 42 U.S.C. § 7704(a)(2).

[75] See Pub. L No. 116-323.

[76] 42 U.S.C. § 7704(a)(2).

[77] Scientific Earthquake Studies Advisory Committee, Annual Report (Reston, VA: Oct.11, 2019).

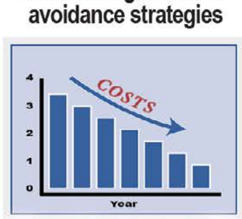
USGS Has Taken Actions to Ensure the Earthquake Hazards Program Meets Its Mission but Has Not Followed Leading Practices for Strategic Planning, Performance Measurement, and Human Capital

USGS Has Taken Several Actions to Ensure the Earthquake Hazards Program Meets Its Mission, Including Avoiding and Cutting Costs

USGS officials reported taking several cost-cutting and avoidance actions to meet its mission, which we found were consistent with our framework for managing with declining resources.[78] In 2012, we developed a framework that outlines three broad themes for agencies to effectively manage in an environment of declining resources. The framework can help guide agencies through budget challenges by providing strategies for leading from the top, using data analytics to guide decisions, and reducing costs now and in the future. Figure 6 depicts our framework themes and subthemes, and provides examples of activities that address its themes.

[78]See GAO-17-79. Cost savings are a reduction in actual expenditures below the projected level of costs to achieve a specific objective. Cost avoidance is an action taken in the immediate time frame that will decrease costs in the future.

Figure 6: Overview of GAO's Framework for Examining Agencies' Efforts to Manage Declining Resources

Key theme	Subthemes	Examples of activities that address this theme
Top management should lead efforts to manage declining resources 	Has agency management • Reexamined core mission • Taken actions to ensure the agency maintains capacity (e.g., skills, resources) to achieve its mission • Consulted with Congress and involved internal and external stakeholders	• Develop a long-term strategy for managing budget uncertainty. • Reexamine programs and organizational structures to determine if the current environment still warrants continuing certain programs and activities. • Identify current or potential mission critical skills gaps and develop a plan to address them through training, hiring, retention, and other strategies. • Clearly define and communicate the key principles & priorities for guiding budget reductions. • Engage employees, unions, and other stakeholders to inform the decision making process. • Seek congressional direction if unclear of congressional intent from budget reductions. • Evaluate and implement recommendations from stakeholders (e.g., advisory groups, Inspector General, etc.) to improve efficiency and achieve cost savings.
Data analytics should guide decision making 	Has the agency • Assessed availability and quality of data • Identified programs and activities that may be duplicative, overlapping, or fragmented • Reviewed operations to achieve additional efficiencies • Connected performance information to the budget	• Collect and use data that is sufficiently granular, reliable, timely, and accessible to make informed decisions. • Set specific cost-savings goals and monitor progress toward reaching those goals. • Reach agreement with other federal agencies, state and local governments, and the nonprofit sector on how to coordinate activities to avoid duplication and overlap. • Use a data-driven continuous process improvement approach to improve how products and services are provided. • Use strategic goals, objectives, and performance information to inform budget decisions.
Agencies should consider both short- and long-term cost-cutting and cost-avoidance strategies 	Has the agency • Developed both short- and long-term strategies • Protected key investments to avoid longer-term costs • Considered or used shared services • Implemented benchmarking practices • Established incentive structures	• Centralize the agency's contracting decisions or use government-wide strategic sourcing vehicles to lower prices and reduce duplication and administrative costs. • Reduce the size and cost of real property by consolidating, co-locating, and disposing of properties. • Use capital funds or another mechanism to support upfront investments in key areas such as information technology. • Expand the use of shared services for functions that can be shared within or among agencies such as finance, purchasing, payroll, and information technology when appropriate. • Identify best practices—through benchmarking studies or other means—then make the improvements necessary to emulate those practices. • Institute an employee-input cost savings incentive program.

Source: GAO analysis. | GAO-21-129

USGS officials reported taking several actions to manage limited resources that align with all three of our framework's themes. Specifically, the first theme in our framework states that top management should lead agencies' efforts to manage declining resources. Examples of the actions USGS officials reported taking that align with this theme follow in table 1 below.

Table 1: Actions Related to Using Data Analytics to Guide Decision-Making Reported by U.S. Geological Survey (USGS)

Activity related to top management leading USGS efforts to manage declining resources	Action USGS officials reported
Clearly define and communicate key budget principles and priorities.	USGS officials reported defining and communicating budget principles and priorities and seeking input on budget decisions for the Earthquake Hazards Program (EHP) from internal stakeholders through the EHP program council. According to USGS officials, the council is responsible for setting annual guidance for internal work, and planning and executing the program's budget. The council consists of EHP regional and topical coordinators, science center directors, and program coordinators. For example, officials reported that, starting in fiscal year 2018, annual guidance from USGS's Natural Hazards Mission Area, which oversees the EHP, stated that USGS science centers' programs should prioritize expanded work in support of the goals of USGS's 2017 Subduction Zone Science Plan as current budget levels allowed. USGS officials requested their research scientists identify "shovel-ready" targeted research projects that could be undertaken within existing USGS budget levels, and additional high-priority projects that required additional funding. In response to this direction, USGS officials reported initiating two major multi-year research projects focused on hazards of the Cascadia subduction zone, among other efforts.
Evaluate and implement recommendations from stakeholders to improve efficiency and achieve cost savings	USGS officials also reported that they seek input and evaluate the recommendations from external stakeholders, such as the EHP's Scientific Earthquake Studies Advisory Committee. For example, in 2017 and 2018, the committee recommended that EHP not adopt 72 Alaska EarthScope stations with existing core funding.[a] The committee stated that the cost of adopting all of the Alaska stations, would dramatically undermine earthquake-monitoring capabilities in the contiguous U.S.. The officials stated that the EHP accepted this recommendation.

Source: GAO analysis of USGS documents and testimonial evidence. | GAO-21-129

[a]In 2016, the Alaska Earthquake Monitoring Working Group issued a study of the costs and benefits for USGS to adopt 72 of the 158 state-of-the-art seismic stations temporarily deployed across Alaska by the National Science Foundation's US Array Project. These stations were originally to collect data between 2014 and 2018. NSF planned to decommission and remove the stations starting in 2020. However, with support from USGS and the National Science Foundation, the Alaska Earthquake Center adopted 96, and the Alaska Volcano Observatory adopted 11 of these stations.

As described in our framework, when deciding how to implement reduced appropriations, data analytics should guide agency officials' decision-making. Data analytics involves turning data into meaningful information accessible to budget and program staff and agency leaders to help them make informed decisions. USGS officials also reported examples of how they used data analytics to guide decision making. Examples of actions USGS officials reported taking that align with this theme follow in table 2 below.

Table 2: Actions Related to Using Data Analytics to Guide Decision-Making Reported by U.S. Geological Survey (USGS)

Activity related to using data analytics to guide decision-making	Action USGS officials reported
Collect and use data that is sufficiently granular, reliable, timely, and accessible to make informed decisions	The Earthquake Hazards Program (EHP) collects data from ANSS regional seismic and geodetic networks related to, among other things, the quality, consistency, and timeliness of seismic monitoring, product generation, and data. This information is used to evaluate the extent that regional and seismic networks had met performance targets. For example, EHP officials reported prioritizing monitoring capabilities in the highest risk areas as defined by the National Seismic Hazard Maps. Specifically, EHP officials stated that they had prioritized about $2.1 million in ANSS deferred maintenance funding for improvements to regional seismic networks around Salt Lake City, Utah and Memphis, Tennessee because the hazard maps had identified these as high risk urban areas.
Set specific cost-savings goals and monitor progress toward reaching those goals.	According to USGS Earthquake Hazards Program (EHP) officials, USGS regions and science centers set specific cost-savings goals and monitor progress on a case-by-case basis. For example, EHP officials report that the cost to use commercially-licensed databases rose prohibitively. As a result, EHP's two science centers set a goal of replacing these databases with low-cost or open-source database software and USGS monitored their progress.[a] EHP officials reported that the Geologic Hazards Science Center had migrated to a low-cost alternative by April 30, 2019, and had reduced its costs by about $250,000 per year. USGS officials reported that the Earthquake Science Center is conducting analyses necessary for determining alternatives that meet the requirements for its earthquake monitoring functions and its partners. These officials stated that once an alternative is selected, the center will begin migration to a lower-cost alternative.

Source: GAO analysis of USGS documents and testimonial evidence. | GAO-21-129

[a]The Earthquake Hazards Program is composed of primarily the Earthquake Science Center and the Geologic Hazards Science Center. The Earthquake Science Center is headquartered in Menlo Park, California, with field offices in Pasadena, California, and Seattle, Washington. The Geologic Hazards Science Center is headquartered in Golden, Colorado, with a field office in Albuquerque, New Mexico.

As described in our framework, when facing declining resources, agencies should employ strategies that consider both short and long-term cost cutting and cost avoidance strategies. EHP officials also reported taking actions to cut or avoid costs that align with our declining resources framework including protecting key investments to avoid longer-term costs, using capital funds or other mechanisms to support investments in key areas such as information technology, and using shared services. Examples of actions USGS officials reported taking are included in table 3.

Table 3: Short and Long-term Cost Cutting and Cost Avoidance Actions Reported by U.S. Geological Survey (USGS)

Short and long-term cost cutting and cost avoidance activity	Action USGS officials reported
Reduce the size and cost of real property by consolidating, co-locating, and disposing of properties	USGS officials reported relocating multiple Earthquake Hazards Program (EHP) programs and centers, including the Earthquake Science Center, from its Menlo Park campus to Moffitt Field, California. USGS expects to complete relocation by the end of 2023, and estimates doing so will save $300 million over 20 years.
Use capital funds or another mechanism to support upfront investments in key areas such as Information Technology.	EHP officials using capital funds to support upfront investments. According to EHP officials, EHP science centers are located in high cost of living areas making USGS salaries uncompetitive with the private sector, and negatively impacting recruitment and retention efforts for nonscientist (e.g., information technology, field technician, and administrative) positions. To address this problem, the officials plan to establish a new small office for network staff in the lower cost-of-living Stockton, California area.
Consider or use shared services	USGS officials reported that USGS has taken advantage of shared services for functions that could be shared by USGS and the program. For example, EHP officials reported that Albuquerque Seismological Laboratory's seismic instrument contracts are shared for use by the ANSS and USGS's Volcano Hazards Program.

Source: GAO analysis of USGS documents and testimonial evidence. | GAO-21-129

USGS Has Cut Costs for Earthquake Hazards Program, but Has Not Followed Leading Practices for Strategic Planning, Performance Measurement, and Human Capital Planning

USGS has taken a number of cost-cutting and cost-avoidance actions, but has not followed leading strategic planning, performance measurement, and human capital planning practices for managing its limited resources. Our declining resource framework identifies developing a long-term strategy for budget uncertainty as an example of how agencies could better manage their resources.[79] We have reported in the past that a primary purpose of federal strategic planning is to improve the management of federal agencies. In doing so, it is particularly important for agencies to develop strategic plans that address management challenges, such as budget uncertainty, threatening their ability to meet long-term strategic goals as documented in their strategic plans.[80] We have also previously identified leading practices in federal strategic planning that are most relevant to initial strategic planning efforts, including: (1) defining the mission and goal; (2) defining strategies that address management challenges and identifying resources needed to

[79]GAO-17-79.

[80]GAO, *Managing for Results: Critical Issues for Improving Federal Agencies' Strategic Plans*, GAO/GGD-97-180 (Washington, D.C.: Sept. 16, 1997).

achieve goals; (3) involving stakeholders; and (4) developing and using performance measures.[81]

Strategic planning and performance measurement. USGS has not developed a long-term strategic plan for the Earthquake Hazards Program (EHP) that articulates the mission of the entire program, lays out its long-term goals for implementing that mission for all major components of the program, identifies the strategies including the resources that are needed to reach these goals, or linked performance measures necessary for determining whether it has achieved success. Specifically, USGS has issued strategic planning documents for ANSS and its component programs, including a 10-year plan for ANSS, and 5-year plans for both the National Earthquake Information Center and the National Strong Motion Project.[82] However, USGS has not developed similar plans for the other major non-monitoring functions of the program—such as the National Seismic Hazard Map, Urban Seismic Hazard Studies, or those related to conducting or supporting applied earthquake science research, such as mapping faults and other hazard zones. As a result, USGS cannot be assured that it has fully defined the mission and long-term goals, or identified the resources needed to achieve the EHP's mission and goals for all major functions of the program.

USGS officials stated that they had not developed a strategic plan for the EHP because strategic planning practices, such as developing a strategic plan, do not apply to agencies below the departmental level. However, we have previously reported that agency-wide strategic planning practices required under the Government Performance and Results Act of 1993 (GPRA)—which were amended and expanded by the GPRA Modernization Act of 2010 (GPRAMA)—can also serve as leading

[81]GAO, *Environmental Justice: EPA Needs to Take Additional Actions to Help Ensure Effective Implementation*, GAO-12-77 (Washington, D.C.: Oct. 6, 2011). We identified six leading practices in federal strategic planning for initial strategic planning efforts: (1) defining the mission and goal; (2) defining strategies that address management challenges and identifying resources needed to achieve goals; (3) ensuring leadership involvement and accountability; (4) involving stakeholders; (5) coordinating with other federal agencies; and (6) developing and using performance measures. We selected the four that were most applicable to USGS's efforts.

[82]See USGS, *Advanced National Seismic System Current Status, Development Opportunities, and Priorities for 2017-2027*, Circular 1429 version 1.1 (Reston, VA.: Jul., 2017), *U.S. Geological Survey National Strong-Motion Project Strategic Plan*, 2017–22 (Reston, VA.: 2017), *and National Earthquake Information Center Strategic Plan, 2019–23*, Circular 1457 (Reston, VA.: 2019).

practices for planning at lower levels within federal agencies, such as individual programs or initiatives.[83] By developing a long-term strategic plan that articulates the fundamental mission of the entire program, defines its long-term goals, and identifies the strategies and resources that are needed to reach these goals, USGS can better ensure that it effectively addresses challenges to the EHP's capacity to meet its mission.

While the planning documents USGS has developed are a step in the right direction, our review of these documents found they lacked key elements of effective strategic planning. First, only one of the three plans, USGS's plan for ANSS, identifies the resources necessary for meeting the goals of the plan. Second, none of these three plans included performance measures for assessing whether the specific programs had met established goals. For example, the ANSS plan states that its goals include (1) improving coverage in the Central and Eastern U.S., and (2) expanding coverage in areas of high seismic hazard. However, the plans do not include performance measures necessary to effectively assess the EHP's progress in meeting these goals.

USGS officials stated that these documents were not intended as strategic plans but as science planning documents, as such GPRAMA requirements for strategic planning are not applicable. In addition, they stated that strategic planning practices, such as establishing performance measures, do not apply to agencies below the departmental level. They further stated that two performance measures had been established within the Department of Interior's strategic plan to evaluate USGS performance. According to these officials, these performance measures combined with the additional information provided in the department's strategic and performance plans provide a sufficient long-term strategic planning framework to objectively measure progress towards meeting the goals of the EHP, USGS, and Department of Interior. However, we have previously reported that agency-wide strategic planning practices required under GPRAMA can also serve as leading practices for planning at lower

[83]Pub. L. No. 103-62, 107 Stat. 285 (1993); Pub. L. No. 111-352, 124 Stat. 3866 (Jan. 4, 2011); GAO, *U.S. Tsunami Preparedness: Federal and State Partners Collaborate to Help Communities Reduce Potential Impacts, but Significant Challenges Remain*, GAO-06-519 (Washington, D.C.: June 5, 2006); GAO, *Veteran-Owned Small Businesses: Planning and Data System for VA's Verification Program Need Improvement*, GAO-13-95 (Washington, D.C.: Jan.14, 2013).

levels within federal agencies, such as individual programs or initiatives.[84] By developing performance measures linked to the goals established within a strategic plan, USGS can better determine whether the EHP has achieved long-term goals.

Finally, USGS sought input from multiple stakeholders, but did not engage one group of key stakeholders—Congress—in its planning efforts. Specifically, USGS sought input from stakeholders who participated or were associated with ANSS and its components while developing its strategic plans for ANSS, National Earthquake Information Center or the National Strong Motion Project. For example, USGS sought input from the members of the ANSS National Steering Committee, the ANSS National Implementation Committee, and Scientific Earthquake Studies Advisory Council to develop the ANSS strategic plan. USGS also sought input from 35 domestic and international researchers and seismic network representatives prior to developing the strategic plan for the National Earthquake Information Center.

EHP officials acknowledged they did not consult Congressional stakeholders for input when developing these strategic planning documents because they are not required to do so, under the GPRAMA.[85] However, we have previously reported that agency-wide strategic planning practices required under GPRAMA can also serve as leading practices for planning at lower levels within federal agencies including as individual programs or initiatives, such as the EHP.[86] Our work has found that involving stakeholders in strategic planning efforts can help create a basic understanding among the stakeholders of the competing demands that confront most agencies, the limited resources available to them, and how those demands and resources require careful and continuous balancing.[87] Further, our work has found that, because of its power to create and fund programs, Congressional input is indispensable to

[84]Pub. L. No. 103-62, 107 Stat. 285 (1993); Pub. L. No. 111-352, 124 Stat. 3866 (Jan. 4, 2011); GAO-06-519 (Washington, D.C.: June 5, 2006); GAO-13-95.

[85]See Pub. L. No. 111-352, 124 Stat. 3866 (2011). GPRAMA amends GPRA, Pub. L. No. 103-62, 107 Stat. 285 (1993).

[86]Pub. L. No. 111-352, 124 Stat. 3866 (Jan. 4, 2011); GAO-06-519; GAO-13-95.

[87]GAO, *Managing For Results: A Guide for Using the GPRA Modernization Act to Help Inform Congressional Decision Making*, GAO-12-621SP: (Washington, D.C.: Jun 15, 2012).

agencies' efforts to define their mission and establish goals.[88] Our previous work has also emphasized the importance of seeking Congressional input as agencies develop their strategic planning documents, not after they have completed them.[89] By consulting relevant Congressional committees as it develops its strategic plan for EHP, USGS could better ensure Congress understands the competing demands for the program's limited resources, and it establishes program priorities and goals that reflect congressional input.

Strategic workforce planning. USGS has not followed leading practices for effective strategic workforce planning principles. As previously mentioned, USGS officials, state geologists, and representatives from other stakeholders we interviewed stated that reductions in staffing and increases in the number of vacant positions were a major challenge to identifying earthquake hazards across the country. Further, USGS's 2013 Natural Hazards Science Strategy recommended that the agency perform a staffing gap analysis across the Natural Hazards Mission Area, which includes the EHP, to ensure USGS retains and hires sufficient staff with expertise necessary to study, monitor, and provide notifications and assessments of natural hazards, including earthquake hazards.[90]

However, according to USGS officials, USGS has not conducted an analysis of staffing needs. Consistent with leading practices for effective strategic workforce planning principles, such an analysis could include succession planning and a data driven assessment of its needs for critical skills and competencies.[91] USGS officials stated they have not conducted such an analysis for EHP because the highly specialized nature of the majority of the program's positions limits the benefit of a generalized analysis of critical skills and competencies. Instead, according to USGS officials, the program's two science centers regularly perform gap analyses to identify the staffing needs at the individual project level. Then, each science center creates a staffing plan and associated organizational

[88]GAO, Executive Guide: *Effectively Implementing the Government Performance and Results Act*, GAO/GGD-96-118 (Washington, D.C.: June 1996).

[89]GAO-12-621SP.

[90]USGS, *U.S. Geological Survey Natural Hazards Science Strategy: Promoting the Safety, Security, and Economic Well-Being of the Nation*, Circular 1383–F (Reston, VA.: 2013).

[91]GAO, *Human Capital: Key Principles for Effective Strategic Workforce Planning*, GAO-04-39 (Washington, D.C: Dec 11, 2003).

chart, which are maintained and revised as programmatic needs and funding levels change. However, because USGS has performed staffing gap analyses to identify staffing needs for individual projects and not across the entire EHP, USGS cannot be assured that it has identified the number of staff and the skills and competencies that are needed to meet the program's mission and its long-term goals.

Our work has shown that it is essential that agencies determine the skills and competencies that are critical to successfully achieving their missions and goals, especially when facing budget constraints.[92] Further, our work has shown that agencies must ensure that the skills and competencies identified are clearly linked to the agency's mission and long-term goals developed with input from key congressional and other stakeholders during the strategic planning process. Otherwise, the needs assessment conducted may be incomplete and premature. By completing a staffing gap analysis to determine what is necessary to achieve the missions and goals identified in the Natural Hazards Mission Area and Earthquake Hazard Program's strategic plans, USGS can be better assured that it has determined the skills and competencies needed to achieve program's missions and goals.

USGS and Its Partners Have Implemented Seismic Stations for the Early Warning System, but Several Challenges Remain

USGS and Partners Have Implemented 69 Percent of the Seismic Stations in California and 58 Percent in Oregon and Washington

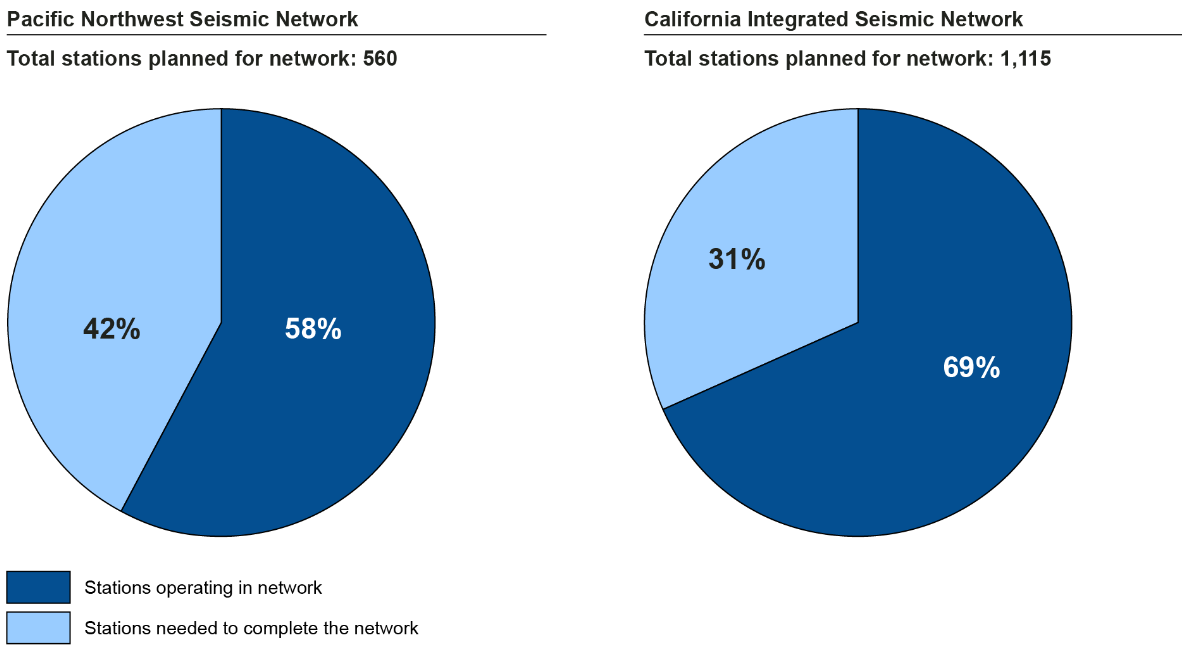
USGS and its partners have implemented 69 percent of the seismic stations planned for USGS's earthquake early warning system (ShakeAlert) in the California Integrated Seismic Network and 58 percent

[92]GAO-04-39 and GAO-17-79.

of the seismic stations in the Pacific Northwest Seismic Network.[93] The seismic stations' implementation consists of upgrading and installing new seismic stations. As of August 31, 2020, USGS updated or installed 764 of the 1,115 planned seismic stations in the California Integrated Seismic Network and 325 of the 560 planned seismic stations in the Pacific Northwest Seismic Network. According to USGS, the timeline for completing the seismic stations implementation is in fiscal year 2024 for the California Integrated Seismic Network and the end of fiscal year 2025 and for the Pacific Northwest Seismic Network. Appendix III provides additional information on USGS and other federal agencies efforts to expedite the permitting process for the seismic stations. Figure 7 shows the percent of seismic stations operating in the two networks as of August 31, 2020.

[93]California Integrated Seismic Network is a regional network within the Advanced National Seismic System consisting of seismic stations located throughout California. The regional network is owned and operated collectively by USGS, California Institute of Technology, University of California, Berkeley, California Geological Survey, and California Governor's Office of Emergency Services. Pacific Northwest Seismic Network is also a regional network within the Advanced National Seismic System consisting of seismic stations located throughout Washington and Oregon. The regional network is owned and operated collectively by USGS, University of Washington, and the University of Oregon.

Figure 7: Percent of ShakeAlert Seismic Stations Operating in the California Integrated Seismic Network and the Pacific Northwest Seismic Network as of August 31, 2020



Source: GAO analysis of U.S. Geological Survey data, as of August 31, 2020. | GAO-21-129

According to USGS, companies and organizations across industry and government sectors in California, Washington, and Oregon are using ShakeAlert to generate Earthquake Early Warning (EEW) alerts. Systems and applications are being developed to interface with ShakeAlert to provide (1) an automated response to the alert that automatically shuts down an operation, (2) an announcement over an intercom that alerts employees to take protective action, or (3) an alert over the a cellular phone to “Drop, Cover, and Hold On”. In addition, in October 2019, USGS and the state of California began using FEMA’s Integrated Public Alert and Warning System Wireless Emergency Alert in California on a test basis to send EEW alerts to the general public.

In 2016, we reported technical challenges with no-alert zones occurring with ShakeAlert implementation and false positives—or false alarms where an alert is out in error.[94]

Pacific Northwest Seismic Network monitoring station

Field engineers with the Pacific Northwest Seismic Network team at the University of Washington install an earthquake monitoring station on the slopes of Mount St. Helens. The station detects seismic waves close to where the earthquake begins.

Source: University of Washington | GAO-21-129

According to USGS, increasing the density of seismic stations would allow ShakeAlert to more quickly detect the earthquake and distribute the warning more rapidly, thereby decreasing the size of potential no-alert zones. USGS outlined a plan to address this issue in its 2018 Technical Implementation Plan, which identified the need for 500 new seismic stations in California and 310 new stations in Washington and Oregon. In addition, since 2014, USGS and its partners developed two algorithms to improve earthquake detection and to mitigate the likelihood of false positives.[95]

USGS's 2018 Technical Implementation Plan states that USGS and its partners are upgrading the Global Navigation Satellite System along the west coast to provide real time data processing with capabilities for transmitting data by satellite.[96] As of September 8, 2020, the number of Global Navigation Satellite System stations remaining to be upgraded to support ShakeAlert Operations is 103 out of 580 in California and 17 out of 233 in the Pacific Northwest.

[94]GAO, *Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System*, GAO-16-680 (Washington, D.C.: Aug. 31, 2016).

[95]These are an earthquake point-source integrated code algorithm that locates the earthquake and estimates its magnitude and a finite-fault detector algorithm that estimates the fault's centroid location, orientation, and length.

[96]The majority of Global Navigation Satellite System upgrades focus on improving the robustness and efficiency of network operations and data acquisition to ensure data flow from as many real-time stations as possible in the event of an earthquake. Specifically, these upgrades focus on two aspects: hardening telemetry and replacement of obsolete Global Positioning System receivers with modern instrumentation.

USGS Followed Two of the Best Practices for a Comprehensive Cost Estimate, but Did Not Fully Establish Work Breakdown Structure

USGS followed (i.e. fully met or substantially met) two of the best practices associated with a comprehensive cost estimate in developing its 2018 estimate for ShakeAlert, such including all life cycle costs and ensuring it is based on a technical baseline description. However, USGS did not fully follow (i.e. partially met) the best practice of establishing a standard Work Breakdown Structure for ShakeAlert. A Work Breakdown Structure is to provide a basic framework for estimating costs, developing schedules, identifying resources, and determining where risks may occur. It also provides the framework needed to develop a schedule and cost plan that can track technical accomplishments—in terms of resources spent in relation to the plan, as well as completion of activities.[97]

According to our cost estimating guide, one of the four characteristics of a high quality, reliable cost estimate is that it is comprehensive. The comprehensive characteristic has four associated best practices that state cost estimates should (1) include all life cycle costs, (2) be based on a technical baseline description, (3) document all ground rules and assumptions and, (4) be based on a Work Breakdown Structure. As shown in table 4, we assessed whether USGS met the standards for the four best practices by scoring them as having 1) fully met, 2) substantially met, 3) partially met, 4) minimally met, or 5) did not meet the standards for the best practices.[98]

[97]WBS deconstructs a program's end product into smaller specific elements that are suitable for management control. It is initially set up when a program is established and becomes successively detailed over time as more information becomes known about the program. It serves as the cornerstone of every program because it defines in detail the work necessary to accomplish a program's objectives.

[98]Partially Met – USGS provided evidence that satisfies about half of the criterion; Substantially Met – USGS provided evidence that satisfies a large portion of the criterion; and, Fully Met – USGS provided complete evidence that satisfies the entire criterion. GAO considers a score of "Substantially Met" or "Fully Met" as an indicator that the best practice was followed.

Table 4: Summary of Our Assessment of U.S. Geological Survey Cost Estimate for ShakeAlert Compared to Best Practices of a Comprehensive Cost Characteristic

Best practices for Comprehensive Cost Characteristic	Our assessment Score[a]	Our assessment
Includes all life cycle costs	◕	Technical Implementation Plan includes the cost to implement ShakeAlert as $39.4 million with a yearly operation and maintenance cost of $28.6 million.[b] The estimate is comprised of the cost to build or upgrade seismic stations and computer upgrades. Although the cost for telemetry is included, the cost of improving the infrastructure to withstand a strong earthquake is excluded.[c]
Based on a technical baseline description	●	Technical Implementation Plan provides technical descriptions and overview of the ShakeAlert program. It documents the main components of the ShakeAlert system to include alert generation, supporting tasks, alert services, and user applications. In addition, the plan and accompanying technical description was approved by management, but does not provide technical detail, but does not provide technical detail.[d]
Documents all ground rules and assumptions	◑	No formal document or process identifies the ground rules and assumptions for historical cost or identification of the risk associated with the assumptions. However, some of the ground rules and assumptions are documented in the Technical Implementation Plan and other associated planning documents.[e]
Based on a work breakdown structure	◑	Cost estimate does not use a standardized work breakdown structure for collecting and sharing data among programs, nor does it use a work breakdown structure dictionary.[f] Technical Implementation Plan identifies some high-level cost categories for ShakeAlert, such as Seismic Stations and Global Navigation Satellite Systems stations. However, the plan does not define what is included in each cost element and how each element relates to others in the hierarchy of cost.

● Fully met ◕ Substantially met ◑ Partially met

Source: GAO presentation of U.S. Geological Survey information. | GAO-21-129

[a]Partially Met – USGS provided evidence that satisfies about half of the criterion; Substantially Met – USGS provided evidence that satisfies a large portion of the criterion; and, Fully Met – USGS provided complete evidence that satisfies the entire criterion. GAO considers a score of “Substantially Met” or “Fully Met” as an indicator that the best practice was followed.

[b]USGS Revised 2018 Technical Implementation Plan for ShakeAlert System was co-developed by experts at USGS and universities with experience in seismic and geodetic networks, software, and scientific analysis of earthquakes. In addition, the plan was peer reviewed, went through formal USGS review.

[c]Telemetry is the name of the process of transmitting data from the seismic and GPS stations back to the central processing facility. The estimated cost of adding the telemetry infrastructure is $20.5 million in one-time cost with $9.8 million annually.

[d]USGS officials said its partners operating the California Integrated Seismic Network and Pacific Northwest Seismic Network and researchers from the universities used the best-known information in developing the technical baseline.

[e]USGS officials said some risks identified in the 2018 Technical Implementation Plan include uncertainty with continued funding for the network build out and obtaining timely permits for upgrading and installing seismic stations on federal lands. In addition, while risks are identified in the implementation plan, they are not assigned to any cost elements because there is no work breakdown structure.

[f] Work Breakdown Structure provides a basic framework for estimating costs, developing schedules, identifying resources, and determining where risks may occur. The WBS dictionary should state where the functional elements fall within the products and how the statement of work elements come together to make specific products.

USGS officials acknowledged that their cost estimate for ShakeAlert did not establish a Work Breakdown Structure because they do not consider ShakeAlert to be a standalone project.[99] However, according to our cost guide, a Work Breakdown Structure is needed for all cost estimates and should be developed early to provide a conceptual idea of the program size and scope and continuously developed as the program matures. As shown above in table 4, USGS 2018 Revised Technical Implementation Plan identified some high-level cost categories for ShakeAlert, such as Seismic Stations and Global Navigation Satellite Systems stations. However, the plan does not define what is included in each cost element and how each element relates to others in the hierarchy of cost. This information is important for breaking out common costs, such as government furnished equipment costs that can help ensure the estimate includes all relevant costs and avoids cost overruns.

Without a Work Breakdown Structure, the program lacks a framework to develop a schedule and cost plan that can easily track technical accomplishments—in terms of resources spent and completion of activities and tasks. In addition, by not using a Work Breakdown Structure, it causes difficulty in comparing costs from one contractor or program to another, which can results in substantial expense when collecting and reconciling contractor cost and technical data.

USGS Has Not Followed Best Practices in Establishing Schedules and Milestones for ShakeAlert Implementation

USGS has not followed best practices in establishing schedules and milestones for implementing ShakeAlert in California, Washington, and Oregon. USGS's 2018 Technical Implementation Plan states that it will take approximately 3 years to complete ShakeAlert implementation; however, the plan does not provide schedules and milestones for when these initiatives are to take place. For example, there are no schedules and milestones for completing the California Integrated Seismic Network and Pacific Northwest Seismic Network, telemetry infrastructure, hiring and training of personnel to maintain and operate the system, and completing the public education and training. In August 2020, USGS officials told us they established updated timeframes for completing the networks buildout—fiscal year 2024 for the California Integrated Seismic Network and the end of fiscal year 2025 for Pacific Northwest Seismic Network. According to USGS, as of February 2021, as a result of further delays caused by the pandemic, scheduling estimates for completing both

[99]A Work Breakdown Structure dictionary should state where the functional elements fall within the products and how the statement of work elements come together to make specific products. This dictionary is to be a document that describes in brief narrative format what work is to be performed for each element.

networks are the end of fiscal year 2025. However, there is no formal document showing the updated timelines nor has USGS established interim milestones for completing the network buildouts, specifically, or ShakeAlert, generally. According to USGS officials, they have not established schedules and milestones for ShakeAlert implementation because doing so is unrealistic and given the uncertainty of funding from Congress and the states' legislatures.[100] Specifically, officials said in looking out 3 to 5 years, USGS does not have an increment of funding covering the costs for the buildout of the networks or for the maintenance and operations. Our schedule guide states that a comprehensive schedule reflects all activities for a program and recognizes that there can be uncertainties and unknown factors in schedule estimates because of inadequate resources, limited data, technical difficulty, or other factors in the organizational environment. Further, it states that scheduling allows program management to determine the flexibility of the schedule according to available resources and allocate contingency plans to mitigate risk.

According to our schedule guide, a well-planned schedule is a fundamental management tool that can help government programs use public funds effectively by specifying when work will be performed in the future and measuring program performance against an approved plan. As a model of time, an integrated and reliable schedule can show when major events are expected, as well as the completion dates for all activities leading up to them, which can help determine if the program's parameters are realistic and achievable. The schedule should reflect all activities as defined in the program's Work Breakdown Structure. Additionally, a well-formulated schedule can facilitate an analysis of how change affects the program. Accordingly, a schedule can serve as a warning that a program may need an over target budget or schedule.

Our schedule guide also states the importance of establishing milestones within the schedule.[101] Two important milestones that every schedule should include are the project start and the finish. No work should begin before the start milestone, and all project scope must be completed

[100]According to USGS, in fiscal year 2020, $19 million in base funding and $6.7million in capital funding was appropriated for a total of $25.7 million. In fiscal year 2019, $16.1 million in base funding and $5 million in capital funding was appropriated for a total of $21.1 million. In fiscal year 2018 $12.9 million in base funding and another $10 million in capital funding was appropriated for a total of $22.9 million.

[101]Milestones are points in time that have no duration but that denote the achievement or realization of key events and accomplishments such as program events or contract start dates.

before the finish milestone. Milestones should also have clear conditions for completion. Examples of milestones include the start and finish of the design stage, start and finish of subcontractor work, and key hand-off dates between parties.

Without established schedules and milestones, USGS will not be able to identify a path forward that includes the identification of labor, materials, and overhead needed to implement the project, and whether those resources will be available when needed. By establishing schedules and milestones, USGS will be able to determine how long each activity will take, allowing for progress measurement with specific start and finish dates. Further USGS will be in a better position to track completion of key activities to which they are held accountable, and account for schedule delays that impact the overall cost of ShakeAlert.

Licensed Operators and Organizations Use Early Warning Application Systems to Respond to Notification Alerts, But Challenges Remain

As of September 2020, seven commercial technical operators licensed by USGS and 46 organizations within government and industry sectors are using application systems in California, Washington, and Oregon to provide automated responses to an EEW notification alert.[102] We interviewed four licensed commercial operators that developed application systems and seven organizations that developed or adopted application systems to identify how their systems are being used, and whether they are providing training and education to the end users. The organizations also discussed some of the challenges they encountered using the application system.

According to all four licensed operators, they developed the EEW system's applications under a USGS pilot process that took 1 to 4 years to complete.[103] Some of the system applications have the capability to automatically open garage doors to fire stations, close water valves for

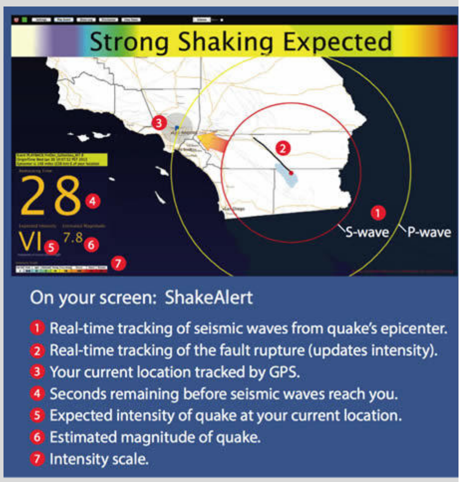
[102]Commercial technical operators are companies that develop and implement application systems for organizations within the government, transportation, entertainment, education, public health, and emergency management sectors, among others. The seven licensed operators are Early Warning Labs, Google, MyShake, RH2 Engineering, SkyAlert, Valcom, and Varius.

[103]All four licensed operators said they received a License to Operate agreement from USGS between 2019 and 2020.

utility companies, or make an announcement over an intercom system.[104] Other applications, such as the cell phone application, have the capability to provide EEW alert notifications to users who download the application on their mobile device. Three of the four licensed operators said the research, development, and testing required to validate their system application took a significant investment of resources.

Sample ShakeAlert data on magnitude and intensity of earthquake

Commercial licensed operators can access data from USGS on the earthquake's magnitude, intensity scale, expected intensity of the quake, and seconds remaining before the waves reach their location.



Source: U.S. Geological Survey | GAO-21-129

Two of the four licensed operators told us they provide education and training to organizations that adopted their application systems. The type of training and education generally depends upon the application system being used. For example, employees of organizations that use automated systems to open garage doors or close water valves are trained on the application system operations and protocols to follow once an alert is received.

All four licensed operators said they would like to see more outreach and education by USGS and its stakeholders to better inform industries government sectors about the benefits of application systems. Some of the benefits described to us include saving lives and minimizing damage to equipment and the infrastructure.

We also met with seven of the 46 organizations that are using EEW application systems in California, Oregon, and Washington across government and industry sectors.[105] Our selection criteria and other details about how we analyzed these responses is presented in more detail in appendix I. All seven organizations told us they are using the

[104]System applications are connected with USGS servers to allow access to data streams and notification alerts. In those instances where the earthquake exceeds a pre-determined minimum magnitude and intensity threshold, the application system triggers an automated response. Alert threshold is a pre-determined minimum magnitude and intensity threshold that must be exceeded before an application system triggers an automated response. For example, a utility company may set its application system to automatically shut down a water line valve when earthquake shaking exceeds a magnitude of 4.0. According to USGS, organizations set up their alert threshold within their application system based on their preferences.

[105]The 46 organizations use EEW application systems to alert employees and activate systems to take protective actions. System applications developed by the 46 ShakeAlert partners are connected to USGS servers to allow access to data streams and alert notifications.

EEW systems and applications to save lives and minimize damage to their equipment and infrastructure.[106]

Promising Practices identified by organizations using Early Earthquake Warning (EEW) application systems

- Building in multiple redundancies for internet support in the event the internet system goes down. For example, the Menlo Fire Department uses Comcast broadband as its primary internet support, and has a backup internet connection with AT&T.
- Working with emergency management in using the application system to alert the public about other types of disasters, such as COVID 19.
- Bringing in internal stakeholders such as (Information Technology, Safety and Security, and Property Management) and educating them on the benefits of having an application system.
- Bringing in state regulatory agencies early in the implementation process to educate them on the need to develop exceptions to standards to allow the use of internet for EEW application systems.

Source: GAO analysis of best practices identified by 7 of the 46 organizations using EEW application systems. | GAO-21-129

Five of the seven organizations told us they are using application systems to initiate an automated action to shut down a process such as closing garage doors, slowing down trains, or making a public announcement. [107] For example, according to the Menlo Park Fire Protection District, two of its fire stations are using application systems to automatically turn on warning lights and open garage doors in those instances when an earthquake exceeds the minimum magnitude and intensity alert threshold.

Five of the seven organizations told us they are educating and training their employees on the EEW application system, such as what steps to take once an alert is received. For example, according to a Los Angeles Unified School District official, students and teachers are being educated and trained to help them understand what action they need to take when an EEW alert is announced over the intercom. Through monthly earthquake drills, the school district practices the scenario where the alert is announced and the students and teachers drop, cover, and hold on.

In our discussions with officials from the organizations that are using application systems within government and industry sectors, we were told about the challenges they faced during the development, testing, and operations. For example, some organizations faced challenges in determining where to set the EEW alert threshold because it requires them to take into consideration their tolerance for false positives and to make decisions about how much risk they are will to accept. See table 5

[106]In August 2016, we reported USGS and its stakeholders had not developed a certification plan defining the requirements for education and outreach. The certification plan is to ensure organizations using the EEW application systems act responsible when issuing warnings. According to USGS, in July 2020 the pilot license program was amended to require the technical partners (those with pilot license and license to operate agreements) to develop an education and training plan. Upon completing the pilot, licensed operators are required to implement the plan and collaborate with USGS to ensure the education and training standards are being met. USGS also required its non-technical partners to define and develop communication, education, and outreach programs that meet USGS and partner expectations. The products and programs should include training materials, drill exercises, campaigns, and videos.

[107]System applications trigger an automated response in those instances when the earthquake exceeds the organization’s pre-determined minimum magnitude and intensity threshold.

below for a summary of challenges identified by the organizations adopting EEW application systems.

Table 5: Summary of Challenges Identified by the Organizations Adopting Earthquake Early Warning (EEW) Application Systems

	Summary of challenges
Vulnerability with application systems	Application system relies on the internet to operate and is therefore vulnerable to outages and the internet's capability to operate the system.
Public understanding of EEW alerts	Sending an EEW alert to the general public created challenges because some may not understand the message due to a language barrier.
Setting EEW alert thresholds[a]	Determining where to set alert thresholds when setting up the application system is challenging because it requires the organization to take into consideration the tolerance for false positives and to make decisions about how much risk it is willing to accept.
Alerting public by general announcement	Sending an alert to the general public by a public announcement is challenging because it can create a negative psychological response. For example, hundreds of people congregating on a station platform during rush hour could cause panic and cause injuries as many rush to station exits.
Agencies concerns over public announcements	Using a public announcement system to send an EEW alert to the public is challenging because USGS or local agencies have concerns about liability, false positives, and social science issues.
Funding EEW Application Systems	Obtaining funding to implement ShakeAlert is challenging because the perception is that an earthquake disaster will never happen to them.
Cost for application systems	Cost to operate EEW systems may be cost prohibitive. For example, in the education sector, this is because many schools do not have the funding to support the cost of the device, subscription for data, and the time investment needed to fully operate the system.

Source: GAO analysis of challenges identified by organizations adopting EEW systems and applications. | GAO-21-129

[a]Alert threshold is a pre-determined minimum magnitude and intensity threshold set up by the organization. The earthquake must exceed the threshold to have the application system trigger an automated response. For example, a utility company may decide to have its application system automatically shut down a water line valve when the earthquake reaches a magnitude of 4.0. According to USGS, organizations set up alert threshold within their application system based on their preferences.

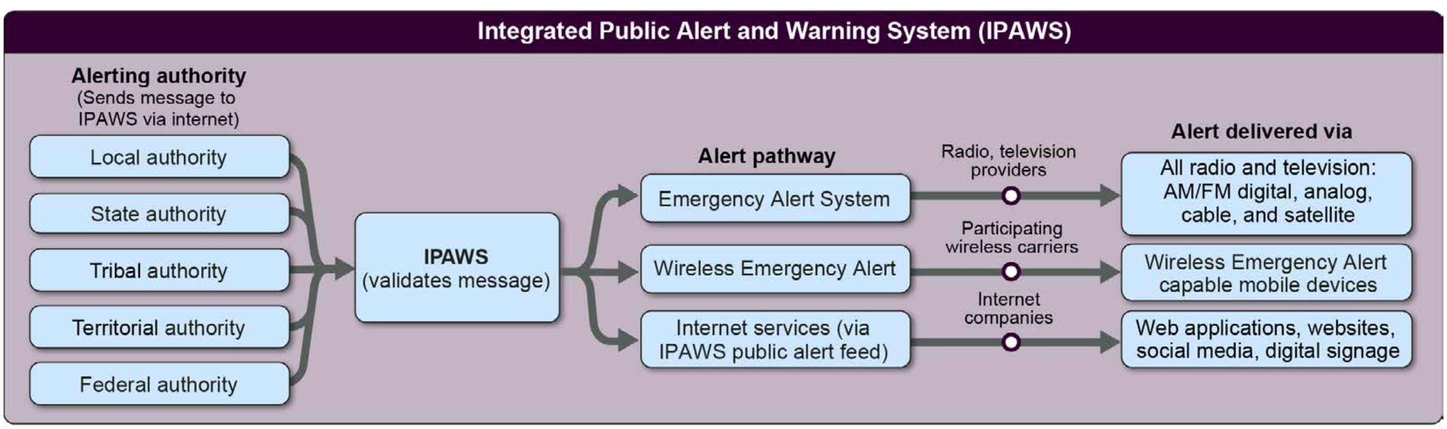
Officials from all seven organizations told us they are working with USGS, ShakeAlert Joint Committee on Communication, Education, and Outreach, and working groups, and relevant state and local agencies to address the challenges. Some of the initiatives by the Joint Committee for

Communication, Education, and Outreach addressing the challenges are discussed later in the report.

USGS Experienced Reliability Challenges with FEMA's Integrated Public Alert and Warning System and, Is Taking Steps to Address Key Issues

USGS and the State of California experienced reliability challenges using FEMA's Integrated Public Alert and Warning System (IPAWS) to deliver alerts from ShakeAlert, but steps are being taken to address key issues. On October 17, USGS and the State of California selected FEMA's Integrated Public Alert and Warning System (IPAWS) to deliver EEW alerts from ShakeAlert to end user's mobile devices.[108] According to USGS, IPAWS was selected as the mechanism to deliver earthquake early warning alerts to mobile devices because it has the capacity to deliver mass notifications to the general population. In addition, according to USGS, they also selected the system because it does not require the users of mobile devices to download an application. Figure 8 shows the IPAWS pathways available to agencies to send alerts to the general public. The different pathways can deliver alerts to radios, television, wireless emergency alert, web applications, and social media.

Figure 8: Alerting Capabilities through the Integrated Public Alert and Warning System



Source: GAO analysis of Federal Emergency Management Agency information. | GAO-21-129

In August 2016, we reported that USGS and its stakeholders were considering IPAWS but had not defined the communication methods for

[108]In 2004, FEMA initiated the IPAWS program to integrate the Emergency Alert System and other public-alerting systems into a larger, more comprehensive public-alerting system. The Wireless Emergency Alert allows authorized federal, state, territorial, tribal, and local government agencies to send text messages to mobile devices in geographically selected areas.

distributing ShakeAlert warnings to the public.[109] However, according to the EEW Coordinator, there were concerns about using IPAWS because the system did not immediately announce a warning and the resulting delays could render ShakeAlert useless during earthquakes where the warning only precedes shaking by a few seconds.

In March 2019 and June 2019, USGS and its partners conducted two controlled tests in Oakland, California and San Diego County, California respectively to (1) identify the extent there are delays delivering EEW alerts to mobile devices using IPAWS, and (2) determine whether the delivery times for EEW alerts provide sufficient time for most people to take protective action.[110] Based on preliminary findings, the results of both tests showed reliability challenges delivering EEW alerts to end users.[111] For example, the technical tests conducted in Oakland showed 49 percent of the EEW alerts were not received by the end users; in San Diego County, 31 percent of the alerts were not received.[112]

In addition, some observations from the tests showed (1) pre-2008 cellular devices were problematic with alert delivery times, (2) marginal differences in delivery times among network providers, (3) newer or more expensive technology did not correlate to faster message delivery times, and (4) use of geofence for targeting messages to geographic areas specified by an electronic boundary was effective.[113] USGS concluded from the tests that further testing is recommended to understand how

[109]GAO-16-680.

[110]USGS partnered with the California Governor's Office of Emergency Services (Cal OES), Federal Communications Commission, and local emergency management partners to conduct controlled tests in Oakland and San Diego County.

[111]USGS, *Latency Testing for Wireless Emergency Alerts intended for the ShakeAlert, the earthquake early warning system for the West Coast of the United States of America*, draft manuscript, September 14, 2020.

[112]Results from the technical test in Oakland showed 3 percent of the EEW alerts were received within 3 to 5 seconds, 40 percent within 6 to 10 seconds, 49 percent were not received, and 9 percent were received, but unsure about the time the alert was received. Results from the technical test in San Diego County showed 1 percent of the EEW alerts were received within 3 to 5 seconds, 49 percent within 6 to 10 seconds, 13 percent within 11 to 20 seconds, 3 percent beyond 20 seconds, 31 percent were not received, and 3 percent were received, but unsure about the time the alert was received. According to USGS, ideally they would like to have the EEW alerts delivered to the end user's mobility device within 5 seconds.

[113]Geofencing (sometimes called geo-targeting) defines a virtual perimeter representing a real world geographic area.

technical upgrades like 5G and other improvements may improve delivery times.[114]

According to USGS officials, they are working with FEMA, the Federal Communications Commission, and wireless carriers to improve IPAWS effectiveness and speed in disseminating ShakeAlert early warning alerts.[115] For example, on June 21, 2019, Director of USGS sent a letter to the Federal Communications Commission requesting that (1) IPAWS messages generated by ShakeAlert bypass the requirement of targeting messages to geographic areas specified by an electronic boundary; (2) wireless carriers improve their system's capability to deliver alerts to end user's mobility devices, ideally within 5 seconds; and (3) IPAWS support a unique alert attention sound for the EEW system.[116] In September 2019, the Federal Communications Commission granted the first of these three requests; as of December 2020, two requests remain pending. In addition, USGS officials said they work with FEMA to monitor the processing times of live EEW alert sent through the IPAWS gateway and identify upgrades planned by FEMA in 2020 and 2021.[117]

[114]USGS, *Latency Testing for Wireless Emergency Alerts intended for the ShakeAlert, the earthquake early warning system for the West Coast of the United States of America*, draft manuscript, September 14, 2020.

[115]FEMA is responsible for operating, maintaining, and administering access to IPAWS. FEMA, in consultation and coordination with Federal Communications Commission, must also carry out various actions to modernize and implement IPAWS. For example, FEMA must ensure IPAWS can send alerts to specific geographic locations and conduct nationwide tests of IPAWS, among other things. Federal Communications Commission creates the rules for IPAWS Wireless Emergency Alerts and establishes technical requirements participating wireless carriers must follow for delivering alerts to mobile devices.

[116]According to USGS, a unique ShakeAlert warning alert sound is needed but is not supported under current FCC rules. Wireless Emergency Alerts make the same sound so users cannot distinguish between Amber, weather, or ShakeAlert without finding their phone, waking it up, and reading the message. These actions will consume most or all of the warning time reducing or eliminating the time a user has time to take protective action before shaking has arrived.

[117]For example, FEMA plans to launch its v3.11 gateway software in August 2020 to help improve processing times for Wireless Emergency Alerts. In addition, FEMA plans to begin work on an initiative to provide a fast-path for ShakeAlert EEW alerts in 2021.

Further, in February 2020, we reported on the limitations using IPAWS for emergency alerting.[118] For example, alerting authorities expressed concerns about the ability to target wireless emergency alerts to specific geographic areas, which caused some alerting authorities to lack confidence in the system or not use it at all.[119] Alerting authorities also said that because wireless alert is a one-way communication system, they do not know if the alerts reached the intended public.[120] FEMA officials said they are preparing to conduct the next nationwide wireless emergency alert test in late 2020, and are developing a survey to accompany the test to collect data on message delivery. We recommended that the Federal Communications Commission develop specific, measurable goals and performance measures for its efforts to monitor the performance of new Wireless Emergency Alert capabilities, such as enhanced geofencing and expanded alert message length. As of March 2021, the Federal Communications Commission has not provided documentation on any efforts actions under way to address this recommendation. It is too soon to tell whether these actions will address the earthquake early warning challenges identified in this section.

USGS Has Not Clearly Defined Stakeholder Roles and Responsibilities for ShakeAlert Communication, Education, and Outreach Efforts

USGS has not clearly defined the roles and responsibilities of state emergency managers and other stakeholders for communication, education, and outreach activities related to ShakeAlert in their respective states. In July 2016, USGS formed the ShakeAlert Joint Committee for Communication, Education, and Outreach (Committee). However, in August 2016, we found that USGS's expansion of its governance structure could better define roles and responsibilities and create the plans needed to fully implement ShakeAlert.[121] This committee, led by

[118]GAO, *Emergency Alerting: Agencies Need to Address Pending Applications and Monitor Industry Progress on System Improvements*, GAO-20-294 (Washington, D.C.: Feb. 6, 2020).

[119]Alerting authorities include emergency management or law enforcement agencies at the state, county, or city government level that issue alerts through IPAWS. Non-governmental organizations such as a local emergency management association may be granted an authority to issue alerts through IPAWS with approval from FEMA or an alerting authority. Agencies that wish to use IPAWS must apply to FEMA to become approved alerting authorities.

[120]During the southern California wildfires in December 2017 and November 2018, California officials said that WEA messages were targeted to certain areas during the fires, but they did not know whether people received them because geofencing was not precise and cell towers may have been damaged.

[121]GAO-16-680.

USGS, is comprised of stakeholders representing the emergency management communities of California, Oregon, and Washington; the various university partners; and geological surveys.[122]

USGS officials reported that the primary responsibility of the committee is to develop communication, education, and outreach resources. These resources include research-based advice on how to design ShakeAlert's message contents to ensure people respond to earthquake warnings. For example, USGS officials told us of the Committee's efforts that include: issuing a white paper in June 2017, that identifies the behaviors of wireless device users after receiving a ShakeAlert warning. Additionally, the committee issued a ShakeAlert Messaging Toolkit, which is designed to be used by emergency management professionals and other earthquake preparedness practitioners.[123] The toolkit is used to augment existing earthquake preparedness efforts, provide consistent information about ShakeAlert, and promote protective actions.

In addition, USGS and the Committee collaboratively developed a draft ShakeAlert Communication, Education, and Outreach Plan (outreach plan) in July 2018.[124] The outreach plan, among other things, outlines how USGS, the states, and local agencies are to coordinate on their respective communication, education, and outreach efforts for ShakeAlert. For example, the outreach plan states that USGS's role is to encourage and coordinate public education and training activities related to ShakeAlert. Specifically, the state emergency management offices and local organizations are to coordinate with the Committee to develop, test, and implement education and training materials. The outreach plan also identifies five priority areas identified by the Committee and other stakeholders as being necessary for the successful implementation of the ShakeAlert Communication, Education, and Outreach Program: (1) Public Safety, Preparedness, and Resilience; (2) Technical Implementation and User Engagement; (3) Consistent Messaging and Communication; (4) Integration with Other Federal and State Earthquake Hazards Products;

[122]The Joint Committee for Communication, Education, and Outreach was formed to provide advice on necessary communication, education, and outreach approaches and resources that take into consideration the technical capabilities and limitations of the system, best practices, social science, and user-specific needs.

[123]See ShakeAlert Messaging Toolkit (June 2020).

[124]See "Draft" ShakeAlert Joint Committee for Communication, Education, and Outreach, Communication, Education, & Outreach (CEO) Plan: 2018 ShakeAlert – Phased Alerting (July 2018). USGS officials stated that although this document was labeled as draft, the plan is considered to be in effect and operational.

and (5) ShakeAlert Educational Resources Development and Dissemination.

However, as of December 2020, USGS and the Committee have not completed the outreach plan. Specifically, the draft outreach plan states that it does not (1) include a timeline and milestones for issuing the plan; (2) assign roles and responsibilities for who will do the work described in the plan; and (3) prioritize the activities listed in the plan. The draft plan further acknowledges that, as a result, it lacks critical elements necessary to facilitate sound decision-making for utilizing limited resources and time necessary to support ShakeAlert. Our prior work has identified mechanisms federal agencies can use to implement interagency collaborative efforts including: (1) outcomes and accountability, and (2) bridging organizational cultures, (3) leadership, (4) clarity of roles and responsibilities, (5) participants, and (6) written guidance and agreements.[125] Specifically, theses mechanisms can be used to address a range of purposes including policy development, program implementation, information sharing, and communication.

USGS officials stated the committee has six standing working groups that align their roles and responsibilities with the five communication, education, and outreach priorities outlined in the outreach plan, and activities are not undertaken if they do not fit within the priorities. USGS stated that roles and responsibilities between state and local agencies and other stakeholders have been sufficiently defined, because Committee members have a role in deciding whether an activity is within their scope.

However, all of the officials we interviewed from the three state emergency management offices responsible for developing and implementing ShakeAlert communication, education, and outreach efforts in their states, stated that USGS had not clearly defined roles and responsibilities related to such efforts. For example, two of the three officials said that they had experienced challenges in the activation of the ShakeAlert in their states because roles between the different stakeholders are not clearly defined. For instance, a representative told us that the lack of clarity on roles and responsibilities hinders states and other stakeholders from making decisions, including implementing

[125]*GAO, Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012). Our work identified a seventh collaboration mechanism, resources. We did not include this mechanism in our evaluation of USGS efforts because it was not applicable.

improvements, to the alerting process. Further, this state representative reported the states' decision-making is not aligned related to the rollout of the ShakeAlert system. For example, according to this official, the states have not agreed on what the ShakeAlert "alert" tone should sound like prior to the system's rollout in California. As a result, there potentially could be multiple different "alert" tones, which could, for example, confuse an individual from California who is visiting Washington State. This official further stated that because stakeholders have not agreed on a standardized ShakeAlert tone, cell phone app developers could also use different alert tones potentially further increasing confusion. In addition, the representative stated ShakeAlert Plan's goals have not been met because the responsibilities regarding communication education and outreach activities between USGS and California, Oregon, and Washington have not been clearly defined.

Moreover, the three states have established their own plans that highlight the importance of having clear roles and responsibilities. Specifically, the Cascadia Region Earthquake Workgroup released its Pacific Northwest Strategy for Earthquake Early Warning Outreach, Education, and Training.[126] The strategy defines how Oregon and Washington plan to ensure the successful development, implementation, and preparedness activities associated with earthquake early warning in the U.S. According to the strategy, one of the most critical activities for the future success of earthquake early warning, is the formalization of an organizational structure with clearly defined roles and responsibilities for outreach, education, and training.

In addition, the California Governor's Office of Emergency Services published its Business Plan for the California Earthquake Early Warning System (California Plan) in May 2018.[127] California's Business Plan states that defining roles and responsibilities is particularly important given the decentralized nature of earthquake early warning management in California, in which both state and federal agencies, as well as university partners within and outside of California, have responsibility for the ShakeAlert system. In addition, the California Plan states that due to the

[126]Over 100 stakeholders representing all levels of government and business collaborated to develop the Pacific Northwest a strategy that focuses on the role of stakeholders in the socialization of earthquake early warning. This project, led by the Cascadia Region Earthquake Workgroup, the Oregon Office of Emergency Management, and the Washington Emergency Management Division released the *Pacific Northwest Strategy for Earthquake Early Warning Outreach, Education, and Training*, (March 2018).

[127]See *Implementing Earthquake Early Warning in California,* (May 2018).

lack of defined roles and responsibilities, there is no mechanism for determining who would inform the public or respond to questions about how to access the signal from the system. A representative from another state also expressed concern that unclear roles and responsibilities in regard to who is to inform the public could cause public confusion and distrust.

USGS officials acknowledged that they have not completed the draft outreach plan to include the missing elements, but have been incorporating the missing plan elements in various projects and published papers. For example, USGS worked with an external contractor to develop a messaging toolkit, as well as two social science projects that are currently underway to educate people on how ShakeAlert works and how to use it. USGS officials also stated that the lack of existing model programs to follow, along with the constant growth within the ShakeAlert system, and budget uncertainty for USGS and its state partners were challenges to establishing timelines and prioritization. Officials stated that they expect to updated and complete the plan within calendar year 2021. However, USGS officials stated that they have not documented their timeframe for finalizing the plan, due to lack of sufficient staff.

We recognize that implementing new technology such as earthquake early warning presents unique challenges for USGS. However, with an updated and completed outreach plan, USGS could better ensure it develops the guidance and identifies the resources necessary to fully implement ShakeAlert's Communication, Education, and Outreach Program. Additionally, by completing the outreach plan, USGS can better ensure its decision-making for the ShakeAlert education and outreach program effectively identifies and utilizes limited resources and time necessary to accomplish the outreach plan's priorities and goals. Furthermore, by updating and completing the plan USGS can better ensure that USGS and the other stakeholders all have a shared understanding of how to communicate and educate the public on the ShakeAlert system.

USGS and NOAA Have Established But Not Fully Implemented a Memorandum of Understanding for Coordinating and Sharing Tsunami Related Information

In 2016, USGS and NOAA signed a memorandum of understanding to establish a framework for coordination including sharing data and information-sharing, but the agencies have not fully implemented the terms of the memorandum.[128] NOAA's NWS and USGS both gather data from their sensors on earthquakes that may potentially generate a tsunami (i.e., tsunamigenic). In addition, each agency uses the data gathered from its sensors, and those of its partners, to make its own determination of the location and magnitude of an earthquake. For example, NWS officials reported that near real-time data from USGS's ShakeAlert system is available and may be used by the tsunami warning centers to help determine potential for a tsunami. However, NWS officials told us that they face challenges in coordinating and sharing information with USGS. Specifically, NWS officials stated that the differences in the agencies' respective mission priorities, and the time necessary to issue an alert or other notifications in a timely manner, pose challenges.

NWS officials stated that, to determine whether to issue a tsunami warning, scientists at its Tsunami Centers must first determine the location and magnitude of a potentially tsunamigenic earthquake. According to NWS officials, these scientists must make this determination within 5 minutes of an earthquake's origin. Otherwise, NWS cannot issue a tsunami alert with sufficient time for the public to take protective action. In contrast, USGS is responsible for determining the size and location of significant domestic and international earthquakes.[129] Because of this responsibility, USGS officials stated that scientists at the National Earthquake Information Center prioritize quality and accuracy of information over speed when determining the location and magnitude of an earthquake. As a result, internal procedures require the public release of earthquake origin information (location and magnitude) within 20 minutes of the earthquake.

To help address the different priorities of the two agencies and improve interagency coordination and information-sharing, USGS and NOAA signed a memorandum of understanding in 2016.[130] The memorandum sets forth general terms and conditions that state how both agencies are

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[128]*Memorandum of Understanding between the U.S. Geological Survey of the U.S. Department of the Interior and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce,* (October 2016).

[129]42 U.S.C. § 7704(b)(3).

[130]The memorandum was signed by USGS and NOAA on March 3, 2016 and October 13, 2016, respectively.

to coordinate and cooperate. For example, the agreement states that USGS and NOAA should, among other things, endeavor to cooperate in mutual areas of interest and share data, information, and findings of mutual concern. However, our analysis indicates that the memorandum of understanding does not detail specific, actionable items for either agency on how to share data, information, and findings of mutual interest. For example, NWS officials stated that the current provisions on information-sharing are too broad, and that an annex to the memorandum of understanding detailing how USGS and NWS specifically are to coordinate and share data and other information could be helpful.

In particular, NWS officials told us that the Tsunami Warning Centers could benefit from the National Earthquake Information Center sharing its preliminary determination of the source and magnitude of an offshore earthquake within 5 minutes of its detection. NWS officials said they understood that USGS cannot complete its analysis within 5 minutes and that it final analysis may change. Nevertheless, these officials stated that receiving USGS's preliminary analyses would give the Tsunami Warning Centers greater confidence in the accuracy of their determination, and help them to do so quickly. For example, according to NWS officials, when a major earthquake occurs along the approximately 750-mile Cascadia subduction zone, shaking likely will exceed 5 minutes.[131] In this instance, officials stated, it would be difficult for the Tsunami Warning Centers to determine the location, magnitude, whether the earthquake will generate a tsunami, where and when the tsunami will arrive, and issue warnings and alerts to the public over such a large area within such a short amount of time. Further, a 2011 National Research Council Report on the Tsunami Warning System found that the Tsunami Warning Centers could benefit from obtaining estimated earthquake locations and magnitudes from USGS's National Earthquake Information Center. The report also stated that an interagency agreement could be established to make these initial estimates available on secure lines between USGS and NOAA.[132]

NWS officials said they have discussed partnering with USGS, such that the National Earthquake Information Center would provide preliminary

[131]The Cascadia Subduction Zone stretches from mid-Vancouver Island in southern British Columbia, Canada to Cape Mendocino in northern California

[132]National Research Council, *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts*. (Washington, DC: 2011).

results regarding the source and magnitude of an earthquake to the Tsunami Warning Centers within five minutes, or perform the analysis for them. However, NWS officials stated they were unsuccessful in engaging USGS officials because USGS is not required to provide its preliminary analyses to the NWS.

USGS officials told us that there was no specific need or benefit to justify an update or annex to the current memorandum of understanding between USGS and NOAA. USGS officials acknowledged having informal discussions with NWS regarding sharing the National Earthquake Information Center's preliminary results, but they stated they have not received a formal request to share such data. USGS officials told us that the National Earthquake Information Center has the technology and technical expertise necessary to meet the NWS's 5-minute objective for issuing a tsunami alert. However, they said USGS would need additional staffing and sustained funding necessary to do so without overwhelming its capacity to meet its earthquake hazards mission.

Further, the memorandum of understanding states that USGS and NOAA should establish a USGS and NOAA Interagency Committee for Program Coordination.[133] As of March 2021, USGS and NOAA had not established the Interagency Committee for Program Coordination per their MOU, though it was chartered in 1982. However, USGS and NOAA headquarters and NWS officials we interviewed acknowledged that the agencies have not met through this committee. These officials stated that the agencies meet on a sufficient basis through other formal mechanisms to ensure effective coordination and information sharing. For example, they noted that USGS and NOAA leadership met in 2017 and 2019 to identify and discuss, among other things, areas of collaboration and opportunities to achieve efficiencies in common services. However, our review of the meeting summaries that NOAA provided found neither USGS's Earthquake Hazards Program nor the NWS's Tsunami Warning Centers were discussed at the directors' 2019 meeting. By fully implementing the memorandum of understanding through both the establishment of the interagency committee and holding regular meetings through the committee, USGS and NOAA could be better assured that the agencies effectively coordinate and cooperate including sharing data and other information necessary to carry out their respective missions

The USGS/NOAA Interagency Committee for Program Coordination is to be jointly chaired by individuals that have been nominated from each agency. The Joint Committee will have authority to establish working groups to undertake studies, and will meet on an annual basis. [133]

related to detecting earthquakes and tsunamis and issuing warning for these hazards.

Conclusions

Major earthquakes are infrequent but catastrophic events. They have the potential to claim many lives and cause unprecedented damage, as well as social and economic upheaval to affected communities in the U.S.. For example, FEMA estimates that annualized loss from earthquakes to be $6.1 billion in losses per year. Further, population growth in areas known to be vulnerable to earthquakes has grown since 2006. As a result, the number of people in the U.S. who are estimated to live or work in areas with the potential for experiencing damaging ground shaking has grown from 75 million to 143 million.

To meet its mission and to help ensure public safety, mitigate losses, and improve resilience to earthquake hazards, USGS monitors and studies earthquake hazards and uses this information to provide warnings, create assessments, or generate products for earthquake response and planning efforts. USGS officials, state geologists, and other stakeholders we interviewed stated that USGS's capacity to meet its mission has been impeded by limited discretionary resources for its core capabilities, such as conducting assessments and applied scientific research. For example, USGS officials report that flat discretionary resources and vacancies in staffing have resulted in, among other things, the curtailment of additional major urban seismic hazard study at this time—an activity that is specifically designated as one of USGS's responsibilities under federal law.[134]

In response, EHP officials reported taking several actions to manage its limited resources. However, USGS could improve its strategic planning in three areas. By developing a comprehensive strategic plan for the EHP that includes performance measures linked to the goals established in the strategic plan, USGS can better ensure it has the long-term planning framework necessary to facilitate an appropriate balance between the program's monitoring and other aspects of the program. By consulting Congress and other stakeholders as it develops future strategic planning documents and revises existing ones, USGS can better determine and share with Congress information that enhances the EHP's ability to meet its mission, under different scenarios including directing discretionary resources to or from the EHP's research, monitoring, or assessment functions. By completing a staffing gap analysis to determine what is

[134] 42 U.S.C. § 7704(b)(3)(A).

necessary to achieve the missions and goals identified in the Natural Hazards Mission Area existing strategic science plan, and a future Earthquake Hazard Program's strategic plan, USGS can be better assured that it has determined the skills and competencies needed to achieve EHP's missions and goals.

USGS has made progress implementing seismic stations and expediting the permitting process for the installation of seismic stations for ShakeAlert. USGS also substantially met two of the best practices associated with a comprehensive cost estimate when developing its 2018 estimate for ShakeAlert. However, opportunities exists for USGS to improve the cost estimate by establishing a work breakdown structure and updated timeframes for completing ShakeAlert implementation. By taking these actions, USGS can ensure it has, among other things, a framework for estimating costs, developing schedules, identifying resources, and determining where risks may occur to ShakeAlert implementation and if the program's parameters are realistic and achievable.

USGS formed the ShakeAlert Joint Committee for Communication, Education, and Outreach and drafted a ShakeAlert Communication, Education, and Outreach Plan. By completing the outreach plan to include the three areas the plan identified as missing, USGS can better ensure USGS decision-making for ShakeAlert education and outreach program effectively utilizes limited resources and time necessary to accomplish the priorities and goals outline in its plan.

USGS and NOAA have established memorandum of understanding to establish a framework for coordination including data and information sharing. However USGS and NOAA have not fully implemented the memorandum, including establishing the USGS and NOAA Interagency Committee for Program Coordination. By fully implementing the memorandum of agreement, including establishing the interagency committee, USGS and NOAA could be better assured that the agencies effectively coordinate and cooperate, including regarding sharing data and other information necessary to carry out their respective missions related to detecting earthquakes and tsunamis and issuing warning for these hazards.

Recommendations for Executive Action

We are making a total of nine recommendations, including seven to the Director of USGS, and one each to the Secretaries of Commerce and the Interior. Specifically:

The Director of USGS should develop a strategic plan for the Earthquake Hazard Program that articulates the fundamental mission of the entire program, lays out its long-term goals for implementing the plan, and identifies the strategies and resources that are needed to reach these goals. (Recommendation 1)

The Director of USGS should develop performance measures for the strategy to determine whether the Earthquake Hazard Program has achieved the strategy's goals after it has drafted the strategic plan. (Recommendation 2)

The Director of USGS should consult with relevant Congressional committees when developing its strategic plan for EHP. (Recommendation 3)

The Director of USGS should complete a staffing gap analysis for the Earthquake Hazard Program that is clearly linked to the mission and long-term goals of the Natural Hazards Mission Area and Earthquake Hazard Program's strategic plans. (Recommendation 4)

The Director of USGS should establish a Work Breakdown Structure with identified costs for ShakeAlert consistent with best practices in GAO's cost guide. (Recommendation 5)

The Director of USGS should establishing a schedule and milestones for ShakeAlert implementation consistent with best practices in GAO's schedule guide. (Recommendation 6)

The Director of USGS should update and complete the ShakeAlert Communication, Education, and Outreach Plan to clarify and define roles and responsibilities between USGS, the states, and other communication, education, and outreach stakeholders. (Recommendation 7)

The Secretary of Commerce, jointly with the Secretary of the Interior, should fully implement memorandum of understanding between USGS and NOAA by establishing the Interagency Committee for Program Coordination. (Recommendation 8).

The Secretary of Interior, jointly with the Secretary of the Commerce, should fully implement memorandum of understanding between USGS and NOAA by establishing the Interagency Committee for Program Coordination. (Recommendation 9).

Agency Comments

We provided a draft of this report to the Department of Interior (DOI) and to the Department of Commerce for their review and comment. The Department of Interior provided written comments, which are reproduced in appendix IV. In its comments, both departments generally concurred with our recommendations and described actions under way or planned to address them. DOI partially concurred with our fifth recommendation. DOI, USGS and the National Oceanic and Atmospheric Administration (NOAA) provided technical comments, which we incorporated as appropriate. Additionally, the Department of Homeland Security, the Federal Emergency Management Agency, the National Science Foundation, the Department of Agriculture, and the U.S. Forest Service provided technical comments, which we incorporated as appropriate.

With regard to our first recommendation, DOI concurred that the Director of USGS should develop a strategic plan for the Earthquake Hazard Program (EHP) that articulates the fundamental mission of the entire program, lays out its long-term goals for implementing the plan, and identifies the strategies and resources that are needed to reach these goals. DOI stated that, it is important to distinguish Strategic Planning documents–which are created at the Agency level, and outline Agency responsibilities and progress towards those goals via tracking performance through established measures, in accordance with the Government Performance and Results Act (GPRA) and the GPRA Modernization Act of 2010 (GPRAMA) – from program-and project-level science planning documents (often also called strategic plans), which describe short- or long-term science goals. DOI also stated that, the EHP is in the process of undertaking science planning efforts and plan to eventually publish a science plan for the whole of the Earthquake Hazards Program. This action, if fully implemented, should address the intent of our recommendation.

With regard to our second recommendation, DOI concurred that the Director of USGS should develop performance measures for the strategy to determine whether the EHP has achieved the strategy's goals after it has drafted the strategic plan. According to DOI, the DOI 2018 – 2022 Strategic Plan and the DOI Annual Performance Plan and Report both include detailed information on performance for EHP, including strategies, goals, and performance measures directly linked to those Departmental goals and strategies, in compliance with the requirements of the Government Performance and Results Act Modernization Act of 2010 (GPRAMA). This Strategic Plan includes two indexed performance measures for EHP that are reported on in DOI's Annual Performance Plan and Report, which we recognize in this report as well.

According to DOI, these performance measures combined with the additional information provided in the department's strategic and performance plans provide a sufficient long-term strategic planning framework to objectively measure progress towards meeting the goals of the EHP, USGS, and Department of the Interior. However, we have previously reported that agency-wide strategic planning practices required under GPRAMA can also serve as leading practices for planning at lower levels within federal agencies, such as individual programs or initiatives. By developing performance measures linked to the goals established within the science plan it publishes for the whole of the EHP, USGS can better determine whether the program has achieved long-term goals.

DOI stated that, the USGS will work with the Department of the Interior during the development of the Department's FY 2022 – 2026 Strategic Plan to ensure that it includes appropriate measures for its programs, including the EHP. Additionally, according to DOI, the USGS will continue to utilize its various mechanisms, as listed above, to assess how EHP and its components are achieving its strategic goals and requirements, as the bureau does for all programs and centers. EHP already utilizes internal performance measures for the subset of activities where this approach is most beneficial (e.g., ANSS performance metrics; ShakeAlert quarterly reports) and will continue to evaluate whether the creation of additional measures is needed. We will continue to monitor USGS's efforts in this area to assess the extent to which they fully address the intent of our recommendation.

With regard to our third recommendation, DOI concurred that the Director of USGS should consult with relevant Congressional committees when developing its strategic plan for the EHP. DOI stated that it will consult with Congress, as appropriate, when developing a strategic science plan for EHP. We will continue to monitor USGS's efforts in this area to assess the extent to which they fully address the intent of our recommendation.

With regard to our fourth recommendation, DOI concurred that the Director of USGS should complete a staffing gap analysis for the EHP that is clearly linked to the mission and long-term goals of the Natural Hazards Mission Area and the program's strategic plans. DOI stated that, as part of EHP's science planning efforts, the Program Office will combine science center staffing plans and identify program-wide needs and overlap of those needs with the strategic directions of the program. We will continue to monitor USGS's efforts in this area to assess the extent to which they fully address the intent of our recommendation.

With regard to our fifth recommendation, that the Director of USGS should establish a Work Breakdown Structure with identified costs for ShakeAlert consistent with best practices in GAO's cost guide. DOI stated that it partially agrees with our recommendation. DOI noted that the ShakeAlert Technical Implementation Plan was based on a detailed internal breakdown of costs in accordance with the Work Breakdown Structure (WBS) approach. In its technical comments USGS provided additional details on the high-level cost categories. However, the plan did not include a dictionary of terms. DOI stated that EHP will develop such a dictionary to accompany the cost breakdown. We are pleased that USGS plans to develop a dictionary, and reiterate that USGS continue its efforts to fully identify all costs for ShakeAlert, by doing so USGS can help ensure the estimate includes all relevant costs and avoids cost overruns. We will continue to monitor USGS's efforts in this area to assess the extent to which they address the intent of our recommendation.

With regard to our six recommendation, DOI concurred that the Director of USGS should establish a schedule and milestones for ShakeAlert implementation consistent with best practices in GAO's schedule guide. DOI stated that, the EHP will establish an estimate of schedule and milestones for the remainder of system implementation. These actions, if fully implemented, should address the intent of our recommendation.

With regard to our seventh recommendation, DOI concurred that the Director of USGS should update and complete the ShakeAlert Communication, Education, and Outreach Plan to clarify and define roles and responsibilities between USGS, the states, and other communication, education, and outreach stakeholders. DOI stated that the EHP will update and complete the draft Communication, Education and Outreach Plan for ShakeAlert. These actions, if fully implemented, should address the intent of our recommendation.

With regard to our eighth recommendation, Commerce concurred that the Secretary of Commerce, jointly with the Secretary of the Interior, should fully implement memorandum of understanding between USGS and NOAA by establishing the Interagency Committee for Program Coordination. NOAA stated that it agrees with the recommendation. We will continue to monitor NOAA's and USGS efforts to fully implement the memorandum of understanding.

With regard to our ninth recommendation, DOI concurred that the Secretary of the Interior, jointly with the Secretary of the Commerce, should fully implement memorandum of understanding between USGS and NOAA by establishing the Interagency Committee for Program Coordination. DOI stated that an Interagency Committee for Program Coordination was first established in 1982, and the USGS will work with NOAA to establish teams necessary to promote improved program coordination, as discussed in the USGS-NOAA MOU. We will continue to monitor NOAA's and USGS efforts to fully implement the memorandum of understanding.

We provided a draft of this report to the Department of Interior (DOI) and the U.S. Geological Survey (USGS) for their review and comment, and to the Department of Commerce and the National Oceanic and Atmospheric Administration (NOAA). The Department of Interior provided written comments, which are reproduced in appendix IV. In its comments, both agencies concurred with our recommendations and described actions under way or planned to address them. The Department of the Interior, USGS and NOAA provided technical comments, which we incorporated as appropriate. Additionally, the National Institute of Standards and Technology, the Department of Homeland Security, the Federal Emergency Management Agency, the National Science Foundation, the Department of Agriculture, and the U.S. Forest Service provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretaries of the Interior, Commerce, Agriculture, and Homeland Security and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (404) 679-1875 or curriec@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

Chris P. Currie

Chris P. Currie
Director, Homeland Security and Justice

List of Committees

The Honorable Maria Cantwell
Chairman
The Honorable Roger Wicker
Ranking Member
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Joe Manchin III
Chairman
The Honorable John Barrasso
Ranking Member
Committee on Energy and Natural Resources
United States Senate

The Honorable Gary C. Peters
Chairman
The Honorable Rob Portman
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Committee on Homeland Security and Governmental Affairs
United States Senate

The Honorable Bennie G. Thompson
Chairman
The Honorable John Katko
Ranking Member
Committee on Homeland Security
House of Representatives

The Honorable Raúl M. Grijalva
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The Honorable Bruce Eugene Westerman
Ranking Member
Committee on Natural Resources
House of Representatives

The Honorable Eddie Bernice Johnson
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The Honorable Frank Lucas
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

The Honorable Peter DeFazio
Chairman
The Honorable Sam Graves
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

Appendix I: Objectives, Scope, and Methodology

We were asked to review the U.S. Geological Survey's (USGS) efforts to identify earthquake hazards and implement its earthquake early warning system.[1] This report addresses: (1) the efforts has USGS taken to identify earthquake hazards, and the challenges that stakeholders reported to such efforts; (2) the actions USGS has taken to ensure the Earthquake Hazards Program (EHP) can meet its mission, and additional actions could be taken; (3) the progress USGS and its partners have made in implementing its Earthquake Early Warning (EEW) system, and the challenges they reported; and (4) the extent to which USGS and National Oceanic and Atmospheric Administration (NOAA) coordinated and shared data when identifying the source and magnitude of an earthquake that may result in a tsunami.

To address our first objective, we reviewed USGS guidance, such as *Circular 1429: ANSS Current Status, Development Opportunities and Priorities for 2017-2027*, and planning documents, such as USGS's 2017 Subduction Zone Science Plan that identify and describe USGS efforts to identify and assess seismic hazards including developing and updating earthquake hazard products, such as the National Seismic Hazard Model.[2] In addition, we also reviewed USGS's Scientific Earthquake Studies Advisory Committee annual reports to review the findings and recommendations the committee made to USGS on the EHP's efforts to identify earthquake hazards and challenges to doing so. Further, we interviewed USGS officials located at USGS headquarters in Reston, Virginia; Seattle, Washington; and Menlo Park and Moffitt Field, California regarding USGS's efforts to identify earthquakes hazards, and challenges to doing so. In addition, we interviewed officials from NOAA's National Weather Service (NWS) to discuss how the agencies coordinate with each other, the states, and U.S. territories to identify tsunami hazards.

To obtain the perspectives of state officials, we conducted semi-structured interviews with officials from 16 state geological surveys to discuss the extent that earthquakes hazards are identified in their states, the challenges to identifying these hazards, and the extent that USGS and NOAA coordinate with each other, and state geological surveys,

[1]Pub .L. No. 115-307, § 4, 132 Stat. 4408, 4414.

[2]USGS, *Advanced National Seismic System Current Status, Development Opportunities, and Priorities for 2017-2027,* Circular 1429 (Reston, VA: Jul., 2017) and *Reducing Risk Where Tectonic Plates Collide—A Plan To Advance U.S. Geological Survey Subduction Zone Science,* Circular 1428, (Reston, VA:Jun. 19, 2017).

among other things.[3] Of these, we interviewed representatives from 11 of the 16 state geological surveys from the Intermountain West and the Midwestern and Southern U.S. via two virtual roundtables. We interviewed representatives from one as part of our Menlo Park, California site visit, two state geological surveys via telephone interviews, and representatives from one state geological survey provided written responses in lieu of an interview.

We selected states using the following criteria: (1) states determined by USGS to have moderate to very high earthquake hazard; (2) states where a major earthquake occurred after January, 2018;[4] (3) states from the Pacific Coast; Intermountain West, Midwest, and the South.[5] We selected these regions to ensure we selected states that experienced frequent damaging earthquakes as well as those who are known to experience infrequent damaging ones. The states selected were Alabama, Alaska, Arkansas, California, Colorado, Hawaii, Idaho, Illinois, Indiana, Kentucky, Missouri, Montana, Nevada, Oregon, Tennessee, and Washington State. We analyzed the responses of these officials to identify common themes regarding the challenges reported to identifying earthquake hazards in their states.

To further ensure we obtained perspectives on earthquake hazards from across the country and a broad range of stakeholders, we interviewed representatives from all four earthquake consortia, as well as academic or research institutions including the Southern California Earthquake Center, the California Integrated Seismic Network, and the Pacific Northwest

[3]To interview these officials, we conducted two site visits in Seattle, WA, Menlo Park and Moffitt Field, California prior to the Coronavirus Disease 2019 (COVID-19) pandemic. After the onset of the pandemic, we interviewed USGS and NOAA officials as well as state geological survey officials via telephone interview or virtual roundtable.

[4]For the purposes of selection, we define a major earthquake as an earthquake of magnitude 6 or higher.

[5]According to USGS, the 16 states with the highest earthquake hazard from natural earthquakes are Alaska, Arkansas, California, Hawaii, Idaho, Illinois, Kentucky, Missouri, Montana, Nevada, Oregon, South Carolina, Tennessee, Utah, Washington, and Wyoming. The states with the lowest ground shaking hazard are Florida, Iowa, Minnesota, North Dakota, and Wisconsin.

Seismic Network.[6] In addition, we attended the 2020 quadrennial National Earthquake Conference in San Diego, California, to obtain a broad range of viewpoints from stakeholders on federal and state agency efforts to identify earthquake hazards. While the information gathered during these interviews cannot be generalized to all states or other stakeholders, it provides a range of perspectives on a variety of topics relevant to earthquake hazards and efforts to identify them.

To determine the trends in the EHP's resources and their effects on the program, we reviewed USGS budget requests for fiscal years 2014 to 2021, and other agency documentation on the effects of resources on the program, such as Scientific Earthquake Studies Advisory Committee annual reports. We also reviewed federal laws, as well as Congressional explanatory statements and committee reports directing resources to the EHP during this period of time.[7]

To address our second objective, we reviewed USGS guidance and other documents that EHP officials provided as evidence of their efforts to manage the program under declining resources and compared them to our declining resources framework.[8] These documents include annual budget guidance, implementation and performance plans for the Advanced National Seismic System (ANSS), the National Strong Motion Project, and the National Earthquake Information Center. We also reviewed the National Hazards Mission Area's 2013 strategic plan and USGS's Subduction Zone Science Plan. We also interviewed EHP officials to discuss the actions they had taken to ensure the EHP meets its mission. We compared these documents as well as USGS officials' testimonial evidence and written statements to the framework we

[6]The four earthquake consortia are the Western States Seismic Policy Council, Central United States Earthquake Consortium, Northeast States Emergency Consortium, and Cascadia Region Earthquake Workgroup. These consortia are multi-state regional and multidisciplinary organizations. These consortia coordinate multi-State response and recovery planning and public awareness, education, and outreach efforts. They also serve as forums for developing and adopting policy recommendations on earthquake hazard mitigation, and advocating their implementation.

[7]We reviewed these documents during this period of time because appropriations committees directed appropriations be set aside for the EHP within appropriations made to USGS, but had not in prior years. For example, see House of Representatives; Congressional Record, Vol. 165, H11288, Dec. 171, 2019, excerpt from Committee report.

[8]GAO, *Declining Resources: Selected Agencies Took Steps to Minimize Effects on Mission but Opportunities Exist for Additional Action,* GAO-17-79 (Washington, D.C: Dec. 20, 2016).

developed for examining agencies' efforts to effectively manage in an environment of declining resources in 2017.[9] For our comparison of USGS efforts to our framework for manage declining resources to our declining resources, we compared USGS efforts to relevant leading practices that past work identified, such as federal strategic and human capital planning.[10] These include practices required at the federal department/agency level under the Government Performance and Results Act of 1993 (GPRA)—which was amended and expanded by the GPRA Modernization Act of 2010 (GPRAMA)—which we have previously reported also can serve as leading practices for planning at lower levels within federal agencies such as individual programs or initiatives.[11]

To address our third objective, we reviewed USGS's 2018 Technical Implementation Plan and other documents, including the National Earthquake Hazards Reduction Program Reauthorization Act of 2018.[12] We also conducted interviews with USGS officials and other stakeholders about the ShakeAlert system, including the Northern California Seismic Network, Pacific Northwest Seismic Network, and a range of officials from academia to discuss the potential benefits, limitations, implementation challenges, and any improvements that could be made to the system.

We also conducted semi-structured interviews with seven of the 46 organizations that are operating EEW application systems in California,

[9]GAO-17-79.

[10]For example, GAO, *Executive Guide: Effectively Implementing the Government Performance and Results Act*, GAO/GGD-96-118 (Washington, D.C.: June 1996), *Managing for Results: Critical Issues for Improving Federal Agencies' Strategic Plans*, GAO/GGD-97-180 (Washington, D.C.: Sept. 16, 1997), *Agencies' Strategic Plans Under GPRA: Key Questions to Facilitate Congressional Review*, GGD-10.1.16: (Washington, D.C.: May 1, 1997), *Managing For Results: A Guide for Using the GPRA Modernization Act to Help Inform Congressional Decision Making*, GAO-12-621SP: (Washington, D.C.: Jun 15, 2012), *Human Capital: Key Principles for Effective Strategic Workforce Planning*, GAO-04-39 (Washington, D.C: Dec 11, 2003), and *Environmental Justice: EPA Needs to Take Additional Actions to Help Ensure Effective Implementation*, GAO 12-77: (Washington, D.C.: Oct. 6, 2011).

[11]Pub. L. No. 103-62, 107 Stat. 285 (1993); Pub. L. No. 111-352, 124 Stat. 3866 (Jan. 4, 2011); GAO, *U.S. Tsunami Preparedness: Federal and State Partners Collaborate to Help Communities Reduce Potential Impacts, but Significant Challenges Remain*, GAO-06-519 (Washington, D.C.: June 5, 2006); GAO, *Veteran-Owned Small Businesses: Planning and Data System for VA's Verification Program Need Improvement*, GAO-13-95 (Washington, D.C.: Jan.14, 2013)

[12]National Earthquake Hazards Reduction Program Reauthorization Act of 2018, Pub. L. No. 115-307, § 4, 132 Stat. 4408, 4414.

Washington, and Oregon, and four of the seven licensed technical operators to obtain their perspectives on the guidance provided by USGS and the benefits, limitations, and challenges to developing, implementing, and operating EEW systems.[13] The seven organizations were selected from the 46 organizations and represent sectors from across public health, transportation, education, emergency response, entertainment, utility, and government. The four licensed technical operators we selected represented all licensed operators at the time of their selection. However, USGS subsequently licensed three additional technical operators.[14] We then reviewed and summarized interview write-ups and identified common themes. While the information gathered during these interviews cannot be generalized to all 46 organizations operating EEW application systems and licensed technical operators, it provides a range of perspectives on a variety of topics relevant to earthquake early warning systems and applications.

To assess the extent USGS followed best practices for comprehensively estimating the cost for ShakeAlert implementation, we compared USGS practices from their 2018 cost estimate for ShakeAlert against the four best practices for a comprehensive cost estimate identified in our Cost Estimating and Assessment Guide (Guide).[15] We focused on the comprehensive cost characteristic because, according to our cost guide, a cost estimate that is not comprehensive cannot fully meet the other best practice characteristics because it is not complete.[16] The four best practices defined under the comprehensive cost characteristic (1) includes all life cycle costs, (2) is based on a technical baseline description, (3) documents all ground rules and assumptions and, (4) is

[13]The 46 organizations use EEW application systems to alert employees and activate systems to take protective actions. The 7 organizations are the LA Unified School District, City of Los Angeles, Cedars-Sinai Hospital, Menlo Park Fire Protection District, NBCUniversal, Bay Area Rapid Transit, Pacific Gas & Electric. The 4 licensed operators are Early Warning Labs, RH2 Engineering, SkyAlert, and Varius.

[14]Commercial technical operators are companies that developed and implemented earthquake early warning systems for organizations within the government, transportation, entrainment, education, public health, and emergency management sectors. As of September 2020, seven technical operators completed a pilot with USGS and received a license to operate early warning systems.

[15]GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: March 2020).

[16]The four characteristics for establishing a reliable cost estimate are that it is comprehensive, well-documented, accurate, and credible.

based on a work breakdown structure. In assessing whether USGS followed best practices, we reviewed USGS documents and held discussions with USGS officials and categorized USGS practices as having 1) fully met, 2) substantially met, 3) partially met, 4) minimally met, or 5) not met the standard for the best practice.[17] To assess the extent that USGS followed best practices in establishing schedules and milestones, we reviewed USGS 2018 ShakeAlert Technical Implementation Plan and other relevant documents, interviewed relevant USGS officials, and compared these documents and officials' testimony to the best practices from our Schedule Assessment Guide (schedule guide).[18] However, since USGS did not establish any schedules or milestones for ShakeAlert, we were not able to assess how well the agency met the 10 best practices provided for in our schedule guide.

To determine the extent USGS experienced challenges using FEMA's Integrated Public Alert and Warning System (IPAWS) wireless emergency alert in the delivery of EEW alerts, we reviewed documentation of the two controlled tests conducted in Oakland, California and San Diego County, California. We also discussed the challenges identified in the tests with senior USGS officials to determine what steps USGS is taking to address them.

In order to assess progress and challenges related to implementing ShakeAlert, in particular USGS' communication, education, and outreach efforts, we reviewed USGS' draft Communication, Education, and Outreach Plan to assess the extent to which USGS uses collaborative mechanisms to coordinate program administration.[19] We also reviewed states' relevant planning documents such as the Cascadia Region Earthquake Workgroup's 2018 Pacific Northwest Strategy for Earthquake

[17]Individual assessments are defined as "fully met" where USGS provided complete evidence that satisfies the best practice, "substantially met" where USGS provided evidence that satisfies a large portion of the best practice, "partially met" where USGS provided evidence that satisfies about half of the best practice, "minimally met" where USGS provided evidence that satisfies a small portion of the best practice, and "Not met" where USGS provided no evidence that satisfies the best practice.

[18]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015). GAO's schedule guide is a compilation of best practices associated with developing and maintaining a reliable, high-quality schedule.

[19]See "Draft" ShakeAlert Joint Committee for Communication, Education, and Outreach, *Communication, Education, & Outreach (CEO) 2018 Plan: ShakeAlert – Phased Alerting* (July 2018).

Early Warning Outreach, Education, and Training and California's Business Plan to determine how the states planned to coordinate with USGS to implement communication, education, and outreach activities.[20] We compared these documents and USGS and state officials' testimonial evidence to interagency collaboration mechanisms identified in prior work which identified mechanisms used by federal agencies to implement interagency collaborative efforts.[21] We applied six collaboration mechanisms from among seven that were identified in our prior work: (1) outcomes and accountability, and (2) bridging organizational cultures, (3) leadership, (4) clarity of roles and responsibilities, (5) participants, and (6) written guidance and agreements.[22] We selected these collaboration mechanisms because we found them to be the most relevant to the nature and scope of USGS' partnership with the states. Additionally, we interviewed USGS officials and officials from the state emergency management agencies in California, Oregon, and Washington to discuss USGS efforts and how USGS and the states collaborate in such efforts.

To address our fourth objective, we assessed the extent that USGS and NOAA have coordinated and shared data, and reviewed the 2016 memorandum of understanding between USGS and NOAA.[23] We compared this document to the actions taken by USGS and NOAA as of January 2021 to coordinate and share information. Moreover, we interviewed officials from USGS, NOAA's National Weather Service (NWS), and officials from the state emergency management offices in California, Oregon, and Washington regarding the extent that USGS and the National Weather Service have coordinated and shared data when identifying the source and magnitude of an earthquake that may result in a tsunami. We conducted this performance audit from June 2019 to March 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for

[20]See *Pacific Northwest Strategy for Earthquake Early Warning (EEW) Outreach, Education, and Training*, (March 2018) and *Implementing Earthquake Early Warning in California (*May 2018).

[21]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: September 27, 2012).

[22]Of the seven collaboration mechanisms identified in GAO-12-1022, we identified six that are relevant to the relationship between USGS, the state emergency management offices, and other stakeholders. The remaining mechanism we did not use is resources.

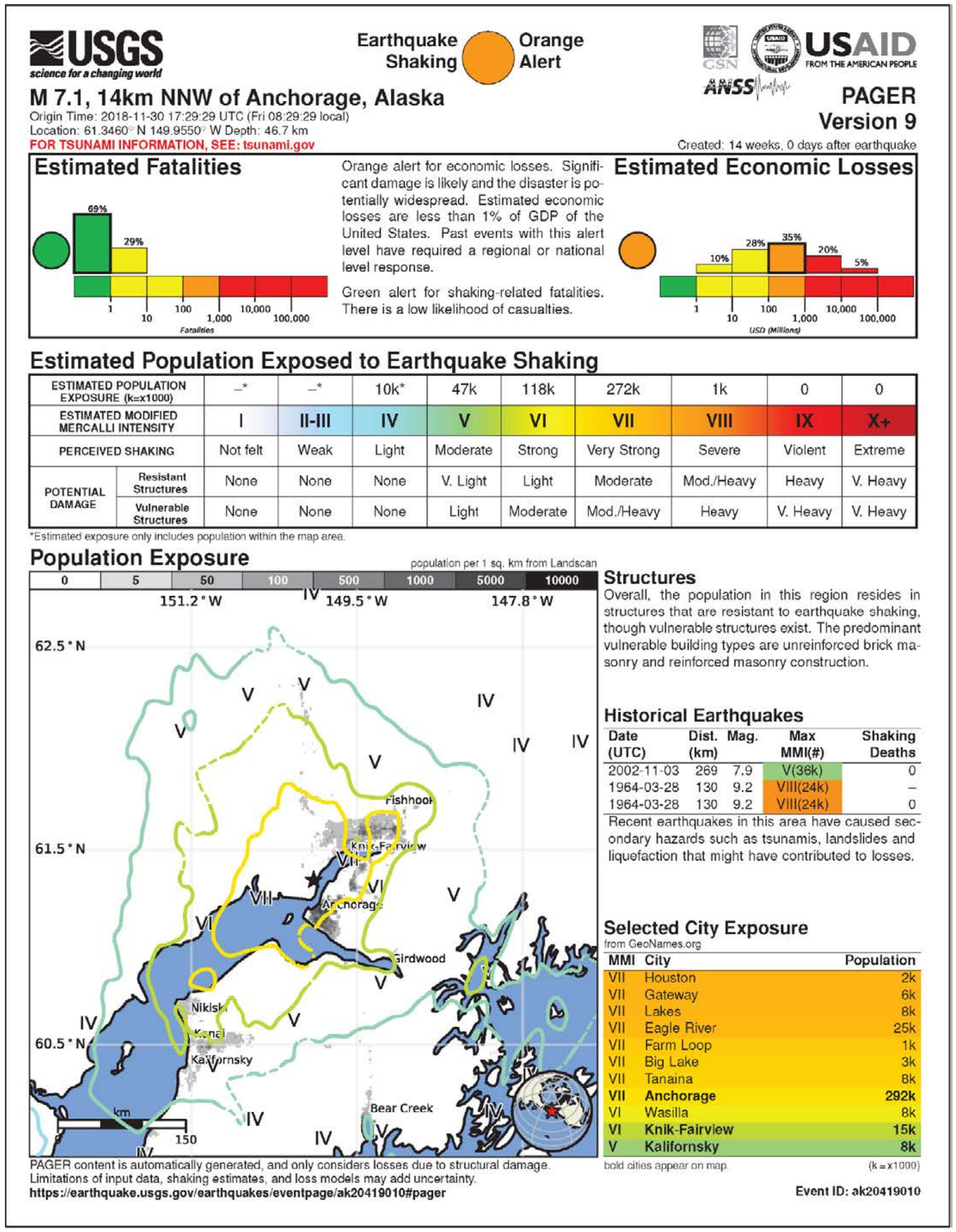
[23]*Memorandum of Understanding between the U.S. Geological Survey of the U.S. Department of the Interior and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce* (October 2016).

our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Examples of U.S. Geological Survey Products on Earthquake Severity and Damage

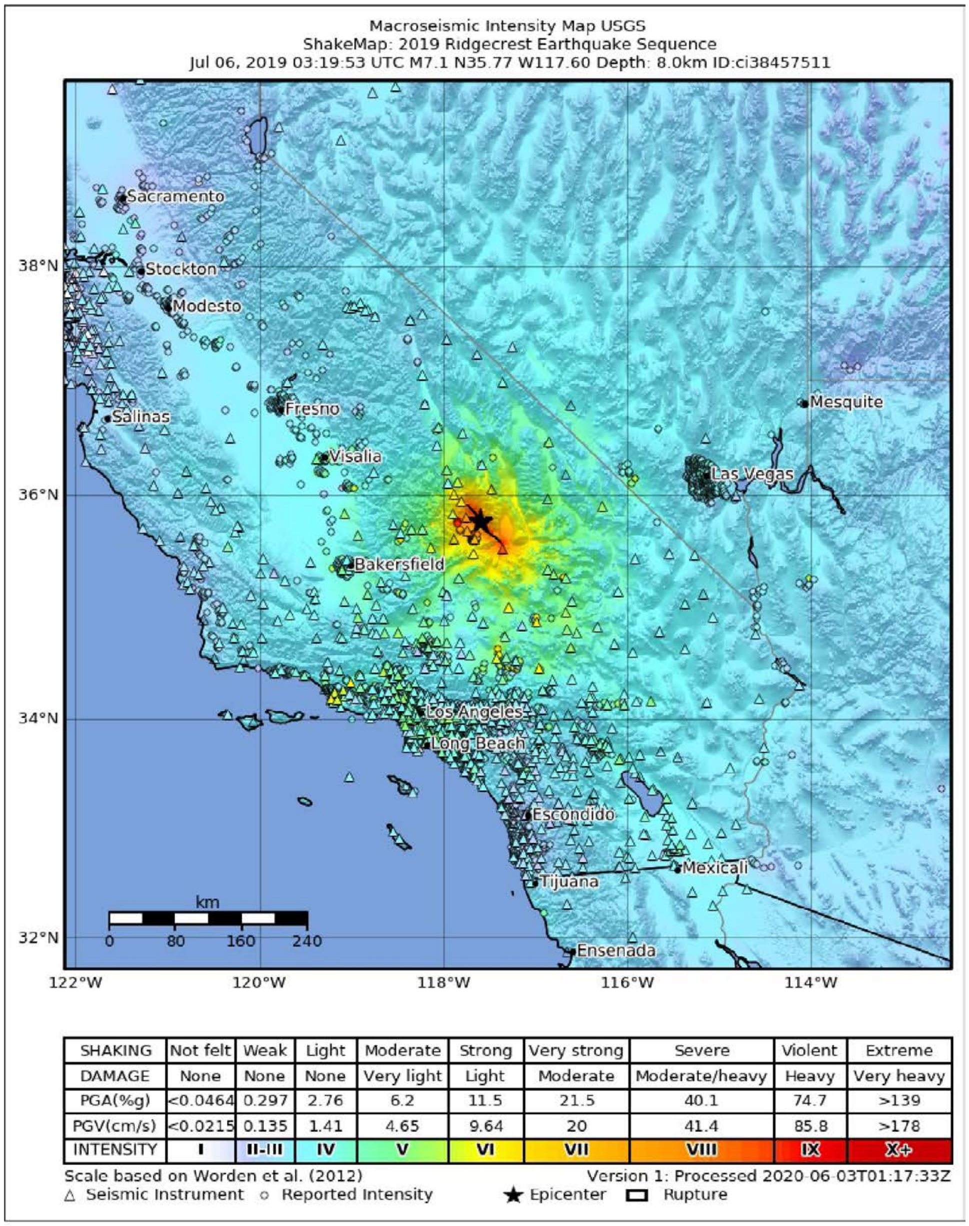
This appendix provides examples of ShakeMaps and other products U.S. Geological Survey (USGS) has issued for earthquakes that occurred in Anchorage, Alaska in 2018, Ridgecrest, California in 2019, Indios, Puerto Rico, and Néon Karlovásion, Greece in 2020.

Figure 9: Prompt Assessment of Global Earthquakes for Response Issued for 2018 Earthquake in Anchorage, Alaska



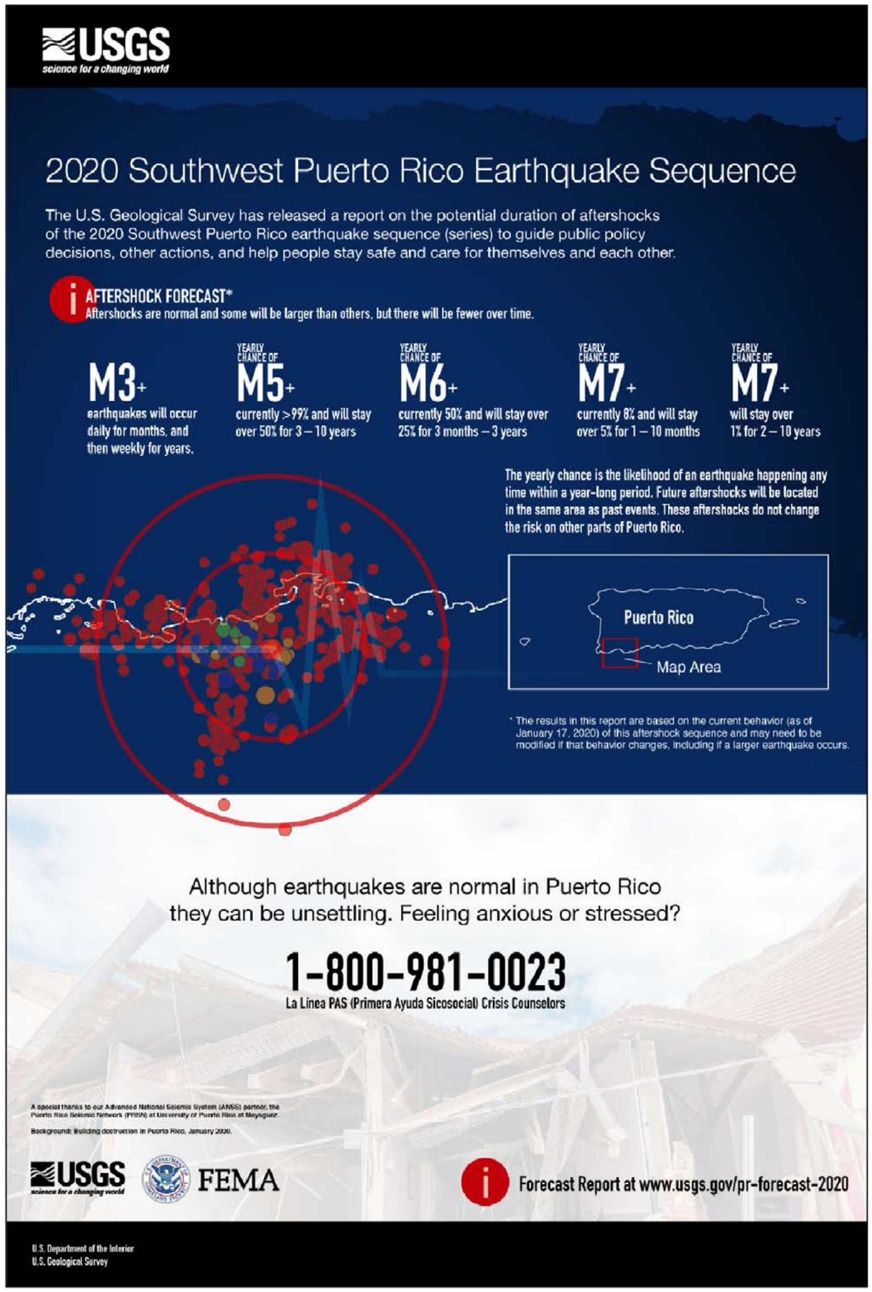
Source: U.S. Geological Survey. | GAO-21-129

Figure 10: ShakeMap for 2019 Earthquake in Ridgecrest, California



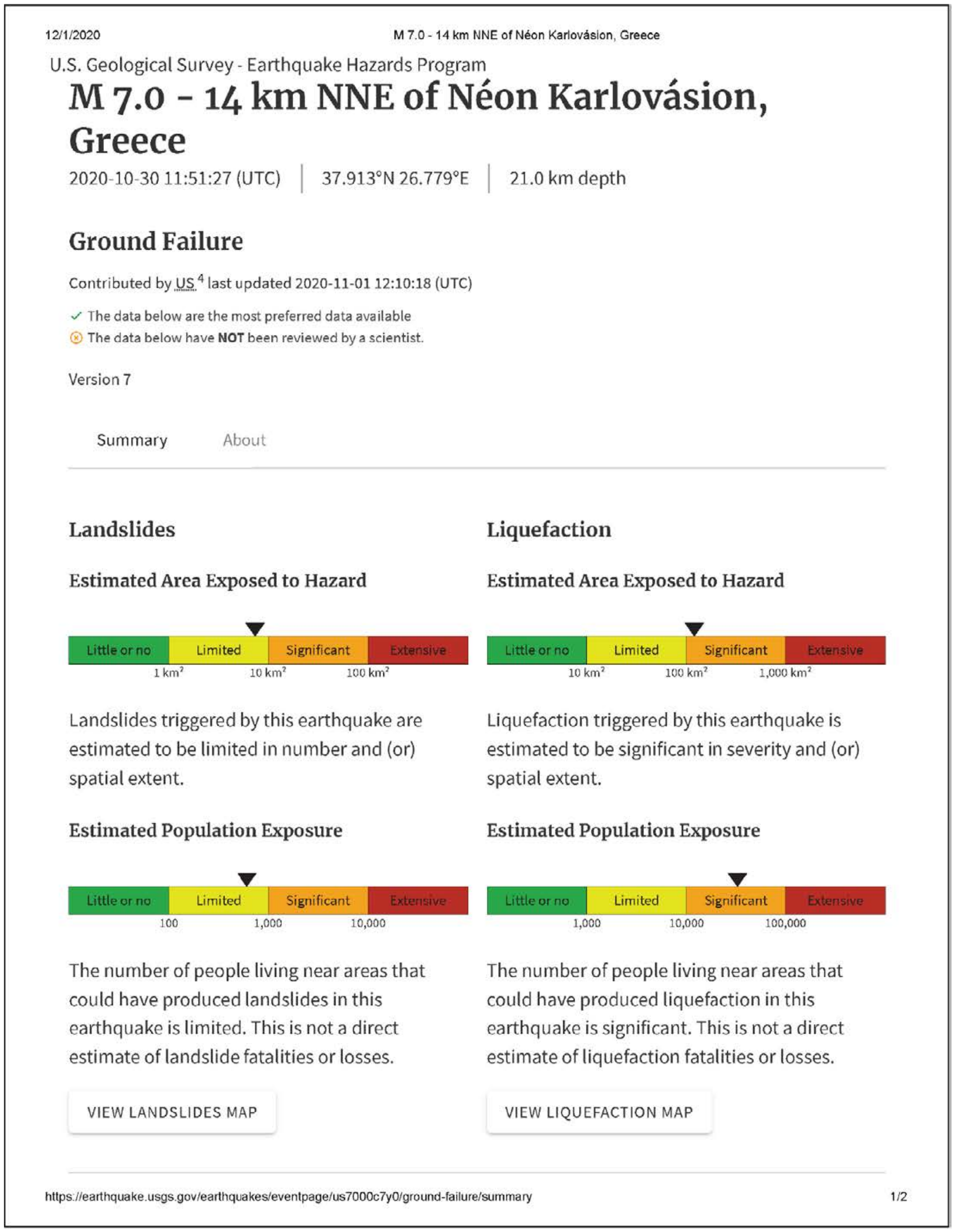
Source: U.S. Geological Survey. | GAO-21-129

Figure 11: Aftershock Forecast for 2020 Earthquake in Indios, Puerto Rico



Source: U.S. Geological Survey. | GAO-21-129

Figure 12: Ground Failure Product Issued for 2020 Néon Karlovásion, Greece Earthquake



12/1/2020 M 7.0 - 14 km NNE of Néon Karlovásion, Greece

U.S. Geological Survey - Earthquake Hazards Program

M 7.0 - 14 km NNE of Néon Karlovásion, Greece

2020-10-30 11:51:27 (UTC) | 37.913°N 26.779°E | 21.0 km depth

Ground Failure

Contributed by US [4] last updated 2020-11-01 12:10:18 (UTC)

✓ The data below are the most preferred data available

The data below have **NOT** been reviewed by a scientist.

Version 7

Summary About

Landslides

Estimated Area Exposed to Hazard

Landslides triggered by this earthquake are estimated to be limited in number and (or) spatial extent.

Estimated Population Exposure

The number of people living near areas that could have produced landslides in this earthquake is limited. This is not a direct estimate of landslide fatalities or losses.

VIEW LANDSLIDES MAP

Liquefaction

Estimated Area Exposed to Hazard

Liquefaction triggered by this earthquake is estimated to be significant in severity and (or) spatial extent.

Estimated Population Exposure

The number of people living near areas that could have produced liquefaction in this earthquake is significant. This is not a direct estimate of liquefaction fatalities or losses.

VIEW LIQUEFACTION MAP

https://earthquake.usgs.gov/earthquakes/eventpage/us7000c7y0/ground-failure/summary 1/2

Source: U.S. Geological Survey. | GAO-21-129

Appendix III: Efforts to Expedite the Permitting Process for Installing Seismic Stations

USGS is working with other federal agencies to streamline the permitting process for updating and installing new seismic stations on large areas of federal lands across California, Oregon, and Washington. According to USGS, obtaining permits to upgrade or install hundreds of permanent stations on federal and state lands is costly and time consuming because the lands are subject to numerous regulations.[1] For example, U.S. Forest Service officials told us it takes time to determine whether there are endangered species on the lands and whether the seismic stations will have an impact on the habitat.[2]

USGS and the U.S. Forest Service established an interagency agreement on November 6, 2018, to streamline the permitting process and hire a third party contractor to assist in completing the regulatory requirements. As shown in table 7, as of August 2020, 78 permits are needed from U.S. Forest Service for stations requiring upgrades or new installation in California and 31 permits are needed in Washington and Oregon. According to USGS, the agency expects to receive all 109 permits from U.S. Forest Service by the end of spring, 2021.

Table 6: Number of Seismic Stations and Systems Needing Permits on Federal, State, and Private-owned Lands as of August 2020

	Number of stations requiring upgrades	Number of stations requiring new installation	Total number requiring upgrades or new installation
California			
Bureau of Land Management	15	14	**29**
National Park Service	3	7	**10**
U.S. Fish & Wildlife Service	0	0	**0**
U.S. Forest Service	37	41	**78**
State and local	0	23	**23**
Private	52	81	**133**

[1]Obtaining permits for long-term station operation involves consideration of the National Environmental Policy Act, 42 U.S.C. §4231, the Endangered Species Act, 16 U.S.C. §1531, and the National Historic Preservation Act strictures,16 U.S.C. §470. In addition, the permitting process requires the agency to prepare an environmental impact statement or assessment.

[2]According to the Forest Service, they also perform desktop audits of lands using geographic information system data to determine if the proposed locations are habitat for endangered species.

	Number of stations requiring upgrades	Number of stations requiring new installation	Total number requiring upgrades or new installation
Washington and Oregon			
Bureau of Land Management	3	7	**10**
National Park Service	0	8	**8**
U.S. Fish & Wildlife Service	0	1	**1**
U.S. Forest Service	15	16	**31**
State and local	4	32	**36**
Private land owners	65	84	**149**

Source: GAO analysis of U.S. Geological Survey information. | GAO-21-129

In addition to efforts aimed at streamlining the permitting process, the Secretary of the Interior issued a memorandum on October 5, 2018, directing the Bureau of Land Management, the National Park Service, and the U.S. Fish and Wildlife Service to work with USGS to provide categorical exclusions for the installation and upgrade of monitoring equipment or network devices.[3] As shown in table 7, 39 permits are needed from these three agencies for station upgrades or new installation in California and 19 permits are needed in Washington and Oregon. As of November 2020, USGS officials did not provide a date by which they expect to receive the permits, but did say the permitting process has begun to speed up.

According to USGS officials, other permitting options, such as using private lands, are being considered to expedite the upgrades and new installation of seismic stations because the permitting process for private lands is not subject to as many regulations and is much faster. As of September 2020, USGS and its partners plan to obtain permits from private landowners for 133 stations in California and 149 stations in Washington and Oregon. USGS officials added that in many instances, the Coronavirus Disease 2019 has caused delays with the permitting process because they are not able to pursue and finalize the permits with private landowners, which must be done in person.

[3]Under the National Environmental Policy Act, if the agency determines that the activities of a proposed action fall within a category of activities that the agency has previously determined to have no significant environmental impact, individually or cumulatively—what is known as a categorical exclusion, then the agency generally does not need to prepare an environmental impact statement or an environmental assessment.

Appendix IV: Comments from the Department of the Interior

United States Department of the Interior

OFFICE OF THE SECRETARY
Washington, DC 20240

Chris Currie
Director, Homeland Security & Justice
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Currie,

Thank you for providing the Department of the Interior (Department) an opportunity to review and comment on the draft Government Accountability Office (GAO) report entitled, *EARTHQUAKES: Progress Made to Implement Early Warning System, but Actions Needed to Improve Its Program Management* (GAO-21-129). We appreciate GAO's review and feedback.

The GAO issued eight recommendations to the Department as part of its overall findings. The report contains seven recommendations to the U.S. Geological Survey (USGS) and one recommendation to the Secretary of the Interior. Below is a summary of actions taken or planned to implement the recommendations.

Recommendation 1: "The Director of USGS should develop a strategic plan for the Earthquake Hazard Program that articulates the fundamental mission of the entire program, lays out its long-term goals for implementing the plan, and identifies the strategies and resources that are needed to reach these goals."

Response: Concur. USGS believes it is important to distinguish Strategic Planning documents – which are created at a Bureau or Agency level, and outline Bureau or Agency responsibilities and progress towards those goals via tracking performance through established measures, in accordance with the Government Performance and Results Act (GPRA) and the GPRA Modernization Act of 2010 (GPRAMA) – from program- and project-level science planning documents (often also called strategic plans), which describe short- or long-term science goals. USGS' interpretation of GAO Recommendation #1 is a need for the USGS Earthquake Hazards Program (EHP) to produce a program-level science plan, rather than a GPRA-mandated agency strategic plan, which is already in place (please see the USGS Response to Recommendation #2 for additional detail on the agency strategic plan).

EHP is in the process of undertaking science planning efforts and plan to eventually publish a science plan for the whole of the Earthquake Hazards Program.

1

Recommendation 2: "The Director of USGS should develop performance measures for the strategy to determine whether the Earthquake Hazard Program has achieved the strategy's goals after it has drafted the strategic plan."

Response: Concur. The DOI 2018 – 2022 Strategic Plan and the DOI Annual Performance Plan and Report (APP&R) both include detailed information on performance for EHP, including strategies, goals, and performance measures directly linked to those Departmental goals and strategies, in compliance with the requirements of the Government Performance and Results Act Modernization Act of 2010 (GPRAMA). This Strategic Plan includes two indexed performance measures for EHP which are reported on in DOI's APP&R. USGS will work with the Department to ensure that the FY 2022-2026 DOI Strategic Plan has appropriate measures for its programs, including the EHP. USGS believes that this is sufficient for ensuring that the EHP achieves the goals set in the Strategic Plan.

In addition, a variety of governance committees have been established to track EHP's ability to identify and resolve issues, including the Earthquake Hazards Program Council, Scientific Earthquake Studies Advisory Committee, National Earthquake Prediction Evaluation Council, Advanced National Seismic System (ANSS) Steering Committee, Earthquake Early Warning External Working Group, and ANSS National Implementation Committee. Additionally, USGS participates in the four-agency National Earthquake Hazards Research Program (NEHRP) Interagency Coordinating Committee. Following USGS-wide policy, Natural Hazards Mission Area (NHMA) annual guidance for EHP describes the set of requirements for EHP strategic goals that centers should respond to via annual proposals for work to meet and advance those requirements. Performance measures for EHP are established and utilized internally for a subset of activities that are most beneficial (e.g., ANSS performance standards and ShakeAlert quarterly reports), and are evaluated appropriately to help achieve program goals.

The USGS will work with the Department of the Interior during the development of the Department's FY 2022 – 2026 Strategic Plan to ensure that it includes appropriate measures for its programs, including the Earthquake Hazards Program. Additionally, the USGS will continue to utilize its various mechanisms, as listed above, to assess how EHP and its components are achieving its strategic goals and requirements, as the bureau does for all programs and centers. EHP already utilizes internal performance measures for the subset of activities where this approach is most beneficial (e.g., ANSS performance metrics; ShakeAlert quarterly reports) and will continue to evaluate whether the creation of additional measures is needed.

Recommendation 3: "The Director of USGS should consult with relevant Congressional committees when developing its strategic plan for EHP."

Response: Concur. The USGS will consult with Congress, as appropriate, when developing a strategic science plan for EHP.

Recommendation 4: "The Director of USGS should complete a staffing gap analysis for the Earthquake Hazard Program that is clearly linked to the mission and long-term goals of

2

the Natural Hazards Mission Area and Earthquake Hazard Program's strategic plans."

Response: Concur. As part of EHP's science planning efforts, the Program Office will combine science center staffing plans and identify program-wide needs and overlap of those needs with the strategic directions of the program.

Recommendation 5: "The Director of USGS should establish a work breakdown structure with identified costs for ShakeAlert consistent with best practices in GAO's cost guide."

Response: Partially concur. As described in the comments, the ShakeAlert Technical Implementation Plan was based on a detailed internal breakdown of costs in accordance with the Work Breakdown Structure (WBS) approach. However, the plan did not include a dictionary of terms. EHP will develop such a dictionary to accompany the cost breakdown.

Recommendation 6: "The Director of USGS should establish a schedule and milestones for ShakeAlert implementation consistent with best practices in GAO's schedule guide."

Response: Concur. EHP will establish an estimate of schedule and milestones for the remainder of system implementation.

Recommendation 7: "The Director of the USGS should update and complete the ShakeAlert Communication, Education, and Outreach Plan to clarify and define roles and responsibilities between USGS, the states, and other communication, education, and outreach stakeholders."

Response: Concur. EHP will update and complete the draft Communication, Education and Outreach Plan for ShakeAlert.

Recommendation 9: "The Secretary of the Interior, jointly with the Secretary of Commerce, should fully implement memorandum of understanding between USGS and NOAA by establishing the Interagency Committee for Program Coordination."

Response: Concur. An Interagency Committee for Program Coordination was first established in 1982, and the USGS will work with NOAA to establish teams necessary to promote improved program coordination, as discussed in the USGS-NOAA MOU.

USGS notes that earthquake origin and magnitude information is already automatically shared between USGS and NOAA for the purposes of coordination of their respective earthquake monitoring missions, and, inclusive of the Interagency Committee, several mechanisms are in place to communicate earthquake information and paths towards improvements to existing data sharing efforts.

3

Additionally, general and technical comments are enclosed for your consideration when finalizing the report.

If you have any questions or need additional information, please Anne Barrett, Associate Director, Office of Budget, Planning, and Integration at abarrett@usgs.gov.

Sincerely,

RACHAEL TAYLOR Digitally signed by RACHAEL TAYLOR Date: 2021.03.11 08:05:27 -05'00'

Rachael S. Taylor
Principal Deputy Assistant Secretary - Policy, Management and Budget

Enclosure

4

Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact

Chris P. Currie, (404) 679-1875 or curriec@gao.gov

Staff Acknowledgements

In addition to the contact named above, Aditi S. Archer (Assistant Director), Michael C. Lenington (Analyst-in-Charge), Aaron Chua, Chloe Kay, James Lawson, Russell Brown, Katrina Pekar-Carpenter, Elizabeth Dretsch, Jennifer Echard, Eric Hauswirth, David Hooper, John Mingus, Kristiana Moore, Kevin Reeves, and John Vocino made key contributions to this report.

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