ShakeAlert® activities for formal and informal learning settings

Geologic Hazards Related to Earthquakes:
Identifying geologic hazards in your community

Version 07/11/22

OVERVIEW

Strong ground shaking from seismic waves can trigger geologic hazards that critically impact communities and public safety. Several of these hazards include liquefaction, ground shaking amplification, landslides, and tsunamis. A 5-minute demonstration reveals how liquefaction can cause buildings to tip and underground storage tanks to migrate to the surface of the ground (Figure 1). A 15-minute hands-on activity engages learners to better understand liquefaction and landslides by experimenting with damp sand, water saturated sand, and slopes of gravel. In a 45-minute activity, learners complete a hazard inventory for their own or another community by applying their understanding of geologic hazards and geologic hazard maps. Hazards and risks are assessed, strengths and vulnerabilities of essential services and infrastructure are identified using maps, and an action plan is developed to address these risks.

Why is it important to learn about earthquakes and their effects, like tsunamis? More than 143 million people are exposed to potential earthquake hazards in the U.S. that could cost thousands of lives and billions of dollars in damage. An understanding of earthquakes and their potential to cause additional significant geologic hazards is fundamental to earthquake preparedness and mitigation. An important tool for preparedness is the ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. which detects significant earthquakes quickly so that alerts can be delivered to people and automated systems. A vocabulary in Appendix A provides helpful terms.

OBJECTIVES

Learners will be able to:

- Explain the difference between a geologic hazard and a risk.
- Identify types of seismic-related geologic hazards.
- Describe which earthquake-related hazards present a risk to a specific community.
- Inventory critical community structures and infrastructure that could be threatened by earthquake-related hazards.

Beginner

5 min 15 min 30–45 min

Large Group Small Group

Demo Materials

Time: 5-, 20- and 45-minute guided activities that can be adapted for audience and venue.

Audience: Novice and experienced geoscience learning groups.

Subject: Natural Hazards: Earthquakes, Geoscience

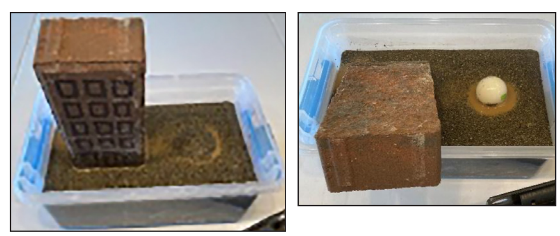

Figure 1: Before and after photos of brick and buried ping-pong ball shows what happens when water-saturated soil is vibrated. (Larger images in Figure 6.)

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MATERIALS

Materials for the 5-minute activity:

- Instructor computer projection system to show Appendix B or
- print Appendix B Earthquake Induced Geologic Hazards (3 images)

Liquefaction demonstration:

- Sturdy rectangular plastic or metal container – shoe box sized 7.5 Qt.
- 1 brick – squares drawn on with felt tipped pen to represent windows
- 1 ping-pong ball
- Sand – to fill container 3.5″ deep
- Water – enough to saturate the sand
- A rubber mallet or
- Electric reciprocating saw (blade removed) to create strong vibrations
- **Optional*: two rubber mallets to create a vibration (rapidly strike a table similar to playing a kettle drum)

Materials for the 15-minute activity:

- Instructor computer projection system to show Appendix B or print Appendix B Earthquake Induced Geologic Hazards (3 images)

Liquefaction exploration:

- 9 oz plastic or paper cups – two cups for each learner pair or group
- Sand to fill cups ¾ full
- water
- 8 metal washers ≈ 1″
- Pencil or pen to tap the cups to create a vibration

Landslide exploration:

- Paper core from a toilet paper towel roll – one for each learner pair or group (or a paper towel core cut into 4.5-inch segments)
- ¾ cup angular aquarium gravel – enough for each learner pair
- **Optional*: ¾-inch minus gravel could be substituted – remove larger pieces.
- 10″ sturdy paper or aluminum plate
- Several miniature ½-inch toy houses or small houses made from modeling clay
- Pencil or pen to tap the lip of the plate

Materials for the 45-minute activity:

- Computers for learners – individual computers, iPads, cell phones
- Appendix C—Hazard Inventory Checklist
- Appendix D—Hazard Inventory Worksheet – 2 pages
- Local city maps showing locations of schools, medical centers, police, fire, and infrastructure – often available from tourist/visitor's centers

RELEVANT MEDIA RESOURCES

Animations:

- Buildings & Bedrock: Effects of amplification & liquefaction *(1:25 sec)*
- Hazard vs. Risk—What is the difference?

Website Resources:

- Washington: Geologic Hazard Maps s
- Washington Geologic Information Portal
- Oregon: Oregon HazVu: Statewide Geohazards Viewer
- Oregon: Beat the Wave Technical Reports & Maps
- California Department of Conservation: Interactive GIS Hazard maps (select layer list)
- California: California Department of Conservation: Geologic Hazards

INSTRUCTOR PREPARATION

Large earthquakes cause a variety of geologic hazards. A given area has a geologic hazard AND risk. The two are related but different. Geologic hazard is the potential for an area to experience earthquakes, landslides, liquefaction, and other natural events. Risk is the potential for people to suffer serious damage if those events occur. Human built structures are at risk when they are located in an area where hazards exist - the structures are the vulnerability (see Figure 2).

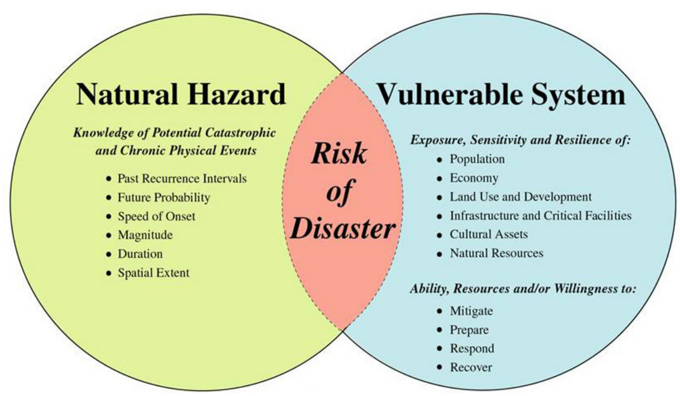


Figure 2: The intersection of hazards and vulnerabilities create risks. For a larger copy and image source, see Appendix C.

There's not much we can do to change the geologic hazards around us; they are mostly a result of forces humans can't control, like plate tectonics. However, we can change our degree of risk to those hazards, making it less likely that communities will suffer serious damage if they occur. It's possible for a community to experience low risk in a high-hazard area. Some important ways to reduce risk include obtaining good geologic mapping, establishing building codes, employing seismic engineering design, retrofitting vulnerable buildings and structures, and educating residents on hazards and preparedness.

In this activity we will explore: a) ground shaking amplification, b) liquefaction, and c) slope instability, which cause landslides and rock falls. (Appendix B)

a.) Ground shaking amplification: Seismic waves from an earthquake can cause structures to move from side to side and up and down, sometimes in rolling motions. Ground shaking will vary over an area due to topography, bedrock type, and the location and orientation of the fault rupture. Seismic waves travel faster through hard rock than through softer rock and sediments like soil and sand. As the waves pass from harder to softer rocks, they slow, causing their strength to increase (amplify), so shaking is more intense where the ground is softer. Figure 3

b.) Liquefaction: Seismic shaking can turn loosely packed, water-saturated soil to liquid in a process called "liquefaction." Liquefied soil loses strength as grains separate and become suspended in the soil-water matrix, reducing the soil's load bearing capacity. Heavy structures and objects can sink down into the ground or tilt over, while underground pipes and tanks may break and rise to the surface (float). When the shaking stops, the sediments settle, squeezing groundwater out of fissures and holes in the ground causing flooding and depositing sediments. The aftermath of liquefaction can leave large areas covered in a deep layer of mud (Figure 4).

c.) Slope instability: Ground shaking can destabilize cliffs and steep slopes, causing landslides and rockfalls, resulting in significant and even catastrophic damage to structures and transportation lines. Structures in the path of an earthquake-induced landslide are at risk from being damaged by landslide debris, as well as sliding downhill. Heavy rain and unconsolidated soil or fractured rock can greatly increase the size and scope of the slope failure (Figure 5).

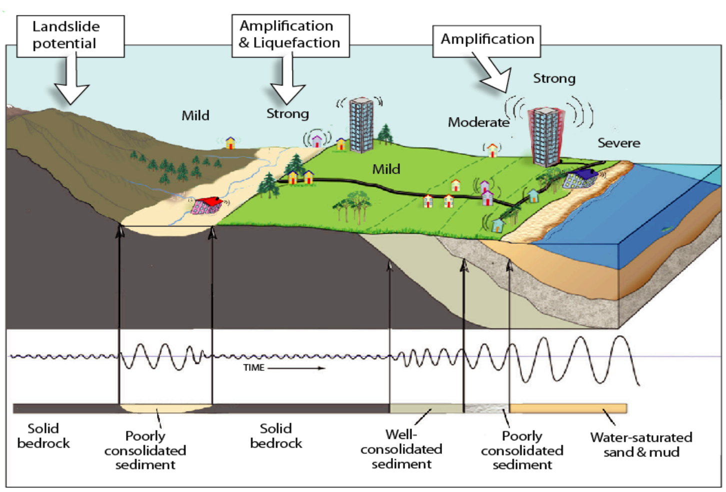


Figure 3: Diagram showing seismic generated geologic hazards, including landslides, amplification, and Liquefaction. For an expanded version and image source, see Appendix B.

Familiarize yourself with the Resources and Appendices

- APPENDIX A Vocabulary
- APPENDIX B Earthquake Induced Geologic Hazards
- APPENDIX C Hazard Inventory Checklist
- APPENDIX D Hazard Inventory Worksheet
- APPENDIX E NGSS Science and 3-Dimensional Learning

Figure 4: Liquefaction in Christchurch New Zealand 22 February 2011. (For larger image and image source, see Appendix B.)

Figure 5: Houses along Puget Sound, Seattle, Washington, showing impact of deep-seated landslide (For larger image and source, see Appendix B.)

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that there are several geologic hazards caused by earthquakes, for example, earthquake-caused liquefaction can cause structures to float as well as to sink?

Three different types of geologic hazards (ground amplification, liquefaction, and slope instability) can cause serious damage to homes, buildings, infrastructure, transportation, and critical supply lines as well as injury or loss of life. This 5-minute activity focuses on liquefaction in the demonstration.

Instructor Preparation

- Have a computer projection system ready to show Appendix B or print Appendix B Earthquake Induced Geologic Hazards (3 images)
- Prepare and practice the liquefaction demonstration (Figure 6):

1. Fill a sturdy rectangular plastic or metal container – about the size of a shoe box (7.5 qt.) 3.5″ deep with sand.
2. Gradually add water to the sand until the top of the sand is saturated, but no water lays on the top.
3. Place a brick (which has squares drawn on with felt tipped pen to represent windows) on end onto the sand as seen in Figure 6.
4. Bury a ping-pong ball about a ½″ below the level of the sand near the brick as seen in Figure 6.
5. Experiment to find the best option you have available to create vibrations into the sand filled shoe box. Options:
   - Rapidly tap the edge of the box with a hammer or rubber mallet.
   - Place an electric reciprocating saw (blade removed) on the side of the box next to the brick.
   - Use two rubber mallets to create a vibration (rapidly strike a table similar to playing a kettle drum) This works best if the box is placed on a lightweight table or desk to amplify the vibrations.

Procedure:

1. Show learners Appendix B images using either a projection system or printed images of geologic hazards explaining each one.
2. Introduce the liquefaction demonstration pointing out the saturated sand, the brick representing a building and that a ping-pong ball is buried to represent an underground storage tank.

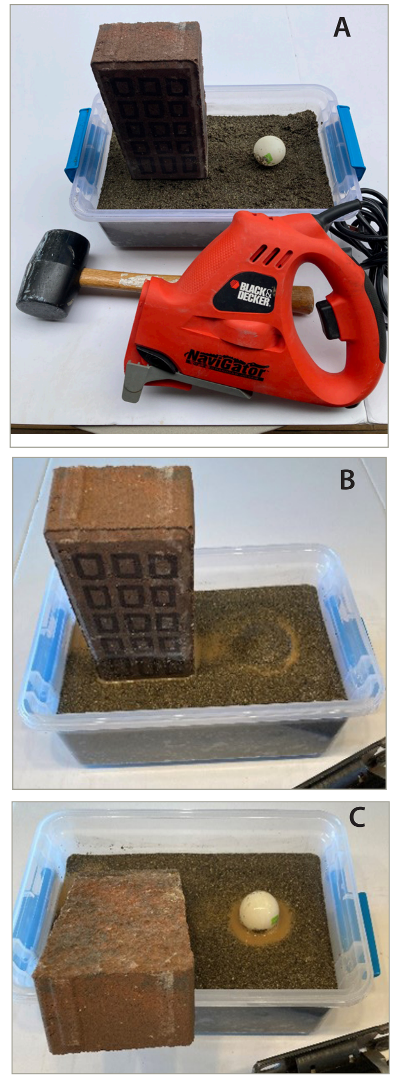


Figure 6: Demo setup and results:
***A**) brick "building" and a ping-pong ball representing an underground storage tank sit on saturated sand. Mallet and reciprocating saw provide the shaking of the container.*
***B**) the ping-pong ball has been buried and after tapping with the rubber mallet, begins to migrate to the surface and the brick building tips.*
***C**) the brick building has tipped over and the ping-pong ball is now on the surface.*

3. Explain what you will use (from the list above) to simulate

   seismic waves moving through the earth.
4. Before starting the demonstration ask the following questions for discussion:

   What do you predict will happen to the brick and the ping-pong ball when vibrations move through the sand? (*Answers will vary. The brick will fall over; the ping-pong ball will rise.*)
5. Demonstrate the liquefaction experiment. Think safety so the brick doesn't fall on learners.

Questions for Discussion:

- In an earthquake, the strong vibrations that cause shaking are called seismic waves. What are some things you already know about seismic waves? (*Answers will vary.*)

- Why did the strong vibrations or seismic waves cause the brick to fall and the ping-pong ball to rise? (*Answers will vary. The water causes the sand grains to move and lose their strength in response to strong ground shaking. Liquefied soil loses density as grains separate, reducing their load bearing ability so the brick will tip and fall, and the ping-pong ball will move/ migrate towards the ground surface*.)
- Where would liquefaction be a concern in a community? (*Anywhere loose soils are near groundwater, such as lands built on artificial fill next to bays and the ocean.*)
- If you were designing a building in an area prone to liquefaction, what sorts of things might you do to reduce the risk of collapse? (*Structures can be designed and reinforced to mitigate this hazard using special footings and foundations or dewatering the ground around critical structures*.)

IF YOU HAVE 15 MINUTES

Did You Know?

- Did you know there is a difference between a geologic hazard and a risk for that hazard?

Geologic hazards created by earthquakes are natural occurrences capable of causing loss or damage. A given area has a geologic hazard AND risk. For example, while landslides are a common geologic hazard, not all landslides cause a risk that endanger life or damage structures.

Hazards and risk are related but different. Geologic hazard is the potential for an area to experience earthquakes, landslides, liquefaction, and other natural events. Risk is the potential for people or property to suffer serious damage if those events occur.

Soil covered hillsides can be a geologic hazard to landslides due to earthquake shaking. We can reduce the risk by not building on the hill, or not building at the bottom of the hill, or by stabilizing the hillside. Here we'll explore two geologic hazards often caused by earthquakes: liquefaction and landslides.

Instructor Preparation

- Have a computer projection system ready to show Appendix B or print Appendix B Earthquake Induced Geologic Hazards (3 images).
- Optional extension: Have learners experiment with liquefaction and landslides with additional variables such as using different materials such as different gravel or sand types. Consider the Engineering Design Cycle as they create their experiments (Appendix E).

Liquefaction prep:

Prepare sets of two 9 oz plastic or paper cups for each learner pair or group. (Figure 7A)

Fill cups with sand ¾ full.

Add water to both cups. One cup should have saturated sand, but <u>not</u> have water standing on the surface. The second cup should have sand that is completely damp but firmly hard packed. Figure 7

Provide 8 metal washers about 1-inch in diameter for each set-up.

Provide paper towels to clean up.

Landslide prep (Figure 8)**:**

- Prepare sets of the following supplies for each learner pair or group:
  - One paper core from a toilet paper roll – one for each learner pair or group (or cut a paper towel core into 3-inch segments)
  - ¾ cup angular aquarium gravel
  - 10" sturdy paper or aluminum plate
  - Several miniature ½-inch toy houses or small houses made from modeling clay

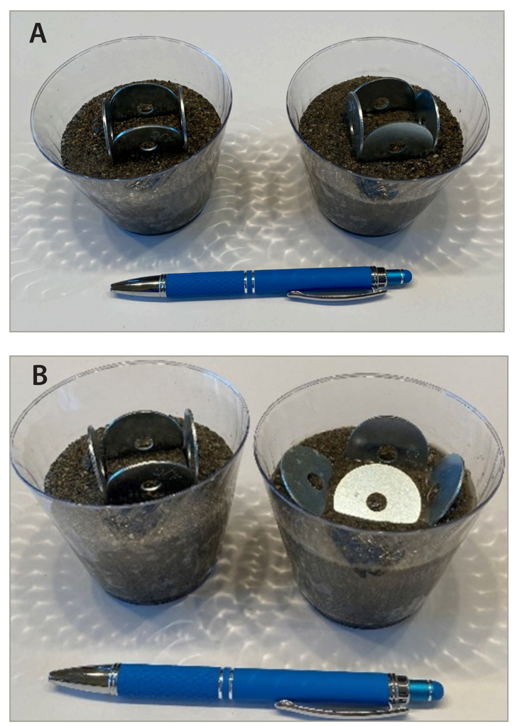


Figure 7: Liquefaction activity.
A) *Before. Damp sand in cup on left, saturated sand in cup on right. Washer "walls" are set upright before tapping.*
B) *After. The washer "walls" in the damp sand on the left are still standing. The "walls" in the saturated sand on the right, tipped over when the sand became liquified.*

Procedure:

1. Show and explain the Appendix B images of geologic hazards using either a projection system or with printed images of geologic hazards.
2. Explain that learners will be able to explore liquefaction and landslides in two short activities.

<u>Liquefaction Exploration</u>

3. In the liquefaction exploration, we will use metal washers to represent walls of a building.
4. Show one set up of two cups explaining the differences in the amount of water in each cup.
   a. Ask learners to place 4 washers on edge into the sand just below the center hole at right angles to create a square. See Figure 7A.
   b. Explain that they will tap each cup with a pencil or pen to create a vibration.

   Questions for Discussion:

   Why do you think we use metal washers rather than pieces of cardboard to represent walls? (*The metal washers are heavier and would better represent how a building would respond to shaking; cardboard is light and will soften in damp soil.*)

   What does tapping the cup resemble in the real world? (*Answers will vary. Learner might answer that each tap is an earthquake or that the energy from the tapping represents seismic waves. In an earthquake, the strong vibrations that cause shaking are called seismic waves.*)

5. Before starting the experiment, ask learners as a team to predict what they think will happen in each cup and why.
6. Pass out the supplies and start the first activity.
7. Following the liquefaction activity ask:

   Question for Discussion:

   Why did the vibrations or seismic waves cause the washers to tip over in the cup with the saturated sand? (*Answers vary. The strong ground shaking causes the sand grains and water to move and vibrate, causing the soil to lose its strength. Because the soil is weaker, it can not hold as much weight, (load bearing ability) so the washers will tip and fall.*)

Landslide Exploration

8. In the landslide exploration, learners will create a hill slope using aquarium gravel. Figure 8
9. Show the parts of the experiment and how to create the hill slope using the cardboard tube.
   a. Place the gravel into the cardboard tube which is firmly held against the paper plate.

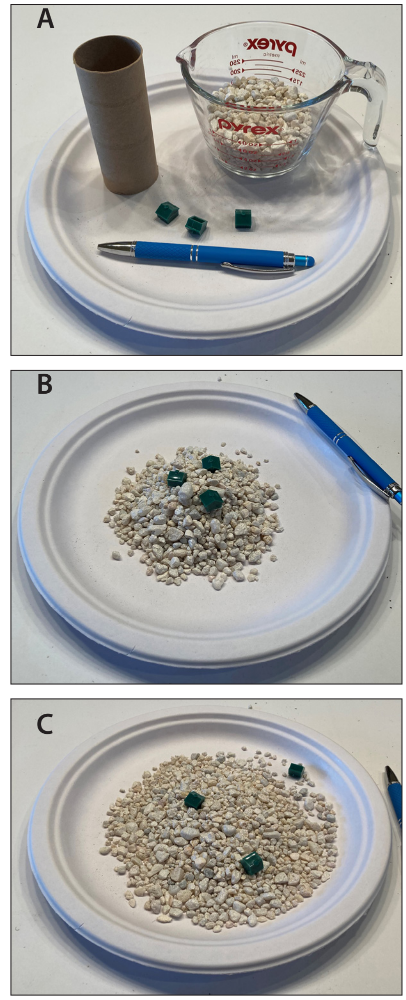


*Figure 8: Landslide activity: **A**) Landslide materials set-up. **B**) Gravel dropped from a tube creates a slope with houses. **C**) gentle tapping causes the hillside to fail and the houses tip and fall with the landslide.*

   b. Slowly lift the tube 2-3" allowing the gravel to slowly fall out creating a hill.
   c. Carefully place 2-3 toy or clay houses onto the slope.
10. Before starting the experiment, ask learners to predict with their team what will happen when the pan begins to shake the hill and houses
11. Gently tap the edge of the plate with a pencil or pen.
12. Have learners do the activity including tapping the edge of the plate.

    Questions for Discussion

    - In this example, the hillside fell apart. Do all hillsides fail during an earthquake ground shaking? (*No.*)
    - What conditions do you think would cause a hill slope to fail? (*Some examples include: water saturation can destabilize the slope, over-steepening of the slope by removing the toe from the base of the slope with a road cut, and the material the slope is made of – less compacted material is at greater risk for failure. Rock falls on cliff faces are also a risk.*)

13. While it is important to understand what geologic hazards are, it is also important to understand what risks the hazard can have for a community. Describe some examples of hazards and risks, such as a landslide susceptible hill in a forest with no roads, trails, or houses. There is a hazard of a landslide, but the risk of impact on property and human life is low.

Questions for Discussion

- Where would liquefaction be a risk in a community and what can be done to minimize or mitigate the risk? (*Anywhere loose soils are near groundwater such as rivers, harbors, lakes, ocean. Structures can be designed and reinforced to mitigate this hazard using special footings and foundations or dewatering the ground around critical structures*.)
- Where would landslides be a risk for a community and what can be done to minimize or reduce the risk? (*Landslides are a risk anywhere slopes are considered steep and the strength of materials on the slope is low, such as wet clay soils. Water saturation increases the weight of soil and increases slope instability. Landslide maps provide best hazard information where available. Be aware of landslide and rockfall potential in planning and mitigation*.)

IF YOU HAVE 45 MINUTES

Did You Know?

- Did you know that taking time to identify geologic hazards, risks, and vulnerabilities can greatly increase public safety, leading to increased earthquake resilience in cities and communities?

Creating resilient communities that can better survive and recover from large earthquakes requires knowledge and informed planning and mitigation. Most cities and communities have emergency management plans in place in case of a major disaster. However, most cities and communities lack resources to fully implement the identified needs. Public awareness, education and financial limitations are major challenges in meeting resilience needs. This activity encourages learners to investigate available community emergency planning documents. If documents do not exist, this activity helps learners identify gaps in current resources available for community planning.

In this group planning activity, learners apply their understanding of geologic hazards to complete an assessment of hazards and risks to a specific community. The location could be their own, or one that is selected to demonstrate specific hazards such as a coastal city where a tsunami hazard is present (Figure 9).

Figure 9: Workshop participants study Geologic Hazard Maps. (Image Source: [Beth Pratt-Sitaula](). This item is offered under a Creative Commons.)

Instructor Preparation

Familiarize yourself with types of geologic hazards. See the initial Instructor Preparation for explanations. Before conducting the 45-minute activity, consider conducting the 5-minute or 15-minute demonstrations to engage their curiosity and illustrate a few geologic hazards.

- Identify which community or communities you want groups of learners to investigate. Suggested options:
  - Multiple locations: groups could investigate two or more locations such as a coastal city with a tsunami risk and an inland city with greater infrastructure risk.
  - One location: groups could more deeply investigate different examples of the hazard inventory categories, such as: essential services, essential infrastructure, large gathering areas, or vulnerable populations.
- Assemble maps and helpful computer websites that can assist learners with their investigation including:
  - Maps of the city found from visitor or tourist centers.
  - Geologic hazard maps that show landslides, liquefaction, tsunami, and strong motion ground shaking. (See resources listed on page 1.) If maps do not exist for the location being investigated, learners need to apply their understanding of geologic hazards and use other types of resources such as topographic maps or local geophysical understanding of an area.
  - Tsunami evacuation maps if applicable.
  - Google Maps: learners can search for locations of hospitals, police stations, etc.

- Print enough copies of Appendix C: Hazard Inventory Checklist for each learner (Figure 10).
- Print one copy of Appendix D: Hazard Inventory Worksheet for each learner *group*.
- Provide or allow each learner to use computers or other internet accessible devices.

Procedure:

1. Distribute the Hazard Inventory Checklist (Appendix C), and the Hazard Inventory Worksheet; Appendix D).
2. Provide an overview of the activity to engage learners in a community preparedness planning process for a potential great earthquake. The activity uses a hazard inventory (Part 1) which focuses on how geologic hazards affect specific examples of a community including: essential services, infrastructure (roads, bridges, power lines), large gathering areas, and vulnerable populations. These categories are then evaluated for their risks to potential exposure to geologic hazards. Risk is determined by looking at vulnerabilities (or assets) such as type of building construction materials used, and access to emergency supplies. The second part of the activity asks learners to summarize their investigation of both strengths and vulnerabilities. Learners then propose possible ways to mitigate the risks and provide actionable steps to address the identified needs (Appendix D).

<u>Part 1: Hazard Inventory Checklist</u>

3. Part 1: Ask learners to look at the Hazard Inventory and the hazards and vulnerabilities/assets that are shown across the top of the table. Review what each geologic hazard involves and check for understanding. (Building construction materials might be known if there is personal knowledge or if using photos.) Emergency supplies and meeting areas might be known or if unknown, place a "?" or "NA" in the box for each item.
4. Ask learners to look at the different categories on the left column of the inventory. Each category has different examples that fit within the category. It is those examples that will be considered for their vulnerabilities or risks for damage.
5. Explain that groups or teams of learners will investigate a community or city you have chosen (see Instructor Preparation).

   A. If using two or more cities, each table group will take an assigned city and inventory examples from all three categories including: Essential Services, Essential Infrastructure, and Large Gathering Areas. Each group will be assigned one or more specific examples for the category they will inventory.

	Location Describe an approximate location using street names. or landmarks	Hazard (high, moderate, low or none)							
		Landslide	Ground Amplification	Liquefaction	Tsunami Inundation	Dangerous debris (Logs, mobilized objects, etc.)	Construction (Age, masonry, multi-level, etc.)	Access to High Ground	Access to Basic Survival Supplies
Current Location									
Your Home									
Essential Services									
Police									
Fire									
Hospital/Clinic									
City/County Government									
Emergency Ops Center									
Jail									
School									
School									
Banks/$ Institutions									
Essential Infrastructure									
Communications Networks									
Water/Waste-Water Supply Systems									
Utility Plants									
Bridges									
Harbors/Ports									
Airports									
Main Roads									
Haz Mat Structures									
Large Gathering Areas or Vulnerable Populations									
Hotel/Resort									
Parks									
Beach Access									
Bank									
Nursing Homes, Asst. Living, etc.									
Casino									
Event Center									
Shopping Areas									
Other:									
Other:									

Figure 10: Hazard Inventory Worksheet found in Appendix C.

Table-top Charette Workshop Activity

Community engagement is a powerful tool in developing awareness, and building allies with civic leaders, and emergency planners. Earthquake preparedness, and mitigation is an ongoing need in building safer more resilient communities. The 45-minute activity, Earthquake Hazard and Mitigation Planning Activity, is ideally suited for workshops or as a group activity for a meeting. The activity could extend over varying lengths of time or multiple sessions. Community engagement creates a more informed public more likely to understand, support and promote resilience initiatives.

B. If one city is used, different table groups will be assigned a category including: Essential Services, Essential Infrastructure, and Large Gathering Areas. (You may need to double up with two table groups doing the same category.) Each group will assign one or two specific examples for the category they will inventory.

6. Explain that dividing up inventory assignments is important since the table group teams will have approximately 15 minutes to do their research.

<u>Part 2: Hazard Analysis and Mitigation Ideas</u>

7. When the research time is over, reconvene the table groups to complete Part 2 of the activity (10 minutes) which is found on the Hazard Inventory Worksheet (Appendix D). Learners share with their table group what they discovered in doing their research on the Hazard Inventory and as a group write:
   - a summary statement that provides examples of the risks from the geologic hazards as well as the strengths (assets) and vulnerabilities for the group's assigned investigation.
   - Propose actions for mitigating and reducing the vulnerabilities, thereby decreasing the potential risks.
   - Create an action plan to address the identified needs.

   Note: Time will be short to complete Part 2 in detail. Ask learners to prioritize only one or two examples they found most interesting. If more time is possible (beyond the overall activity's 45-50 minutes), allow learners additional time to complete this section.

8. Reconvene the entire large group and have each table group share one or two examples that they found most interesting from their findings and include possible ideas for mitigating the risks and next steps for how the needs could be addressed. (20 minutes)

Questions for Discussion

- How did your investigation of geologic hazards help you better understand the vulnerabilities and constraints that communities face in preparing for a great earthquake? (Answers vary and may include the challenges of aging and unprepared infrastructure, celebrating steps already taken in a community such as moving a school out of a tsunami inundation zone, or seismically retrofitting a bridge.)
- What are some of the best ideas you learned that can help communities move forward with resilience planning? (Answers vary and may include educating the public about the hazards that great earthquakes create and appreciating the effort and complexity that goes into emergency planning by community agencies and leaders. An informed voting public is also more likely to support city codes and ordinances for seismic resilience and approve funding to address mitigation needs.)
- The Hazard Inventory was limited in scope due to time and to reinforce understanding of geologic hazards. What are some other areas of concern that could be investigated? (Answers vary and may include initiatives for community, personal and family emergency preparedness supplies, specific plans for assisting vulnerable populations, emergency signage, alerts such as ShakeAlert-powered alerts, and researching state and federal funding to help communities.)

APPENDIX A — VOCABULARY

Charette—is a collaborative planning or design session, in which problems relating to a proposed project are discussed and solutions adopted in a limited time frame.

Debris—Solid objects or masses carried by or floating on the surface of moving water.

Impact loads—Loads that result from waterborne debris transported by tsunami waves striking against buildings and structures or parts thereof.

Ground shaking amplification—refers to the soils and soft sedimentary rocks near the surface that can modify ground shaking from an earthquake. Such factors can increase or decrease the amplification (i.e., strength) as well as the frequency of the shaking

Geologic Hazard—created by earthquakes are natural occurrences capable of causing loss or damage.

Landslide—the movement of rock, earth, or debris down a sloped section of land. Landslides often occur on steep hillsides with a 15’ > vertical rise over 100’ of horizontal run and where the strength of materials on the slope is low [wet clay soils are especially vulnerable].

Liquefaction—A phenomenon that occurs in loosely packed, water-saturated soil when the soil loses strength as grains separate and become suspended in the soil-water matrix, reducing the soil’s load bearing capacity.

Risk—is the potential that the hazard will lead to a negative consequence such as loss of life or economic loss.

Risk mitigation—A strategy to reduce the risk of impact from a hazard.

Subsidence—a gradual settling or sudden sinking of the Earth's surface due to removal or displacement of subsurface earth materials.

Tsunami—A naturally occurring series of ocean waves resulting from a rapid, large-scale disturbance in a body of water, caused by earthquakes, landslides, volcanic eruptions, and meteorite impacts.

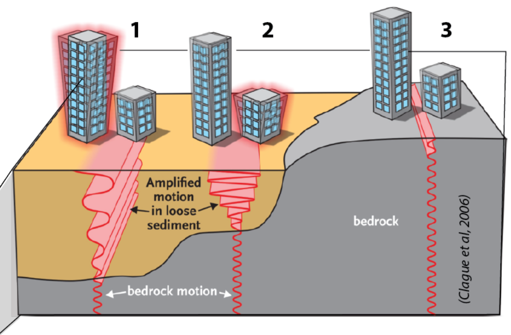
APPENDIX B — EARTHQUAKE INDUCED GEOLOGIC HAZARDS

The following images show: A) Amplification, B) Liquefaction, and C) Landslides.
For larger version of the the left image in A), go to: [Earthquake Hazard Maps & Liquefaction: Alaska emphasis.]

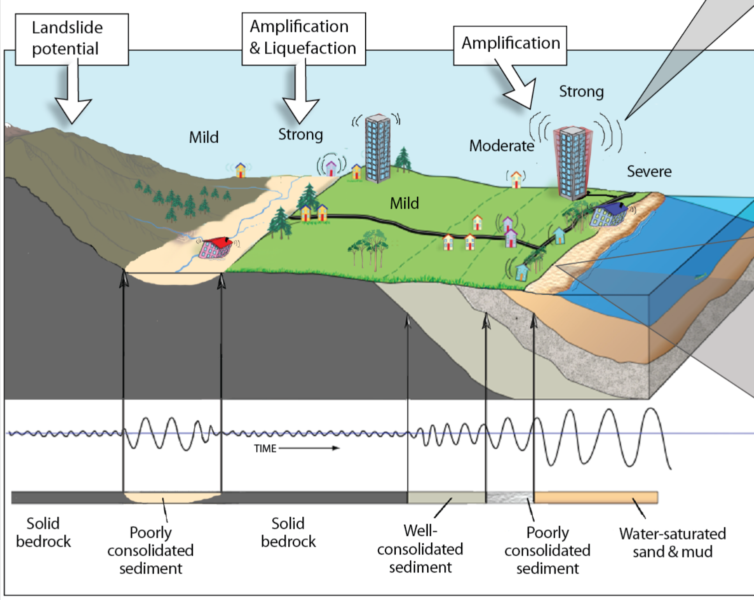
A. Ground Shaking Amplification

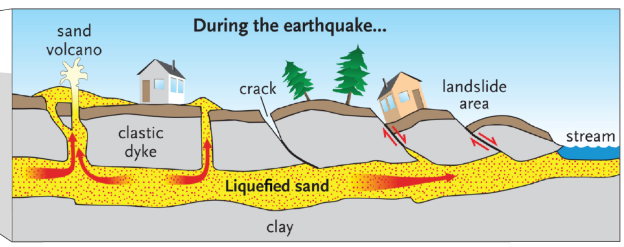
Why does ground shaking from an earthquake change so much with location?

The figure below shows that seismic waves traversing solid bedrock have low amplitude & high frequency. In weaker less-consolidated material, seismic waves oscillate with higher amplitude but with a lower frequency. Imagine dropping a rock on concrete and recording the vibration compared to dropping a rock on a vat of Jello©.



Amplification—*Tall buildings on thick unconsolidated sediments (1 & 2) such as river deltas or ocean shorelines, will be more strongly shaken than those lying directly on bedrock (3). Low-frequency, long-period seismic waves are amplified as they enter the thick sediment pile. Tall buildings resonate with high-amplitude, low-frequency seismic waves (1), but if the waves are high-amplitude but higher-frequency (2), smaller buildings will be affected.*





Liquefaction & Seismic Landslides—*Liquefaction of water-saturated silt or sand may cause the ground to lose strength, fracture, and slide downhill during an earthquake, damaging or destroying buildings and other human works.*

B. Liquefaction

Liquefaction in Christchurch New Zealand, Tuesday 22 February 2011. Image source: [Mark Lincoln](#).

C. Landslides

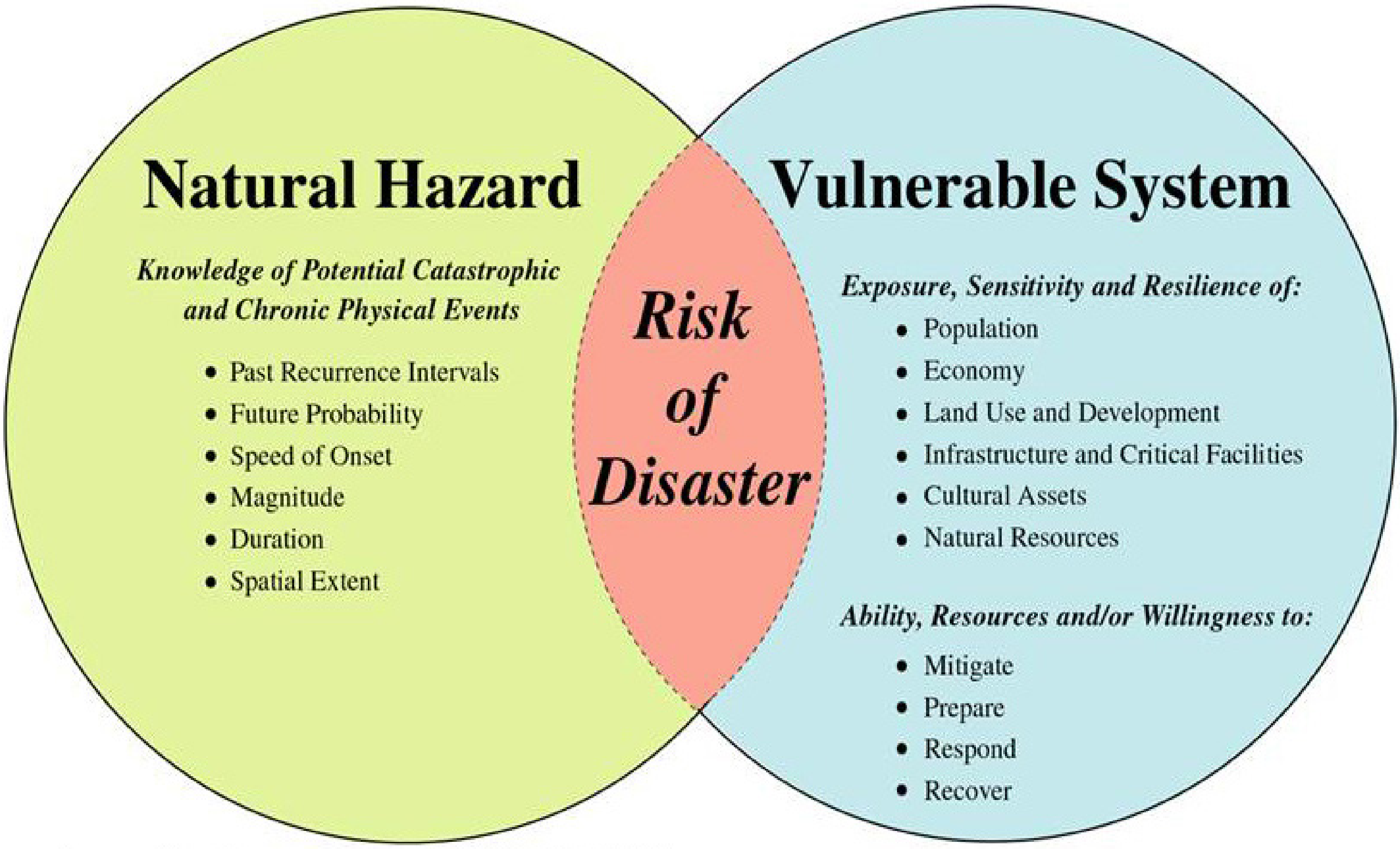
Houses in the Magnolia Bluffs area overlooking Puget Sound that were struck by a rapidly moving landslide. (USGS Photo)

APPENDIX C—HAZARD INVENTORY CHECKLIST

Part 1: Complete this worksheet using the maps and resources provided.
Use (H), (M), (L), or (n/a) for high, moderate, low or none in the Hazards columns.

	Location Describe an approximate location using street names. or landmarks	Hazard (high, moderate, low or none)							
		Landslide	**Ground Amplification**	**Liquefaction**	**Tsunami Inundation**	**Dangerous debris** (Logs, mobilized objects, etc.)	**Construction** (Age, masonry, multi-level, etc.)	**Access to High Ground**	**Access to Basic Survival Supplies**
Current Location									
Your Home									
Essential Services									
Police									
Fire									
Hospital/Clinic									
City/County Government									
Emergency Ops Center									
Jail									
School									
School									
Banks/$ Institutions									
Essential Infrastructure									
Communications Networks									
Water/Waste-Water Supply Systems									
Utility Plants									
Bridges									
Harbors/Ports									
Airports									
Main Roads									
Haz Mat Structures									
Large Gathering Areas or Vulnerable Populations									
Hotel/Resort									
Parks									
Beach Access									
Bank									
Nursing Homes, Asst. Living, etc.									
Casino									
Event Center									
Shopping Areas									
Other:									
Other:									

In doing your reflection while completing the worksheet, consider the hazard, vulnerability, and risk diagram below.



The intersection of hazards and vulnerabilities create risks. (Image source: [Brittany Brand.] Found in context in the following learning InTeGrate learning module: [Unit 1: Hazards, vulnerability and risk]. This image is offered under a Creative Commons from the [U.S. Geological Survey].)

APPENDIX D—HAZARD INVENTORY WORKSHEET

Part 2: Mitigating Hazard Vulnerability to increase Community Resilience

1. **Write a Summary Statement** assessing strengths and vulnerabilities of essential services or infrastructure.
2. **Propose Actions** for mitigating vulnerabilities.
3. **Create an Action Plan** to address identified needs.

1. **Summary Statement**: Using the Hazard Assessment chart developed in Part 1, select at least 5 essential services or infrastructure in your city or area of interest and write a summary statement assessing their strengths and vulnerabilities. Include specific examples.

2. **Mitigation Actions**: Propose potential mitigation actions that could be taken to reduce risk at the 5 essential services or infrastructure you selected. Additional sites may be included.

Site/Facility	Possible Mitigation Actions

3. **Create an Action Plan to address identified needs.** Consider things such as: community information, education, and/or focus groups; forming an Ad Hoc committee; presenting findings to a responsible jurisdiction such as city council, county commission, parks department, school board; feasibility studies; professional consultants, identifying funding mechanisms, implementation & construction, etc.

	Action Plan Steps	Who is Involved and What Happens
1.		
2.		
3.		
4.		
5.		
6.		
7.		

APPENDIX E— NGSS Science Standards & 3 Dimensional learning

NGSS Science and Engineering Practices

1. Asking Questions (for science) and Defining Problems (for engineering)
2. Developing and Using Models
3. Planning and Carrying Out Investigations
4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations (for science) and Designing Solutions (for engineering)
7. Engaging in Argument from Evidence
8. Obtaining, Evaluating, and Communicating Information

NGSS Engineering Design Process

1. Identify a problem
2. Identify design constraints
3. Research and brainstorm
4. Identify possible solutions
5. Define a final solution
6. Develop a prototype
7. Test the prototype
8. Analyze and communicate results

NGSS Science and Engineering Standards

Earth and Human Activity

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

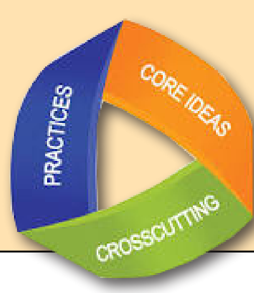
Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings.

Disciplinary Core Ideas

ESS3.B: Natural Hazards
Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)



Crosscutting Concepts

Patterns
Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2)

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.

Incorporated Research Institutions for Seismology

IRIS

FACILITATE. COLLABORATE. EDUCATE.

Founded in 1984 with support from the National Science Foundation, IRIS is a consortium of over 100 US universities. In partnership with its Member Institutions and the scientific community, IRIS manages and operates comprehensive, high-quality geophysical facilities that enable exciting discoveries in seismology and the Earth sciences. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of a Comprehensive Test Ban Treaty.

NSF