(Reid Middleton)

PROBLEM BASED LEARNING
EDUCATING *for* SUSTAINABILITY

EARTHQUAKE!

What Happens When Our Water Infrastructure Breaks?

Grade Level: 6-12
Subject: Earth and Space Science, Geography, LASS, Civics

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(SkyNews)

PROBLEM STATEMENT

When a major earthquake occurs in our region, what might happen to our water systems infrastructure and how do we prepare before, during, and after?

SUMMARY

The Water Supply Forum (Forum) is a voluntary organization with representatives from public water systems and local governments from King, Pierce, and Snohomish Counties in Washington State. In an unprecedented planning effort spanning three counties, Forum member utilities brought together staff with expertise in **engineering, planning, and the sciences** to evaluate the potential risks to our shared water supply system and to identify opportunities to improve the region's resiliency.

Resiliency is generally defined as the ability to reduce the impact of and recover rapidly from disruptive events, so that an "acceptable level of service" is maintained and the impacts on public health and safety and the economy are minimized. The Forum selected four initial risk topics: **earthquakes, water quality, drought, and climate change.**

This collection of lessons is focused on **earthquakes** and draws significantly from the Forum's Regional Water Supply Resiliency Project: Summary Report and the Forum's Earthquake Vulnerability Assessment Technical Memorandum.

Though we cannot feel it happening right under our feet, the North American plate is moving eastward 3 to 30 millimeters a year, about as fast as your fingernail grows. In what geologists understand to be an **earthquake return period**, the time between earthquakes in a specific area, most predict the earthquake return period for the Cascadia Subduction Zone is **about 243 years**.

The last Cascadia earthquake was in the early 1700s. Knowing this, the return period would place another Cascadia earthquake in the mid-nineties. This, obviously, did not occur which leads us to wonder...***when will the big earthquake happen?***

These lessons offer a range of curricular entry points to encourage systems thinking. The lessons can be followed sequentially or separately, catalyzed by an entry event where students assume the roles of a local **Earthquake Emergency Response Team**. Students will explore science, engineering, civics, economics, geography, and environmental justice issues related to disaster planning. They will examine local planning documents, graphs, tables, and maps as **"living textbook"** resources for supporting standards in the context of real-world problem-solving.

As a **summative assessment**, students **produce an accurate and realistic roleplay** of how collaborative teams of local managers and decision makers would respond to a major earthquake in our region. This will include deliverables like social media posts, media communication strategies, and public safety announcements.

Students will personalize what they learn by creating an **earthquake preparedness plan** for their family.

The activities in this collection include:

Entry Event: Role Play - Round One

Activity 1 The Big One & Magnitude Math

Activity 2 Four Earthquake Scenarios Under Our Feet

Activity 3 Science Communication for Community Awareness

Activity 4 A Day in the Life of a Seismologist

Activity 5 Stakeholder Collaboration

Activity 6 How do People Behave in a Disaster?

Activity 7 Economic Fallout - Reading a Table of Estimates

Activity 8 Exciting Engineering Solutions

Activity 9 Role Play Round Two: Community Resilience

Activity 10 Get Ready! Personal and Community Planning

Learning Objectives / Student Outcomes

1. **I understand the basic science behind earthquake vulnerability in the Puget Sound region.**
2. **I can analyze the consequences of a major earthquake on our water systems infrastructure.**
3. **I understand the importance of collaborative planning to be prepared before, during, and following an earthquake.**
4. **I can take personal action to improve my family's earthquake preparedness.**

Formative Assessment

Menu of possibilities...

1. An initial personal reflection, mind map or video-self-interview on how a major earthquake might impact me, my family, and some of the basic services in my community such as water supply and wastewater treatment.
2. An initial mind map of the various roles involved in preparing for and dealing with a major earthquake in our region.
3. A detailed draft description of one or more specific planning and responding roles.
4. A set of hand-drawn schematics modeling what we know about the geology of earthquakes in our region.
5. A comparative analysis of the known fault line maps and related earthquake scenarios in our region with a focus on the one I live closest to.
6. Jigsaw notes and analysis of readings, websites, and group discussion.

(Luzdelia Caballero)

Summative Assessment

1. **Produce an accurate and realistic roleplay of how collaborative teams of local managers and decision makers would respond to a major earthquake in our region. This will include deliverables like social media posts, media communication strategies, and public safety announcements.**
2. **Produce an earthquake preparedness plan for my family.**
3. **Produce a final personal reflection, mind map, or video-self-interview on what I have learned, the new skills I have applied, and how I feel about it.**

ACADEMIC STANDARDS

NGSS #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. *Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes, surface processes, or severe weather events . Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global or local.*

NGSS #HS-ESS3-14

Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. *Examples of key natural resources include access to fresh water, fertile soils, and fossil fuels. Examples of natural hazards can be from things like volcanic eruptions and earthquakes, tsunamis and soil erosion, and severe weather. Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation.*

NGSS #HS-ETS1-2

High School Engineering Design. *Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.*

NGSS #HS-ETS1-3

High School Engineering Design. *Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.*

OSPI Environmental Sustainability Standards

Standard 1: Ecological, Social, and Economic Systems *Students develop knowledge of the interconnections and interdependency of ecological, social, and economic systems. They demonstrate understanding of how the health of these systems determines the sustainability of natural and human communities at local, regional, national, and global levels.*

Standard 2: The Natural and Built Environment *Students engage in inquiry and systems thinking and use information gained through learning experiences in, about, and for the environment to understand the structure, components, and processes of natural and human-built environments.*

BIG PICTURE

NGSS Global Climate Change

NGSS Human Sustainability Standards

OSPI Environmental Sustainability Standards

OSPI Social Studies Standards

College, Career, and Civic Life (C3)

Common Core State Standards

COMMUNITY CONTEXT

My family's earthquake plan

My School District's Earthquake Plan

Community-Based Organizations, Social Services

My City's Earthquake Plan

My County's Earthquake Plan

Public Health Plans

First Response Plans

Hospitals

My Energy Utility

My Water Supply Utility

My Wastewater Utility

Water Supply Forum

Puget Sound Regional Council

Transportation Department

Communication Networks

Pacific Northwest Seismic Network

United States Geological Survey

Washington State Department of Natural Resources

Washington Dept of Ecology

Tribal Governments

Breaking Down the Problem Statement

When a major earthquake strikes... in our bioregion... what might happen to our water systems infrastructure... and how do we prepare before, during, and after?

When a major earthquake strikes...

- What causes the earthquake?
- Are there different sizes of earthquakes based on the cause?
- What do we mean by "major earthquake?"
- What would that feel like?

in our bioregion...

- What defines our bioregion?
- What is the relationship between a georegion and a bioregion?
- What is the role of weather, climate, and water flow in shaping our bioregion?
- How have animals and plants evolved and adapted to the ecological conditions of our bioregion?
- Have we experienced earthquakes here before?
- How do we read the geologic record of local earthquake patterns?
- What knowledge do indigneous people, who have lived here since time immemorial, have of earthquakes?
- How do we know that we are due for a major earthquake?

what might happen to our water systems infrastructure...

- What would happen to our water supply infrastructure and how would that impact us personally?
- What would happen to our wastewater treatment infrastructure and how would that impact us personally?
- What would happen to our transportation infrastructure and our communications infrastructure and how would these disruptions impact our ability to fix our water supply or wastewater treatment systems?

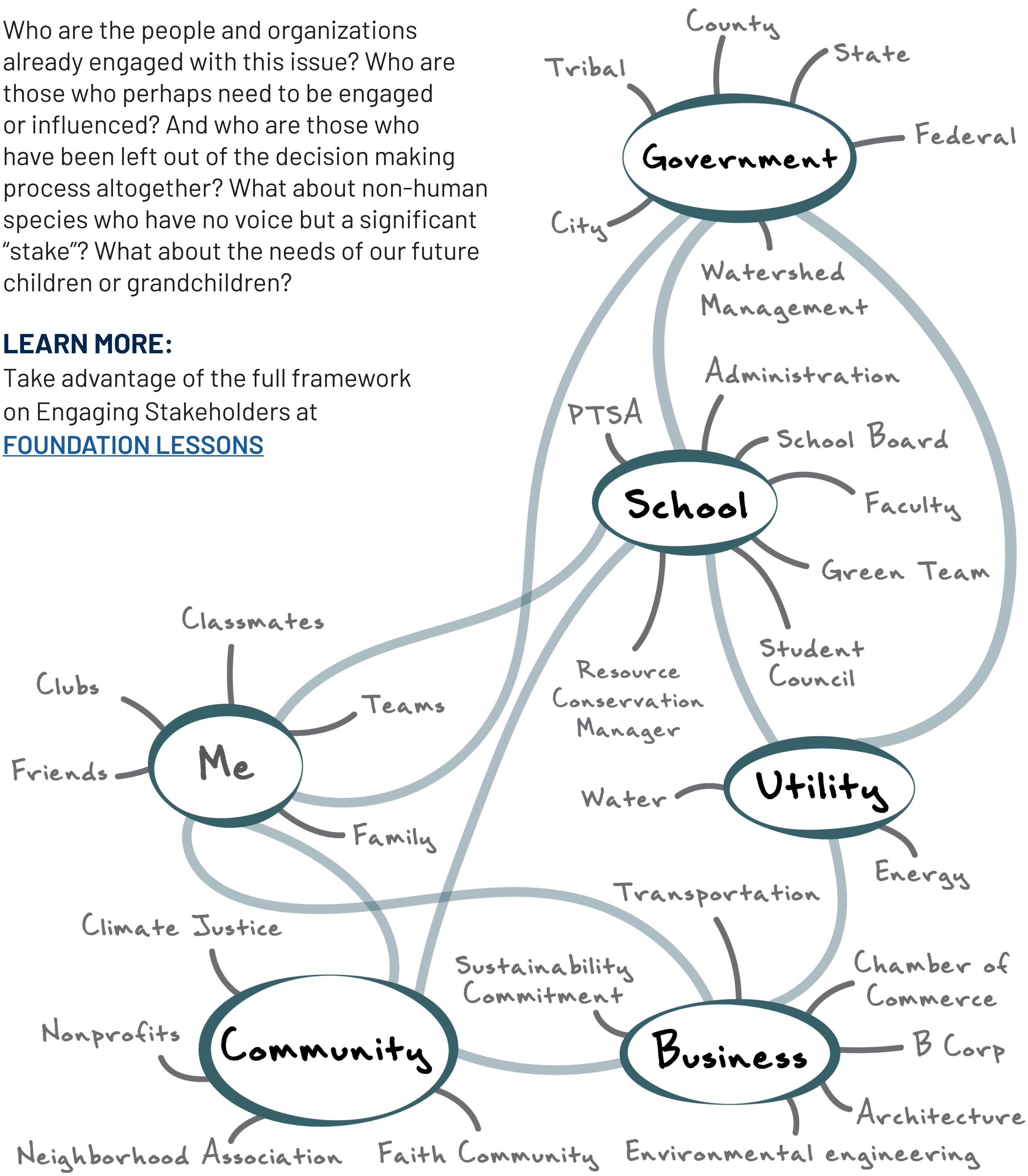
and how do we prepare before, during, and after?

- Is my family ready for a major earthquake? What is the right way to be prepared?
- How is my school prepared? How is my city prepared?
- Who is involved in earthquake response in my community? How are they collaborating? Do they have a plan? Do they practice or roleplay the plan?
- How are equity concerns addressed in these plans? Are marginalized communities, those who would be most impacted by a major earthquake, involved in preparations, information sharing, and communications?
- What happens when the ground is done shaking and there is significant damage and disruption of services, what is the list of priority actions? How long will it take for the systems we depend on like water supply and wastewater treatment to come back on line?
- What are the engineering solutions that can help our infrastructure be more resilient?
- What are the environmental justice solutions that can help our communities be more resilient?

Stakeholder Brainstorming

Who are the people and organizations already engaged with this issue? Who are those who perhaps need to be engaged or influenced? And who are those who have been left out of the decision making process altogether? What about non-human species who have no voice but a significant "stake"? What about the needs of our future children or grandchildren?

LEARN MORE:
Take advantage of the full framework on Engaging Stakeholders at [FOUNDATION LESSONS]



Stakeholder Perspectives

As students identify specific stakeholders relevant to this topic, they will want to consider each point of view with integrity. This practice provides a critical opportunity to develop social-emotional learning skills and cultural competency by building an awareness of our own internalized biases and expanding our capacity for empathizing with stakeholder perspectives different than our own.

EXAMPLE: Stakeholder Engagement Table

STAKEHOLDERS	INTERESTS	GOALS	APPROACH
Name of stakeholder group	**What motivates them? What do they care about? What are they responsible for?**	**Do they have specific action plans, goals, or projects they are pursuing?**	**What is the best message and timing to engage with this group?**
People I live with, like my family	Keeping people, pets, and property safe during and after an earthquake.	Survival. Access to food, water, and shelter. Getting important information efficiently.	Family discussions. Earthquake plans and preparedness websites. Access to social media platforms.
School District	Protecting students, staff, and property. Returning to normal operations as soon as possible.	Connecting communities and serving as a temporary shelter or aid distribution center.	Helping with classroom, school, and district safety plans. Attending School Board meetings.
Community-Based Organizations, Social Services	Offering services and safe places for the most vulnerable people in communities.	Connecting vulnerable populations with food, water, and shelter. Distributing resources. Providing resources in multiple languages.	Word of mouth, social media, attending community meetings, sharing resources on behalf of these groups.
My City and My County	Maintaining safety of community members, getting services back online. Maintaining communication channels.	Providing community and local businesses support. Coordinating communication between governments and aid agencies.	Connect with staff and committees focused on hazard planning. Advocate for community policies that fund emergency planning.
Local Utilities	Providing water, electricity, and clean up services. Maintaining communication channels.	Limiting time without water, electricity, and clean up services. Mitigating damage to infrastructure.	Connect with staff focused on hazard planning and engineering. Information from utility websites.

Continued on next page

Public Health, First Responders, and Hospitals	Maintaining basic and life-saving services. Responding to injuries, fires, and other emergencies.	Respond to emergencies. Access to roadways, medical facilities, equipment, generators.	Connect with staff focused on hazard planning. Information from websites.
Communication and Media Systems	Communicating messaging from public health officials, scientific monitoring agencies and emergency managers.	Sharing accurate, up-to-date information with the public. Utilizing multiple media pathways: online, print, social media, live reporting.	Connect with staff who are responsible for covering emergencies and rapidly evolving news stories.
Scientific monitoring agencies	Monitoring seismic activity and other geologic hazards. Publishing data and sharing recommendations with policy makers.	Provide information to the public about earthquake preparedness on their website and education.	Connect with scientists who can explain the nuance of earthquake hazards, types of earthquakes, and severity of impact.

(KYDO)

BACKGROUND

"The Big One" is likely in Puget Sound region

TEACHER's NOTE: You can download the following pages of [Science Background Information] all in one document, but formatted as a series of short, independent handouts for classroom jigsaw.

The mountainous scenery of the Pacific Northwest is the result of actively shifting pieces of the Earth's crust called **tectonic plates**. Off the coast of western Washington, the Juan de Fuca tectonic plate is sinking beneath the North American plate in a process known as **subduction**. The interaction of these two plates cause volcanoes to build up as tall mountains framing the skyline of the city of Seattle.

Volcanoes are just one geologic phenomena formed by the interaction of two plates in a **subduction zone**. Great forces and pressure cause the crustal plates to buckle, fold, and slip. When strain builds up along cracks called faults in these plates, energy is released in energetic waves called **earthquakes**.

The **Puget Sound region** is one place in the Pacific Northwest at the highest risk for earthquake hazards in the United States. How might communities in this region prepare for earthquakes - especially major earthquakes - which are infrequent but dramatic in their scale?

Are we prepared?

A magnitude 9.0 earthquake (M9.0), **"the big one"** is due to happen in the Pacific Northwest. It is overdue.

The **Cascadia Subduction Zone** runs for 700 miles off the coast from northern California to Vancouver, British Columbia. Along this underwater fault line, the **Juan de Fuca tectonic plate** is slowly sliding underneath the **North American plate** in a process called **subduction**. As pieces of earth's crust slowly slip along this fault, earthquakes are generated. For the 700 mile long Cascadia Subduction Zone, any slip between the two plates would release an unfathomable amount of energy - enough to generate a M9.0 earthquake.

The Cascadia Subduction Zone is not the only place that can generate earthquakes in the Puget Sound Region- there are other fault zones along which earthquakes occur. Each of these fault zones have different **earthquake recurrence intervals or return periods**, the average estimated time between earthquakes. Imagining how an **earthquake** may affect communities in the Pacific Northwest is important to building disaster preparedness and resilience especially in areas of high risk.

The **Puget Sound region** is one place in the Pacific Northwest at the highest risk for earthquake hazards in the United States. How might communities in this region prepare for earthquakes - especially major earthquakes - which are infrequent but dramatic in scale?

Understanding the roles of individuals, city planners, scientists, school administrators, emergency responders, and other stakeholders in the face of a large-scale natural disaster is important. Knowing that such a **large-scale natural disaster is likely** in the Puget Sound region is a reason to stop and evaluate current ways of living.

The Less than 90 seconds

Natural disasters such as earthquakes are **natural hazards**. Hazards are natural phenomena that affect an area regardless of whether there are people to witness them or not. **Earthquake hazards** include any physical phenomena associated with an earthquake that may **adversely** affect human communities. Earthquakes produce two types of hazards:

Primary earthquake hazards occur during the actual earthquake and include **ground shaking, liquefaction, rupture or breaking apart** of the ground surface.

Secondary earthquake hazards are additional phenomena that result from the earthquake and include **tsunamis, flooding, fires, seiches or waves in enclosed bodies of water** such as lakes and reservoirs. Scientists determine the likelihood or **risk** of certain hazards based on quantitative assessments and models.

Earthquakes are sudden and violent natural disasters. Scientists closely monitor earthquakes to better understand how earthquakes of different magnitudes affect **infrastructure** such as hospitals, schools, or stormwater and wastewater pipelines. Preparing for earthquake hazards is crucial as the most advanced warning occurs ***within less than 90 seconds*** of an earthquake but because earthquakes move in a predictable manner it is possible to quantify the impact of earthquakes on communities and infrastructure based on their magnitude.

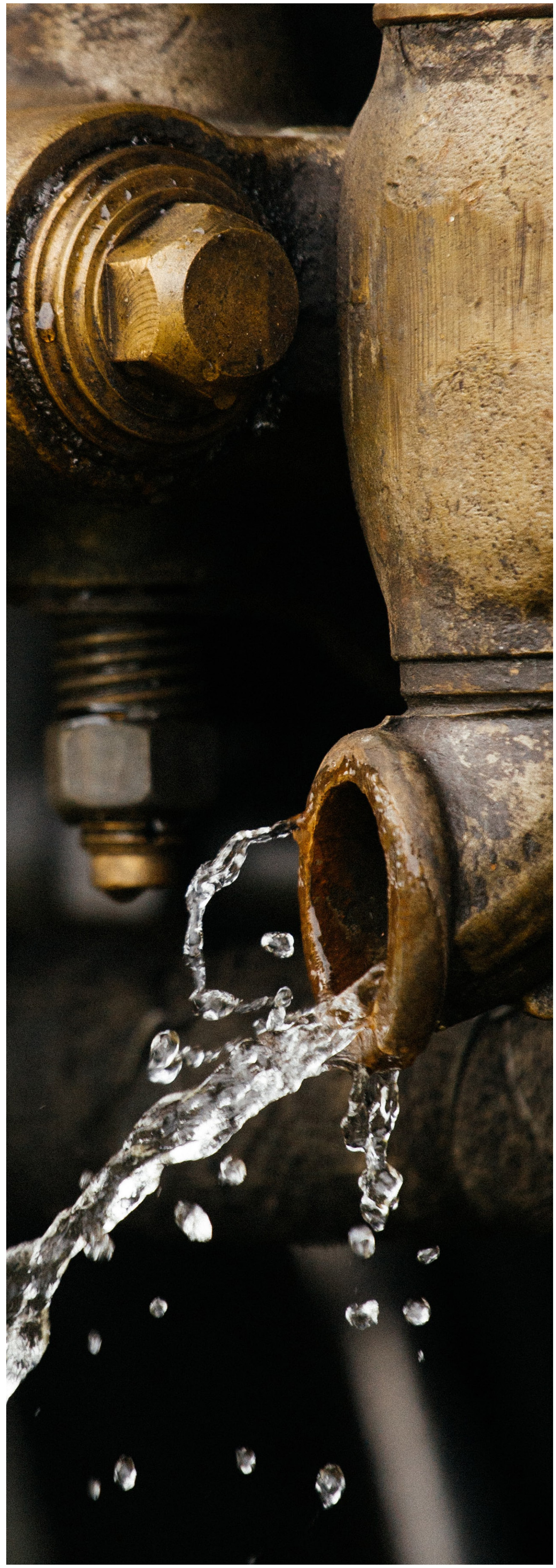
Scientists can quantify how an earthquake will move through different substrates or ground types.

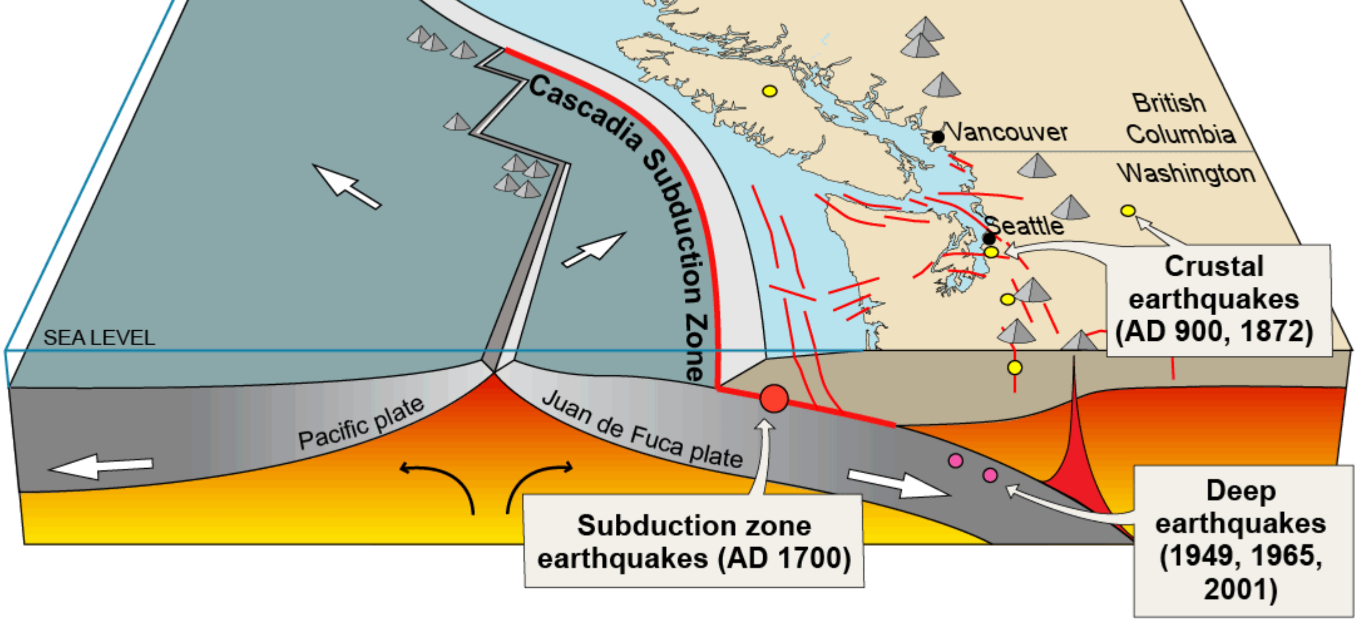
Engineers can assess the risk of an earthquake on existing infrastructure such as buildings and roads and design upgrades to reduce damage during an earthquake.

Geologists can quantify the recurrence interval at which earthquakes occur on a particular fault to estimate how frequently, on average, earthquakes may occur.

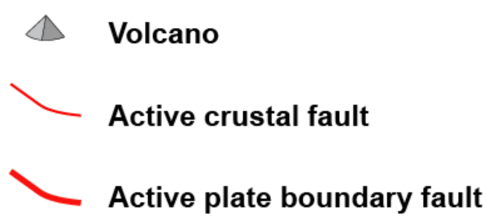
Despite all of this, there is no way to predict when exactly an earthquake will happen.

Existing infrastructure such as **water supply, wastewater treatment, and stormwater management** are extremely vulnerable to earthquakes. Risk of catastrophic failure of these systems is particularly high for systems that were built before scientists and city planners were aware of the risk of major earthquakes in the Pacific Northwest. Knowing that such major earthquakes are likely to occur in our region, what can we do to improve our understanding of the hazard and preparedness? How can we be proactive?





Source	Max. Size	Recurrence
Subduction zone	M 9+	200–600 years
Deep Juan de Fuca plate	M 7+	30–50 years
Crustal faults	M 7+	Hundreds of years?



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Three Earthquake Types

The Earth's crust is made from brittle rock that is constantly experiencing strain from multiple directions. Earthquakes occur when strain builds up along cracks called faults and is released as the rock shifts along these faults. All earthquakes occur along faults and thus, all earthquakes occur in specific predictable areas.

Three types of earthquakes are possible in the Puget Sound region. Each type of earthquake is generated along a different type of fault. Different faults are of different sizes and under varying levels of strain. This produces earthquakes of varying intensity, ground motion and recurrence intervals.

Crustal (shallow) earthquakes: Shallow earthquakes (up to 21 miles deep) occur in the crust of the North American Plate and result from compression due to **regional tectonic plate motions**. Earthquake size is proportional to the size of the movement or rupture along the fault. Crustal faults in the Puget Sound region can produce earthquakes as large as 7.5. Read more about crustal earthquakes on the Pacific Northwest Seismic Network webpage. Crustal earthquakes are potentially most dangerous to infrastructure in the Puget Sound region because faults that generate these earthquakes such as the Seattle Fault run directly through major cities. The USGS estimates a 15% chance of a crustal earthquake above M7 occurring in the next 50 years.

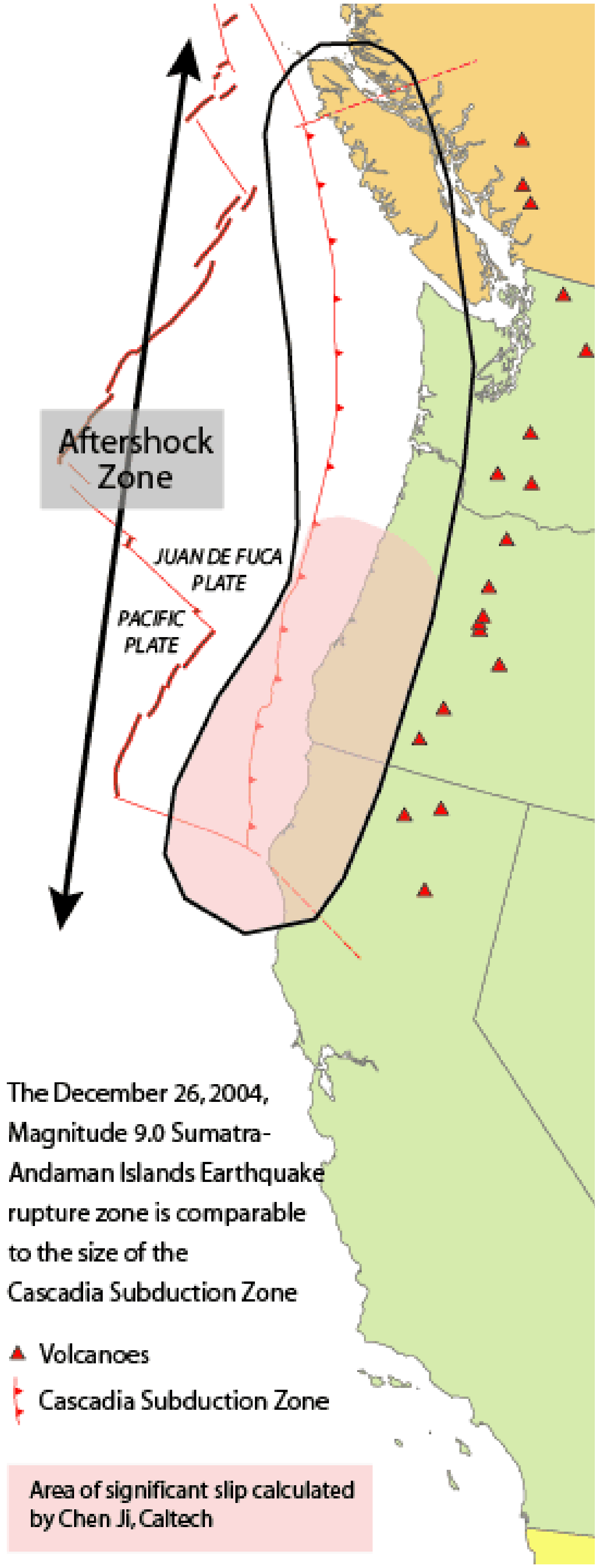
Subduction zone earthquakes: Subduction zone earthquakes are caused by the buildup of strain along the fault line between two tectonic plates. Subduction Zone faults produce the largest earthquakes in the world, and are the only source zones that can produce earthquakes greater than M8.5. In the Pacific Northwest this occurs along the **Cascadia Subduction Zone** where the Juan de Fuca plate is **subducting** beneath the North American plate. The Cascadia subduction zone is uncharacteristic of other subduction zones because it historically has produced very few earthquakes. Geologists consider this fault zone to be "locked" and estimate that the amount of strain that has built up could release energy in an earthquake larger than M8.0. Read more about subduction zone earthquakes on the Pacific Northwest Seismic Network webpage.

Deep earthquakes: Deep earthquakes occur when the subducting Juan de Fuca tectonic plate is placed under strain as it is forced beneath the North American plate. Deep earthquakes occur 20 - 40 miles beneath the surface. Because these earthquakes occur so deep the shaking experienced on the surface is often spread over a wide area because the energy is dispersing so far from the source. Many damaging earthquakes in the Puget Sound region are deep earthquakes. Deep earthquakes are the most frequent type of earthquakes in the region and occur on average every 30 to 50 years. The USGS estimates an 85% chance that a deep earthquake will happen in the next 50 years. The 2001 Nisqually earthquake is an example of a deep earthquake. Read more about deep earthquakes on the Pacific Northwest Seismic Network webpage.

So...how do we know?

While the topic of earthquakes may be familiar to those living in the Puget Sound region today, only recently has the **science of earthquake hazards** been understood and incorporated into policies, building codes and public education. Just fifty years ago there was no unifying theory to describe why earthquakes occur in certain places on the Earth.

The **theory of plate tectonics** which explains the mechanisms of behavior of plates on the Earth's crust was only conceived in the 1960s.



Before the theory of plate tectonics along with mapping of the ocean floor, the 700 mile long Cascadia Subduction Zone - which stretches from Mendocino California to Vancouver British Columbia - was not known to geologists.

This fault zone hidden beneath the ocean produces the largest earthquakes in the Pacific Northwest but until recently remained out of the consciousness of scientists, policy makers and the public.

Only after the 1980s did scientists develop awareness about the capacity of the Cascadia Subduction Zone to produce large (>M8.0) earthquakes.

Scientific understanding of the risk of a major earthquake along the **Cascadia Subduction Zone** is relatively new. An earthquake along this plate boundary is rare in a human lifetime - occurring on average once every 243 years. The last earthquake (M9.2) on the Cascadia Subduction Zone occurred 315 years ago, in the year 1700.

When one compares this date to the average, it becomes apparent that the Pacific Northwest is overdue for an earthquake on the Cascadia Subduction Zone. And, given that so much strain has accumulated on the subduction zone without being released by smaller earthquakes, scientists expect that it will likely be a major earthquake, greater than M8.0.

Why worry?

Earthquakes happen almost every day in Washington State. Most of these earthquakes are too small to notice or cause damage to communities, buildings, roads and other infrastructure. Large or **major earthquakes** are common in the Puget Sound region as well. Major earthquakes can be devastating to communities and infrastructure especially when communities are not prepared.

Because large cities in the Pacific Northwest such as Seattle are built on or near major fault zones, the Puget Sound region is one of the regions of highest seismic risk in the United States.

Tsunamis are secondary hazards caused by earthquakes. Tsunamis occur when water is displaced from movement along a fault line. In the case of the Cascadia Subduction Zone, the length of the fault is hundreds of miles long and the buildup of strain on the fault is substantial.

If the plates were to shift in an earthquake the edge of North America could **drop as much as 6 feet and rebound 30 to 100 feet** to the west. This action would generate a massive tsunami wave that would rocket across the Pacific Ocean to the shores of Japan and a wave that would inundate coastal areas of the Puget Sound region in ***less than 15 minutes***.

Indigenous Knowledge of Natural Hazards

Major earthquakes are much less frequent in the Pacific Northwest than in other places along subduction zones, such as Alaska and Japan. The "quiet" and large gap of time between major earthquakes leads to a form of quiescence.

Although scientific recognition of the earthquake hazards presented by the Cascadia Subduction Zone (CSZ) is relatively recent, Indigenous people who have lived on the Cascadia coast for thousands of years transfer knowledge from generation to generation through storytelling.

Pacific Northwest Indigenous stories related to the earthquake in 1700 speak about strong shaking and coastal flooding. "Native traditions tell of shaking and flooding along the Cascadia coast and estimate the date of the last earthquake by using stories that count the number of generations since its occurrence" (Native American Stories Overview from the Pacific Northwest Seismic Network).

Indigenous communities in the Puget Sound Area have made their homes in this region **since time immemorial**, meaning "before the time of human memory." Oral histories and cultural narratives contain many references to natural disasters such as earthquakes and tsunamis in the last 300 years.

Western scientists have integrated the **geologic record** with oral histories from indigenous communities to gain a more complete picture of the history and frequency of major earthquakes in the Puget Sound region.

Since major earthquakes can cause tsunamis that can cross the Pacific Ocean, records from communities in Japan and other places around the Pacific are important as well as evidence.

Oral histories and geologic evidence support **both subduction zone and crustal earthquakes** occurring in the Puget Sound region in the last 2000 years. **Radiocarbon dating** and other paleoseismic methods are ways that scientists obtain dates from the geologic record.

Geologic evidence and oral histories support the last major earthquake on the Cascadia Subduction Zone 320 years ago (~AD 1700).

Stories from tribes near Seattle provide evidence for the last major earthquake on the Seattle fault at AD 900–950.

Freelan, 2009, WWU

Four Scenarios for Puget Sound Earthquakes

Earthquakes can be of different sizes and are rated on a scale of "moment magnitude" (M_W). **Moment magnitude M_W** is the scale used to measure the size (energy released) of an earthquake. Moment magnitude (Mw) is a measure of energy release, and the **return period** is the average time between earthquakes anywhere on a particular fault. Earthquakes have a history of severely damaging water systems in the past.

The Puget Sound region is susceptible to earthquake hazards produced predominantly by the three shallow crustal faults (**South Whidbey Island Fault**, **Seattle Fault**, and **Tacoma Fault**) and the Cascadia Subduction Zone. The 2016 Regional Water Supply Resiliency Project Summary Report outlines four earthquake scenarios which are likely in the Puget Sound region. In each scenario, earthquakes are generated along major faults that run through or are near King, Pierce, and Snohomish counties:

The Big One Cascadia Subduction Zone (CSZ) Scenario, Mw9.0 | 500-year average return period

South Whidbey Island Fault Zone (SWIFZ) Scenario, Mw7.4 | 2700-year return period

Seattle Fault Zone Scenario, Mw6.7 | 1000-year return period

Tacoma Fault Zone Scenario, Mw7.1 | 4500-year return period

The report estimates that each earthquake scenario ***would damage at least one*** of the three major water suppliers (Seattle Public Utilities, Everett Public Works, Tacoma Water) enough to **take up to 60 days or more to restore drinking water**.

Why the call to action?

Japan is a good baseline for comparison when it comes to earthquake infrastructure and seismically resilient water supply systems because the frequency of major earthquakes in Japan is higher than in the Pacific Northwest. Cities in Japan have strict requirements and building codes to ensure that pipes, wastewater treatment plants, and stormwater systems can withstand major earthquakes as well as early earthquake detection and warning systems. Awareness of the high risk of earthquakes in the Pacific Northwest did not exist until after the 1970s.

The majority of infrastructure for drinking water, wastewater treatment, and stormwater runoff in Seattle was built before city planners understood the risk of earthquakes, especially large (greater than 8.0 magnitude) earthquakes in the Pacific Northwest. This is in contrast to places like Japan where earthquakes above magnitude 7.0 magnitude occur nearly ***every year***. It is possible for residents of the Puget Sound region to live a lifetime and not experience many (if any at all) major earthquakes.

Significant federal funding will be needed to upgrade water infrastructure to match the scale of earthquake hazards in the Puget Sound region. Updating water supply infrastructure in the Puget Sound region alone to match recommendations for seismic upgrades is a monumental task that would take many years and significant funding. The goals of **seismic upgrades** to buildings, pipes and other infrastructure are to create stronger, stiffer, safer, and more resilient structures to decrease the damage that will incur in an earthquake. The project of seismic upgrades across multiple systems of water infrastructure - including drinking water, wastewater, stormwater - would generate millions of **green collar jobs**.

In the United States, the majority of funding for natural disasters comes retroactively: disaster relief organizations such as the Federal Emergency Management Agency (FEMA) receive congressionally designated funding after a disaster occurs. Funding for disaster preparedness constitutes a small percentage of governmental budgets. The National Earthquake Hazards Reduction Program (NEHRP) is the federal government's coordinated approach to addressing earthquake risks.

The Pacific Northwest is an excellent example of a place where planning and design for earthquake resilient infrastructure has only recently become more common. If an earthquake larger than M9.0 was to occur in the Pacific Northwest, it could take months to years to repair water infrastructure and to restore clean drinking water and sewer services. These estimates do not apply to areas in the **tsunami inundation zone** in which all infrastructure would likely be eradicated.

Updating Infrastructure to Meet Seismic Risk

Much of the water infrastructure in the Puget Sound region was built prior to the adoption of modern seismic safety codes. Older and more vulnerable types of buildings and other construction methods are more susceptible to damage from earthquakes hazards. Buildings and other infrastructure can be categorized as **seismically noncompliant** or **seismically compliant** structural components. A particular type of infrastructure such as a wastewater treatment plant can have a mix of given seismically compliant and noncompliant elements.

Without upgrading infrastructure to match the projected risk, earthquakes in the Puget Sound region will be not only devastating and economically damaging but will have a significant impact on people including loss of life and bodily injuries.

Economic setbacks due to earthquakes would cause long-term disinvestments that can permanently change the character of a community.

The Puget Sound region has a critical need for investment in resilience planning, policy updates, and significant funding to seismically upgrade water infrastructure in the Puget Sound region.

Infrastructure without seismic upgrades constructed before the mid-1970s and located in high seismic hazard areas are especially vulnerable to damage during earthquakes. The projected cost of upgrading infrastructure can be less than the costs of major damage following an earthquake. This may not be true for less vulnerable structures in lower risk areas.

Overall, seismic upgrades can make infrastructure stronger, stiffer, safer, and more resilient, therefore decreasing the damage during an earthquake to the building and people.

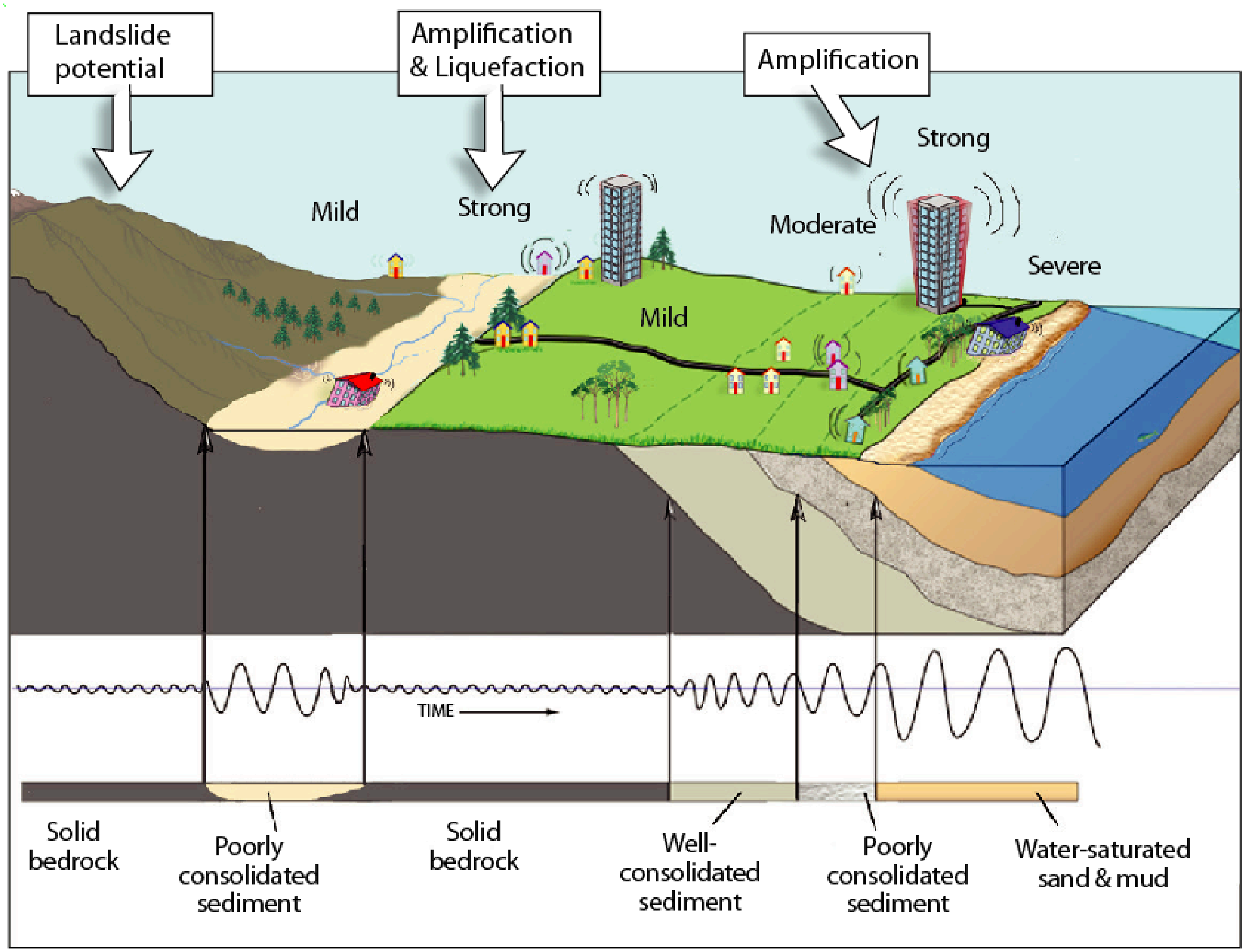
The presence of all three earthquake sources and the relatively high likelihood of a major earthquake occurring in the next 100 years constitutes a significant seismic hazard in the Puget Sound region. Coupled with high population densities of urban centers such as Seattle, this puts the Puget Sound region and other major metropolitan areas of the Pacific Northwest at high seismic risk.

Water Systems That Could Fail

The damage we might see.
The damage we cannot see.

Geologists collect seismic data to measure how local soils underlying infrastructure amplify earthquake shaking. This data analysis is used to assess existing buildings, water treatment plants and other water infrastructure.
The way that particular buildings or other infrastructure would be damaged is also a product of the type of ground or **substrate** upon which the infrastructure is built. The diagram shows a simplified cross section or cut into the Earth's surface with different types of substrates highlighted. Seismic waves travel differently through **hard bedrock** as compared to softer rock or **unconsolidated sediment** (such as sand, gravel, etc.). Ground motion can be amplified when seismic waves travel through sediment that is **poorly consolidated** or **water-saturated**. Much of the infrastructure of the Puget Sound region is built not upon hard bedrock but upon these other substrate types.

Take a moment to imagine all of the different infrastructure that supports clean drinking water and wastewater treatment in our communities. Some of these components include pipelines, drinking water reservoirs, wastewater treatment plants, household plumbing lines, commercial plumbing lines, drinking water testing, electric lines that turn on and off these systems, and more. Given the complexity and number of systems involved, the volume and pressure of water that can be supplied may be reduced for months or even years after a major earthquake.



Let's now imagine how the **primary** and **secondary earthquake hazards** could affect water infrastructure.

Primary earthquake hazards include **ground shaking, liquefaction, rupture or breaking apart** of the ground surface. This could cause:

Leaks & breaks in water lines

Contamination of drinking water supply

Rupturing of pipes and other equipment

Damage to wastewater treatment plants

Power outage for communications and electronic grid infrastructure

Pipeline failures

Failures in electricity transmission lines

Secondary earthquake hazards are additional phenomena that result from the earthquake and include **tsunamis, flooding, landslides, fires** and more. This could cause:

Transmission lines and pipes to be buried by landslides

Transmission lines damaged by fires

Power outage for communications and electronic grid infrastructure

Damage to wastewater treatment plants that can infiltrate drinking water supply

It is important to remember when imaging these different scenarios earthquakes do not result in uniform intensity or ground motion. As discussed, seismic waves move differently through different substrates and across distances. It thus is challenging to predict how a particular water system - that often spans a large geographic area - will be impacted by a particular earthquake scenario. For whatever type of major earthquake that will eventually occur in the Puget Sound region, the impact on water infrastructure will not be distributed evenly across location or time.

ShakeAlert! and Community Resilience Planning

In the last 5 years, earthquake preparedness in the Pacific Northwest has improved.

A new **earthquake early warning system** called ShakeAlert was implemented in Oregon and Washington in 2021. The ShakeAlert early warning system includes over 150 high quality seismic monitoring stations throughout the region.

Seismic data and stations are monitored by the Pacific Northwest Seismic Network, a scientific organization that monitors over 300 seismic stations.

The Pacific Northwest Seismic Network is an example of an organization that links scientists and government officials and people who make policy/decision makers.

To be more prepared for disasters, we need more flexible **water management systems** that allow for innovation and adaptation. Policy makers have been averse to overhauling drinking water systems because the process is widely disruptive.

However, the risk of infrastructure failure in the event of a mid to large sized earthquake in the Pacific Northwest is incredibly high.

LESSON OUTLINE

Materials Needed:

Internet Access

This collection of lessons draws significantly from the Water Supply Forum's

Regional Water Supply Resiliency Project: Summary Report

Earthquake Vulnerability Assessment Technical Memorandum

Other PDFs and websites are linked in the activities

Templates for study and replication

See Foundation Lessons

Impact project Design

Engaging Stakeholders

Time Needed:

Each of the lesson ideas in this unit may take 2-3 class periods.

VOCAB AND KEY SEARCH WORDS

Earthquake

Subduction zone earthquake

Deep earthquake

Crustal (shallow) earthquake

Earthquake return period

Natural hazards

Earthquake hazards - primary and secondary

Fault

Tectonic plate

Geologic record

Subduction zone

Cascadia Subduction Zone

Juan de Fuca plate

North American plate

Infrastructure

Liquefaction

Ground shaking

Rupture of ground surface

Tsunami/inundation zone

Seiche

Substrate

Since Time Immemorial

Transmission line

Moment magnitude

Resiliency planning

Community resilience plan

Earthquake response plan

Earthquake early warning plan

Drinking, storm water, and wastewater infrastructure

Seismic upgrades

Green collar jobs

Seismic compliance

ENTRY EVENT

It is just a few minutes before lunch time when phones start ringing and dinging. The earthquake early alert system has been triggered - meaning shaking could begin ***momentarily***. Everyone from seismologists (earthquake scientists) to students get this information at the same time. The immediate response is critical - **DROP, COVER, and HOLD ON**. The shaking begins a few minutes after the first notification. People throughout the community experience shaking ground, loud noises like banging and creaking from things falling down, and water quickly rushing from broken pipes. The shaking lasts three minutes.

*Teacher note: If you would like to include components of earthquake drills like sound effects/announcements these are available from Great ShakeOut Earthquake Drills. There are audio and video recordings of earthquake drill instructions.

Students will take on various roles in a community response role play "after the earthquake" using what they already know about crisis and hazard management. It's okay if this knowledge is from television, movies, or social media. They may not know every aspect to address, but through exploration they can begin to understand the necessary components of community response and the value of proactive, collaborative resiliency planning.

Encourage students to structure their response plan around the basic needs of their communities first, then dive into the more complicated aspects later in the second iteration of the role play. This example/template of a media release handout can be used or modified to fit a more or less specific earthquake scenario in your area or at your school.

Find example roles with short descriptions on this handout which also contains more specific roles for students to use in a later activity. Depending on student interest and engagement, there are blank role sheets as well.

In small groups, students will begin building a response plan with the following priorities:

Keep people safe and avoid fatalities.

Assess and reduce damage to buildings.

Protect and work to get utility services back online quickly - specifically water systems.

Limit the economic toll on local businesses and supply chains.

Maintain communications like telephone, TV, radio, and internet.

With this list of priorities as impetus, give students time to think through aspects of earthquake response planning using the basic following questions.

What people and resources are needed for your suggested response?

How will you communicate with resources and next steps with the general public?

How will you know your response was successful?

ACTIVITY 1

The Big One & Magnitude Math

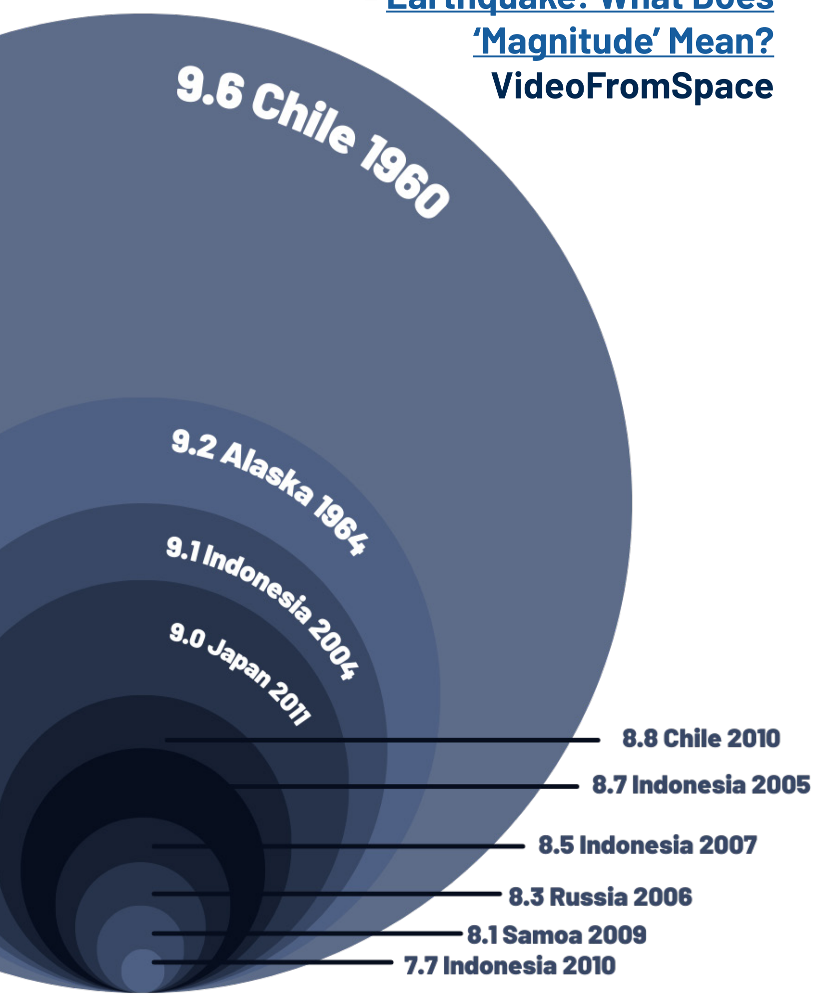
Throughout history, people observed natural hazards and the associated phenomena from earthquakes to tsunamis to wildfires. As with much of human history, some of the earliest information about earthquakes can be traced to knowledge from Indigenous communities. What scientists now consider "The Big One" - the earthquake that is predicted to occur at any time along the Cascadia Subduction Zone (CSZ) fault - is supported by evidence of major earthquakes along this fault in the past, the last one being in the year 1700.

The size of the CSZ fault line is substantially larger than other fault lines that would cause earthquakes in the Puget Sound region. Scientists refer to the future earthquake that will inevitably happen on the CSZ as **"The Big One"** because it will be so much larger (on an exponential scale) in magnitude than earthquakes generated by other faults. This is because the CSZ is a fault along the intersection of **two tectonic plates** while other faults that cause earthquakes in the Puget Sound region are cracks within the North American continental tectonic plate.

The scale used to compare the size of different earthquakes is **exponential**, meaning each step up (from an 8.0 earthquake to a 9.0 earthquake) equates to 10 times the amount of ground motion than the previous. This ground motion requires 33 times more energy. Watch [this video](#) on the [Pacific Northwest Seismic Center webpage](#) to learn more about comparing earthquakes of different magnitudes.

"A magnitude 9.0 earthquake [Mw9.0]... is 35,937 times more powerful than a magnitude 6.0 [Mw6.0]."

- [Earthquake: What Does 'Magnitude' Mean?](#) VideoFromSpace



Magnitude, Intensity, Duration

Earthquake magnitude is commonly used to represent the size of an earthquake. However, most people want to understand how much impact or damage earthquakes will cause. Earthquake **magnitude** can be measured in a variety of ways, most commonly moment magnitude (Mw) or Richter magnitude. Shaking is measured in units of acceleration. Damage or **intensity** can be measured by the modified Mercalli intensity scale (MMI).

The amount of shaking (acceleration) at a specific location depends on three factors:

Distance to the origin of the earthquake (called the ***focus****)*

Magnitude of the earthquake

How the earthquake is moving through certain mediums such as water-saturated ground (which can amplify ground shaking)

Scientists are in active discussion about how to measure the various aspects of an earthquake like magnitude, intensity, and duration. Earthquakes are a release of energy - called **seismic waves** - from a slip along a crack in the Earth's crust. Seismic waves travel through rock, sand, buildings, roads, and water. How these waves move through different mediums will cause significant variation in the expression of an earthquake. Some questions we might ask:

Do we measure magnitude from the epicenter?

Do we measure magnitude for the moment an earthquake shakes a place where there are humans?

How do we measure and understand the intensity and duration of an earthquake?

Remember - an earthquake is a three-dimensional event moving in many directions all at once.

Invite students to create an initial model to estimate the proximity of a quake to its epicenter, the types of geological substrate layers it will move through, and degrees of shaking that buildings and water infrastructure will experience at set distances. Consider the following:

Below ground geological substrate layers (clay, sand, loose rock, compacted rock, bedrock)

A few sample houses and larger buildings

A change in elevation such as hills and lowlands

A river flowing to a lake or coastal area

A sample water supply pipe, pumping station, water tower, treatment facility

A sample wastewater treatment pipe, pumping station, treatment facility

A few major roads

Sample electrical wires and cell phone towers

Using this initial model template, students estimate the magnitude and intensity of a sampling of earthquakes that have affected the Puget Sound region.

More Math Applications

Shaking Ground: Linking Earthquake Magnitude and Intensity. In this activity students model earthquakes of various magnitudes to determine the amount of shaking that these quakes will cause. They then convert the shaking to modified Mercalli intensity and generate an isoseismal map for a M8 and M6 earthquake.

Describing a Seismic Event. In this roleplay activity, students prepare to be interviewed by the local media about a recent newsworthy quake.

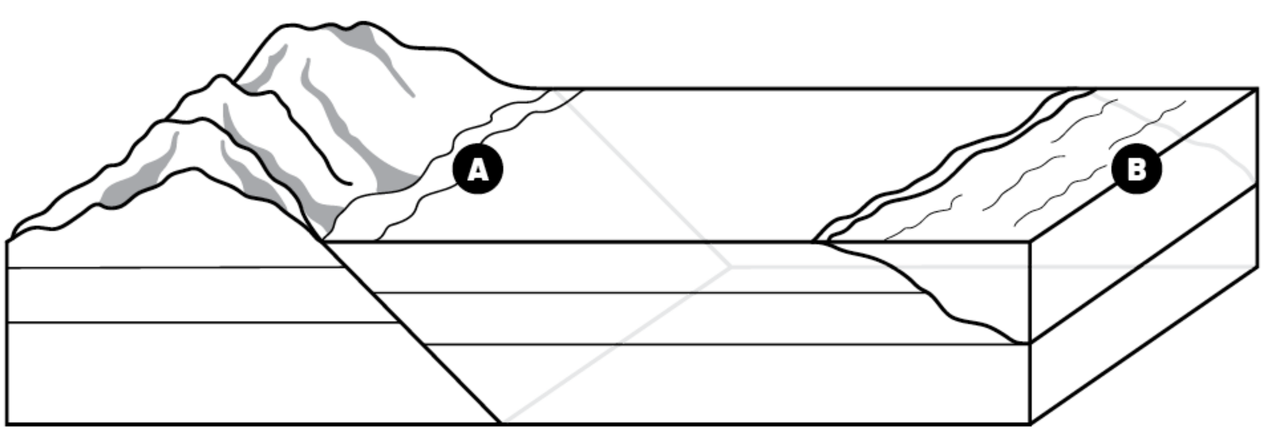
Earthquake Hazards: the Next Big One? In this activity students will explore earthquake data to compare and contrast the probability of an earthquake occurring in different regions. Students will describe at least 3 factors that affect the intensity of an earthquake at a given time.

Modeling Earthquake Magnitude with a "pasta quake".

Advanced students may want to review the complexity displayed in this table of magnitude types that scientists use at the United States Geological Survey.

EARTHQUAKE! Name: Date: Period:

Consider Epicenter A (land-based) and Epicenter B (Puget Sound). Create an initial model to estimate the proximity of surface level damage of an earthquake relative to its epicenter. Consider the types of geological substrate layers it will move through, and degrees of shaking that buildings and water systems infrastructure will experience at set distances. Add some houses, a few skyscrapers, and some major water pipes and water treatment facilities. Annotate your diagram with brief text describing what you think will happen at different distances from the epicenter.



ACTIVITY 2
Four Earthquake Scenarios Under Our Feet

In 2016, the Water Supply Forum (Forum), a voluntary organization with representatives from public water systems and local governments from King, Pierce, and Snohomish Counties, conducted an evaluation of earthquake risk in the Puget Sound region. This project brought together staff with expertise in **engineering, planning, and science** to evaluate the water supply system risks facing the central Puget Sound region and to identify opportunities to improve the region's resiliency to these risks.

The 2016 report that was generated outlines four earthquake scenarios which are likely in the Puget Sound region. In each scenario, earthquakes are generated along major faults that run through or are near King, Pierce, and Snohomish counties. Also see the Forum's Earthquake Vulnerability Assessment Technical Memorandum which walks you through, point by point, the risk associated for each component of the system.

There are four major water utilities in the Puget Sound region: Seattle Public Utilities (SPU), Everett Public Works, Tacoma Water, and Cascade Water Alliance. These utilities serve approximately 2.3 million people over 1,200 square miles. This region includes approximately 60 cities/water districts, a major metropolitan area, three bustling ports, and world-class businesses with international headquarters or major operations in the Seattle area, including Weyerhaeuser, Starbucks, Amazon, Microsoft, and Boeing.

One scenario imagines a major earthquake along the **Cascadia Subduction Zone** fault, what scientists call The Big One. This would be the largest earthquake. The other three scenarios occur along three shallow or crustal faults: **the South Whidbey Island Fault, Seattle Fault and Tacoma Fault.**

In this activity, students evaluate each of the four scenarios in a jigsaw model, working directly from the primary source report text. Students also evaluate the associated hazard maps created for each scenario and compare how projected hazards may impact their communities. Here are Hazard Maps for these four scenarios.

The Big One Cascadia Subduction Zone Scenario, Mw9.0

South Whidbey Island Fault Zone Scenario, Mw7.4

Seattle Fault Zone Scenario, Mw6.7

Tacoma Fault Zone Scenario, Mw7.1

In small groups, students begin by exploring the digital mapping project mywater.world. **Students explore different map layers and identify where they live, go to school and/or work.**

Students compare the interactive map on mywater.world to the static maps produced by the Forum and listed above.

Students start with analyzing the map of water supply systems in Pierce, King and Snohomish counties in this Student Resource folder. (This map is available on page 36 of the Regional Water Supply Resiliency Project Summary Report)

Using the digital file available in the folder or by printing the map and drawing directly onto it, ask students to identify a set of places on the map, following the prompts provided in the images which can be used as a student worksheet.

Review as a class the four earthquake projected scenarios. Click here for a handout outlining the four different scenarios. Identify important vocabulary and other concepts that will help students understand each scenario - this can include information on magnitude, the location of fault lines, the communities that will be impacted, and the severity of impact.

Break students into four groups and, in a jigsaw ctivity using the four scenarios, **evaluate how each scenario would affect their community**. Provide students with both the scenario description and scenario maps. (These maps are available on page 37-40 of the Regional Water Supply Resiliency Project Summary Report)

Using the digital file available in the folder or by printing the map and drawing directly onto it, ask students to identify a set of places on the map, following the prompts provided in the images which can be used as a student worksheet.

Reflect on this activity in small groups or as a large group. Sample discussion prompts include:

Did you know where your water came from before doing this activity?

Do any of your personal activities that you mapped extend into other water supply service areas?

What was surprising to you when evaluating the four scenarios?

What was similar between the four scenarios? What was a major difference between two of the scenarios?

What information about these scenarios would you want to communicate to your family, friends, school or community?

ACTIVITY 3
Science Communication for Community Awareness

In small groups students will roleplay as **science communicators** who are given the task of sharing information about each of the scenarios with the public.

Students are asked to both **determine what type of content is important to communicate and to brainstorm where their infographics should be posted**.

This activity is designed to work in various "phases" in which student groups will work on their infographic and come together to review and critique the work of other teams.

Review the context for the four earthquake scenarios (from the report) and reflection questions about the scenario jigsaw activity together as a group.

Ask students to step into the role of data science communicators. Now that students have learned a bit about the different scenarios and how they would affect the area where they live, what would they want to **communicate to others about these risks and actions people can take to be ready**.

PHASE 1: Determining audience. As a large group, come to consensus about the audience for the infographics. Now that students have learned a bit about the different scenarios and how they would affect the area where they live, where would they want to communicate to others about these risks?

Example audiences include community centers, public libraries, and schools. The audience for the infographics are people who do not have much background about the science of earthquakes but have likely heard about earthquakes in the news media.

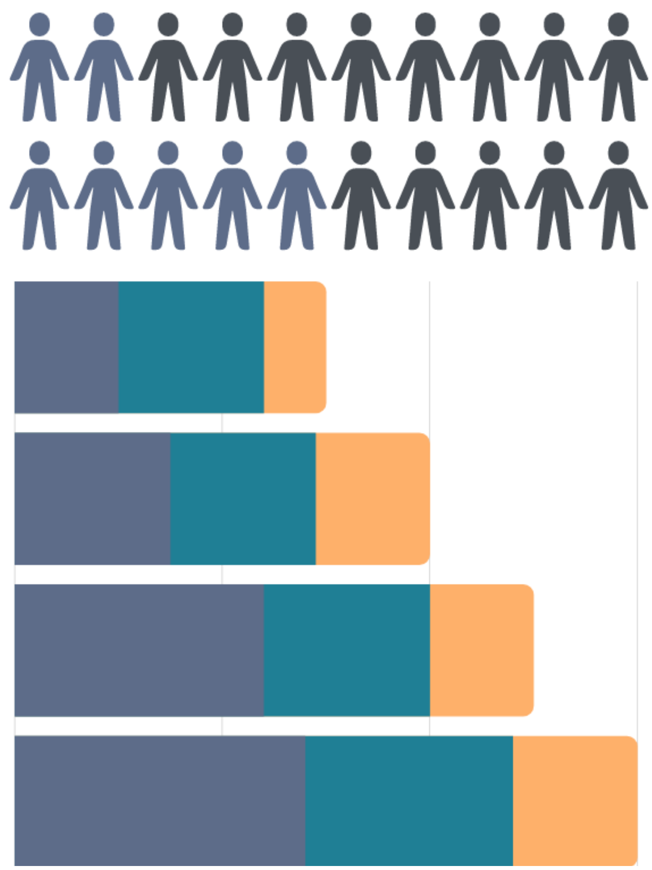
PHASE 2: Initial infographic development. Assign students to small teams. Each team is assigned a different earthquake scenario from the Water Supply Forum report with the task of creating an infographic about it to communicate to a non-technical audience.

Teams are required to use at least two elements from the graphics in this Student Resource Images Folder.

PHASE 3: All groups come together for "inter-department critique" where they rotate and add comments to the design draft of other groups. (The Jigsaw model works well for this). Comment on both the elements included in the infographic design and the audience.

PHASE 4: All groups come together for "final review" and do one final critique of each other's work and their own work.

PHASE 5: Each group presents their infographic in a mock public meeting.



ACTIVITY 4

A Day in the Life of a Seismologist

Introduce the class to the science of earthquakes. Use a combination of the following short activities to engage students with earthquake science.

Start with playing “Who’s Fault is it Anyways?” game published on the Science Education Resources Center webpage. In this game, students simulate the propagation of S and P waves after an earthquake and use the lag between these to determine where in the simulation the earthquake occurred.

Play with the EQLocate web application developed by IRIS (Incorporate Research of Institutions for Seismology). Follow the instructions in the web application to explore how earthquakes in different parts of the United States and the world. Option to break students into groups and to use a jigsaw framework to rotate through exploring different historic earthquakes.

Review the “Day in the Life of a Seismologist” web archive.

Explore the M9 Project, a research group from the University of Washington that conducts research on hazards of the Cascadia Subduction Zone and effects of major earthquakes since 2015.

Review Earthquake Teachable Moments in Google Earth. The Incorporated Research Institutions for Seismology has plotted Recent Earthquake Teachable Moment (RETM) presentations into Google Earth, available here as a .kml file. Touch the red-seismogram icons to see a brief description of each earthquake with a link to IRIS’s individual resource pages. These teachable moments are rapid-response presentations for educators following worldwide earthquakes of greater than magnitude 7.0, and newsworthy smaller earthquakes.

Break students into groups. Based on the earthquakes reviewed in EQLocate and Google Earth, ask each group to identify one historic earthquake on which they want to focus. Groups roleplay as news reporters and are asked to create an article or short video about this earthquake from the perspective of a seismologist.

Lead a short reflection activity in small groups or as a large group using the following questions:

What did you learn that was most surprising about earthquake science?

What did you already know about earthquake science that was reinforced by this activity?

Would you like the job of earthquake scientist (seismologist)? Why or why not?

ACTIVITY 5
Stakeholder Collaboration

If the wastewater or drinking water supply infrastructure fails in one area, collaborating with other utilities could mean access to safe water after an earthquake. A component of the Water Supply Forum's work is bringing regional utilities together for proactive planning. Among the utilities, there are participants across disciplines. The plan included experts who worked on drought, climate change, earthquake, and water quality scenarios. Who's working on it? Why is it critical to collaborate? Analyze (jigsaw?) elements of Regional Water Supply Resiliency Project Summary Report.

To **examine stakeholder responsibilities and interests in resiliency planning**, students can reference the Stakeholder Table earlier in the lesson. Students can look for stakeholders who are compelling to them, who they identify with, or whose role they may want to assume in the role play. They can seek out local people who do this work.

Students might write a class letter or email, set up an informational virtual interview, or even arrange a classroom visit with local people who participate and contribute to hazard planning. With the goal of understanding resiliency planning and career opportunities, the class may cultivate a short list of interview questions. The communication with professionals can prepare students for the summative assessment - Round 2 Role Play - when they step into the various roles.

For inspiration on Green Jobs related to resiliency planning, check out the Green Jobs Youth Pathways job profiles. To extend this lesson, find more activities on Stakeholder Engagement.

ACTIVITY 6
How do People Behave in a Disaster?

Our response to disasters, broken infrastructure, and unexpected chaos varies across communities. When it comes to earthquakes and their unpredictability, we are often surprised despite extensive preparation and research in advance. Understanding and addressing the trauma and emotional toll of these experiences are just as important as the other emergency services. As we watch, read, and listen to disaster responses we may begin to ask ourselves, how would I respond? What would I do first? Do I know where or how to get to the people I care about?

For this activity, there are several **examples of community response to disaster**. The sources range in time, type of disaster, and location, but all occur on the northwest coast of North America. Students can use this graphic organizer to collect observations, reflections, and questions. Students should focus on responses from the general public compared to or in complement to responses from people like medical first responders, community organizations, and responses featured in the sources. To expand this activity, use the template of this lesson published by the Science Education Resource Center at Carleton College.

Examples of Community Response

[Alaska Earthquake and Tsunami of March 27, 1964]

[The Is How You Live When the World Falls Apart, New York Times]

[Mount St. Helens 1980 Cataclysmic Eruption]

[Watch: 1980 eruption of Mount St. Helens], KGW Archives: This fascinating link takes you to a YouTube video with about 20 minutes of raw news footage from 1980. There are interviews with local people, conversations with responders, and footage of the eruption.

[Flooding in British Columbia in November 2021]

[Vancouver, B.C., is cut off by road, rail after 'extraordinary' storms], Seattle Times

Explore the stories of people who were interviewed as part of the [Strengthening Resilience in Volcanic Areas STREVA project] who experienced the devastating volcanic disasters. What is surprising to you about how people respond to experiencing such natural disasters?

Table 1 Facilities and Conveyance System Restoration Times and Associated Economic Losses (Preliminary Estimates)

Utility	Earthquake Scenario (Days to restore supply to 90 percent of customers' taps at average winter day demand, economic losses in $ million attributable to water shortages)[a]			
	Cascadia Subduction Zone	**South Whidbey Island Fault**	**Seattle Fault**	**Tacoma Fault**
Everett Public Works	7 days, $70M	30 days, $490M	$10M[b]	$0[b]
SPU/Cascade	14 to 30 days, $810M	30 to 60 days, $1,550M	30 to 60 days, $1,770M	3 to 7 days, $240M
Tacoma Water	30 days, $750M	$20M[b]	not evaluated	40 days, $1,110M
Total loss	$1,630M	$2,060M	$1,780M	$1,360M

[a] Results presented in this table were generated using high-level analysis methods. Therefore, these results should be considered preliminary and highly approximate.
[b] Greater than 90 percent of customers are expected to have water service immediately following the earthquake event.

ACTIVITY 7

Economic Fallout - Reading a Table of Estimates

As students explore disaster preparation they may begin to realize there are ramifications outside of the initial and immediate repair of water supply and wastewater infrastructure.

This lesson helps students **read a table** that describes the **four earthquake scenarios** described in the report on page 13 and the associated **economic fallout**.

Here is the wording used in the top cell of the table. All other cells in the table refer to this critical problem statement.

"Days to restore supply to 90% of customers' taps at average winter day demand, economic losses in millions of dollars attributable to water shortage."

The estimated costs outlined in the table include all related economic losses connected to water shortages. These losses encompass direct and indirect losses which may result from water shortages after each earthquake scenario.

The report makes it clear that... ***"These results should be considered preliminary. Additional economic analysis would be needed to determine the true economic losses,"*** (page 13).

Each column in the table represents a unique earthquake scenario and each row outlines the economic loss and number of days until water services are restored to the 90% level.

The report states *"these results were generated using high-level analysis methods. Although these methods provide a general understanding of how a water system would respond to a specific earthquake scenario, the results should be considered preliminary and highly approximate,"*(page 12).

To further explain how the economic fall out was estimated *"The Water Supply Forum Earthquake Team used a simplified approach to calculate the potential economic impacts resulting from water loss following an earthquake. The* ***simplified approach focuses on the economic loss to the community due to complete water outage****, based on the Federal Emergency Management Agency value of* ***$103/person/day,"*** (page 11).

Suggested Inquiries...

Which region's service area is most impacted by which scenario?

How is information in this table related to impacts you would experience in your personal life? How about your family's employment?

Which industries do you think might be most impacted? What are the economic activities that are disrupted because of water shortages?

Which services will be most impacted? For example grocery stores, retail outlets, restaurants, hospitals, fire stations.

What did we learn about economic fallout based on our experience with the COVID-19 pandemic? How does this help us understand economic fallout related to sudden damage from an earthquake?

ACTIVITY 8

Exciting Engineering Solutions

Engineering is an important facet of planning for earthquake hazards, especially when it comes to water systems infrastructure. Working through and testing engineering solutions in advance can contribute to a resilient community.

The Water Supply Forum Earthquake Team summarized Earthquake Mitigation strategies in three categories:

Intersystem mitigation

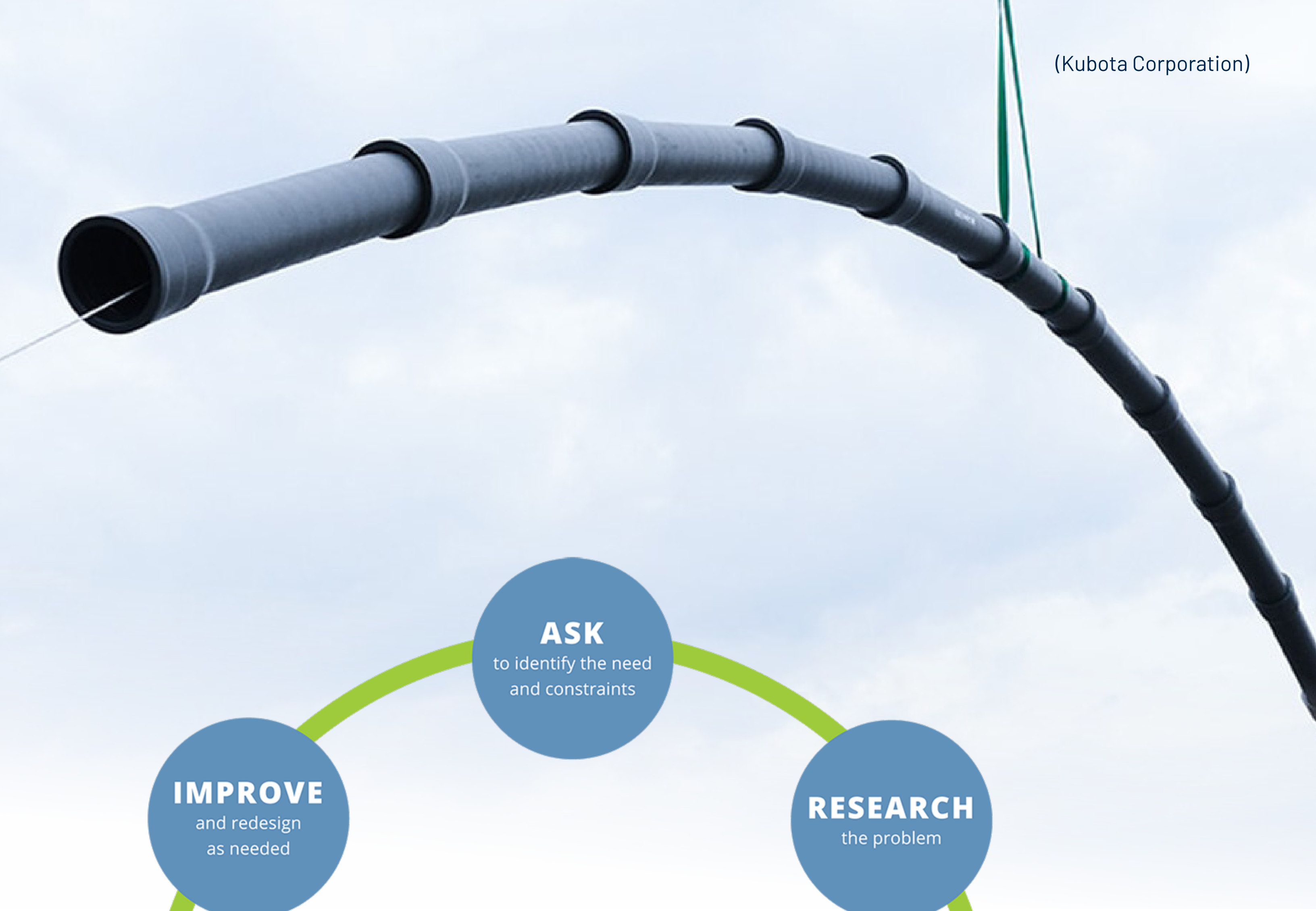
Intrasystem mitigation

General mitigation

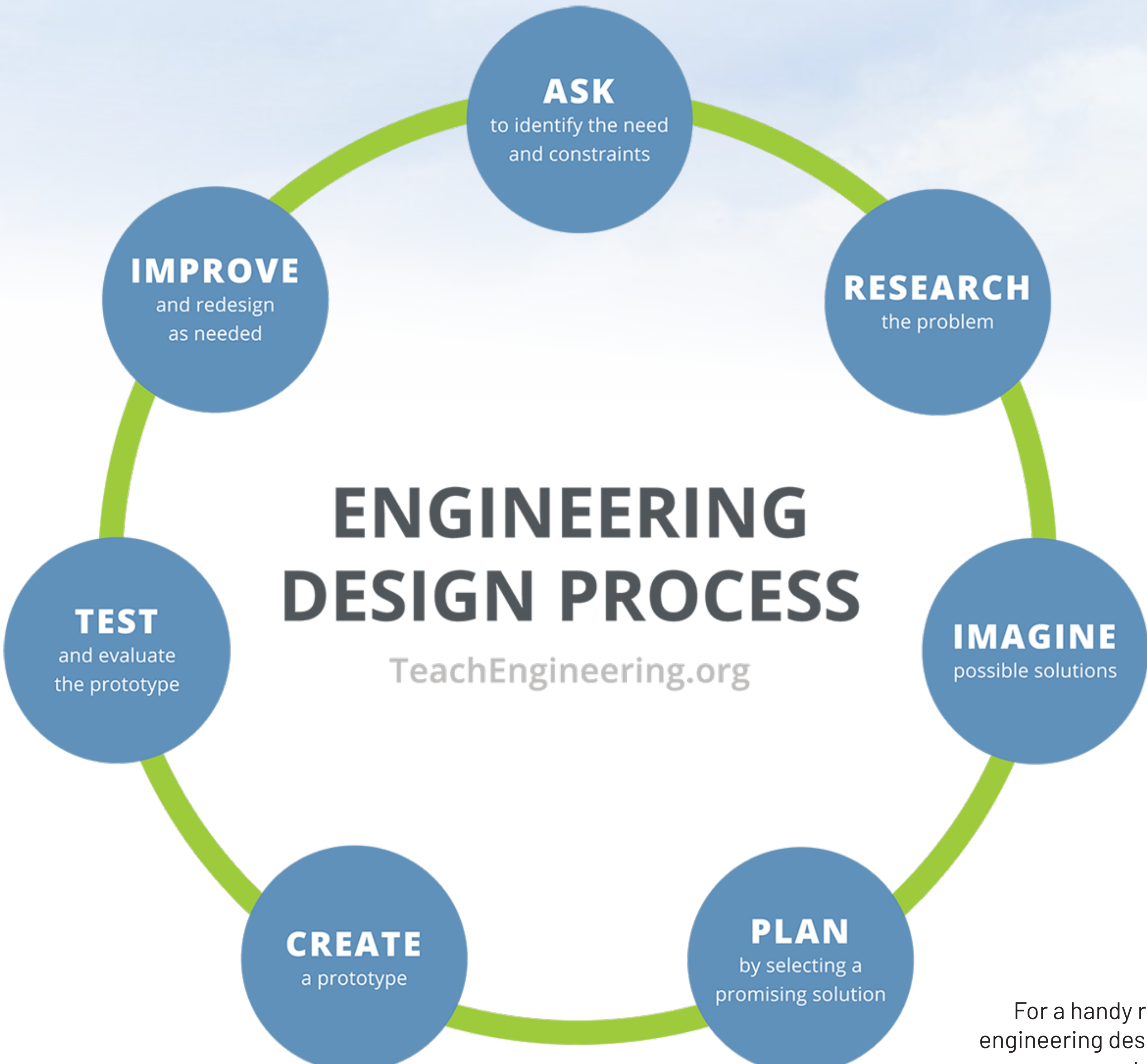
These strategies cover what water utilities can (1) do on their own, (2) do in collaboration with other local utilities, and (3) support in general. The suggestions for mitigation include engineering solutions. Examples of engineering solutions for wastewater systems include things like **redundancy generators (emergency power supply), seismically resilient pipes and valves, back up pumps, and water redirection plans**.

For this activity, students will assume the role of engineers and work to design earthquake resistant water infrastructure.

How would you design a system of pipes that could withstand earthquakes? The design criteria must include pipes that are strong and durable but also flexible to absorb shock. How can we engineer the pipe joints to flex but not leak? If you design it, how would you install it? You can't just break up every road in the city and drop in new pipes. That would be too disruptive and too expensive.



(Kubota Corporation)



For a handy review of the engineering design process, encourage student teams to review this graphic from [TeachEngineering.org.](TeachEngineering.org)

Persuasion

As an engineer, your job is to convince water utility managers and elected officials **why it is critical to invest in these engineering solutions now**. To convince these decision makers, you will work in small teams to build out a compelling and influential visual report. Options for the report format can include:

PowerPoint slide deck

Infographic

Engineering Schematic (a rough construction drawing)

For inspiration on water systems engineering, here are a few **great videos on seismically resilient pipes and other aspects of regional water systems planning**.

See this 4-minute TV news report on how California will install earthquake-proof water pipes.

This 5-minute video from the Environmental Protection Agency (EPA) describes water utilities might do to prepare for and mitigate damage from earthquakes.

Wellington, New Zealand is working to prepare and build resilient communities. This 5:47-minute video from a company called Cardno describes their approach to earthquake response.

The Los Angeles Department of Water and Power has a long term plan for installing earthquake resilient water pipes. This 2-minute video describes their plan in the coming years.

Suggested inquiries...

What considerations do the videos cover when it comes to earthquakes and wastewater management? What technology is used?

Are all people involved in decision making regarding engineering for earthquake resilience? How can engineering help communities plan to serve vulnerable populations after an earthquake?

How do the engineering solutions connect drinking water and wastewater management? Why do you think it is important to have mitigation strategies in place for both systems?

ACTIVITY 9

Round 2 Role Play: Community Resilience

After exploring the science, engineering, and economic analysis of earthquake resilience planning, students are prepared to work through the role play a second time but with much greater depth. In their various roles, the students should also be able to demonstrate the critical need for ***cross-jurisdictional cooperation and communication***. Students are encouraged to revisit and expand upon the resources provided through this unit.

Role Play Roles and Descriptions

Press Release template (From the body of this lesson but provided here as a series of flexible handouts for possible classroom jigsaw)

Science Background information

Regional Water Supply Resiliency Project Summary Report

Earthquake Vulnerability Assessment Technical Memorandum

Students will also want to analyze some of the drill manuals and other planning documents from the Great ShakeOut. The Great ShakeOut is an international organization with resources to help communities plan and execute realistic earthquake drills. Depending on their role, students can explore any number of the drill manuals provided.

With drill manuals and supporting documents **as models** students can prepare **their own** action agenda or manual for enacting the second round of the role play. ***As a reminder – the priorities for student response plans include...*** (See classroom POSTER)

Making it Real

The role play will start at the beginning of a class period (ideally a block period). Because this is a purposely condensed and dramatic timeframe for problem solving, students will need to prepare carefully for their roles and/or teams in advance. The goal is to respond to the earthquake scenario efficiently and as comprehensively as ***possible within the class period.***

Suggested inquires for role play preparation and post-role play reflection

With each priority, what people and resources are needed in your role for an efficient and effective response?

In your role, how will you communicate with the people and get the resources needed to respond to each priority item? If you can't use your preferred communication method (like a cell phone) what other communication pathways can you make use of?

In your role, how will the people and resources get to where they are needed? What transportation do you need? If your first choice (like a car) is not available, what else can you do to move people and resources around?

In collaboration with the other role players, how will you determine which priority to respond to first? Do you have enough resources to coordinate a concurrent response to each priority? What if there are aftershocks that disrupt your efforts?

In collaboration with the other role players, how will you tell the community about available services and response times? How will you ensure people are getting what they need? How can you leverage media and news?

After completing the role play how would you improve the process or shift the priorities for a better response? Are there any priorities that you felt were missing?

What did you learn about yourself and your community through this process?

ACTIVITY 10

BE PREPARED!

Personal and Community Planning

The best time to prepare for any disaster is ***before it happens***. Watch this (1-minute) video of earthquake preparedness showing how a school was prepared for an earthquake.

"Resiliency is generally defined as the ability to reduce the impact of and recover rapidly from disruptive events, so that an acceptable level of service (LOS) is maintained and the impacts on public health and safety and the economy are minimized."

- Water Resilience Forum Regional Water Supply Resiliency Project Report (2016)

In this activity, students will round out the earthquake unit by reviewing their readiness as an individual, a part of a family, and part of a classroom. This final lesson also invites students to do some reflective letter writing to their future selves who may be experiencing a disaster.

Explore the online tool and online quiz "What You can do to Prepare" for earthquake preparedness.

What was a surprise when taking this quiz?

What have you already done to prepare?

What can you do to better prepare?

Think through earthquake preparedness in your home, school and/or workplace.

Create a family emergency communications plan. If possible, try to include an emergency contact who does not live in the Puget Sound region. Plan out what would happen in your home, school and/or workplace including where to meet if you get separated. Make a supply kit that includes enough food and water for several days, a flashlight, a fire extinguisher and a whistle.

Practice doing a ShakeOut drill as your class using this slideshow.

Do some research about earthquake preparedness in your own local community. Washington State citizens can find active links to their county emergency management agencies in addition to a wealth of preparedness and hazard mitigation information and plans put together by the Washington State Emergency Management Division. Resources on ready.gov provide another place for starting research.

Write a letter to your future self if you were to face such a disaster. What would you tell yourself to give yourself support? What guidance? What guidance would you want to receive?

WHAT ELSE COULD HAPPEN?

For teachers and students who are interested in other disaster scenarios and their water quality implications, find language below from the Water Supply Forum's ***Water Quality Resilience Assessment*** that briefly outlines **Six Risk Events**. The first one, of course, is earthquakes which was the focus of this unit.

For the full analysis of each of these Risk Events see pages 11-53 in the [Water Quality Resilience Assessment].

1 Earthquake

Earthquakes can pose risks to water quality by damaging critical infrastructure, producing tsunamis that inundate low-elevation areas, leading to supply chain disruptions, causing major landslides, and potentially damaging or disrupting groundwater supplies—nearly simultaneously. Water quality risks to surface waters include increased turbidity because of earthquake-induced landslides. Potential impacts on groundwater quality can result from mixing of water between different aquifers, influx of water from different areas, changes in dissolved gas and mineral concentrations, and infiltration of pollutants from soil or ground surface. Earthquakes can also damage source water treatment facilities, thereby affecting their ability to ensure continued operation and production of clean drinking water. Earthquakes can also damage pipelines, resulting in cross-connection contamination and/or introduction of microbial or chemical contaminants.

2 Wildfire

The potential water quality effects of a wildfire vary widely and are site-specific. Because the vast majority of the region's drinking water comes from surface water resources, the impacts of wildfire are potentially significant. The watershed recovery rate is highly variable depending on the intensity and duration of the fire. In general, water quality impacts to surface water supplies resulting from wildfire include increases in turbidity and total suspended solids, nutrient loading, pH, alkalinity, temperature, and metals, as well as effects of suppression chemicals.

3 Volcanic Eruption

Each volcano can differ in the severity and extent of hazards it produces. Mt. Baker, Mt. Adams, Glacier Peak, Mt. Rainier, and Mt. St. Helens are all active volcanoes in Washington State. Volcanic hazards most likely to occur and posing the greatest threat to water quality in this region include ash fall, tephra falls (rock fragments ejected during an eruption), and lahar flows (debris flows caused when pyroclastic material mixes with snow, causing rapid mudflows with the potential to travel long distances). In general, water quality impacts on surface water supplies due to volcanic eruptions include increases in turbidity, acidity, and metal concentrations.

4 Resource Supply Chain

Water treatment supply chain issues could significantly upset water treatment plant operations and thereby potentially have an immediate adverse effect on public health, lead to regulatory violations, or require boil water orders. A resource supply chain risk event was defined as an inability to get staff, chemicals, fuel, or equipment to water treatment facilities by road. The definition also included inadequate availability of water treatment chemicals and critical equipment and issues with chemical quality. This could result in the inability to produce safe and reliable drinking water despite adequate water supply.

5 Accidental Contamination

An accidental contamination risk event is defined as when a fuel, oil, or any hazardous material contaminates a utility's water supply and creates unsafe drinking water conditions. For this study, the focus of accidental contamination is at the source water prior to reaching the withdrawal point (intake or well). Naturally occurring contamination or internal chemical overdosing are not included.

Unless the source water lies in a completely protected environment where human activity is minimized, the source water is subject to accidental contamination. If utilities lack an alternative water source, the option to close off their treatment facilities may not be feasible and contaminants may bypass treatment, which could eventually lead to the distribution system and put consumers at risk.

The use of early warning systems has been implemented by many utilities across the nation as a means of detecting a spill. Early detection of an accidental contamination event can help delay or prevent a chemical spill from reaching the withdraw point. In addition, understanding where water flows and areas that can be used to divert a spill are some ways utilities can prevent a contaminant from reaching the withdraw point. Utilities can also apply a multibarrier approach, which involves installing instrumentation and monitoring systems that can measure various parameters to detect changes in water quality throughout the system.

6 Severe Adverse Weather

While the focus of this particular risk is short-term adverse weather events rather than long-term climate change, it has generally been recognized that the frequency of high-intensity, short duration events in the region (for example, wind and rain) appears to be increasing. Examples of severe, adverse weather include intense wind, snow, rain, lightning, or ice storms of sufficient magnitude to trigger flooding, freezing, fires, landslides, or power loss that affect systems and could jeopardize water quality. Impacts could include treatment facility failure, equipment damage, communication loss, supervisory control and data acquisition (SCADA) loss, supply chain disruptions, and inability for employees to come to work.

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About Sustainability Ambassadors

Sustainability Ambassadors is a professional development program for student leaders, teacher leaders and community leaders committed to rapidly advance a sustainable future by aligning classroom rigor with community relevance for real world impact.

We support a year-round training program for over 60 highly motivated youth, a paid Equity Advocacy Internship, a Green Jobs Youth Pathways Portal, and a Teacher Fellows Program, working with hundreds of educators to design new models of problem-based, place-based learning around a shared vision of ***educating for sustainability.***

We focus on middle school and high school youth, the teachers and school districts that guide their learning, and the community stakeholders, local government and business leaders who are relying on the next generation to be engaged voters, informed taxpayers, conscious consumers, and employees who can create and lead sustainability initiatives.

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