1 **Introduction to**
Environmental Geology, 5e
Chapter 7
Tsunami

2 **Case History: Indonesian Tsunami**
- December 26, 2004, within a few hours, close to 250,000 people were killed
- With no warning system in place
- The source of this tsunami was the largest earthquake on Earth in the past 4 decades, magnitude 9.1
- A large amount of displacement along the thrust faults in the subduction zone, geologists classify this earthquake as a “megathrust event”
- The total length of the rupture over 1500 km (930 mi)

3

Figure 7.3

4 **Indonesian Tsunami (2)**
- Over three-quarters of the deaths were in Indonesia
- A warning of a half hour or so would have been sufficient to move many people from low-lying coastal areas. The first tsunami wave took 1 to 2 hours to reach Sri Lanka and India; 7 hours to reach Somalia on the west coast of Africa
- In Thailand, a 10-year-old British girl sounded the warning in time for 100 people to evacuate a resort beach. In Sri Lanka, a scientist recognized signs (dramatic sea level change) and sounded the alarm. In Thailand, elephants, not people, sounded the warning and saved lives
- Vital role of education in tsunami preparedness

5 **Introduction**
- Tsunamis: The Japanese word for “large harbor waves”, produced by the sudden vertical displacement of ocean water
- Can be triggered by any rapid uplift or subsidence of the seafloor, such as submarine earthquake, landslide, volcanism, and impact of asteroid or comet
- Mega-tsunami, from asteroid impact, a wave about 100 times higher than the largest tsunami produced by an earthquake
- Tsunamis produced by earthquakes are by far the most common

6 **Historic Tsunamis**

7 **How Do Earthquakes Cause a Tsunami?**
- Cause a tsunami by movement of the seafloor and by triggering a vertical displacement/ landslide
- M 7.5 or greater earthquake create enough displacement of the seafloor to generate a damaging tsunami
- A four-stage process that eventually leads to landfall of tsunami waves on the shore

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Figure 7.7

9 **Tsunami Movement**
- When an earthquake uplifts the seafloor close to land, both distant and local tsunamis may be produced
- Distant tsunami: Travels out across the deep ocean at high speed for thousands of kilometers to strike remote shorelines with very little loss of energy
- Local tsunami: Heads in the opposite direction toward the nearby land and arrives quickly following an earthquake
- When the initial tsunami wave is split, each (distant and local) tsunami has a wave height

about one-half of that of the original dome of water

10 **Distant and Local Tsunami**

Figure 7.8

11 **Landslides Cause a Tsunami**

- Submarine landslides can generate very large tsunamis
- Large rock avalanches falling from mountains into the sea can also generate very large tsunamis
- 1998, a M 7.1 earthquake triggered a submarine landslide and caused a tsunami of 15 m (50 ft), leaving 12,000 people homeless and over 2,000 dead
- Lituya Bay, Alaska, in 1958. The landslide set in motion by a M 7.7 earthquake on a nearby fault. The huge mass of broken rock caused waters in the bay to surge upward to an elevation of about 524 m
(1720 ft) above the normal water level

12 **Regions at Risk**

- All ocean and some lake shorelines are a risk for tsunamis, some coasts are more at risk than others
- Coasts close to a major subduction zone or directly across the ocean basin from a major subduction zone are at greatest risk
- The greatest tsunami hazard with return periods of several hundred years
- High risk regions: The Cascadia subduction zone, the Chilean trench, the subduction zones off the coast of Japan, parts of the Mediterranean, as well as the northeastern side of the Indian Ocean

13 **Global Tsunami Hazard Ranks**

Figure 7.11

14 **Effects of Tsunamis**

Primary

- Damage to both the landscape and human structures from resulting flooding and erosion
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Secondary

- Fires may start in urban areas from ruptured natural gas lines or from the ignition of flammable chemicals
- Water supplies may become polluted
- Damaged wastewater treatment systems
- Disease outbreaks

15 **Minimizing the Tsunami Hazard**

- Detection and warning
- Structural control
- Construction of tsunami runup maps
- Land use planning
- Probability analysis
- Education

16 **Tsunami Warning System**

Figure 7.14

17 **Detection and Warning**

- For distant tsunamis: Can be detected in the open ocean and accurately estimated their arrival time to within a few minutes
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- A tsunami warning system has three components:
- A network of seismographs to measure submarine movements
- Automated tidal gauges to measure unusual rises and falls of sea level
- A network of sensors connected to floating buoys

18 **Structural Control**

- Many houses and small buildings are unable to withstand the impact of an 1 to 2 meter high tsunami
-
- Larger structures, such as high-rise hotels and critical facilities, can be engineered to greatly reduce or minimize the destructive effects of a tsunami
-
- The current building codes and guidelines do not adequately address the effect of a tsunami on buildings and other structures

19 **Tsunami Runup Maps**

- Shows the level to which the water traveled inland
-
- Before a tsunami strikes, a community can produce a hazard map that shows the area that is likely to be inundated by a given height
-
- Many coastal cities and areas have produced tsunami runup maps, and this trend will undoubtedly continue

20 **Land Use Planning**

- The 2004 Indonesian tsunami showed tropical ecology played a role in determining tsunami damage
- Villages spared from destruction were partly protected from the energy of the tsunami by either a coastal mangrove forest or several rows of plantation trees that reduced the velocity of incoming water
- Planting or retaining native vegetation could provide a partial buffer from a small to moderate tsunami attack
- Don’t rely on land use planning, the best and safest approach to lessen the tsunami hazard is quick evacuation. Trees cannot stop large tsunami

21 **Probability Analysis**

- The risk of a particular event may be defined as the product of the probability of that event occurring and the consequences
- Developing a probabilistic analysis of the tsunami hazard is to:
- Identify and specify the potential earthquake sources
- Specify relationships that will either attenuate or reduce tsunami waves
- Apply probabilistic analysis to the tsunami hazard similar to what is currently being done for earthquake hazard analysis
- Probabilistic approach to tsunami hazard assessment is still being developed

22 **Probability Analysis Map**

Figure 7.16

23 **Education (1)**

- The educational component is of particular importance. Most people don’t even know if a tsunami watch or warning is issued
- In 2005 in Santa Barbara, nothing was said about the size of the possible tsunami, some people, on hearing the notice, drove too far to the top of a nearby mountain pass thousands of feet above sea level
- No plan for people to directly observe the tsunami, some went to sea cliff and some climbed up trees, bad approaches

24 **Education (2)**

- Educate coastal residents and visitors as to the difference between a tsunami watch and tsunami warning
- Tsunami watch: An earthquake that can cause a tsunami has occurred
- Tsunami warning: That a tsunami has been detected and is spreading across the ocean toward their area
- Tsunamis come in a series of waves, and that the second and third waves may be larger

than the first one

25 **Tsunami Ready Status**

- Establish an emergency operation center with 24-hour capability
- Have ways to receive tsunami warnings from the National Weather Service, Canadian Meteorological Centre, Coast Guard, or other agencies
- Have workable ways to alert the public
- Develop a tsunami preparedness plan with emergency drills
- Promote a community awareness program to educate people concerning a tsunami hazard

26 **Adjustment to Tsunami Hazard(1)**

- If you feel a strong earthquake and are at the beach, leave the beach and low-lying coastal area immediately
- If the trough of a tsunami wave arrives first, the ocean will recede. This is one of nature's warning signs, run from the beach
- A tsunami may be relatively small at one location, it may be much larger nearby

27 **Adjustment to Tsunami Hazard (2)**

- Generally consist of a series of waves, and there can be up to an hour between waves, stay out of dangerous areas until further notice
- Coastal communities, as they gain tsunami readiness status, will have warning sirens
- Move away from the beach to higher ground, at least 20 m (60 ft)
- If you are aware that a tsunami watch or warning has been issued, do not go down to the beach to watch the tsunami

28 **Critical Thinking Topics**

- What is the role of human population increase in impacting the Indonesian tsunami of 2004?
- Why do you think that prior to the 2004 Indonesian tsunami there was no warning system in the Indian Ocean? Was this a function of science or values?
- What is the probability of your community being impacted by tsunami?
- Do you think that there is any strong link between sustainability and a tsunami?

29 **Figures Follow:**

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End of Chapter