

LESSON:

Tsunami Simulation Experiment

Summary: Students read the article, "Building a Tsunami Warning System," and discuss what a tsunami is and why it is important to have a tsunami warning system. Then, students conduct an experiment in a wave tank to show how the velocity of a wave in water changes with depth. Students then calculate wave velocities of tsunamis at differing depths using an equation and compare their experimental results with the mathematical results. Students are asked to explain the differences in the results and what happens to tsunamis as they approach the shoreline. This lesson extends discussion of a topic addressed with the article.

EHP Article: "Building a Tsunami Warning System," *EHP Student Edition*, May 2005: A90. <http://ehp.niehs.nih.gov/docs/2005/113-2/forum.html#buil>

Objectives: By the end of this lesson students will be able to:

1. Explain how a tsunami forms and is transmitted across the ocean;
2. Discuss why tsunami warning systems are important;
3. Record data accurately and graph the results; and
4. Describe the relationship between wave velocity and depth for tsunamis.

Class Time: 1 hour

Grade Level: 10–12

Subjects Addressed: Environmental Science, Physics

Prepping the Lesson: (15–20 minutes)

► **Prepping the Lesson (10–15 minutes)**

INSTRUCTIONS:

1. Obtain a class set of *EHP Student Edition*, May 2005 or download article at <http://www.ehponlin.org/science-ed> and make copies.
2. Review the article, "Building a Tsunami Warning System."
3. Make copies of the student instructions.

MATERIALS (per student or group):

- 1 copy of *EHP Student Edition*, May 2005, or 1 copy of the article "Building a Tsunami Warning System" per student
- 1 copy of the student instructions per student or group
- 1 wave tank or equivalent per group. A rectangular, 32 quart, flat plastic ClearView Sterilite® container that fits under a bed may be used as a wave tank.
- 1 metric ruler capable of measuring 0.1 centimeters per group
- 1 stop watch measuring 0.01 seconds per group
- 2 sheets of graph paper per student or group
- 1, 2" x 4" piece of wood cut to the width of the wave tank per group
- 1 calculator per group
- 1 container or source of water to fill the wave tanks
- 1 cup or similar device to add or remove water from the wave tanks, as needed

VOCABULARY:

tsunami



**National Institute of
Environmental Health Sciences**

Community Outreach & Education Program

BACKGROUND INFORMATION:

A tsunami is a series of huge waves caused primarily by an underwater earthquake. The word tsunami is Japanese for "harbor wave." On December 26, 2004, an underwater earthquake (magnitude 9.0 on the Richter scale) occurred 155 kilometers southwest of northern Sumatra. The resulting displacement of the earth's crust created a large tsunami with wave lengths in the order of 100–400 km and wave heights of 30 to 60 cm that raced at speeds of 600–800 km/h towards land. As the waves approached the shallower water near land, they slowed down and increased in height. The energy of the waves' speed was transferred to height and sheer force as it neared the shore. The wavepeaks moved faster than the water below and broke forward as they approached the beach. Waves as high as 30 meters hit the coastlines of many countries resulting in hundreds of thousands of lives lost and billions of dollars in damage.

The velocity (v) of a wave on the ocean in shallow water is approximated by the following equation:

$$v = \sqrt{gd}$$

where

v = m/sec

g = acceleration of gravity (9.8 m/sec²)

d = depth in meters

The actual height and speed of a tsunami that strikes the shore depends on a number of factors including the shape of the shoreline, shape and levelness of the ocean bottom near the shoreline, the steepness of the bottom near the shoreline, the shape of the wave and the presence of other water currents. The effects of the wave can be amplified by a bay, harbor or lagoon.

Demonstrating how the speed of a wave changes with depth can be simulated by generating waves in a wave tank with water of different depths. Although the speeds of waves associated with tsunamis cannot be achieved in a wave tank, the mathematical relationship between the speed of the wave and depth can be demonstrated resulting in similar shaped curves on a graph.

RESOURCES:

Federal Emergency Management Agency, Tsunamis fact sheet, <http://www.fema.gov/hazards/tsunamis/tsunamif.shtm>

Georgia State University, Department of Physics and Astronomy

Tsunami, <http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/tsunami.html>

Ocean Waves, <http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/watwav2.html>

How tsunamis work <http://science.howstuffworks.com/tsunami.htm>

National Oceanic and Atmospheric Administration, National Weather Service, West Coast & Alaska Tsunami Warning Center, <http://wcatwc.arh.noaa.gov/subpage1.htm>

Pacific Tsunami Museum, Hilo, Hawaii, <http://www.tsunami.org/>

PBS Online including excellent animation showing how a tsunami is created by an earthquake, <http://www.thirteen.org/savageearth/tsunami/index.html>

United Nations Educational, Scientific, and Cultural Organization, International Tsunami Information Center, <http://www.prh.noaa.gov/itic/>

Wikipedia, online encyclopedia, <http://en.wikipedia.org/wiki/Tsunami>

► Implementing the Lesson**INSTRUCTIONS:**

1. Have students read the "Building a Tsunami Warning System" article.
2. Discuss with students what a tsunami is and why a tsunami warning system is necessary.
3. Tell students they are going to further investigate what happens to tsunamis as they approach the coastline.
4. Divide students into groups and pass out the materials and student instructions for the "Tsunami Simulation Experiment."
5. Once each group has completed the activity, have each group present their findings and conclusions to the class.
6. After all the groups have presented, discuss and summarize the groups' results.



NOTES & HELPFUL HINTS:

Wave tanks or equivalent containers must be at least 40 cm in length. The longer the travel distance for the wave, the better. You could experiment with timing the wave to travel the length of the wave tank and back.

It helps to have a clear wave tank on a white or other light colored surface. This aids in being able to see the waves being generated more clearly. It is also helpful to have light shining onto the surface of the water at an angle.

Do not go past water depths of more than 3 cm in the wave tank since the wave velocities do not show measurable increases in speed past 3 cm.

A 2" x 4" piece of wood seems to work well at generating a suitable wave for the wave tank although other objects of similar size and shape may work as well.

▶Aligning with Standards

SKILLS USED OR DEVELOPED:

- communication (note taking, oral, written—including summarization)
- comprehension (listening and reading)
- computation
- critical thinking and response
- experimentation (conducting and data analysis)
- graphing; graph reading, manipulation
- observation
- research
- tables and figures (creating, reading)
- unit conversions.

SPECIFIC CONTENT ADDRESSED:

- conducting experiments
- making observations
- recording data
- creating and using tables and figures
- making conclusions
- waves
- tsunamis

NATIONAL SCIENCE EDUCATION STANDARDS MET:**Science Content Standards****Unifying Concepts and Processes Standard**

- Systems, order and organization
- Evidence, models and explanation
- Change, constancy and measurement

Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science Standards

- Motions and forces
- Interactions of energy and matter

Earth and Space Science Standards

- Energy in the earth system
- Origin and evolution of the earth system

Science in Personal and Social Perspectives Standards

- Personal and community health
- Natural and human induced hazards



Assessing the Lesson

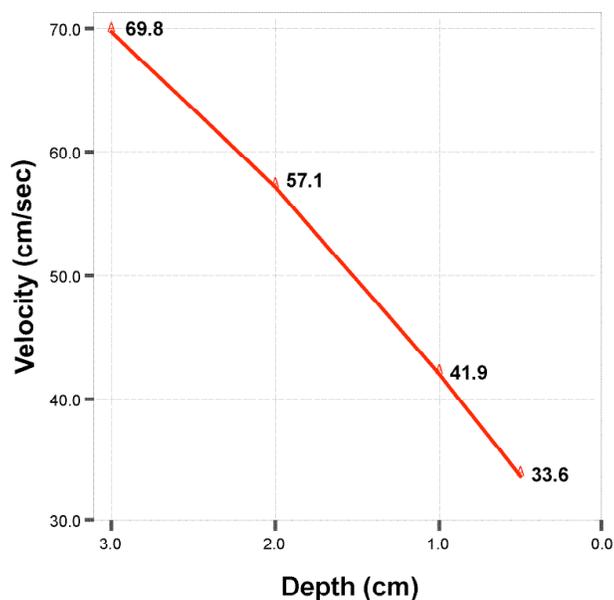
Steps 2 and 6: Table I and Figure 1 show how the experimental velocity of a wave in a wave tank might change with depth as an example.

Table 1: Tsunami Simulation—Experiment Results

Depth of Water (cm)	Travel Distance of Wave (cm)	Time for Each Wave to Travel Across Wave Tank (sec)										Average Time (sec)	Velocity of Wave (cm/sec)
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10		
3.0	44	0.71	0.67	0.70	0.67	0.60	0.60	0.52	0.68	0.62	0.49	0.63	69.8
2.0	44	0.77	0.87	0.84	0.78	0.63	0.80	0.81	0.75	0.79	0.69	0.77	57.1
1.0	44	1.10	0.97	1.13	0.97	1.13	1.00	1.07	0.99	1.05	1.04	1.05	41.9
0.5	44	1.10	1.39	1.40	1.32	1.34	1.20	1.29	1.44	1.40	1.24	1.31	33.6

Figure 1

How the Velocity of a Wave Changes with Depth—Experimental Results

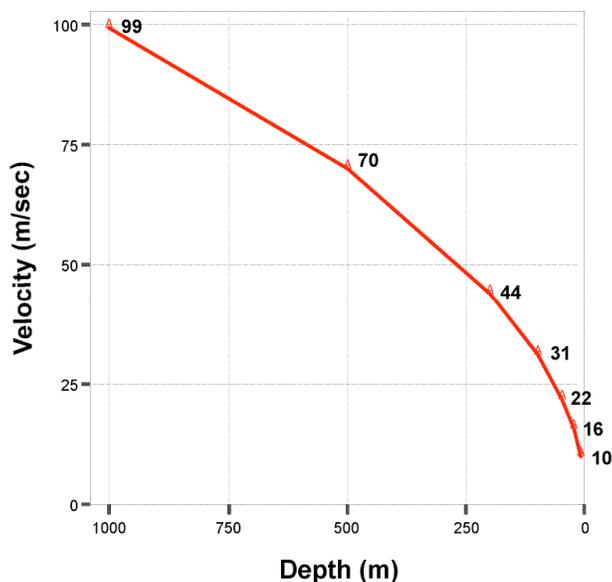


Step 7 and 8: Table II and Figure 2 show how the calculated velocity of the wave changes with depth in an ocean.

Table II
How the Velocity of a Tsunami
Changes with Depth—Calculated Results

Depth (m)	Velocity (m/sec)
1000	99
500	70
200	44
100	31
50	22
25	16
10	10

Figure 2
How the Velocity of a Tsunami
Changes with Depth—Calculated Results



Step 9: The experimental velocities are much less than would be predicted by the equation. This is due to the smaller energy and wave length of the wave being generated in the wave tank, as well as other limitations associated with the wave tank, such as its irregular shape and inconsistencies in how the experimental waves were generated. The shapes of the graphs for the experimental and calculated results, however, are similar with a decrease in depth resulting in a decrease in speed of the wave.

Step 10: Students should show their calculations and unit conversions to obtain full credit. An example of the unit conversion is below.

1000 m depth: $99 \text{ m/sec} \times 0.0006214 \text{ miles/m} \times 60 \text{ sec/min} \times 60 \text{ min/hr} = 222 \text{ miles/hr}$

The velocity at a depth of 1000 m = 222 miles/hr and at a depth of 10 m = 22 miles/hr. The 10 m/sec, or 22 mph, velocity is the fastest recorded human running speed. Most tsunamis arrive at the shoreline at speeds in the area of 30 to 40 mph, making it impossible to out run a tsunami.

Step 11: As the tsunami approaches the shoreline, the wave slows down, transferring some of its energy to increasing its height.

► Authors and Reviewers

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STUDENT INSTRUCTIONS: Tsunami Simulation Experiment

Step 1: Fill your wave tank or other container with water to a depth of 3 centimeters (cm). Adjust the depth of the water by adding or removing water to reach the desired depth. Using the 2x4 piece of wood cut to fit the width of the container, press the 2x4 into the water close to the shorter edge of the container just enough to make a visible, flat wave that moves across the surface of the water to the other end of the container. Do not drop the 2x4 into the water. Practice making waves till you are sure you can make strong, visible and consistent waves. Once you have perfected your wave making technique, try to make your waves all the same way. Allow the water to become calm between each attempt.

Step 2: Record all your measurements on "Table 1: Tsunami Simulation – Experimental Results." Measure and record the length of the travel distance of the wave from the edge of the 2x4 to the other side of the wave tank. At a water depth of 3 cm, make a wave and time, using a stopwatch, how long the wave takes to reach the other side of the wave tank from the edge of the 2x4. Record the time. Repeat making waves and recording the travel time until you have 10 acceptable times. Calculate the average time for the wave and the velocity. (Note: velocity = distance ÷ time).

Table 1: Tsunami Simulation—Experimental Results

Depth of Water (cm)	Travel Distance of Wave (cm)	Time for Each Wave to Travel Across Wave Tank (sec)										Average Time (sec)	Velocity of Wave (cm/sec)	
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10			
3.0														
2.0														
1.0														
0.5														

Step 3: Make a prediction about what will happen to the wave velocity as the depth gets smaller. Explain.



Step 4: Adjust the depth of the water to 2.0 cm, measure the time for the wave to travel across the wave tank for 10 successive trials and record your results. Repeat this step again at water depths of 1.0 cm and 0.5 cm. Calculate the average time and velocity at each depth and record your results.

Step 5: Compare the experimental results with your prediction. If your prediction was incorrect, provide a new explanation for the wave velocity results.

Step 6: On a piece of graph paper, make a line graph of the results of the experiment showing how velocity changes with depth. Make sure to label your axis and provide a title.

Step 7: The velocity (?) of a wave on the ocean in shallow water is approximated by the following equation:

$$v = \sqrt{gd}$$

where

$v = \text{m/sec}$

$g = \text{acceleration of gravity (9.8 m/sec}^2\text{)}$

$d = \text{depth in meters}$

Using this equation, complete Table II by calculating the velocity of tsunami waves at different ocean depths.

Table II
How the Velocity of a Tsunami
Changes with Depth

Depth (m)	Velocity (m/sec)
1000	
500	
200	
100	
50	
25	
10	

Step 8: On a separate graph paper, make a line graph of the results of the calculations from Step 7 showing how velocity changes with depth. Make sure to label your axis and provide a title.

Step 9: Compare the results obtained from the experiment with the results obtained from the equation. Are your experimental results consistent with the calculated results? Explain.



Step 10: Calculate the velocity of the wave from Table II at a depth of 1000 m and 10 m in miles per hour (1 meter = 0.0006214 miles). Show your calculations and unit conversions. Based on your answer, could you out run a tsunami approaching the beach? Explain.

Step 11: Explain why a tsunami builds in height as it approaches the shoreline.

