# THERE'S WATER UNDERGROUND

## Overview

*This activity shows how water can be stored in underground formations called aquifers and the meaning of the term water table. It illustrates the relationship between yield rates and particle size of soil and rocks that might be in an aquifer. Experimenting with water, clay, sand, loam, and gravel, students also see other important groundwater concepts, including those associated with water cycle (percolation, infiltration), and recharge. In this activity, students will visualize how groundwater is stored between soil particles, and identify the aspects of soil that facilitate water storage.*

**Subjects**: Science, Social Studies
**Group Size**: teams of four or entire class observing teacher-led demonstration
**Estimated Teaching Time**: three 45-minute classes
**Curriculum Framework**: IA, ID, IIIA1, IIIB1, IIIB2, IIIB3, VIIC
**Environmental Education Framework**: Goals IA, IIA, IVA, IVB
**Vocabulary**: aquifer, capillary action, groundwater, infiltration, overdraft, percolation, pore space, precipitation, recharge, water cycle, water holding capacity, water table, wells, yield rates

## Objectives

**Students will:**

- compare the water-holding capacities of four different materials.
- identify the water table in models.
- demonstrate what is meant by the term percolation.
- analyze how an aquifer gets and holds water.
- evaluate which soil and rock types are best suited for water recharge.

## Background

**Groundwater** is water that percolates below the surface and infiltrates spaces between soil and rock particles. The rock and soil formations that become saturated and store water underground are called **aquifers**. Aquifers are like sponges because they can accumulate and store large amounts of water. In the U.S., the quantity of groundwater is estimated to be at least twenty times greater than the amount in all our rivers and streams. See related activity, **All The Water in the World.**

The primary replenishment of groundwater is rainfall that seeps down to the **water table**, the upper surface of the aquifer. Because the amount of water in soil changes, water tables rise and fall. When it rains or when snow melts, surface water can travel downward through the soil and become trapped in the soil particles. The downward flow of water is known as **percolation**. The percolation of water through the soil replenishes the aquifer. This process is known as

**groundwater recharge**. Water is also added to aquifers by water moving horizontally by capillary action, or pressure from water moving from above (infiltration). Water is removed by humans or naturally by flowing slowly underground, usually only several inches a year. When it is moving through loose sand or gravel, groundwater can move more than 800 feet a year.

People retrieve groundwater by using a water well specially designed to pump water and leave behind soil particles. After hydrologists locate a site, a hole is drilled through layers of soil and rock to the aquifer. A pipe, with holes in the side, is inserted into the well, allowing water from the aquifer to enter. The entering water is then pumped to the surface. Well depth depends on the depth of the water table and the structure of soil and rock through which it passes. Deep wells generally produce high quality water and are treated only with chlorine. Water from deep wells has percolated through greater volumes of rock and soil and thus has been better filtered to remove contaminants. Deep wells do have disadvantages. They require more energy to pump the water, and the water they release has been in contact with rock for long periods. Because small amounts of rock dissolve in the water over time, the deep-well water contains more minerals than shallow wells. Deep-well water is even harder than Arizona's surface water. See **Properties Of Water: The Universal Solvent** for more information about hard water.

Groundwater supplies are found in hydrological basins throughout Arizona. Many citizens obtain all their freshwater supplies from wells. Cities, the Salt River Project and others operate deep well pumps in Maricopa County. The average depth from ground surface to the water table is about 300 feet. Groundwater historically supplemented surface water because in most years, the water demand exceeded the available surface water supply.

If the same amount of water removed from an aquifer each year is replenished by fresh water, the water table of the aquifer stays about the same. If more groundwater is pumped from aquifers than is naturally replaced by rainfall and runoff, **overdrafting** occurs.

Hydrologists, scientists who monitor yield rates and levels of groundwater basins, determine the **safe yield** of aquifers or the amount of water that can be withdrawn without overdrafting. Safe-yield means that annual groundwater withdrawals do not exceed annual replenishment of the aquifer. Arizonans have been guilty of overdrafting for a long time. Today they consume water at twice the replenishment rate. Some Tucsonans are now drinking water that has been underground for 10,000 years. Problems with overdrafting include increased pumping costs, changes in local groundwater quality, and land subsidence.

A method of saving water currently being practiced in the Phoenix area is underground storage and recovery. Large amounts of water are being stored for later use by artificially recharging groundwater basins that underlie the greater Phoenix area. Artificial recharge involves releasing water over the ground surface and allowing it to infiltrate into the ground and percolate to the subsurface aquifers. Hydrologists are experimenting with methods of spreading water that will reach the aquifer with the smallest amount of evaporation. Water spreading methods include: flooding, injection wells, shallow spreading basins, and deep pits. The best recharge sites may be river bed areas.

Two other methods successfully being used to extend the water resources in the Phoenix area are using treated wastewater and conservation. Wastewater irrigates many Maricopa County acres.

In 1980, Arizona passed the Groundwater Management Act to control the severe overdraft occurring in some parts of the state. The act requires conservation by all water users in Phoenix, Prescott, Tucson, and Pinal County. Cities throughout the Valley of the Sun encourage conservation through educational programs, rebate programs (for installing low-water-use toilets and landscapes), and law enforcement (by law new construction is required to use low-flow plumbing).

# Procedure

### Part 1: WATER HOLDING CAPACITY OF DIFFERENT SOIL TYPES

1. Let students know they will be comparing the **water-holding capacities** of the four soil materials in this part of the activity: sand, gravel, loam (soil with some organic matter), and clay. Ask students to predict which soil type will hold the greatest amount of water . . . the least. Allow students to examine the soil types with hand lenses before making their predictions.

2. Set filled beakers where students can observe you add an equal volume of colored water to each beaker. (The volume of water added should be about 1/4 of the soil volume measure, i.e., to 400 ml of sand add 100 ml of colored water.) Record the water level of each soil type.

3. Ask: *Does the water soak into each soil type at the same rate? Is the* ***water table*** *at the same level in all beakers? Which soil type has the highest water table? Which has the lowest? What might account for the different water tables? Which beaker has the most water?* (This is a trick question for all should have the same amount of water.) *Which material appears to hold the greatest amount of water? What could you conclude about the water-holding capacity of the different soil types?* (If necessary, point out that the soil material with the lowest water table level has the largest particles and more pores or spaces between particles. You probably found gravel and then sand has greater water-holding capacities than the loam and

## Materials

**Part 1**
At least one per team:
- hand lens
- RECORDING SHEET

For teacher-led demonstration or each team of four students:
- four 500 ml beakers (or 1 or 2-liter clear plastic bottles with dark plastic bottoms removed and tops cut off)
- dry sand, gravel, clay, loam (soil with organic matter) to half fill the bottles or beakers. (Samples must be dry at the beginning of each class.)
- food coloring (red or blue preferable) mixed with water
- measuring cup, so equal amounts of water can be added to each sample
- metric rulers, in case you need to decide close water table levels

**Part 2**
At least one per team:
- RECORDING SHEET

For teacher-led demonstration or each team of four:
- four large funnels (or tops of 2-liter bottles with two inches remaining on the side)
- cheese cloth
- rubber bands
- watch with second hand

**Part 3**
For teacher-led demonstration or each team of four:
- small pieces of 4 different types of rock, (about 200 grams each of sandstone, limestone, shale, granite, pumice, or cat litter)
- scale or balance for weighing rocks
- four 500 ml beakers or bottles (recycle from Part I)
- 1 liter of water

At least one per team:
- hand lens

clay. The material with the highest water table level, likely the clay, appears to have the lowest water-holding capacity. An inverse relationship between water table level and water-holding capacity of soil material may appear to exist. A direct relationship between pore space and water-holding capacity may also appear to exist. See extension #4.)

4. *What would you have to do to clay to get it to hold as much water as sand? Could clay ever hold as much water as gravel?*

**Part 2: PERCOLATION AND YIELD RATES**

1. Use rubber bands to securely attach cheese cloth to the funnel spouts. Fill with soil samples. Be sure clay is stuck to the sides of the funnel.

2. Ask students to predict which soil material will allow the water to flow downward or percolate the fastest? ... the slowest? Ask students to explain the thinking behind their predictions.

3. Have students volunteer to time and record the percolation times. They should begin timing when all the water has been poured and stop when the water flowing through the funnel is just a drip.

4. Pour 100 ml of water into the funnels, one at a time. Record times. Ask: *Through which soil materials did the*

*water flow fastest? ... slowest? How do the times relate to the students' hypotheses?*

5. *Which sample yielded the water most quickly? What is the relationship between yield rates and the time it takes the water to flow through the soil materials, the percolation rates?* (If necessary, point out that there is a direct relationship between yield rates and the speed of percolation: the faster the time of percolation, the higher the yield rate.)

6. *Why would water flow through the soil at different rates?* (Water probably ran through gravel and sand the fastest, and slowest through clay. Gravel, or whichever enabled water to run through the fastest, would be best for a recharge area because it would allow the water to seep down to the aquifer quickly. The difference in pore sizes accounts for the difference in percolation rates.)

7. *If it was raining, through which types of soils would the precipitation percolate most quickly to reach the water table? Over which type of soil would water be most likely to runoff rather than percolate?*

**Part 3: WATER-HOLDING CAPACITY OF DIFFERENT ROCK TYPES**

1. Like soils, different types of rocks have different capacities for holding water. Have students examine the samples with hand lenses and predict which sample will hold the greatest amount of water. Which will hold the least?

2. Weigh out about 200 grams each of small pieces of the four samples available. Record the mass of each sample as the before-soaking mass. Place each in a 500 ml beaker. Then add 200 ml of water. Soak the rocks overnight.

3. At the next class meeting, pour the water off the rocks and determine the mass of each sample. Record the after-soaking mass.

4. Calculate the difference between the before-soaking and after-soaking measurements. The difference in mass is the amount of water adhering to the interior pores and surface of the rock.

5. Ask: *Which type of rock held the greatest amount of water? ... the smallest? What might account for the differences in water-holding capacity of rocks?* (If necessary, remind students that there appears to be a direct relationship between pore space and water-holding capacity.) *What is the relationship between mass and water-holding capacity?* (Again, what appears to be a direct relationship.)

6. Remind students that when studying the water cycle they learned that **groundwater** is water stored in the pore

spaces between particles of rocks and soil. When the pore space between the particles is completely saturated, the area holding the water is called an **aquifer** and the surface of the saturated zone is called the **water table**. Water can be added to aquifers by: 1. precipitation percolating downward, 2. water moving horizontally through capillary action, or 3. pressure from water moving from above (infiltration). Wells remove water from aquifers. **Wells** are made up of holes drilled from the surface level down to the water table and pumps which move the water through pipes to the surface. Many Arizona citizens obtain all their freshwater supplies from wells.

7. Ask students to imagine they need to drill a well for drinking water. *From which types of soil and rock would it be hardest to get water? Which types of soil and rock would yield the smallest amount of well water? Which rock and soil combination would make the best aquifer? Which types of materials could store the greatest amounts of water in small space underground?* Challenge students to design and then build a model aquifer that could hold large quantities of water that could be easily pumped when needed.

8. *If a large shopping center and parking lot were built on the recharge area of their aquifer, what could happen to the aquifer?* (If the recharge area is covered by a material through which water cannot percolate, such as asphalt, water can no longer be absorbed into the ground to infiltrate the aquifer. Thus, the aquifer would receive less water and the water table would fall.)

9. *How could pore space effect chemical pollution of groundwater supplies?* (Large pore space could allow chemicals to reach groundwater supplies more quickly; small pore space could delay or even prevent chemicals from reaching groundwater supplies.) Stress the importance of protecting aquifers from contaminants.

10. In many places throughout the world, including Arizona, more water has been removed from the ground than can be replenished naturally. This is called **overdrafting**. Because of overdrafting, water tables have fallen and many of our groundwater supplies are in danger. In the Phoenix area, groundwater is being **artificially recharged**. Excess winter waters from local and imported (CAP) surface water sources are being put back into aquifers. *Based on our experiments, which kinds of soil and rocks would be best to find if you wanted to set up an artificial recharge program to replenish groundwater supplies? Why?*

## Extensions

1. Investigate the water-holding capacity of caliche, the calcium carbonate layers prevalent in Arizona and other arid regions.

   Would caliche be easy to drill through to set a well? Invite a well driller to class to learn about drilling conditions in the Phoenix area. The Hohokam and other native Arizonans built with caliche. Why was it an attractive building material?

2. Investigate these questions:
   a. If you were building a home in the desert and wanted to install a septic system, what type of soil would you prefer?
   b. If you were a geologist responsible for choosing a sanitary landfill site that would not harm the area's groundwater, what factors would you have to consider about the geology of Phoenix?

3. Borrow at least one groundwater model from the conservation education office of your city. Investigate all the properties studied in this activity, and allow students to mess around with pumping water through wells as well as groundwater contamination.

4. Challenge advanced students to investigate relationships among porosity, hydraulic conductivity, and void ratio. A study of soil mechanics shows that porosity is more closely related to void ratio. Soil samples with higher pore space generally also have higher water-holding capacity, but not always. Clay-rich soils usually have higher porosities than sandy or gravelly soils but lower hydraulic conductivities. Because of the nature of clay, the pores take much longer to fill than other soil types. With time, however, most clays could bear the greatest amount of water. It is unlikely the pores of Plasticine or modeling clay would ever fill before experimental water evaporated.

## Evaluation

1. The greatest amount of water will be held by which of these four soil types: clay, gravel, loam, sand?

2. The smallest amount of water will be held by which of these four soil types: clay, gravel, loam, sand?

3. Describe how an aquifer gets and holds water. Use the following words at least once in your description: **water table, percolation**. Feel free to include drawings.

4. Explain which soil and rock types are best suited for a water recharge program?

# Resources


Arizona Department of Water Resources. 1991. **Second Management Plan 1990-2000: Phoenix Active Management Area.**

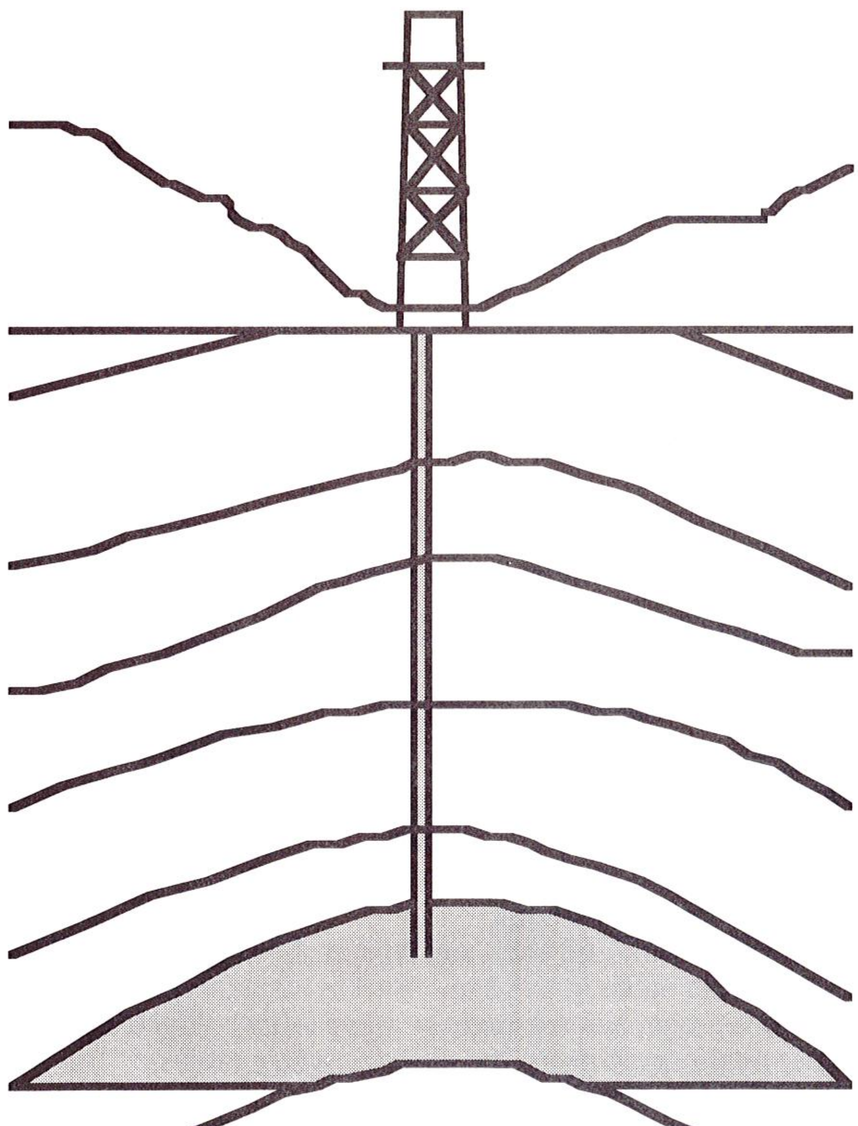
Hardt, A. L. 1989. **Phoenix: America's Shining Star**. Windsor Publications.

Massachusetts Water Resources Authority. "What is an Aquifer?" from **Water Wisdom**. Charlestown, MA.

Salt River Project. 1990. **The Granite Reef Underground Storage and Recovery Project and the Salt River Water Resource Management System.**

Trimble, M. **Arizona: A Cavalcade of History.** Tucson: Treasure Chest.

Ventura County Water Conservation Program. **Water Activities Manual: Grades 6-8.** Ventura County, CA.

# THERE'S WATER UNDERGROUND - STUDENT PAGE

# RECORDING SHEET

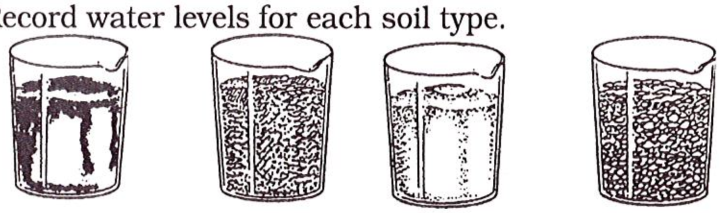
**PART 1**

1. After investigating with a hand lens, draw the relative sizes and spaces between the particles of clay, gravel, loam, and sand.
2. Of clay, gravel, loam, and sand, **circle** your prediction of the soil type that will hold the greatest amount of water. **Draw a box** around the soil type you predict will hold the smallest amount of water.

CLAY GRAVEL LOAM SAND

| **CLAY** | **GRAVEL** |
|---|---|
| **LOAM** | **SAND** |

3. Record water levels for each soil type.



**CLAY** **LOAM** **SAND** **GRAVEL**

4. Think about these questions:
   a. Does water soak into each soil type at the same rate?
   b. Is the **water table** at the same level in all soil types?
   c. Which soil type has the highest water table? Which has the lowest?
   d. What might account for the different water tables?
   e. Which beaker has the most water?
   f. Which material can hold the greatest amount of water?
   g. What does this tell you about the **water-holding capacity** of the different soil types?
   h. What would you have to do to clay to get it to hold as much water as sand? Could clay ever hold as much water as gravel?

# RECORDING SHEET

## PART 2

1. Of clay, gravel, loam, and sand, **circle** your prediction of the soil type that will allow water to flow downward or percolate the fastest. **Draw a box** around the soil type you predict water will percolate the slowest.

   CLAY GRAVEL LOAM SAND

2. Record percolation times for each soil type.

| Soil Type | Percolation times |
|---|---|
| Clay | |
| Gravel | |
| Loam | |
| Sand | |

3. Answer these questions:
   a. Through which soil materials did the water flow fastest? ... slowest?

   b. How do the times relate to your predictions?

   c. Which sample yielded the water most quickly?

   d. What appears to be the relationship between yield rates and the time it takes the water to flow through the soil materials, the percolation rates?

   e. Why would water flow through the soil at different rates?

   f. If it was raining, through which types of soils would the precipitation percolate most quickly to reach the water table?

   g. If it was raining, over which type of soil would water be most likely to run off rather than percolate?

# RECORDING SHEET

## PART 3

1. After investigating with a hand lens, draw the relative sizes and spaces between the rock samples.

**Sample 1:** ___________ **Sample 2:** ___________

**Sample 3:** ___________ **Sample 4:** ___________

2. Weigh each rock sample and record the dry mass.

| Sample | Mass (dry) | Mass (wet) | Difference |
|---|---|---|---|

3. Predict which rock type will hold the greatest amount of water. _________
   Predict which rock type will hold the smallest amount of water. _________
4. After rocks have soaked in water, pour off the water and weigh each again. Record the wet mass in above table.
5. Calculate the differences between wet and dry mass for each rock sample. Record difference in table above. The difference in mass is the amount of water adhering to the interior pores and surface of the rock.
6. Consider these questions:
   a. Which type of rock held the greatest amount of water? ... the smallest?
   b. What might account for the differences in water-holding capacity of rocks?
   c. What is the relationship between mass and water-holding capacity?
   d. Imagine you need to drill a well for drinking water. From which types of soil and rock would it be hardest to get water? Which types of soil and rock would yield the smallest amount of well water?
   e. Which rock and soil combination would make the best aquifer? Which types of materials could store the greatest amounts of water in a small space underground?
   f. If a large shopping center and parking lot were built on the recharge area of their aquifer, what could happen to the aquifer?
   g. How could pore space affect chemical pollution of groundwater supplies?
   h. Which kinds of soil and rocks would be best to find if you wanted to set up an artificial recharge program to replenish groundwater supplies? Why?