Chapter 10. How Water Behaves in the Ground

Lesson 1. Groundwaters, Aquifers, Wells, Pumps and Water Quality

Overview: Although we each use between 120 and 200 gallons of water each day, we seldom have a full understanding of where our water comes from, how it is stored and delivered to us, or what can happen when it is not respected. In the United States, most water used for domestic purposes comes from surface systems (lakes, rivers, streams, reservoirs) or groundwater (wells or springs). Desalinization of ocean water (a surface water system) produces fresh water in only a few coastal areas. Most of us are aware that our actions on land have an impact on surface systems. We can read almost daily about pollution of our major rivers, lakes and oceans. We do not, however, often hear about groundwater systems; yet, in the United States, nearly 50 percent of the people rely on groundwater as their primary source of water. A recent study of well water (not only in Montana but throughout the United States) showed that nearly 50 percent of the well water samples tested were contaminated with bacteria.

With these facts in mind, we must understand groundwater systems how and why groundwater systems exist, how they are affected by land surface activities, and how we can effectively use them.

Purpose: The purpose of this lesson is to help students better understand groundwater systems, aquifers and water storage in the soil. It will explain how wells and pumps work, and explore the size and complexity of problems that can be associated with groundwater contamination.

Materials Needed:

- Several quart glass mason jars or 2 liter pop bottles with tops cut off
- Several atomizer spray pumps (like Windex spray bottles) with uptake tubing long enough to reach from the top to the bottom the jars/bottles
- Washed gravel
- Washed sand
- Old nylon stocking or pantyhose
- Scissors
- Potting soil, sand, or garden soil to fill each bottle/jar
- Scoops
- Quart glass canning jars or clean mayonnaise jars
- Water supply
- Plastic cups

- Graduated cylinders or measuring cups
- Small rubber bands
- Plastic wash tubs or buckets
- Supply of plastic cups or other containers for water
- Plastic tumblers or plastic pop bottles with tops cut off
- Drinking straws
- Crushed ice and ice water (optional)
- Carbonated beverage or colored water (optional)

Procedure: When class begins, start by asking the class the source of the water we drink. The most common answers are that we get our drinking water from rivers, lakes and streams. Students from rural areas will likely say that they get their water from wells.

Ask how many people rely on lakes and rivers, and how many people rely on wells for their water. About 50% of Montanans get their water from wells. Most large cities, particularly those along the rivers, use surface water, while many small towns and farms in eastern Montana use groundwater (i.e., water from wells). These wells draw water from depths of a few feet to several thousand feet. Wells in eastern Montana tend, generally, to be much deeper than wells in central or western Montana.

Ask the class to suggest advantages and/or disadvantages to using groundwater as a water supply for domestic use. You might list the following advantages on the board:

1. requires little treatment (is usually clean) 2. no storage needed
3. generally free of micro-organisms
4. dependable source
5. do not need to pipe it
6. free delivery
7. available where you want to use it

There are, however, some disadvantages, which include the following:

1. not always easy to know the volume
2. difficult to clean if contaminated
3. not always good quality
4. not always where you need it
5. usually expensive to drill and maintain well

Explain that water held in the ground is **groundwater**. This water is contained in geologic formations called aquifers. Aquifers are layers of soil and rock, the spaces of which are filled with water. They are saturated, and the water in them can be withdrawn by pumping. In this lesson, we are going to look at aquifers and groundwater.

As the first part of this activity, we will look at water storage in the soil, and at how aquifers behave. Ask the class to think of an "every day" occurrence that illustrates how soil and rocks store water in "aquifers." Here is a very simple example: Fill a clear plastic pop bottle or glass beaker with crushed ice. Place a drinking straw in the center of the ice and extend it to the bottom of the container. Slowly add ice water to the bottle or beaker. (Use pop or colored water to make it more fun and more obvious.) Have the students watch what happens, and introduce the idea that the ice is like rocks, and the bottle or beaker represents the aquifer. As you fill the container with fluid, the students will see the "rising water table" (i.e., the surface of the fluid rising in the container).

If you want, you can measure the amount of fluid you added without changing the volume of the container or crushed ice. An aquifer is like a big underground storage tank full of coarse material. The coarse material is sufficiently compact to walk on, build roads and houses on, and play on. In some places where water is scarce during the summer months, engineers and soil scientists have devised ways to recharge (artificially fill) these aquifer storage tanks so that they can later withdraw the water for human use.

Now, have a student suck on the straw, drinking some water or pop. You could also pump some fluid with a large veterinary syringe. In either case, the students should watch what happens to the surface of the fluid. This is what happens when many wells are pumped during the summer and it has not rained for several weeks. If you want, you can measure how much fluid you can get out and how much the ice settles when you remove all the water from the container. This type of subsidence (settling) has occurred in places where excessive pumping has been done.

As the second part of this activity, we will design and build a model aquifer and pumping well, and pump the aquifer. This is much like a homeowner or rancher would pump water for home or livestock use. To illustrate this, fill one mason jar or pop bottle with coarse gravel, and fill a second bottle to the same volume with washed sand. Be sure to point out that both bottles are filled to the same level. Now add water to the jar with the gravel, putting in one cup or one liter at a time. Keep track of how much water you added until the water just reaches the surface of the gravel. Do the same with the sand. Note any difference in the amount of water added.

Ask, "Where is the water table?" The correct answer is the surface where the water appears. Here, it is the surface of the soil. If we were to pour out some water, the water table would be lower. Explain that all the saturated soil is an aquifer - a water-bearing layer of soil and/or rock.

While holding all of the gravel in place in the jar, turn the jar on its side at a slight angle. All the free water runs out of the gravel and into the plastic bucket. Pour all of this free water into a jar, and place it beside the jar filled with gravel. Repeat this process with the sand-filled jar. (Prop the jar at an angle inside the bucket. Allow it to set for a few minutes while the water drains out of the sand.) Pour the drainage water into a jar and place it beside the sand-filled jar. Compare the amount put into each jar with the amount that came out of each jar. Summarize your results on the board as follows:

AQUIFER MATERIAL	**Gravel**	**Fine Sand**	**Example**
Water to saturate (ml)			400
Water drained out (ml)			300
Water retained (ml)			100
% of water retained			25%

At this point, you have illustrated the ideas of a water table, an aquifer, drainage and soil water retention. Ask the class what they have observed. (The amount of water an aquifer will hold and release depends on the kind of material of which the aquifer is made. Coarse aquifer material readily absorbs and releases water, but the amount of water absorbed or released is less than for finer-textured materials. Fine materials, on the other hand, retain more water. It also takes longer to drain the water out. Finally, the location of the water table varies with how much water the aquifer holds.)

Tell the class that for the next part of this activity, they are going to build and pump model aquifers. Divide the class into groups of two or three students. Provide each team with a jar or bottle, an atomizer spray pump and tubing, a small piece of nylon stocking or pantyhose, and access to gravel, washed sand and soil.

Instruct the students to:

1. Use a rubber band to secure a small piece of stocking around the bottom of the pump tube, like a filter.
2. Place the bottom end of the intake tubing down into the jar, on the bottom and near the center of the jar.
3. While holding the pump in place, slowly fill the jar at least two to three inches deep with coarse, washed gravel. Students can add as much gravel as they like,

leaving at least two inches at the top for sand or soil.
4. Using gravel, washed sand, or soil, fill the jar to within two inches of the top.
5. Fill the remaining two inches with sand or soil, so the pump extends just above the top of the jar and the sandy soil surface.
6. Pump several times. Note how much water sprays out of the pump. (Obviously, they will not get any water from the pump.)
7. Add about one cup of water and pump again. (They should still not get any water out of the pump.)
8. Continue adding water, one cup at a time, until you see water drip down through the gravel, with most ending up in the bottom of the cup.

The gravel flooded with water is the saturated zone, because the gravel is saturated with water. Water fills all the spaces between the soil and rock material.

In the upper layer of the jar, water "sticks" to the surface of the soil material, but air fills the spaces between the soil particles. The top layer (the layer not saturated with free water) is the unsaturated zone.

The free water moves down through the soil because of gravity. Gravity moving the water down is greater than the adsorptive forces holding the water to the surfaces of the soil particles. The water table is the top surface of the saturated zone. The water table separates the saturated zone from the unsaturated zone. The saturated zone is "groundwater."

9. Pump, directing all the water into a plastic cup, until no more water comes out of the soil. Compare the amount of water pumped with the amount of water applied.

As the water moves down through the soil, soil particles adsorb water, and small pores and spaces trap it along the way. As water is pumped from the saturated zone, some water remains adsorbed to the soil and gravel particles. Nearby groundwater moves in to fill open spaces as the pump pulls out water (like a well out in the country).

How did groundwater get in the well in the first place? When you put a soda straw into a cup of pop and ice, the pop will fill the straw below the "water table." The straw was tike an open space in the pop's "saturated zone." Draw some pop out of the straw. The pop outside the straw flows through the ice chunks into the straw to replace it. If you wait between sips, you can watch the pop fill the straw (below the water table) again. A well works similarly. Like a soda straw, a well leaves an open space into which liquid can flow. In the ground, a well acts like an open space in the saturated zone. Water from the surrounding rocks will keep flowing into the "open space" if the water table is higher in elevation than the well's intake area.

10. Add more water to the jar, until you can see the water table rise at least two inches in the jar. Keep track of the amount of water added.
11. Pump until you can no longer get any water. Keep the water pumped, and compare the amount pumped with the amount added.

With repeated recharge (additions of water) and continued pumping, the amount of pumped water pumping will be nearly equal to the amount of water added. In addition, the water should get cleaner with each subsequent pumping.

If you want to show how soil serves as a filter for removing sediment, silt and particulate matter from water, mix two tablespoons of soil with a cup of water. Stir the mixture very well. Slowly pour the mixture into the jar. Allow a couple of minutes for the water to move through the soil and into the groundwater. After a short time, pump the well, collecting the water in a cup. Note the difference in clarity between the water applied and the water pumped out of the well.

Lessons Learned: Water is stored in and withdrawn from saturated layers of rock and soil below the ground's surface. These water-bearing layers are aquifers. These aquifers can provide relatively clean water.

The lesson above was adapted from "What is Water Quality? A Resource Guide for 4-H Leaders and Teachers," 80 pages of activities and experiments related to water quality. ($5.00) Order from the Montana 4-H Program at Montana State University-Bozeman. Phone 406-994-3501.