Groundwater Flow Model

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Lesson Overview: Through a groundwater follow model demonstration, students will learn about groundwater and the role it plays in the water cycle. They will also observe how pollution moves across a watershed and how they can contaminate water resources, and best management practices that can be implemented to prevent or minimize negative effects on water resources.

Objectives: Students will be able to:

1. Define groundwater and its importance as a valuable source of freshwater.
2. Follow the path of groundwater as it travels through a watershed.
3. Describe the relationship between groundwater and surface water in the water cycle.
4. Identify the watershed in which they live.
5. Identify three ways in which groundwater can be contaminated.
6. Identify three ways people can help prevent groundwater contamination.

This lesson meets the following Michigan Department of Education standards:

Next Generation Science Standards (NGSS):

- ✓ 4-ESS2-1 Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation
- ✓ 3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- ✓ 5-ESS2-1 Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.
- ✓ MS-LS2-5 Evaluate competing design solutions for maintaining biodiversity and ecosystem services.
- ✓ MS-ESS2-4 Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
- ✓ MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- ✓ HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- ✓ HS-ESS2-5 Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

Recommended Grade(s): 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th},

Recommended Subject(s): Science, Biology, Geology, Hydrology

Duration: Prep time: 10 min., Activity: 40-60 min

Materials Required: Groundwater Flow Model, aquarium pump, extension cord, bucket, water, sand, clear plastic cups, bentonite powder, food coloring, squirt bottle, siphon, eye droppers or plastic pipettes,

Suggested Vocabulary for Students: groundwater, watershed, porosity, pollution, contamination, aquifer, confined aquifer, unconfined aquifer, saturated, unsaturated, permeability, infiltration

Background Information for Educator: Some people believe that groundwater is a series of underground caverns, rivers, and lakes. While this can be true in other parts of the United States, in Michigan it is more accurate to describe groundwater as the water that is stored in the spaces between soil particles. When you look at the ground, it seems pretty solid, like the soil fits securely together like pieces in a puzzle or bricks in a wall. However, they don't fit together neatly, rather there are spaces between each particle where air and water can exist.

Groundwater exists when these spaces are completely surrounded or saturated by water (Figure 1). In A, the spaces between soil particles are filled with air and no water (unsaturated). In Figure B, water and air are being stored in the spaces between soil particles (unsaturated). It is possible for plants to grow in soil depicted in Figure B, because plants need soil, air, and water in order to grow. Groundwater is depicted in Figure C, where the spaces are completely filled or saturated with water. The dividing line between the unsaturated zone and the saturated zone is defined as the water table (Figure 2). An aquifer is a geologic formation that is capable of producing significant quantities of groundwater suitable for human use. A confined aquifer is one that is pressurized by overlying soil layers that have low permeability (i.e. clay). An unconfined aquifer is on that does not have a confining layer above it and is therefore unpressurized.

Figure 1: What is Stored in the Spaces between Soil Particles

A. **B.** **C.**

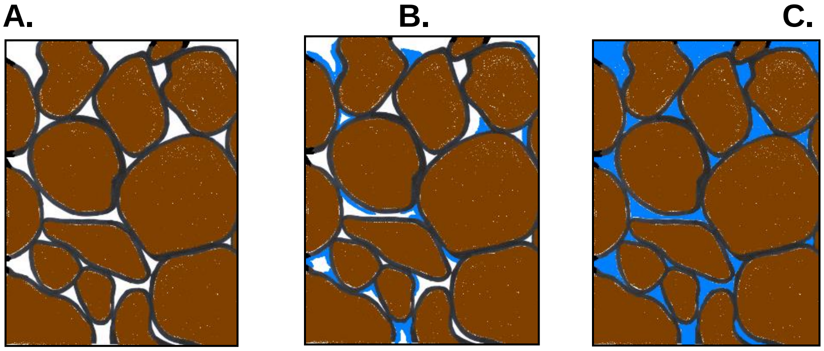
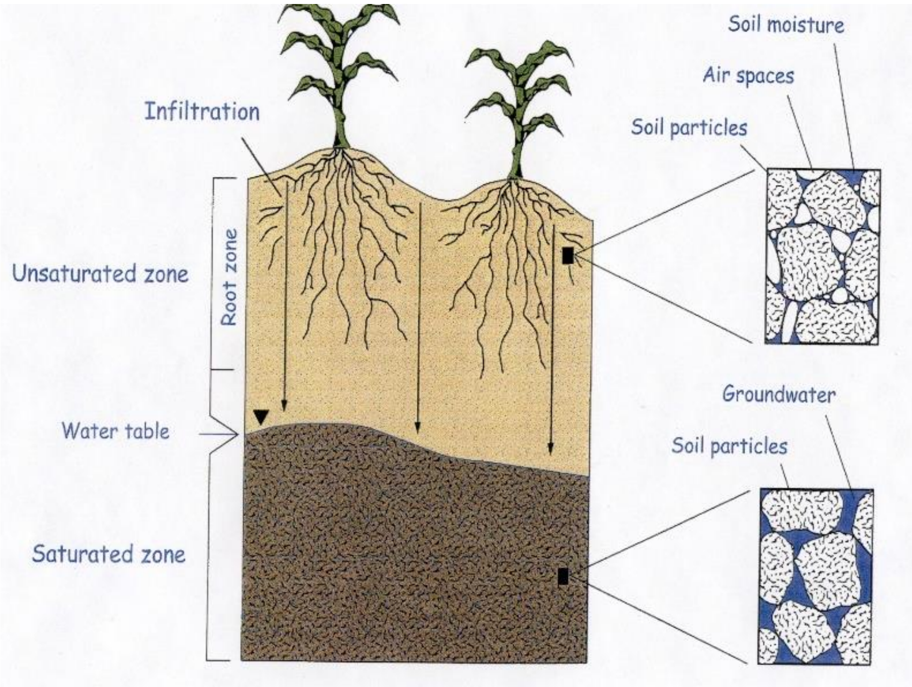


Figure 2: Soil Profile Depicting the Water Table as the Dividing Line Between Saturated and Unsaturated Zones



The size of the soil particle plays a crucial part in determining the amount of water it can hold and how fast the water passes through. Porosity is defined as the water-bearing capacity of soil particles that is due to both the number and size of pores and the extent to which they are interconnected. Clay has the highest porosity, when compared to sand or gravel, because it has many, very tiny pores which hold onto a lot of water.

Permeability is the ability of a material to allow the passage of water, or how fast or easily water can pass through soil. Permeable materials such as gravel and sand allow water to move quickly through them when compared to clay which does not allow water to move freely through it at all. Areas with sandy soils have a greater potential for groundwater contamination due to the ease with which water moves through it. On the other hand, clay layers can help protect groundwater supplies by preventing or slowing the downward flow of pollution through soil layers. However, if clay is found at the surface of the ground, water and the contaminants that it may be carrying may run off rather than infiltrate into the ground, posing a risk to surface water.

Sand is the largest of the soil particles, followed by loam or silt, then clay. At each size, the particles have different properties. A typical sandy soil is very permeable while water takes a lot longer to move through clay. In other words, pollution can move faster through sand when compared to clay. Since sandy soils have high permeability, infiltration of contaminates is the biggest concern to groundwater. Contaminates can pass quickly through the soils and reach the aquifers without spending enough time in the soils to be broken down or filtered. Clay is a very fine soil that fits very closely together. Compacted clay acts very much like cement. Stormwater runoff is the greatest concern in clay soils. Any stormwater, including contamination, on the ground's surface can easily wash away without being absorbed into the ground, entering surface waters.

A watershed, also called a drainage basin, is the land area that drains to a common body of water. The outer-most boundaries of the watershed have the highest elevation. In this analogy, water drains from high to low elevation and drains, and all of this water drains into the same body of water, similar to the way water drains in a bathtub. Watersheds are often named after the water body to which the water drains. You do not live in just one watershed either. For example, all of the water that falls on your property may run into the Grand River, which flows into Lake Michigan that is connected to the St. Lawrence Seaway that runs into the Atlantic Ocean. Water is always flowing into another water body until it reaches the ocean.

Though there are many, here are four common pollutants that can contaminate groundwater:

- Fertilizers – In surface water, fertilizers contain nutrients that can cause algal blooms and growth of other unwanted aquatic plants. Fertilizers also have nitrates in them. Nitrates that get into drinking water supplies can cause Blue Baby Syndrome (Methemoglobinemia) in fetuses and infants. The blood has trouble carrying enough oxygen, which occurs when oxygen in the blood is replaced, in this case, by nitrogen.
- Failing Septic Systems – In order to function properly, a septic tank must be pumped every few years in order to prevent the system from backing up or overflowing, resulting in groundwater contamination. Failing septic systems add nutrients to water systems as well as harmful bacteria. High concentrations of *E. coli,* bacteria that lives in the intestines, is an indicator of waste in the water. Some strains of *E. coli* cause severe sickness.
- Underground Storage Tanks (UST) – Leaking UST can potentially discharge heavy metals and contaminates such as oil, fuel, and fuel additives into groundwater.
- Abandoned wells – Abandoned wells (oil, private, or irrigation) serve as a direct path for contaminants to reach groundwater. If not sealed properly, abandoned wells could allow surface contaminates to leak directly into aquifers, potentially even those usually protected by an aquitard or clay layer. It is estimated that there are over 1 million abandoned wells in Michigan.

Another groundwater issue is withdrawing mass amounts of groundwater. In New York City, they started to discover salt water in their once fresh groundwater. The city was pumping out so much water that it was actually pulling in salt water from the ocean, actually reversing the flow of groundwater. If more water is drawn out of the watershed and not replenished, mass withdrawal may also cause the water table to drop, lowering the level of nearby wells, lakes, and streams.

Lesson Procedure:

Set Up:

~ Fill groundwater model with water.

~ Prepare/fill aquarium pump to be turned on. Do not run the pump dry.

~ Fill a cup half full of sand.

~ Put dried clay and sand in two separate cups for passing.

Introduction:

~ What is groundwater?

~ What does groundwater look like? Ask student what they think groundwater looks like. Groundwater is not a bunch of underground rivers and lakes. Explain where groundwater exists.

~ Ask students to predict what will happen when you pour water into the cup of sand.

- Pour water into the cup of sand.
- Did the sand move when water was added to it? (No)
- Where did the water go? (Filled the pores between the particles)

Activity:

~ Turn on the aquarium pump. Adjust the flow of water by opening the slide on the model and moving the pump left or right.

~ Explain the different layers of the model.

- Point out the differences in the size of the sand used in each layer. Have the students point out which layer has the largest soil particles and so forth.
    - Ask the student to guess which layer the water will travel fastest through.
    - Drop dye down Wells 1, 2, and 3 (UST optional) at about the same time. Have students watch the dye flow through the model. The dye passing through the bedrock (Well 1) should be the fastest followed by the dye thrown down Wells 2 & 3, respectively.

    - Remind them about how the size of the particles effects how well the soil fits together. This determines how much space exists between them for the water to fill. What was that word? (Porosity)
  - Explain the clay/aquitard layer.
    - The soil particles of the clay layer are so fine and fit together so well that few contaminants can pass through.
    - Optional. Pass around cups of dry sand and dry bentonite clay powder for students. Describe each. How are they different?
  - For older students, explain water table and unconfined and confined aquifers.
- ~ Where does groundwater go?
  - Ask students where they think groundwater goes. When you pour a cup of water on the ground does it sink straight down and stay there forever?
  - Explain the concept of a watershed. Even the water underneath the ground moves and feeds lakes rivers and streams.
  - Determine what watershed the school is in.
  - The flow model is a cross-section of a watershed. All of the water in the model flows toward the stream. Name the stream and lake after local bodies of water (they do not have to be one stream and one lake. The "stream" could be called Lake Michigan, and the "lake" could be Reed's Lake or Jim's Bog).
- ~ Now show them how groundwater can get contaminated.
  - Apply excess fertilizer/pesticides (dye) to a lawn (I usually pick the lawn above septic, but the lawn above Wells 2/3 work too as long as the water is not overflowing).
    - Explain how grass can only absorb a limited amount of fertilizer or plant food. Make an analogy to the limited amount of food a person can eat at a time.
    - The excess fertilizer will wash over the surface of the lawn or infiltrate into the ground. To speed up the effect, use the squirt bottle or cup of water to pour extra water over the lawn, simulating rain.
    - Ask the student how they think fertilizer might affect the plants in the water.
    - Explain algae bloom and have the students deduce the effect the blanket of algae can have on an aquatic ecosystem.
    - By now the dye has hit Well 4 or 5. Use the siphon to draw up the dyed water. Explain that the fertilizer filled water is what the people in that house are drinking. Do those people drinking out of Well 4 even know the fertilizer guy across the lake?
    - Older students, explain the effects nitrites have on infants and pregnant women (methemoglobinemia – blue baby syndrome).
  - Septic tank
    - Explain what a septic tank is.
    - The bacteria in a septic tank cannot break down our waste as fast as we put it in. As a result, a septic tank should be pumped every few years. If it isn't, the raw sewage flushed down the toilet leaks out before it is broken down!
    - Put dye in septic tank.
    - The bacteria and nutrients flow into the lake making it unsafe to swim in. Mention *E. coli.*
  - UST – Underground (fuel) storage tanks
    - A UST is a tank underground that holds fuel, like those at a gas station.
    - If a UST is old and corrodes (made of steal) or wasn't installed properly, it may leak and contaminate the groundwater.
    - Add dye to the UST.
    - The most common contaminates are gasoline, diesel fuel, lead, and some gasoline additives (MTBE).

- Abandoned wells
    - In Michigan there are 1 million abandoned wells – old private wells that have are no longer functional or abandoned, irrigation wells, etc.
    - These wells are like big open holes leading directly to the aquifer.
    - Drop dye down Well 2.
    - Before those people with wells underneath the clay layer (aquitard) were at lesser risk for contamination from the surface directly above them. Now with this abandoned well, contaminants are free to wash down directly into the aquifer they drink out of.
    - For older students, also ask them what happens to old metals used to make these wells. These metals corrode, adding heavy metals to the aquifer as well as additional points of entry for contaminants.
- For older students, mass diversion or high-volume withdrawal
    - People can affect the flow of groundwater and significantly lower the water table if they draw out too much water, or draw it out faster than it can be replenished.
    - In NYC they had developed a problem with drawing too much water from the ground. They started drawing in salt water from the Atlantic Ocean.
        - Mark the water table with a rubber band, yarn, or dry erase marker.
        - Put some dye in the stream.
    - Put large siphon in Well 7, and draw up water and dispose of it in the back part of the model or in a separate bucket if illustrating bottling water and shipping it outside of the watershed. Students should be able see the water table deplete as you continue to siphon water out of the well. If you are having trouble showing the water table decreasing, turn off the pump, remark the water table and try again.
    - After a while, the dye in the stream should re-enter the ground and you may start sucking it up in the siphon.

Wrap up and Assessment Options:

~ Review key vocabulary: groundwater, watershed, aquifer.
~ Discuss ways to prevent groundwater contamination.
~ What watershed are we located in?
~ Is groundwater contamination only one person's problem?
~ What is the best way to keep groundwater clean? (prevention!)
~ How can one clean contaminated groundwater? (pump it out, soil replacement, send in bacteria)

Additional Resources:

~ MWSP website: www.miwaterstewardship.org
~ Map of Michigan watersheds: https://www.michigan.gov/documents/deq/lwm-mi-watersheds_202767_7.pdf
~ DEQ groundwater statistics: https://www.michigan.gov/documents/deq/deq-wd-gws-wcu-groundwaterstatistics_270606_7.pdf