

Lesson 1 – How Gravel and Sand Aquifers Store Groundwater

Goals – To learn about 1) how groundwater is stored in the spaces between rock particles and the impacts that differences in geologic materials have on 2) the quantity of groundwater that is stored and 3) the rate at which aquifer recharge may occur. Gravel consists of rock particles that are from 2 to 64 millimeters (mm) in diameter. Sand consists of rock particles that are from 0.62 mm to 2 mm in diameter. The most commonly found deposits of gravel and sand in Minnesota were formed by melt water from continental glaciers that have covered all or parts of Minnesota in the past. Today, they are the most widespread type of aquifer material in Minnesota and are very important sources of drinking water.

Step 1 – Fill the measuring cup with 2 cups of water and pour the water into the mayonnaise jar. Using a marker, draw a reference line on the side of the jar showing the top of the water.

Step 2 – Pour the water back into the measuring cup and fill the mayonnaise jar with gravel beyond the reference mark that you made on the side of the jar. Lightly bounce the bottom of the jar on your work surface to help pack the gravel into the jar. Add more gravel as needed to fill the jar beyond the reference mark.

Step 3 – Slowly pour water into the mayonnaise jar until it comes up to the marker line and record the amount of water that the jar now holds.

Questions –

- What causes the water to move downward into the jar?
- How much water were you able to pour back into the mayonnaise jar once it was filled with gravel?
- Why is there less water in the jar after you added the gravel?
- Where is the water stored now that there is gravel in the jar?
- Where do you think water is stored in underground layers of gravel?

Step 4 – Pour out the gravel and water into the ice cream pail and save the gravel for later. Refill the measuring cup so it now holds as much water as you added to the jar when it was filled with gravel.

Step 5 – Fill the mayonnaise jar with sand about one inch above the marker line on the jar because it will settle more than gravel. A large spoon or scoop is helpful for adding the sand and keeps spilling sand to a minimum. Lightly bounce the jar on your work surface to help pack the sand into the jar as you are filling it.

Step 6 – Slowly, pour water into the mayonnaise jar until it comes up to the marker line and record the amount of water that the jar now holds. This may take some

time because water will like move more slowly through the sand than through the gravel.

Questions –

- Where do you think ground water is stored in underground layers of sand?
- Is there a difference in the amount of water that you could pour into the mayonnaise jar when it is filled with sand versus when it is filled with gravel? Why do you think this happened?
- Did it take any longer to fill the jar with water when it holds sand versus gravel? Why do you think it may take water longer to move through sand than gravel?
- Adding water to the jar represents the recharge that a gravel or sand layer just beneath the land surface receives from precipitation that soaks into the ground. Which would likely allow more rapid infiltration, an area that is underlain by gravel or by sand? Why?
- What percentage of the 2 cups of water does the mayonnaise jar hold when it is filled with gravel versus sand? This percentage reflects the total amount of space that occurs between the gravel particles or the sand particles and estimates the porosity of these materials. Would gravel or sand be a more productive aquifer?
- Do you think that finer-grained sediments like silt (.002 to .004mm diameter) or clay (less than .004mm diameter) will yield more or less water than sand?

Lesson 2 – How a Water Well Works

Goals – To learn about 1) the principle parts of a water supply well and 2) how groundwater moves towards a pumping well.

Step 1 – Fill the mayonnaise jar approximately one third full with gravel.

Step 2 – Place the piece of electrical conduit (We will call it “pipe” for this lesson) or water pipe in the center of the jar and hold it in place while you slowly fill the jar with up to the neck with additional gravel. A large spoon or scoop may help to do this. Place a finger over the top of the pipe to prevent gravel from entering. Gently bounce the bottom of the jar on your work surface to help pack the gravel into the jar.

Step 3 – Slowly pour water into the jar until it comes up to the top of the gravel.

Congratulations! You have just constructed a water well. The pipe represents the well casing that is installed by a water well contractor after a borehole is drilled to the aquifer. Casing prevents the borehole from collapsing into the well and helps keep fine-grained particles such as silt or clay from being pumped with the groundwater.

Questions –

- Lower a pencil into the pipe and slowly pull it out. You will see that it is wet. How did the water enter the pipe?
- Is the water level in the well the same as in the gravel? Why?

Step 4 - Now, you will simulate pumping the well by using the piece of PEX tubing. Place it into the pipe and gently lower it until it touches the gravel at the bottom. Place a finger over the top end of the PEX tubing and gently lift the tubing from the pipe (remember to keep holding your finger over the tubing). Move the PEX tubing over your measuring cup and remove your finger from the top of the tubing. What happened?

Questions –

- How does holding your finger over the PEX tubing allow you to remove water from the pipe?
- What happened to the water level in the pipe after you removed the PEX tubing? Why?

Step 5 - Continue pumping the well with the PEX tubing until you have repeated transferring water to the measuring cup 20 times.

Questions –

- What happened to the water level in the jar and the pipe?
- What will happen if you pour all of the water that you pumped back into the jar?
- What will happen if you only add one half of the pumped water and then pumped the well another 20 times?
- Why do you think that it is important to understand the impacts that pumping wells may have on the amount of ground water that is available both for today and in the future?

Lesson 3 – How Contamination Enters a Gravel Aquifer and a Well

Goals – To learn about 1) the unsaturated zone and water table, 2) how contaminated recharge water reaches the water table, 3) how pumping may move contamination deeper underground once it reaches the water table, and 4) how an unused well should be sealed or it may provide a pathway for contamination to move deeper into an aquifer.

Step 1 – Construct a well by following the first three steps from Lesson 2.

Step 2 – Fill a paper or plastic cup half full with water and add 15 drops of food coloring. This mixture represents contaminated recharge water. Anyone can contribute to contaminating groundwater by 1) improperly disposing of unwanted materials such as used motor oil, old gasoline, or dirty paint thinner or by 2) improperly using everyday things such as fertilizer, lawn chemicals, or cleaning solvents.

Step 3 - Using the PEX tubing and a finger, pump the well 20 times as you did in Step 5 of Lesson 2. Next, mark the water level in the gravel all around the outside of the jar. The surface designated by the marker line shows the boundary between the gravel that is filled with water and the unsaturated gravel above. This boundary is called the water table. The portion of the subsurface between the land surface and the water table is called the unsaturated zone. It typically does not filter out contaminants that are dissolved in recharge water but may help filter out particles such as bacteria and viruses if sand-sized or smaller grains (silt and clay) are present with gravel-sized particles.

Questions –

- What happens where the water table intersects the land surface?
- Where would the water table be more susceptible to infiltrating contamination - where the unsaturated zone is composed of gravel or sand or where it is composed of finer material such as silt or clay? Why?

Step 4 – Pump the well another 15 times and mark the water level in the gravel on the side of the jar. This water level represents the drop in the water table that happens near a pumping well while it is operating.

Step 5 – Slowly pour the water and food coloring mixture into the jar until the water level is back to the level you marked in Step 3. The mixture represents contaminated recharge that occurs during and after pumping as water pressure moves nearby groundwater water laterally and vertically to the lower pressure area that is created by a pumping well.

Questions –

- What do you notice about the boundary between the original “clean” groundwater and the “contaminated” recharge water that you added to the jar?
- What do you think will happen to this boundary when the well is pumped again?

Step 6 - Pump the well another 20 times.

Questions -

- What happened to the “contaminated” recharge water and the boundary between it and the “clean” groundwater?
- What will happen if additional “contaminated” recharge water is added to the water table and the well is pumped again?
- Why is it important to isolate a well from potential contamination sources that may cause contaminated recharge to be pumped into it? What potential contamination sources do you think are important to avoid?

Step 7 – Pour some of the “contaminated” recharge water down the well and observe what happens in the aquifer below the well.

Questions –

- Did the “contaminated” recharge water stay in the well? Why?
- What would happen if a nearby well started pumping?
- What will happen if you continue to pour the “contaminated” recharge down the well?

Lesson 4 – Protecting a City Water Supply Well

Goal – To learn about the challenges of 1) managing contamination sources that may be affecting a city well and 2) preventing future contamination.

North Star is a city of 2,100 people and has a single water supply well that is 70 feet deep. The well, named “Number 2”, is located on the same property as the city maintenance facilities and waste water treatment plant. It is 12 inches in diameter, pumps 500 gallons a minute, and was constructed 10 years ago to replace the original 6 inch diameter city well. This well is 110 feet deep and pumps from the same aquifer but could only yield 100 gallons per minute without pumping fine sand after it was discovered that the casing was rusting out. It is located approximately 50 feet from the city’s wastewater treatment pond and 100 feet from well Number 2. The old well has not been sealed but was disconnected from the water line to the city pumping station shortly after well Number 2 went on line. No contamination was ever detected in this well.

Disinfecting the well water using chlorine is the only treatment provided by the city. The city has doubled the amount of water it pumps from well Number 2 since 2008 when a meat processing company moved into town and requested that its new plant be connected to city water and sewer services. Since increasing pumping, the non-pumping water level in the well has dropped from 10 feet to 25 feet. Also, the city expanded its wastewater treatment plant at a cost of \$800,000 to accommodate the increased flow of sewage from the processing plant.

Water quality testing shows the following contaminant levels have been increasing in well Number 2:

Contaminant (Parts per Million)	Year					
	2004	2007	2010	2011	2012	2014
Nitrate Nitrogen	3	3.8	5.1	5.6	6.1	6.4
Sulfate	30	33	38	45	48	79
Chloride	5	8	11	43	72	166
Benzene	0	0	0	0	.0008	.0009

This table presents the concentrations of these contaminants that either trigger the city to take action because of state/federal regulations or consider treating for them. It also summarizes the human health effects caused by each of the four contaminants:

Contaminant	Regulatory Level (ppm)	Advisory Level	Public Health or Aesthetic Impact

Nitrate Nitrogen	10	-	Prevents the blood from carrying oxygen in infants 6 months or younger
Sulfate	0	250	None, but may require treatment due to taste and odor
Chloride	0	250	None, but may require treatment due to taste and odor. Also, may cause increased corrosion of pumps and pipes
Benzene	.002 (MDH) .005 (EPA)	-	Known to cause cancer. The MDH limit is used as the regulatory limit.

The Minnesota Department of Health (MDH) approved the city's wellhead protection area (WHPA) in 2013 which designates the area that recharges the city well over a ten year time period. A review of existing geological data indicates that the aquifer is vulnerable to contamination throughout the WHPA because the gravel and sand aquifer exists just below the land surface.

The remainder of the wellhead protection plan focuses on determining how the city will manage land use and potential contamination sources that occur in the WHPA. Four property parcels are included in the WHPA and the following potential contamination sources were inventoried:

Parcel Identifier	Description of Land Uses	Size (Acres)	Potential Contamination Sources
1	City Maintenance Yard	35	Waste water treatment pond; main sewer line; unsealed well; road salt storage building; above ground gasoline and diesel fuel tanks; storage yard for transformers and power poles; vehicle storage and maintenance; contamination from a former buried gasoline tank.
2	Abandoned Car Dealership	5	Unsealed well that was bulldozed over when the site was razed; 10,000 gallon gasoline tank was removed 20 years ago but no study of groundwater contamination was conducted.
3	Meat Processing Plant	40	None suspected. The plant is hooked up to city water and sewer services. Animals are delivered to a sheltered area that has a concrete floor and all processing is done inside.
4	Agricultural Field	80	Fertilizer; manure; and herbicides. Crop rotation is corn and soybeans.

The contaminants present in well Number 2 were linked to potential contaminant sources by the local wellhead protection team:

Potential Contaminant Source	Nitrate Nitrogen	Chloride	Sulfate	Benzene
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Diesel Fuel Tank	No	No	No	Yes
Electrical Transformer Storage	No	No	No	No
Fertilizer	Yes	Yes	No	No
Gasoline Tank	No	No	No	Yes
Herbicides	No	No	No	No
Manure	Yes	Yes	Yes	No
Road Salt Storage	No	Yes	No	No
Sanitary Sewer Main	Yes	Yes	Yes	No
Treated Wood Storage	No	No	No	No
Unsealed Well	No	No	No	No
Vehicle Storage/ Maintenance	No	Yes	No	Yes
Wastewater Pond	Yes	Yes	Yes	No

Questions -

These questions focus on addressing the current contaminant levels and potential contamination sources.

- What contaminant do you feel presents the greatest threat to the quality of the city's drinking water? Why?
- What are the most likely sources of this contaminant and which property parcel or parcels should receive highest priority for reducing the threat of releasing any more of the contaminant?
- What impact do you think increased pumping of the city well since 2008 has had on the movement of the contaminants into the aquifer?
- What impact do you think the two unsealed wells may have on aquifer contamination?

These questions focus on managing the wellhead protection area in the future.

- Would constructing a well deeper into the aquifer at the city's maintenance yard solve the problem of increasing contaminant levels in the city's water supply? Explain your reasoning.
- What concerns over drinking water quality would you have if someone proposed developing a gravel pit on the agricultural field? What

additional concern would you have if the proposed operation included constructing a well for washing gravel?

- What if the meat processing plant wants to expand and asks the city for more water? What concerns would you have for drinking water quality and quantity if the plant operators decide to construct another well to obtain the additional water if the city cannot provide it?