

Discussion Items

Lesson 1 - How Gravel and Sand Aquifers Store Groundwater

Gravel and sand layers form the most commonly used types of aquifer in Minnesota. They occur throughout the state and in the western half, are the only types of aquifer materials that will usually yield enough water for a domestic or community well. Large geographic areas where sand and gravel occur just below the soil horizon (within six feet of the land surface) are found in central and north-central Minnesota as well as in the eastern and southeastern portions of the Twin Cities area. Bedrock aquifers in the southeastern quarter of Minnesota often yield as much water as gravel and sand aquifers. Elsewhere, bedrock aquifers typically do not yield as much as gravel and sand aquifers.

Another reason for basing the lesson on gravel and sand aquifers is that groundwater movement in many types of bedrock is difficult to demonstrate or predict because it is controlled by the distribution fractures. Fracture distribution is influenced by factors such as the type of bedrock, the degree to which it has been weathered, and the degree to which it has been deformed by folding or faulting. Usually, it is not possible to accurately determine the distribution of fractures because bedrock is covered by glacial deposits or there is limited exposure of bedrock near a well. Furthermore, the fractures in bedrock such as limestone, dolomite, and some types of sandstone have been enlarged by slightly acidic groundwater to produce an intricate system of conduits or even caves through which groundwater now moves. It is very time consuming and difficult to determine how groundwater moves under these conditions which may be found in southeastern and some parts of east central Minnesota.

Questions after Step 3- These questions are meant to stimulate the student's interest in linking observation to explanation. Water moves vertically into gravel due to the force of gravity just as it does in the natural world. However, the vertical movement of surface water and precipitation into the earth is not uniform everywhere because of differences in subsurface geologic conditions. The gravel-sized particles take up volume in the mayonnaise jar and do not store or transmit water. However, the spaces between them do and the total volume of pore space reflects the amount of water that is stored. Typically, the pore spaces between gravel-sized particles are larger and more interconnected than those of sand-sized particles. Therefore, gravel will more readily yield water.

A follow up exercise would be to determine the percentage of water that is now stored in the gravel by dividing the volume of water that was poured into the gravel by the original 3 cups. The resulting percentage defines the amount of pore space between the gravel particles.

Questions after Step 6 – These questions should help the student understand that the sizes of the rock particles affects 1) the size of the adjoining pore spaces and 2) how quickly water may move through the total pore space in an aquifer. An equal volume of sand will contain more particles than an equal volume of gravel because sand particles are smaller and it takes more of them to occupy an equal volume. As a result, the pore spaces between sand particles are smaller than those between gravel particles and allow sand to become more tightly packed than gravel. Therefore, it will take longer for the water filling the jar to move into the pore spaces in the sand than in the gravel. Depending how tightly the sand is packed versus the gravel, the sand may hold as much or less water than the gravel. The big difference is that water moves more readily through gravel than sand which affects the rate at which recharge occurs. Water will more readily infiltrate into an area that is underlain by gravel than sand.

Geologic materials that are composed of silt-sized (.004 to .062 mm) or clay sized (less than .004 mm) particles will take on or transmit water even slower than sand. Therefore, layers of silt or clay generally do not make good aquifers and tend to retard the vertical movement of recharge to underlying aquifer materials.

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Lesson 2 – How a Water Well Works

A water well is essentially a tube that is constructed into the earth until it reaches an aquifer that will provide enough groundwater for an intended use. House wells typically only need to provide 5 to 10 gallons per minute and usually the casing is 4 to 6 inches in diameter. Community, industrial, or agricultural irrigation wells pump a lot more water and may need to produce 100 to over 1,000 gallons per minute. They may have casing that is from 8 to 24 inches in diameter depending upon the yield needed. There is no accurate statewide average for well depth because of the wide variety of geologic conditions that exist in Minnesota.

The most basic well design is a hole that is constructed from the land surface to an aquifer and the groundwater is lifted upwards for use. A casing prevents the hole from collapsing and there are many types of casing. The earliest wells were hand dug and the hole was kept from collapsing by using wood or masonry casing materials. A bucket or other container is lowered into the well and hoisted up to produce water. People have been constructing hand-dug wells for thousands of years and one of the oldest is found in Austria and is approximately 5,200 years old. However, most wells in Minnesota are now constructed by drilling to an aquifer and are cased using steel or plastic pipe. Today, most pumps are electric although there are still some that operate by hand or are hooked to a windmill. Very few hand dug wells are used in Minnesota anymore because they are often less than 50 feet deep and are easily contaminated by bacteria or chemical compounds relating to nearby land uses.

The design of the well that is used for this lesson is very common in house and lake cabin wells because it is simple to construct and maintain. However, well yield is affected because groundwater enters only from the bottom of the well and fine sand, silt, or clay sized particles that are in the aquifer can easily be pumped in.

Questions After Step 3 – Both the gravel in the jar and the pipe are open to the atmosphere but the weight of the water due to gravity and atmospheric pressure creates a hydraulic pressure in the gravel. This hydraulic pressure forces water into the bottom of the pipe and the water will rise until it reaches the same level (or amount of hydraulic pressure) as in the gravel.

Questions After Step 4 – Placing a finger over the PEX tubing seals the top from the atmosphere and creates a difference in atmospheric pressure between the top and bottom of the tubing when it is raised above the water level in the pipe. The higher air pressure at the bottom of the PEX tubing is great enough to hold the water inside. Releasing the finger eliminates the difference in air pressure and allows air to enter at the top. This creates equal air pressure at both ends and gravity pulls the water out of the PEX tubing. As water is pumped from the well, a lower hydraulic pressure is created in the pipe than exists in the surrounding gravel. Water in the gravel is forced into the bottom of the pipe but, because there is no recharge to the jar, the water in the gravel will go down accordingly. It will require several cycles of removing water with the tubing before the drop in the water level is readily apparent because of the volume of water contained in the gravel versus that contained in the PEX tubing.

Questions after Step 5 – Pumping the well without replacing the water in the jar will drop the water level and represents what happens in an aquifer when pumping greatly exceeds recharge. Pouring all of the water back represents the best condition where pumping equals recharge. Adding only half of the water (recharge) followed by the same amount of pumping will result in a greater decline in the water level than that generated after the first pumping cycle. This represents over pumping the aquifer and will eventually result in dewatering it the bottom of the well. Over pumping can have many long-term consequences such as 1) drying up other wells, 2) reducing flow in rivers and streams, 3) dropping water levels in lakes and ponds, 4) compacting an aquifer with land surface subsidence above the affected area, or 5) moving contamination deeper into an aquifer.

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Lesson 3 – How Contamination Enters a Gravel Aquifer

Snow melt and rainfall are the most common forms of groundwater recharge although some surface waters such as rivers and lakes may provide recharge too. Also, people purposely induce recharge using methods such as 1) a stormwater infiltration basin, 2) a drain field for a septic system, 3) a dry well (gravel drains that take roof and parking lot runoff), and 4) a stormwater drainage well (these types of wells are illegal but were once prevalent). There is increasing interest in protecting surface water quality by infiltrating stormwater locally which is likely a good thing as long as the infiltrating water does not contain levels of contamination that present a concern to those who use groundwater. Therefore, it is important to understand the amount of recharge and the types of contaminants that may be carried to groundwater that result from current or proposed changes in land use or water management.

Usually, groundwater recharge and contaminants that are either dissolved in or carried with it travel vertically through a portion of the subsurface that is not completely saturated with water. Gravity pulls recharge water underground through this unsaturated zone until it reaches the point where all of the underlying spaces in the subsurface are filled with water. The boundary between the unsaturated zone and the saturated zone is called the water table and it forms a surface that extends everywhere beneath and at the land surface. The depth to the water table usually fluctuates with precipitation amounts and the time required for recharge to reach the water table through the unsaturated zone.

Generally, if a contaminant such as chloride (such as from road salt) or nitrate (such as from fertilizer) is dissolved in recharge water then it can be carried to the water table. Other contaminants such as bacteria and viruses (such as from a septic drain field) that are carried along with recharge may reach the water table if they are not filtered out going through pore spaces that are smaller than they are.

Questions after Step 3 – An area becomes flooded when the water table occurs at the land surface. Often, poorly drained depressions on the land surface become lakes or wetlands where the water table elevation is greater than those of the bottoms of these depressions. Rivers and streams may gain flow where the water table intersects their beds.

Generally, areas that are underlain by gravel receive recharge faster than sandy areas because the pore spaces between gravel particles transmit water more rapidly than those in sand. Refer back to Lesson 1.

Questions after Step 5 – The boundary between the “contaminated” and “clean” water should be fairly distinct unless the “contaminated” water is poured in too rapidly. If so, this demonstrates what happens when recharge is concentrated in one area such as beneath a stormwater infiltration basin and the recharge penetrates deeper than elsewhere because there is a greater rate of mixing.

Questions after Step 6 – The “contaminated” water will move deeper into the gravel as the water level is lowered by pumping, just as it does near an actual pumping well. The speed at which it moves depends upon factors including the aquifer pore size, the solubility of the contaminant, the depth between the well intake and the water table, and the pumping rate. Generally, there is a linear relationship between the distance between the water table and the well intake versus the time period over which the well becomes contaminated in a geologically sensitive aquifer.

Repeating the cycle of adding contaminated recharge will result in increasing the level of contamination that is pulled deeper into the aquifer by pumping. Initially, the first round of “contaminated” recharge may be diluted somewhat by mixing with the “clean” groundwater. However, a continuing supply of contaminated recharge will result in increasing contaminant levels in the lower parts of the aquifer and in the well. This is reflected in the increasing color to the aquifer water as more “contaminated” recharge is added.

Questions after Step 7 – Pouring “contaminated” water down the well simulates what happens a well that is not properly sealed but is bulldozed over and covered with soil. Here, infiltrating recharge can easily enter the well and move directly into the aquifer. Also, this simulates what happens when well

casing is not properly installed such as at a poor thread connection or welding joint or when rust holes develop. State law requires that wells that are no longer used be properly sealed by a licensed contractor.

Contamination that enters a well can move large distances into an aquifer over time as groundwater moves toward pumping wells. This is a concern for all well owners because improperly constructed or sealed wells on your property may contaminate the well that you obtain your drinking water from or your neighbors' wells or a city's wells.

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Lesson 4 – Protecting a City Water Supply Well

The scenario used for the lesson is based upon problems that many cities experience regarding the impacts that historical land uses have on their drinking water. Prior to the 1970's, little thought was given to the long-term impacts that potential contamination sources such as buried fuel tanks, wastewater treatment ponds, fertilizer use, and unused wells may have on groundwater quality. As a result, many communities and private well owners face a legacy of potential contamination sources that often impact the use of groundwater, especially for drinking. Also, considering the future impacts of new potential sources of contamination can be difficult when land owners do not understand how their proposed changes in land use may affect groundwater.

Determining what is causing groundwater contamination is often a sleuthing process involving the collection and interpretation of clues. For the scenario used in this lesson, consider the following clues –

Selecting the most important contaminant to address -

Clue #1 – Nitrate nitrogen and benzene are known to affect people's health whereas chloride and sulfate are believed to have aesthetic effects or may damage the water system infrastructure.

Clue #2 – The level of nitrate nitrogen is beyond one half of the drinking water limit as is the level for benzene. The concentration of nitrate appears to be increasing more gradually than the level of benzene.

Clue #3 - Nitrate nitrogen presents the greatest risk to infants whose age is six months or younger whereas benzene affects the entire population.

Deduction – There is uncertainty about how rapidly the benzene concentration will increase until it reaches .002 parts per million (2 parts per billion) and the city will be required to treat the well water. Also, it may affect the entire population of the city and the city currently does not have the capability to treat for any of the contaminants that are being detected. Therefore, reducing benzene levels should receive highest priority because there may be less time before it exceeds the drinking water limit than that of nitrate nitrogen.

Identifying the source(s) of the contaminant

Clue #4 – The city operates above ground storage tanks for gasoline and diesel fuel at its maintenance facility so spills that occurred in the areas surrounding these tanks should be visible or city staff should have documented them. Gasoline contamination from a former buried tank is mentioned in the potential contaminant source inventory but nothing else is known about it.

Clue #5 – A large gasoline storage tank was removed at the abandoned car dealership several decades ago although no study was conducted to determine whether it leaked gasoline while it was in service. This study should be conducted to determine whether benzene contamination is moving from this site to city well Number 2.

Deduction – Two parcels may be sites where benzene may be entering the aquifer. In particular, the city maintenance yard is closest to well Number 2 and the leak site there should be assessed as soon as possible.

Assessing the impact of increased pumping by the city

Clue #6 -The city well pumps from a gravel and sand aquifer that is geologically sensitive.

Clue #7 – Contaminant levels in city well Number 2 started to increase more rapidly within several years of the city doubling the amount of groundwater it pumps. In the case of benzene, it was not present until the past two years.

Clue #8 – The non-pumping water level which reflects the depth to the water table has dropped 15 feet in the aquifer since the city doubled its water use.

Deduction - We learned in Lesson 2 that pumping lowers the groundwater level in an aquifer near a well and if pumping exceeds recharge, the water level will remain lower until a balance is achieved. In lesson 3 we learned that pumping causes contaminated recharge to move deeper into in aquifer and contaminant levels will increase if contaminated recharge continues. Combining the lowering of the water table in a geologically sensitive aquifer with sources that are leaking contaminants will cause the contaminant levels to increase in the pumping well. All of the inventoried potential contaminant sources should be considered a risk to drinking water quality until it is demonstrated that they are not contributing contaminated recharge to the aquifer. In particular, the movement of benzene from the two potential sources may have been altered and now is toward city well Number 2 as a result of greater pumping stress on the aquifer.

Assessing the impact of the unused wells

Clue #9 – The city has not properly sealed its former water supply well that was taken out of service because the casing was rusting out. Rust holes in the well casing can provide pathways for contamination to move into the well and deeper into the aquifer, especially when well Number 2 is pumping.

Clue #10 – The well at the abandoned car dealership was destroyed by a bulldozer and covered with soil when the former car dealership was cleared. The broken casing may provide a pathway for any on-site contamination such as from the old gasoline tank to move deeper into the aquifer.

Deduction – We learned in Lesson 3 that allowing contamination to move into a well can accelerate its movement into an aquifer. Both wells should be considered a high risk to water quality and should be properly sealed, especially the former city well because of its proximity to a known site of fuel contamination and to city well Number 2.

Future management of the wellhead protection area

The three questions are examples of those frequently asked by public water suppliers and local wellhead protection teams. There is no standard answer to each because of the unique combination of geologic and hydrologic conditions, pumping impacts, and the approaches used to manage potential contamination sources in wellhead protection areas. Therefore, each question must be answered on a case-by-case basis. The following discussion applies to the scenario described in Lesson 4.

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.

Here are some clues:

Clue – Gravel and sand occur between the suspected or known contamination sources located at the city’s maintenance yard and the deeper part of the aquifer where a new well would be constructed.

Clue – Pumping from deeper in the aquifer will increase the vertical movement of contaminated groundwater that is already present in well Number 2.

Clue – The city maintenance yard has potential contamination sources for all of the contaminants that are present in city well Number 2.

What concerns over drinking water quality would you have if someone proposed developing a gravel pit on a portion of the agricultural field? What additional concern would you have if the proposed operation included constructing a high capacity well (pumps more than one million gallons per year) for washing gravel?

Here are some clues:

Clue – Excavating gravel will likely extend to the water table and create a window for potential contamination from surface water runoff to directly enter into the aquifer. This could increase the concentration of nitrate nitrogen if runoff is from the adjacent agricultural land.

Clue – Vehicle parking/maintenance and fuel storage within the gravel pit may result in fuel being spilled directly into the aquifer. Over time, this may add to the increasing benzene level in city well Number 2 as well as add other contaminants related to fuel spills.

Clue – Adding another high capacity well within the WHPA will capture groundwater that used to flow toward city well Number 2. It is likely that a well at the proposed gravel pit will pump during the summer when demand for water by the city is greatest. This could result in a seasonal lowering of the water table beyond that caused by the city well and increase the vertical movement of contamination into the aquifer. Furthermore, the new groundwater capture area for the city well may further increase the movement of benzene toward it.

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?

Clue – The increased pumping that was needed to support the plant when it started appears to be accelerating the level of contamination in the city well Number 2. Relying on the current city well to meet the additional demand will result in additional lowering of the water table and increase the risk of elevating current levels of contamination.

Clue - Expanding the operations at the meat processing plant will increase the amount of sewage that the city must process and may create the need to expand the wastewater treatment pond. The pond is a likely source for nitrate nitrogen, chloride, and sulfate and increasing its volume could accelerate the levels of these contaminants in city Well Number 2.

Clue – Constructing a high capacity well at the meat processing plant would raise the same concerns over further lowering of the water table as increasing pumping at city well Number 2 and changing the capture area for the city well as if a well were to be constructed at a gravel pit.

Clue – Adding another city well at a different location may help solve many of the issues relating to the effects of increased pumping from city well Number 2. However, given the geologic sensitivity of the aquifer, what search criteria should the city consider when looking for another well site?