# Hydrogeology Notes

By yours truly, Mao Zedong

**Introduction**

Hydrogeology is a very recent and important field of science. It is the combination of Hydrology, the study of movement, quality, and other properties of water around the world, and geology, the study of the composition and processes of the Earth. Hydrogeologists study the properties of water under the Earth's surface, and how it affects other systems (the study of **groundwater**). This notes page focuses on both hydrogeology as a science and as a Science Olympiad event.

**Some things to consider:**

-About 95% of fresh-water used in the US is groundwater

-50% of drinking water in the US is groundwater

-The amount of groundwater in the US is over 20 times the amount of water in lakes, rivers and streams

-80 billion gallons of groundwater are used by the US each day

-Groundwater is a semi-renewable resource; Unused, it will replenish itself, but if we use too much, it will run out

-99% of the water accessible to humans is groundwater

**Lesson 1; The Water Cycle**

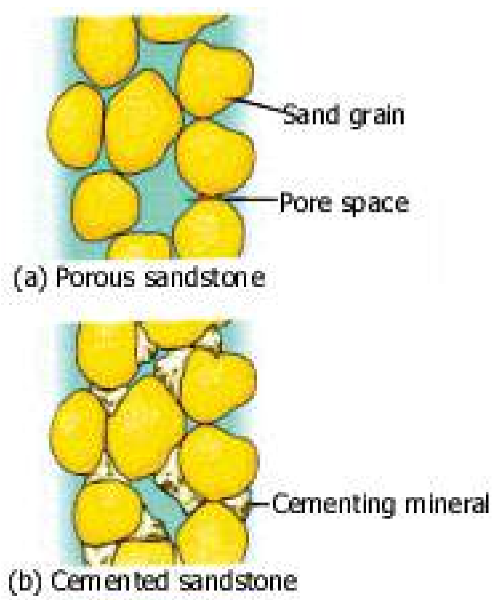
Just like all sources of water on Earth, groundwater comes directly from and is a large part of the water cycle. It begins with precipitation. Water falls from condensed clouds and collects on the surface, which then will move down whatever surface it is on due to gravity. This is called **runoff**. Runoff can either collect in larger streams and rivers, which will eventually flow into lakes or oceans, or runoff can move underground through **percolation**. Percolated water will first move through surface soils, because they are often the top strata, and they easily absorb water. After it moistens the soil, it will move through any permeable strata below, until it reaches an **aquifer**, **aquitard**, or **aquiclude**. Movement of water from the surface to the ground is called **infiltration**. The area of the ground filled with water, either in an aquifer or an aquitard, is the **saturated zone**. Conversely, the area above the saturated zone, where the ground is not filled with water, is called the **vadose zone**. The line separating these areas, above which there is little to no water, below which there is saturated strata, is the **water table**.

**Lesson 2; Soil Moisture**

**Soil moisture** occurs when water is held in the pore spaces of rock or soil. The properties of this soil/rock unit determine whether it is an aquifer, aquiclude, or aquitard. If the water can easily permeate through the unit, because of small open channels throughout the rock (will be explained in more detail with groundwater flow), then it is an aquifer. If the water can easily enter the rock, but cannot move through because of closed-off pore spaces, it is an aquitard. If the water cannot enter or leave unit, then it is an aquiclude. Aquitards and aquicludes are not useful as they are, because as water cannot move out of them on its own, we cannot pump water from them. The **capillary fringe**, the area above the water table in which water is held in **capillary action**, acts much like an aquitard, in that there is water there in capillary, but cannot easily be moved out.

**Lesson 3; Groundwater Flow**

Just like with surface water, groundwater moves by the action of gravity. The main difference is their speed. Unlike surface water, groundwater is constantly blocked by closed pores in the strata it is in. To properly flow, it must have long, open, unblocked channels.




This picture helps explain groundwater flow. In the porous sandstone, water can move freely, as it can easily move around the sandstone particles; it could be an aquifer. But in the cemented sandstone, water flow is blocked, and cannot flow freely; it would be an aquitard.

**Groundwater potential** is the measure of how effective a unit is at moving groundwater through it. **Homogeneity** is an important factor in this measurement, as a unit is much more likely to have water flow through it when the particles are of similar size. This only applies when the particles are large, as gravel, which has large, homogenous grains, permeates water very well, and clay, which has small, homogenous grains, permeates water very poorly. This works because, like the image above, if there are small particles mixed in with the large particles (the cement mixed in with the sandstone), then the small particles will fill the spaces in between the large particles, preventing water from moving through. To have a higher groundwater potential, the unit must also be available for **recharge**. (Recharge: refilling an aquifer through the water cycle)

**Lesson 4; Darcy's Law**

**Darcy's Law** is a very important concept in hydrogeology. It was first an observation made by **Henry Darcy**, an early hydrologist, in 1856. Darcy's law is an equation relating the speed of groundwater to the **permeability** of the aquifer. But before we get to the actual equation, we must go over the **hydraulic gradient**. The hydraulic gradient is simply the slope of the area measured. Hydraulic gradient is denoted by the letter "i" as i=h/L. h stands for **head loss** (the total change in height for the area measured), and "L" is the total change in length of the are measured (length is measured as a straight line from one point to another). Another part of Darcy's law is the permeability constant, denoted by "K". It is very similar to groundwater potential, in that it measures the speed of which water moves through it. The following chart shows the K values of various materials.


The last part of the Darcy law equation is **porosity**, denoted by "n". Porosity is equal to the **void space** in the substance (the volume of the substance that water can flow through), divided by the total volume of the substance. It is always between 0 and 1. The porosity compensates for the length, since the length calculation does not include turns in the water's path, which is made up for through void space. Thus, since we have all of the components of Darcy's law, we can do the equation.

$$V = Ki/n$$

Or, **velocity** V is equal to permeability constant K multiplied by hydraulic gradient i divided by porosity n. Another calculation you may see is $V = Ki$, where V is the **apparent velocity**. Apparent velocity assumes straight lines in water's paths.

**Lesson 5; Water Table Contour**

The water table contour is simply the water table line shown as a plane, oriented in 3 dimensions. Finding the water table contour is an important part of the Hydrogeology Challenge, a large part of the Science Olympiad event.

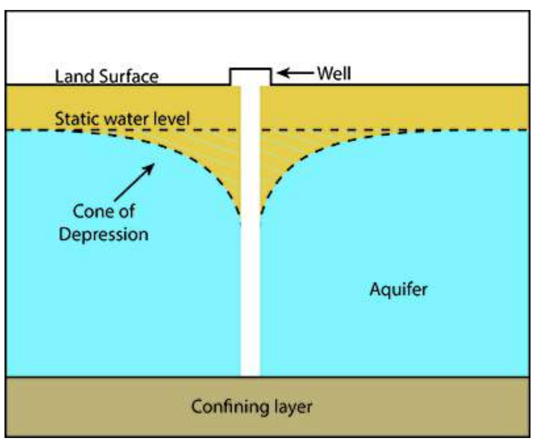
**Lesson 5.5; Confined and Unconfined Aquifers**

Aquifers can either be confined or unconfined. **Unconfined aquifers** are aquifers that have a water table at the surface, and are therefore at atmospheric pressure. **Confined aquifers** are sandwiched in-between layers of aquitards or aquicludes; non-permeable units. Confined aquifers are at a higher pressure than unconfined aquifers. **Artesian well** is a well drilled on a confined aquifer, thus the water comes up more easily than an unconfined aquifer.

**Lesson 6; Groundwater Tapping**

As I said at the beginning, most of the water we use comes from tapping groundwater sources. This is the main job of hydrogeologists; to find where groundwater is, can it be tapped safely, and other similar problems.

Groundwater must be drawn from the ground in wells. A spot for a well is found, drilled on (often just into an impermeable layer below the aquifer), and the well is placed. When the well begins pumping, it will lower the water table. It lowers the water table at a greater rate closer to the well than further from it, as depicted. When groundwater is tapped from an aquifer, it lowers the water table. The water table will recharge on its own, but if humans continue to tap too much from it, problems start to occur.

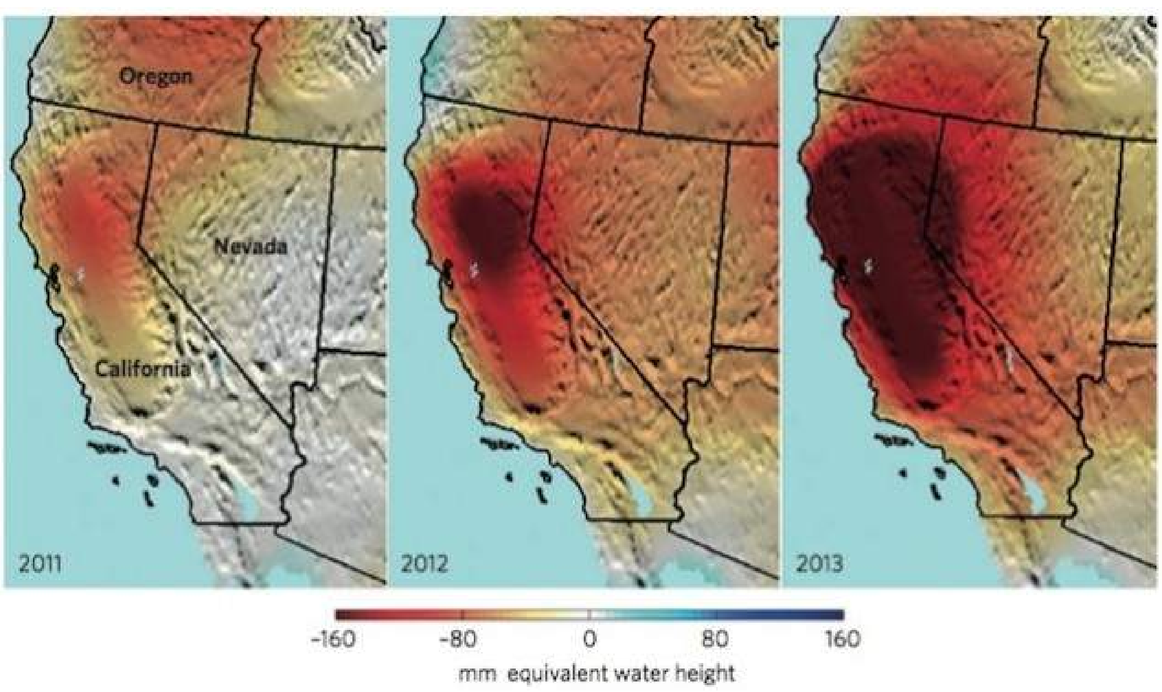



The amount of water that can be removed from an aquifer is its **specific yield**. Specific yield is a percent, and is based off of the material the aquifer is made of. Here is a table for typical rock/soils.

However, we cannot tap all of the specific yield from an aquifer. Doing so would lead to various geologic hazards, that should be avoided. We can only tap a certain amount, enough that we can get water, little enough that the aquifer can be recharged. The amount of groundwater that can be tapped annually without damaging the surrounding area is the **safe yield**.

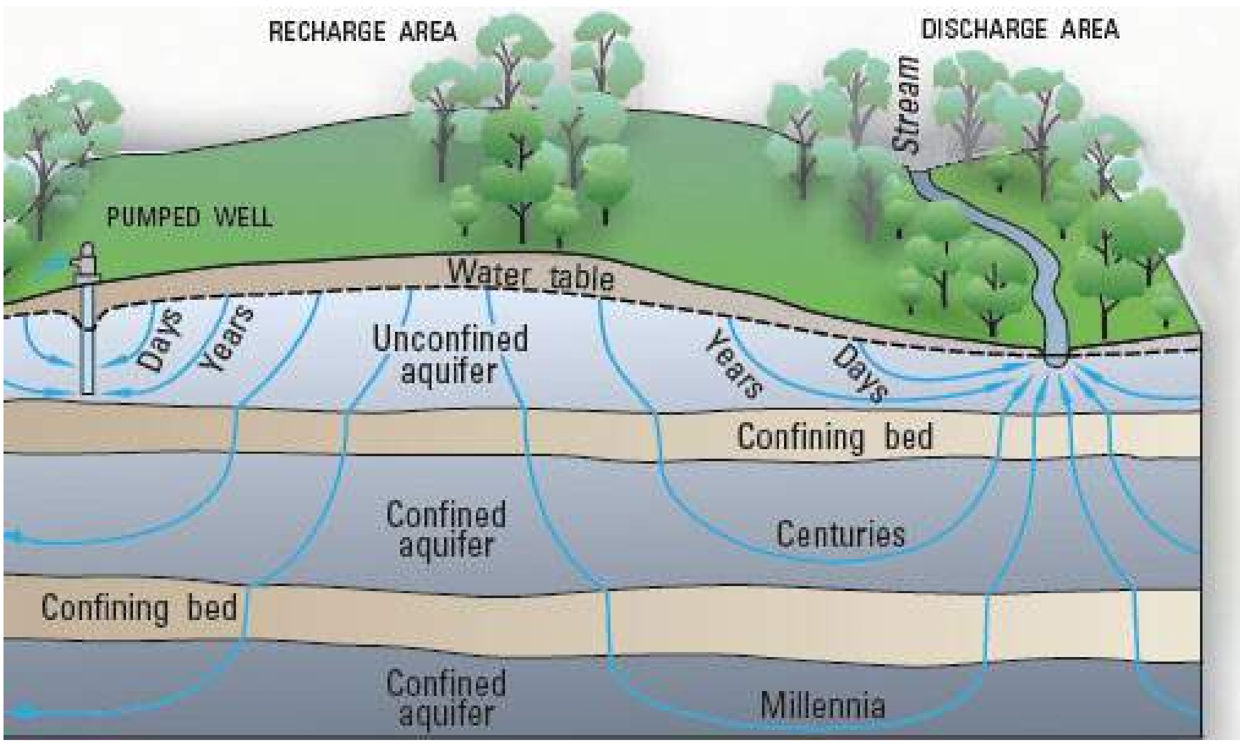
**Lesson 7; Problems with Groundwater Tapping**

When a well is placed in an aquifer, and water is drawn up from it, the water table is lowered. This lesson discusses the problems that can occur due to this. Some of these problems are: **land subsidence**, **ingress** of undesirable water, loss of other freshwater systems, harmful chemical reactions, and rendering groundwater tapping uneconomical. Land subsidence is when part of the ground surface collapses downward, often due to human temperament with the land, such as strip mining, **fracking**, or in this case, depleting the water table. Ingress is when a solute (such as salt in salt water) moves inward due to diffusion. When the water table is lowered, salt water from the ocean can move further inland, acting as a contaminant to aquifers. As lakes, rivers, and streams are also part of the water cycle, they both supply, and depend on groundwater. Lowering the water table will also have adverse effects on the rest of the water cycle. The lack of water in between minerals can start chemical reactions that create dangerous contaminants in groundwater. When the water table is too low to be tapped from with the wells, the expensive wells are taken out or simply left where they are. None of this even mentions the human and biological consequences that would take place if the water table fell. Take California, for example. It is the most populous state, but clearly cannot sustain its high population, as it is already meant to be a desert. One of the reasons it has been able to support 39 million people, is that has been using its groundwater extensively. However, California aquifers are drying up fast, and will be unusable in less than 100 years. Maybe they could switch to a large-scale nuclear power system, where they use the steam from nuclear power plants as drinking water? :|



**Lesson 7.5; Ancient Groundwater**

Back when talking about soil moisture, I didn't specify how long it takes for water to reach an aquifer. That's because it varies depending on how deep the water goes. When the ground is moist after it rains, that is technically groundwater; but as that groundwater is only a few hours old, it has not had time to collect enough water to be useful. That water will probably reach a stream in a few days, which will lead into a large river or lake. But over time, the water in lakes slowly infiltrates the ground, and become large aquifers. Sometimes they can reach under confining layers, forming huge artesian aquifers. These naturally occur over years to centuries, to even millennia and beyond, depending on the size of the body of water, and the number of confining layers. This picture explains this well:

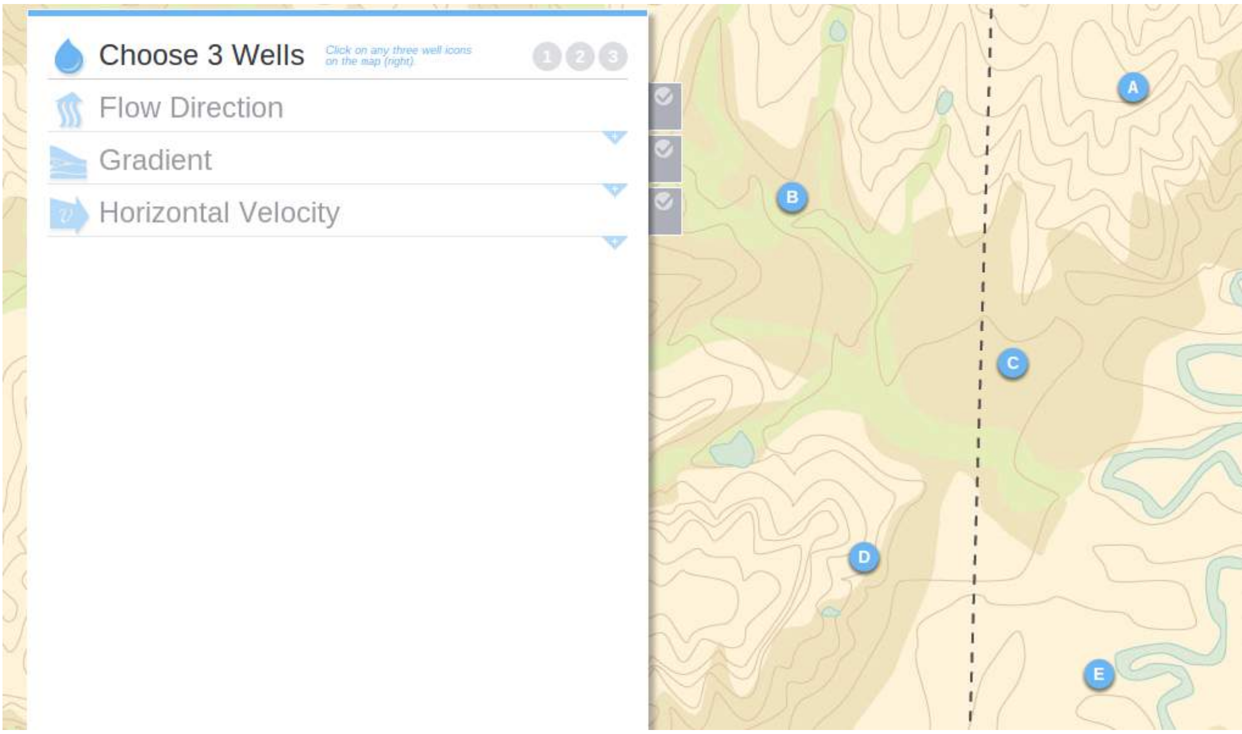



This "ancient groundwater" naturally interacts with the environment and keeps various processes stable. However, as more people require more water, we have to drill deeper in order to get more water. Now that we are tapping into aquifers that take thousands or more years to recharge, we are facing serious environmental crises.

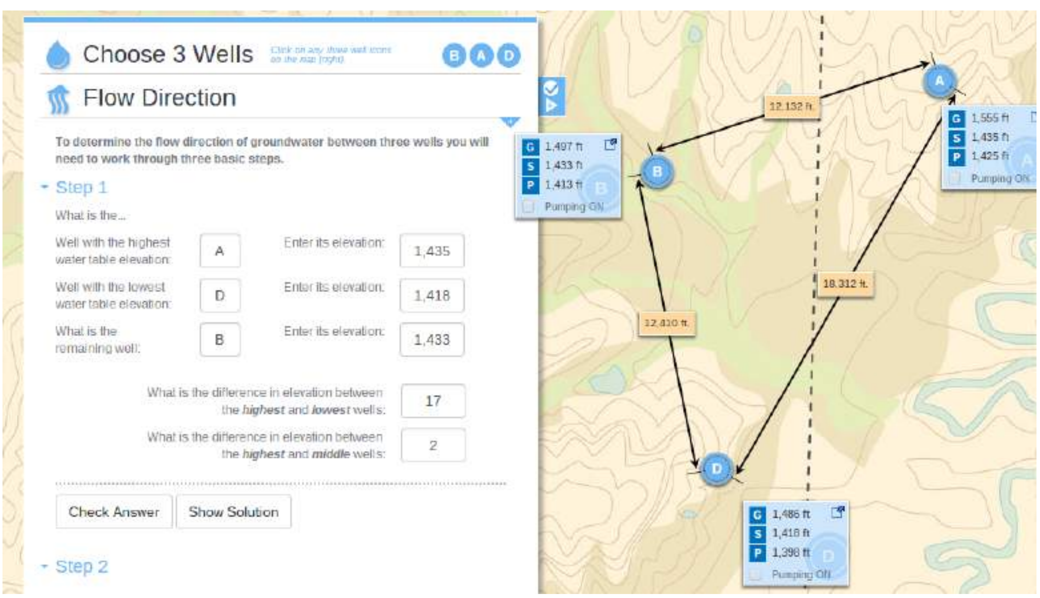
**Lesson 8; The Hydrogeology Challenge**

In this Science Olympiad event, there are three parts. A paper test part, worth 25% of the score. This part simply tests knowledge of Hydrogeology, as a science. Part two, is the Hydrogeology Challenge, also worth 25% of the score. This has you calculate the speed and direction of water in an aquifer, using Darcy's law. Part three is the Hydrogeology Challenge Scenario. This is worth the remaining 50% of the score. It takes the Hydrogeology Challenge solved earlier, adds a contamination source, and asks the competitor to create a solution to repairing the aquifer. This lesson focuses on the part two.

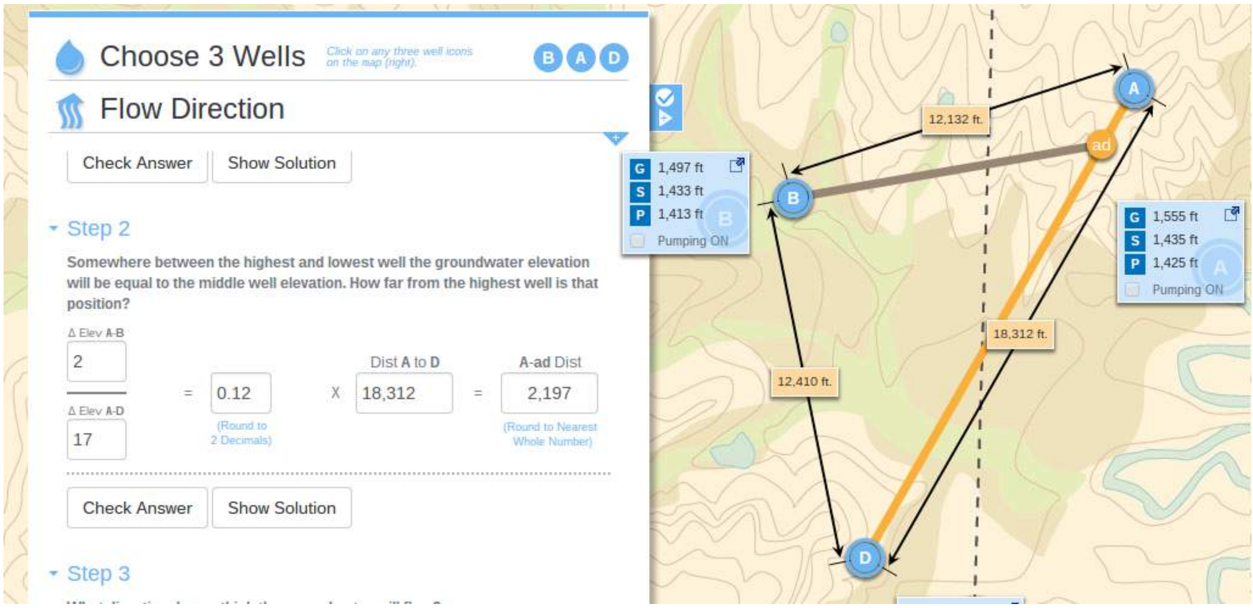
There is a practice page for the challenge at **[http://groundwater.beehere.net/#practice](http://groundwater.beehere.net/#practice).** The first task is to select three wells from which to calculate groundwater velocity.



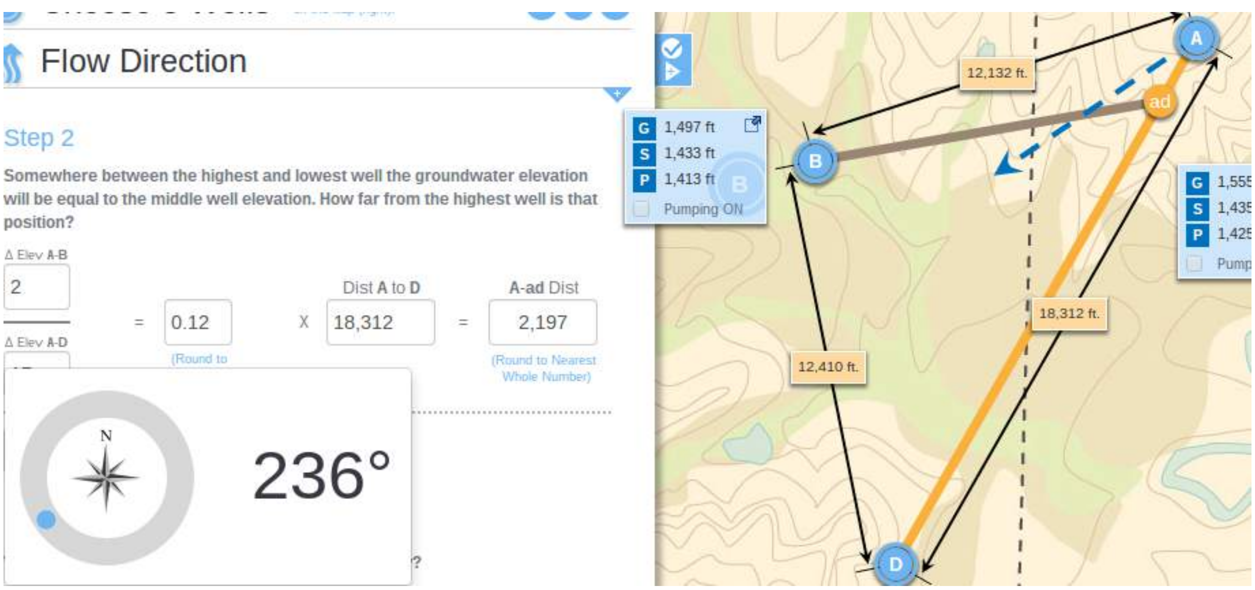

Simply click on the wells to "choose" them. You can select whether to turn pumping on or off for each well, which will change the outcome of the scenario. At the tournament, the event supervisor will give each team a link to a specific setup for the challenge, and the competitors cannot choose the wells or turn pumping on/off.



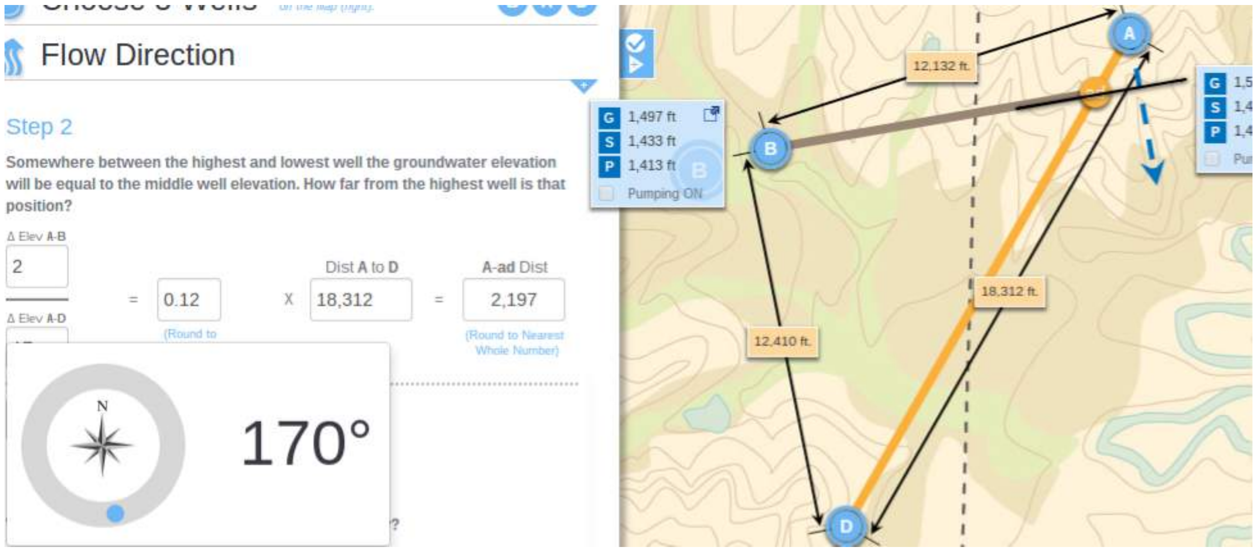
After selecting wells, it asks the competitor about the height of the water table at each of the wells, as well as the difference in height of the water table from the highest well to the other two wells. Water table height is the "S" on the table next to the well. Also on the table (but not useful, unless pumping is on) is "G" ground surface height, and "P" water table height when the well is pumping.



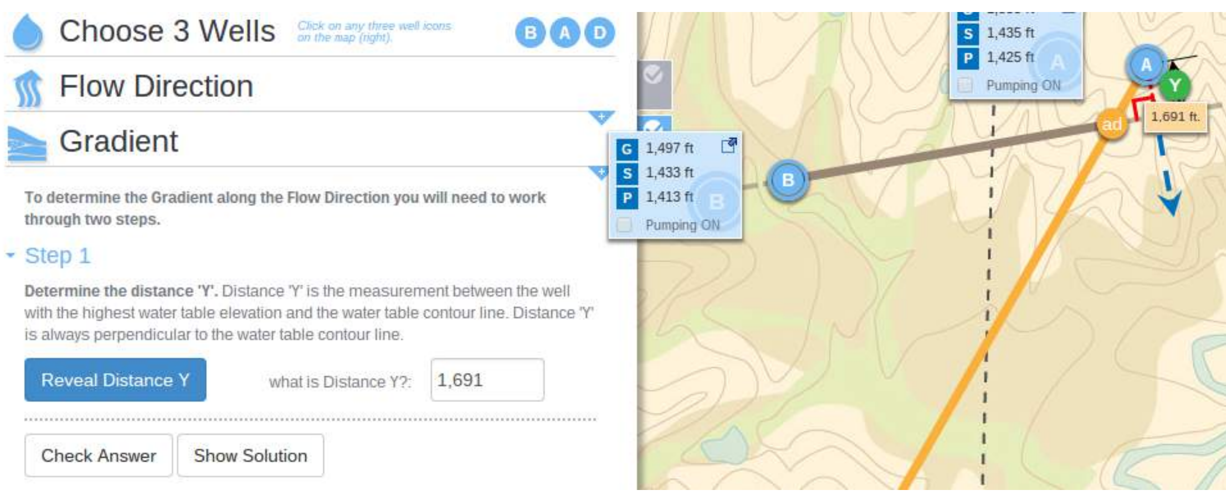

Now we put in the change in heights from the last set of problems. A calculator is permitted in this event, if the calculations get tricky. By the way, the distances between wells are in thousands of feet (the comma representing three digits looked like a decimal point to me. I still can't understand how over miles, the vertical change is only a few feet).



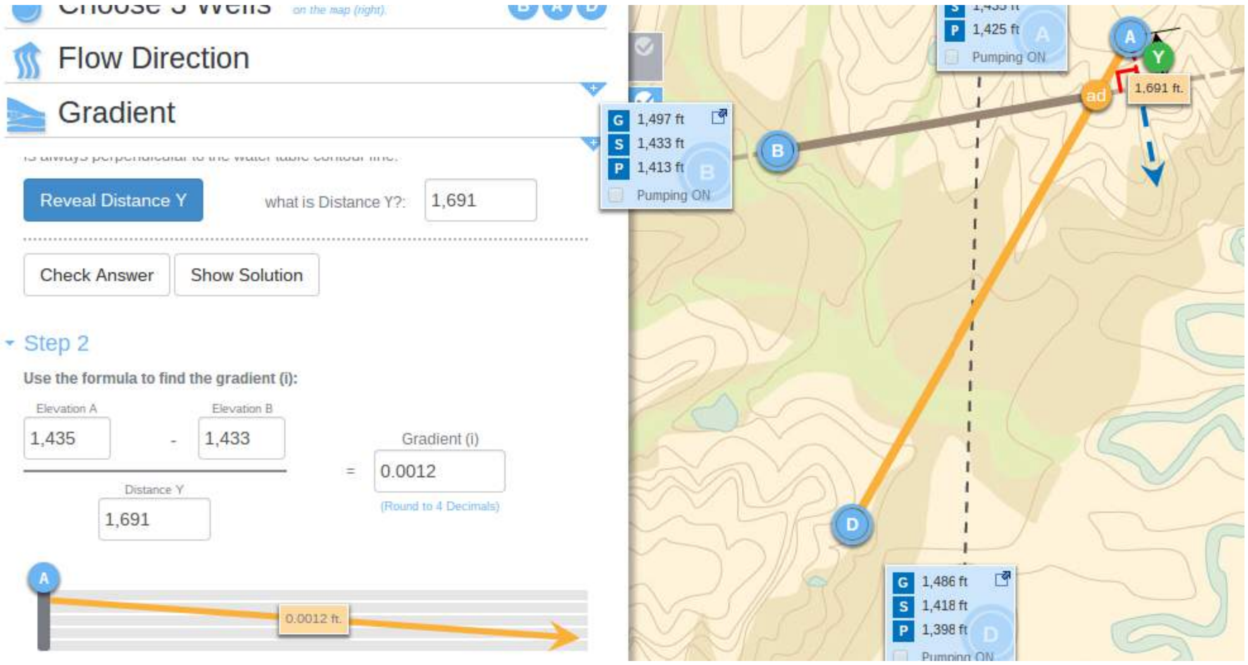
This next part is probably the hardest of the challenge (luckily, it is only worth 1 point on tests, and you can practice it). You have to determine the direction the water will flow from the highest well, as degrees from north. This angle is always perpendicular to the line between the well of medium height and the point on the line between the highest and lowest wells, at the height of the medium well (in this case, line B-AD). However, line B-AD is often not long enough to be perpendicular to the flow direction. If you take a ruler (or other straight material), you can "extend" the line, and have it be perpendicular.




The next part is a free point. It asks for the distance between point A and line B-AD on the line you just made. Do not try to solve this yourself! (I tried to solve this with trig and a protractor before reading the rules, because I was skeptical of the free point; the numbers didn't turn out right.) Simply click "Reveal Distance Y" and it will reveal distance Y.

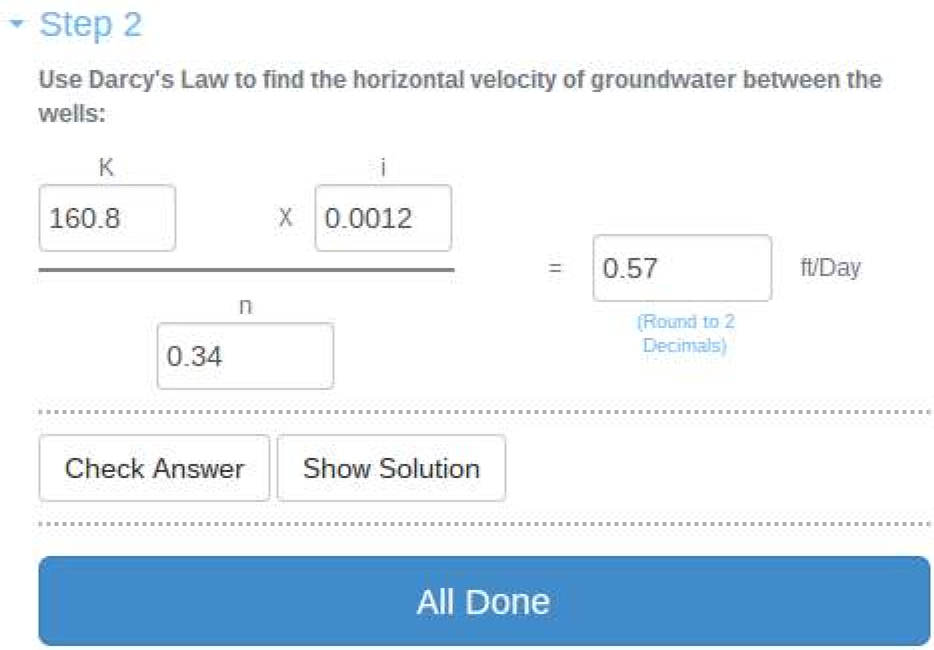


Now time to find the hydraulic gradient, i. Take the change in elevation from A to B, and divide by Y, to get the gradient.




Now we need to find the permeability and porosity of the aquifer, so that we can complete Darcy's Law. By clicking the arrow on the top-right of the table for each of the wells, you can information about the geology of the aquifer. It shows the height of geologic contacts, and the materials of each unit to a certain depth. It also shows the permeability and porosity of each unit. The Hydrogeology Challenge makes an assumption that the entire aquifer is on the unit with the highest "K" value, so find that unit (usually gravel or coarse sand and gravel), and use the permeability and porosity from there. You have to check all of the tables, because there may be a unit in one of them, but not another.

We now have all of the necessary parts of Darcy's Law, so we finish up by calculating the velocity of the aquifer. Plug the numbers into your calculator (don't forget to round), and you've finished the Hydrogeology Challenge.




**Lesson 9; Groundwater Contamination**

As groundwater consists of half the water we drink and use, it is very important that groundwater stays clean. However, this is a very hard task, because of the shear number of ways water can get dirty. For example, take a farmer, who uses fertilizers full of **nitrates** on his/her fields. The nitrates help the crops grow, but the plants don't take in all of it, leaving it in the ground. When that field is watered, the remaining nitrates will infiltrate whatever aquifer it feeds in to. If someone then places a well on that aquifer, they would need to **remediate** the water, or else we would be drinking nitrites. This is just one example, of an uncountable number of different ways contaminants can infiltrate the groundwater. Although, this way is the most common way for contaminants to enter the groundwater; where materials are used or simply exist in the environment, water picks up these materials, and the materials are transferred to the groundwater along with the water they are in.

**Lesson 9.5; Scioly Contaminants List**

**Volatile Organic Compounds**

Halogenated (All are CFCs)

<u>Carbon Tetrachloride-</u> Is a CFC. Synthesized in 1839. Was formerly used as a refrigerant, pesticide, fire extinguisher, dry cleaning agent and nearly everything that required cleaning or

cooling of a sort. Since the 80s, use has dropped dramatically, and is now mostly used in a solvent form as a cleaning agent for machinery; soaps; reducing fire hazards in grain fumigants; and in rubber cement. Its non-solvent form is still used as a catalyst in chemical factories. It can reach aquifers by spills from chemical factories, runoff from farms, wastewater from steel/iron factories, and landfill leaching.

<u>Chloroform (Trichloromethane)-</u> Used as refrigerants, soaps, pesticides, fumigant, and in paper mills. Now, it is only used in the US in exports to other countries, for use as the US formerly did. However, the main concern is its existence in drinking water. Chlorine is put into water, both ground and surface water (and pool water), in order to clean it. It was found that Chloroform is a byproduct of this use. Its sources include pulp and paper mills, wastewater, septic tanks, hazardous waste treatment sites, and sanitary landfills.

<u>Perchloroethylene(PCE) (also called PERC)-</u> It is the main ingredient used in drycleaning soap. Also used in textile mills, vapor degreasing, metal cleaning, and rubber coating. Sometimes found in soaps, aerosol, adhesives, and printer ink. It gets into the environment mainly from metal factories and dry cleaning waste.

<u>Trichloroethylene(TCE)-</u> Mainly used in metal degreasing, refrigerants, cleaning rocket engines, typewriter correction fluid, paint stripper, oils and fats, adhesives, spot removers, and formerly used as an anesthetic. It can dissolve in water with some difficulty, thus enters the groundwater supply. It is the most common organic groundwater contaminant. Leaks from industrial degreasing projects, car factories, chemical waste sites, storage tanks, pipelines, and landfills.

<u>Fluorotrichloromethane(Freon 11)-</u> Used as refrigerants, foam blowing, aerosols, and as a chemical catalyst. Was banned in 1996 for being a CFC. It is easily dissolvable in water, making it a dangerous contaminant. Leaks from illegal drug labs, landfills, and industrial solvent spills.

Non-Halogenated

<u>Acetone-</u> Is used in making fibers, paper, drugs, cleaning supplies, nail polish remover, and similar chemical products. It occurs naturally in many minerals and living organisms. It does not break down easily, so it collects in the environment where it should not. It doesn't **bind to soil**, therefore entering the groundwater very easily. It is released into the environment from production wastewater, plumbing leakage, and landfills.

<u>Methanol-</u> Acts as an intermediate for making more complex chemicals, and is also used in paint strippers, aerosols, paints, engine fuel, and windshield wiper fluid. Its use is increasing throughout the US. Dissolves extremely easily into water. Leaks in tank truck and rail cars, as well as underground storage tanks.

Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)- Found in petroleum products (diesel fuel, home-heating oil, gasoline, etc). When all four chemicals are used together, it is called BTEX. Individually, benzene is used in products such as rubber, plastics, nylon, insecticides, paints, and cigarettes. Toluene is found in paints, gums, oils, and resins. Ethylbenzene is found in paints, inks, plastics, and pesticides. Xylenes are typically used in printer ink, rubber, and leather. It can leak from underground storage, chemical waste, storage spills, and landfills. It has some difficulty dissolving in water, and binds relatively well to soil particles, so it doesn't work very well as a contaminant (but is still dangerous).

Methyl Tertiary-Butyl Ether(MTBE)- Produced in huge quantities as a fuel additive for motor gasoline and diesel. It adds oxygen to the gasoline (called an "oxygenate"), making it burn more completely. In 1990, the clean air act required a higher use of oxygenates in gasolines, thus the use of it has risen dramatically. It leaks from storage and transport tanks, oil refineries, oil spills on roads, and similar places where oil/gasoline/diesel can reach the groundwater. It dissolves very well into water, thus is a groundwater contaminant.

## Semi-Volatile Organic Compounds

### Halogenated

Pentachlorophenol(PCP)- Formerly, it was an extremely common pesticide. However, it was banned in 1987, due to adverse effects on the environment. It was used as a wood preservative and an herbicide. It could reach the groundwater from agricultural fields.

Polychlorinated Biphenyls (PCBs)- Was banned in 1979. Before it was banned, it was used in lubricants, coolants, capacitors and transistors, motor oil, electrical insulation, caulk and other finishes, and thermal insulation.

### Non-Halogenated

Polycyclic Aromatic Hydrocarbons(PAHs)- A family of chemicals made both in nature and synthetically. They are made when burning fossil fuels, as well as burning similar organic compounds. They do not burn or dissolve easily, which lets them stay in the environment for a very long time. PAHs are used in research, pesticides, dyes, plastics, and medicines. It dissolves very easily into air, not so much into water. It leaks from cars, coal/oil energy, and other fossil fuel burning operations.

Pesticides- Herbicides and insecticides used in farming to keep unwanted living organisms out of the crops. They often dissolve well into water and do not bind to the soil. Pesticides reach the groundwater directly from farms and forests.

## Petroleum Byproducts

Creosote- It is used to preserve commercial structures made from wood, most often railroad ties; acting as a pesticide, keeping the wood from being eaten. It is made from highly distilled coal tar at a very high temperature. Enters into the ground by runoff from railroads, landfill, and from utility poles.

Coal Tar- Coal tar is a byproduct of burning coal, and is a viscous liquid. It is used as a sealant for roads and other asphalt surfaces. Many cities and states have banned its use as a sealant. The sealant also often contains PAHs. As it is used on roads, it has many surfaces from which it can enter the groundwater.

Crude Oil- Genuine oil, both refined and unrefined. The fossil fuel all 'muricans know and love. It leaks from oil spills while mining, transporting, refining, distributing, and/or storing said oil. It is stored both above and below ground.

Diesel- A form of petroleum fuel. Used in automobiles. Is much more oxygenated than gasoline. Enters the groundwater system through roads, leaks, etc.

Gasoline- Petroleum fuel, used in automobile engines. Leaks the same ways as all of the other petroleum contaminants.

BTEX- The same chemicals described above. I guess I could just copy/paste the description...

MTBE- Same situation as BTEX.

## Inorganics

### Metals

Cadmium- A soft metal that has recently begun widespread use all over the world. Its main uses are in batteries, metal plating, lasers, paints, and monitor color lights. It is very toxic to many living organisms. Leaks into the ground from natural ores, metal refineries, waste treatment and wastewater, pipe corrosion, and landfills.

Lead- The soft, toxic metal used in buildings, paints, bullets, roofing materials, pipes, radiation shields, and many other things that would be way too much if I listed them all. It can reach the water cycle from ore erosion, pipe decay, landfills, electronic recycling plants, and many other sources.

Nickel- Magnetic metal used in wiring, stainless steel, corrosion-resistant plating, rechargeable batteries, coins, and guitar strings. Is mainly used in alloy forms. Erosion from ore deposits, mining, refinery, and storage, and landfills are the main ways it gets into the groundwater.
Copper- The metal used in almost every single electrical wire ever. It is also used in pesticides, architecture, electric motors, plating, piping, and wood preservatives. It can enter the ground through mining, farming, ore erosion, manufacturing, pipe corrosion, and wastewater.

Chromium- A strong, highly reflective metal, used in mirrors, chrome plating, stainless steels, pigments and paints, lasers, synthetic rubies, leather tanning, and wood preservatives. It can leak from mining and refining, wastewaters, landfills, and natural deposit erosion.

Iron- The most common element on earth, as well as the metal most used by humans, in all of history. Thus, I can list its most common uses: making steels, plating, architecture, radiation shields, vehicles, tools, and many, many other things. It reaches the groundwater from any of the above things rusting/ improperly disposed of, landfills, and natural deposits.

Aluminium- Second most used metal in the modern world. Used in manufacturing, automation, genuine metal items, plating, water treatment, and other uses. It reaches the groundwater by wastewater, mining and refining, water treatment spills, landfills, and natural deposits.

Radionuclides

Radium- An extremely radioactive and toxic metal. It used to be used for luminous paints, cancer treatment, and as an additive in toothpaste in the early 20th century, but its use is now banned. Thus, it can only reach the groundwater from erosion of natural deposits.

Radon- A radioactive gas created by the breakdown of radium. It was formerly used as cancer treatment, and in scientific research, but is now rarely used. It enters the groundwater from radim deposits.

Uranium- A radioactive metal used in nuclear weapons, fission reactors, cancer treatment and research, as well as other scientific research. It reaches the groundwater through natural deposits, mining and refining, occasionally from nuclear reactors overheating or spills.

Other Inorganics

Arsenic- A metal that is highly toxic. It is commonly used in wood preservatives, pesticides, chicken feed, lead alloys for car batteries, chemical weapons, and strengthening lead and copper materials. It can reach the groundwater from landfills, agriculture, natural deposits, and mining.

Nitrate- $NO_3$, a necessary and essential nutrient in plants and animals, synthesized by nitrifying bacteria. Humans use it mainly in the forms of ammonia, sodium, potassium, and calcium salts.

It is used mainly in fertilizers, but also in oxidizing agents, like in gunpowder, and occasionally in meat curing agents. Also exists as a waste product of animals (it's in feces). It reaches the groundwater from agriculture, industrial agriculture production, fertilizer storage, sewage, and septic tanks.

<u>Chloride Salts-</u> A set of salts that include chlorine. They dissolve very well into water, making them a large problem in both surface and groundwater. Humans use them as table salts, road ice removers, and fertilizers. Thus they reach the groundwater from natural deposits, mines, roads, landfills, and human/animal wastes.

**Explosives**

<u>2, 4, 6-trinitrotoluene(TNT)-</u> Formerly used as an explosive, this purpose mainly served as a weapon. It is made by combining toluene (listed above) with nitrates (also listed above), to make a highly-explosive solid. It was the weapon of choice for bombs during WWI and WWII, but soon after was replaced by more destructive weaponry. Its use was completely banned in 1980, for adverse effects on the environment. In the past, it could infiltrate the groundwater by military ammunition storage leaks.

<u>Hexahydro- 1, 3, 5 -triazine(RDX)-</u> A highly explosive solid first used in WWII. It was easier to make, and more explosive than TNT. It is rarely used today. It can leak from active and former military installments, and ammunition depots.

**Pathogens**

<u>*E. coli*-</u> *Escherichia coli*, A gram-negative rod-shaped bacterium, with many harmless strains, as well as some strains that can cause food poisoning. It is the most researched bacterial species. It can reach groundwater through human and animal waste and naturally occurring populations, where, if left untreated, could start an *E. coli* outbreak.

<u>DNAPL</u>- Carbon Tetrachloride, Chloroform, PCE, TCE, Freon 11, PCP, PCBs, Creosote, Coal Tar, and Crude Oil.
<u>LNAPL</u>- BTEX, Crude Oil, Diesel, and Gasoline.

A DNAPL is a Dense Non-Aqueous Phase Liquid. This means that it does not dissolve very well into water, and is denser than water.
A LNAPL is a Light Non-Aqueous Phase Liquid. This means that it does not dissolve readily in water, and is less dense than water.

**Lesson 10; Remediation Techniques**

For obvious reasons, it would be extremely unsafe to ignore the contaminants we put in groundwater, and just leave them in when they are pumped into the water supply (aren't CFC's tasty?). Thus, we must keep the groundwater clean, both for the humans using it and for the environment. There are many ways to clean the groundwater. The different techniques used are **in-situ** and **ex-situ**. In-situ (latin for “in place”) cleanup is done by humans treating the groundwater directly under the ground. Ex-situ (Latin- “out of place”) cleanup is done by pumping the groundwater to the surface, then treating it, to be put into the drinking/human usage water system. The main types of remediation are: mechanical, thermal, chemical, and biological. Mechanical methods involve things such as evaporating liquids to gases, to leave behind contaminants; “washing” by pushing high pressure water, air, or dissolving solvent into soil, which will then push away unwanted particles; or simply natural processes, such as diluting the contaminants naturally and evaporating (leaves behind non-evaporated materials). Thermal remediation normally involves simply putting the water at a high-enough temperature to burn the contaminants. Chemical remediation is done usually by putting highly acidic or basic substance through the water, which will then dissolve the contaminants (but the chemicals must be cleaned out then). Biological remediation (bioremediation) uses microorganisms (or plants, in phytoremediation) to break down the contaminants by creating favorable conditions for them, so they can eat the contaminants. One of the main problems with remediation is its cost. All of the following remediation techniques have differ in costs, which contaminants they dissolve, and whether they are in-situ or ex-situ. Many of these treatment techniques are used in cooperation; multiple techniques are used together to clean the water.

Pump and Treat- Ex-situ. It can treat water for any of the contaminants, because it is always used with another form of remediation. This is simply where the water is pumped above ground, in order to be remediated there. Doing this allows for more control with remediation; however, it is much more expensive than not pumping in the first place.
Activated Carbon Treatment- Ex-situ. Treats water for SVOCs and explosives. Physical remediation. Activated carbon is a material that is made to be able to “stick” to nearly any chemical, because of an incredibly high surface area. Thus, the contaminants particles stick to the active carbon, which can then be easily removed. However, because active carbon is an expensive material, and it is off-site, this process is expensive.
Air Sparging- In-situ. Treats water for VOCs. Physical remediation. This process involves putting air into the groundwater; the contaminants in the groundwater will then evaporate into the air, which leaves the water clean. If the aquifer has low permeability, or is confined, it does not work. It is of low expense, because it simply requires air, and the tools needed to inject the air, and remove the contaminants.
Air Stripping- Ex-situ. Treats water for VOCs. Physical remediation. It is very similar to Air Sparging; it pushes air through the water to evaporate the contaminants. However, air stripping is done above ground, rather than doing it below ground. This way, it can be more easily controlled, but it makes treatment much more expensive.
Bioremediation- In-situ or ex-situ. Treats water for oil and petroleum. Biological remediation (shocking, isn’t it?). It involves creating a population of microorganisms (protists, bacteria, archaea) inside of the contaminated water, and keeping the water at favorable conditions for the organisms. The organisms will then eat the petroleum, making the water clean. This is a low-cost project, unless it is pumped off-site, then it is expensive.

Chemical-Reduction/Oxidation- In-situ or ex-situ. Chemical remediation. Uses chemical reduction to make the contaminants less toxic/dangerous. Sometimes a “zone” of oxidizing chemicals is created within the aquifer; the contaminated water then flows through the zone, which will pick up, or make less harmful the contaminants. This works on metals, radionuclides, explosives, and other inorganics (arsenic, nitrate, and chloride salt). It is very expensive, both with in-situ and ex-situ.

Hydrofracturing- In-situ. It is a preparation technique for other kinds of remediation. It uses high-pressured water to create fractures in the aquifer, to create more space for other remediation techniques to do their thing. This is done to make other kinds of remediation more effective and cheaper; hydrofracturing itself is very cheap.

Incineration- Ex-situ. Thermal remediation. This process is simply where the contaminated water is exposed to heat hot enough to burn the contaminants. Since water takes a lot of energy to heat up, this is less expensive than simply evaporating all of the water. Although, since it is ex-situ, it is already very expensive. It removes explosives, PCBs, dioxins, and chlorinated hydrocarbons.

Monitored Natural Attenuation(MNA)- In-situ. It is its own kind of remediation, but could probably be put in the chemical or physical categories. MNA involves putting a special “remedy” (I couldn’t find the remedies’ components online) into contaminated groundwater. The remedy, along with time, break down the contaminants. This process is low-cost, and is effective on VOCs and SVOCs and petroleum products.

Permeable Reactive Barriers(PRB)- In-situ. Biological and/or chemical remediation. PRB involves creating a “zone” of chemicals (or microbes) that break down the contaminants when the water flows through the zone. This is often used with another form of remediation, such as active carbon or chemical reduction. This technique in normally of low expense, and works on VOCs, SVOCs, and petroleum.

Phytoremediation- In-situ. Biological remediation. This remediation technique involves putting in plants to take in the contaminants. Plants chosen for this are normally ones that can easily acclimate (or can already live in the environment that needs cleanup), deep roots, can break or intake the contaminants, and takes in a large amount of water. If the plant has large enough roots, this can even work on confined aquifers. The cost for this is usually low, but it takes a long time. This can work on metals, oils, pesticides, and explosives.

Reverse Osmosis- In-situ or ex-situ. Physical and chemical remediation. Does not use a lipid bilayer for the semipermeable membrane :( . It normally uses a mesh-like net (ex-situ) or a chemical wall (in-situ) to let only water through (or let everything else go through, and water takes a different path). This works basically all contaminants, other than dissolved gases. However, it can be very expensive, although very effective.

Thermal Treatment- In-situ. Thermal remediation, however it requires another form of remediation to work properly. It uses heat to move the undesired chemicals into wells, where they can then be treated with other forms of remediation. This works on all of the contaminants except for radionuclides, “other” inorganics, explosives, pathogens, and metals. It is very expensive though.

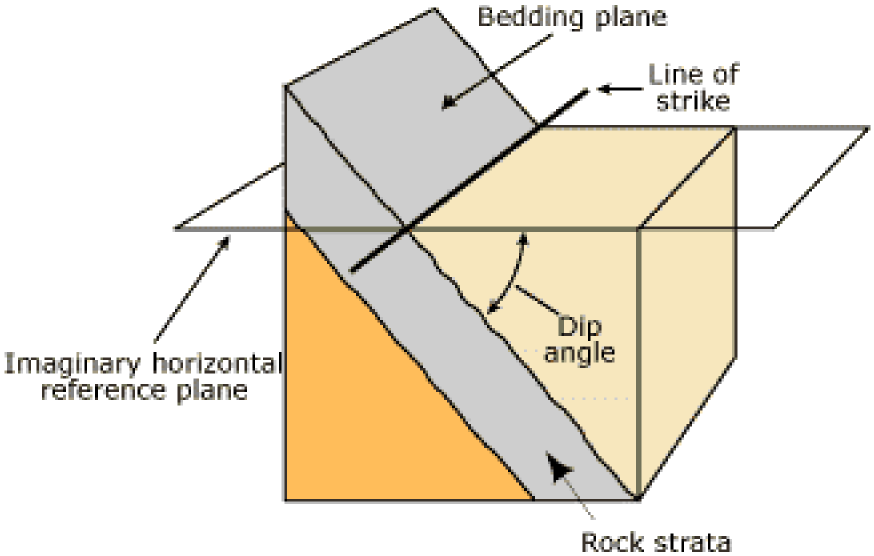
Vertically Engineered Barriers(VEB)- In-situ. It can only contain the contaminated water, and is sometimes used with other remediation techniques. This technique is exactly like the name suggests; physical barriers are made so that the contaminated water cannot pass them. Thus, the contaminants are stuck, and can be kept out of the way, or remediated. This works on all forms of contaminants, but is generally only used on the most dangerous and threatening ones, because it is somewhat expensive, and is not effective in destroying the contaminants.

**Lesson G; Intro to Geology**

I probably should have put this at the beginning when I started this, but I forgot, and if I did so now it would ruin the alignment with pictures.
A basic understanding of geology is required to understand how water reacts with geologic matter and systems. Thus, I will write information on basic geology terms.

Magnitudes of stratigraphic units- A **stratum**, (or strata, for plural) is a single layer of rock or soil, however the term bed, meaning a layer or multiple layers is both more common and useful for this term. **Bedding** refers to processes and properties related to rock/soil layers. **Formations** or units (they are the same term) refer to rocks/soils in the same area and have the same or very similar composition. A **member** is under a formation; it is a compositionally distinct part of a formation. A **group** is a collection of two or more formations that have similar **lithological** properties. A **supergroup** is an aggregate of multiple groups that have similar characteristics.

3d geometry of beds- Beds have orientations that make up some of their characteristics within three dimensions. Two important orientations are **strike and dip**. There are two important properties of dip: its direction and its angle. Dip is basically the slope of the bed; the azimuthal direction the bed slopes down the most is the dip direction; the angle of the slope in this direction is the dip angle. Strike is the azimuthal direction that the bed **trends**, the way it is “pointing”. This is measured 90 degrees in either direction from the dip direction.




**Three point problems**- Three point problems are a common type of problem in geology. The purpose of the Hydrogeology Challenge is a three point problem. The three point problem is a problem where you are given three points, their positions, and their heights, and you must find the dip direction and angle. I explained how to do it in the Hydrogeology Challenge program, but in case you need to solve one without the program (or need a better understanding of the program), here it is. The first step is to draw a line in between the point of highest elevation, and the point of lowest elevation. Next, find the difference of elevation between the point of highest and lowest elevation, as well as the height difference between the highest and medium elevation. Divide the lower number by the higher number, and multiply that decimal by the distance from the point of highest elevation to the point of lowest elevation. Take this number, and measure that distance along the line you drew at the beginning, starting from the point of highest elevation. This new point just made, is the same elevation as the point of middle elevation at the beginning, but is on the same line as the first two points. Now, we can find the dip direction. Take the "new point" (let's call it point X) and draw a line between X and the point of middle elevation. This line is the slope line. Since dip is perpendicular to slope, extend the slope line in both directions, and use a protractor to measure 90 degrees from it, and draw dip lines in regular intervals across the work paper; measure the angle between the dip direction and north, to get the azimuthal dip direction. Make sure to draw a dip line that intercepts with the point of highest elevation. Next, measure the distance of this line between the point of highest elevation and the strike line; this is distance Y. Last step; take the elevation of the highest point and subtract it from the elevation of point X. Take that distance divided by distance Y, and that is the dip angle!

Geological laws- There are four major laws in geology: the law of superposition, the law of original horizontality, the law of lateral continuity, and the law of cross-cutting relationships. The law of superposition states that the strata on the bottom of a unit are the oldest, and the strata on the top of the unit are the youngest; unless the bed has been overturned, then the ages are measured from its original orientation. The law of original horizontality states that strata are originally made from the bottom up, thus the ones on the bottom are the oldest. The law of lateral continuity states that each layer of rock goes on in all directions, unless it reaches a point of which its thickness is zero. The law of cross-cutting relationships states that geologic events that cut across existing rock are younger than the rock that it affects.

***The Grand Glossary of Terms***

| Term | Description |
|---|---|
| Groundwater | Water that exists under the ground surface, most commonly in aquifers, aquitards, capillary fringe, etc. |
| Water table | “Line” that separates the saturated zone and the vadose zone. |
| Saturated zone | Area of the ground filled with water, either in aquifers or aquitards. Is below the water table. |
| Vadose zone | Area of the ground not filled with water. Is above water table. |
| Aquifer | Unit of rock or soil that can easily take in and release water. |
| Aquitard | Unit of rock or soil that can easily take in water, but cannot release it easily. |
| Aquiclude | Unit of rock or soil that cannot take in any water; it is not permeable. |
| Capillary fringe | Area that is in the vadose zone, but contains water. The water is held in capillary, so is not very useful. |
| Capillary action | A property of liquids that let them move up narrow spaces on their own (without external forces). |
| Runoff | Water flowing on the surface due to a collection of water during or after precipitation. |
| Percolation | The action of water moving through a solid substance; in this case a strata of rock and soil to a groundwater source. |
| Soil moisture | Water held in the pore spaces of a soil or rock unit. It may or may not be able to move under the influence of gravity. |
| Infiltration | The act of water moving from the surface, through the ground, to an underwater storage unit. |
| Groundwater potential | The measurement of how effective an underground water unit is. |

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|---|---|
| Homogeneity | A property of substances; how similar is the particle size and make-up of the substance. |
| Recharge | Refilling of an aquifer through the water cycle. |
| Darcy's law | Law in hydrology stating that velocity is equal to permeability times hydraulic gradient over porosity. |
| Hydraulic gradient | Total slope of a measured area. |
| Head loss | Change of height in a measured area |
| Permeability | The speed at which fluids, water in this case, can move through a substance. |
| Porosity | Ratio of void space to total volume of a substance. Is always between 0 and 1. |
| Void space | Volume of a substance that can be filled with a fluid (particularly water). |
| Velocity | Speed at which water moves through an aquifer in a measured area. |
| Apparent velocity | Same as velocity, except it does not account for turns in the aquifer's path. |
| Henry Darcy | French hydrologist in the 19th century, made fundamental discoveries including Darcy's law. |
| Confined aquifer | An aquifer sandwiched in between two confining layers (aquitards and aquicludes). These aquifers take longer to recharge, and are at a higher pressure than unconfined aquifers. |
| Unconfined aquifer | An aquifer with no upper confining layer. Water table is usually at ground surface, and water is at atmospheric pressure. |
| Artesian well | A well drilling into a confined aquifer. Certain fancy water bottle companies claim their water comes from artesian wells to make it seem more "natural" when really it hurts the environment more. |
| Specific yield | The percentage of groundwater that can be removed from an aquifer. |
| Safe yield | The annual amount of groundwater that can safely be tapped from an aquifer. |
| Land subsidence | When the ground surface moves down relative to the surrounding ground. Usually due to human intervention. In hydrogeology, this happens because when the groundwater is no longer in the rocks, it cannot keep the rocks balanced, thus the rocks fall down. |

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|---|---|
| Ingress | The dissolving of one mineral throughout another mineral, through geologic processes. |
| Fracking | A special kind of mining, in which high pressure water and sand are shot at rocks containing natural gas deep underground. The water, sand, and gas can become contaminants in groundwater (and the mining itself can destabilize the land). |
| Nitrate | NO3. A naturally occurring chemical important for the nitrogen cycle. Fertilizers use high amounts of nitrates, which commonly enter the groundwater supply. |
| Remediation | The process of removing unwanted materials from groundwater. |
| Soil binding | A factor determining whether a pollutant can infiltrate groundwater or not. If it binds easily to the soil, then it does not travel with the groundwater, and therefore does not become a dangerous contaminant. |
| In-situ | On-site. An operation of some sort done to something in its natural environment. (In this case groundwater) |
| Ex-situ | Off-site. An operation of some sort done to something out of its natural environment. |
| Stratum/Strata | A single or multiple layers of rock or soil. |
| Bedding | Processes and properties of rock/soil layers. |
| Formation | Area of rock/soil with the same or very similar lithological properties. |
| Member | A section of a formation with the same lithological properties. |
| Group | Multiple formations with similar lithological characteristics. |
| Supergroup | Multiple groups with similar lithological characteristics. |
| Lithological | Properties of rock and soil; such as hardness, luster, streak, permeability, porosity, etc. |
| Three point problem | Problem in which a “geologist” must solve for the dip direction and angle. |