EPSC 201 LECTURE 17 MARCH 22 2016

Hydrogeology – ground water

A brief history of hydrogeology

Where does the water in rivers come from? OR why do the oceans not fill up and the rivers go dry?

Biblical hydrogeology: All stream flow into the sea, yet the sea is never full. To the place the streams come from, there they return again. –Ecclesiastes 1:7 (NIV)

Rainfall? "You may be quite sure that it is not mere rainwater that is carried down in our greatest rivers… Rains cannot produce, they can only enlarge and quicken a river" –Seneca (3 BC-65 AD)

The Answer… Underground rivers bring ocean water inland, starting surface rivers as springs. There are underground rivers and they would bring water inland from the oceans. If we get whirlpools that form in the ocean, water is draining into the ocean floor, and is going down into subterranean rivers and then there are springs in mountain tops, which then forms rivers going downhill. BUT how does the water go up in the mountain? We need an uplift mechanism….

<u>Uplift mechanism</u>

How do we raise water to high elevations?

- Ristoro d'Arezzo (1282) – "virtue of the heavens", that attract water. God is so powerful that he can draw the water upwards – anti gravity system involving divine power.
- Gregory Reisch (1504) – "vapors are drawn up from the earth and condensed", a sort of quasi capillary theory, like with a straw… However this only works 1 m at most given the best conditions
- Joachim Becker (1635-1682) – the great fire in the earth's center vaporized water. As you go deeper into the Earth, it gets hotter (geothermal gradient). This heat is boiling the underground water. Steam rises up inside hollow mountains and then condenses. The condensed water does not have salt in it.
  -Bonus effect – condensed water is pure,
  distilled by boiling process

Pierre Perrault (1668-1670) actually made some measurements and collected data.
-Network of rain gauges and discharge from the River Seine
-He measured that there was on average 60 million m^3 of precipitation over the river and that the river discharges 10 million m^3 of water. This indicated that there was more precipitation then discharge…

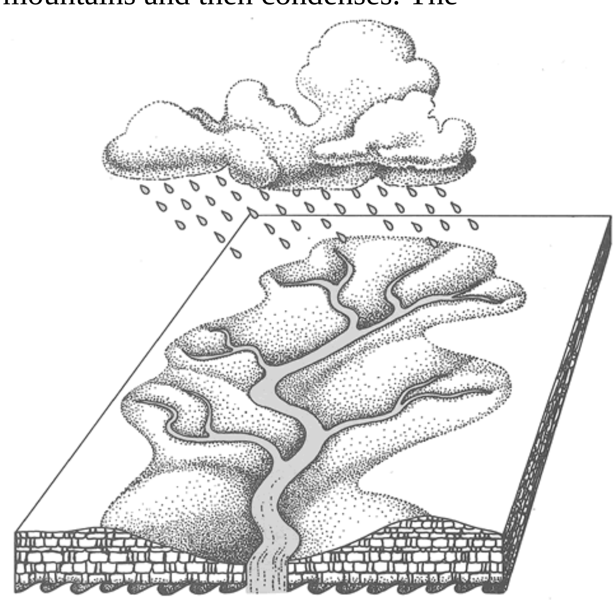


Diagram of a watershed showing the drainage pattern

Henry Darcy – Darcy's Law – developed experimentally in 1855-1856.
Discharge of water is dependent on hydraulic gradient and permeability, Q=KiA

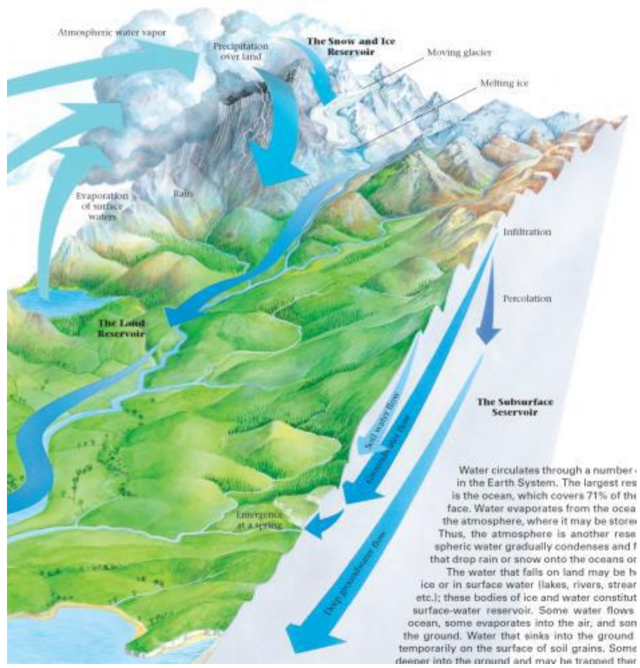
Modern Hydrology: field measurements (drill wells), groundwater modeling (complex numerical methods to understand how water moves in the subsurface), chemistry (water chemistry)

What is groundwater? Any water that is in the ground.

Water (H_2O) in porous earth materials (pores are holes). Examples: Saturated mineral soil, unsaturated mineral soil, peat, Perrier water, seawater in sediments, disgusting oil-field brine.

Groundwater occurs wherever there are pores (space in the ground where water can be put into): in desert soil, in shallow rock, in deep rock, at the crustal-mantle boundary, in seafloor sediments, in volcanoes.

What is hydrogeology? The study of the occurrence and movement of groundwater. Basically, where is there water in the ground. Water in the ground can actually move and it is basically understanding why and how that water is moving.



The Hydrologic Cycle

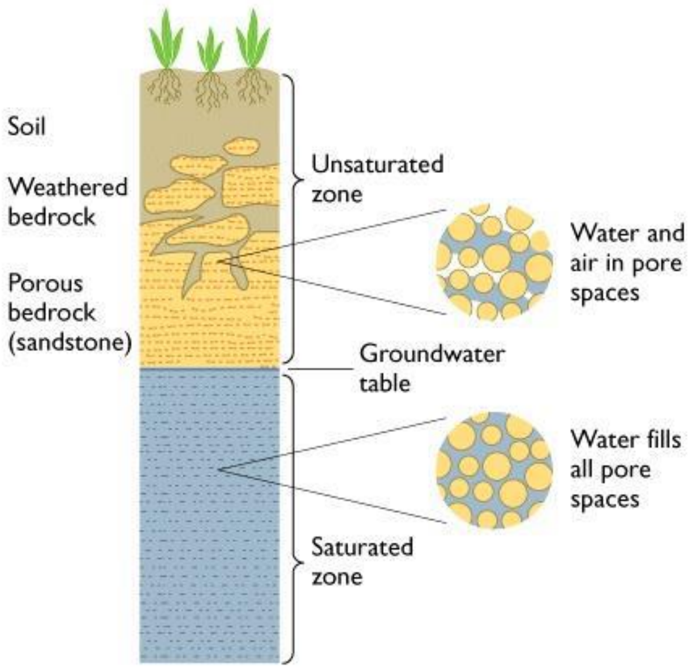
Groundwater is a component of the hydrologic cycle.

- Evaporation
- Transpiration
- Precipitations
- Infiltration
- Runoff

70% of the Earth's surface is covered by the ocean. Ocean water evaporates. Water is going up into the air. Water condenses and comes back down as rain (precipitation). Some of the precipitation falls over the continents (land surface). When rain water lands on the land surface, it can end up in lakes, rivers, land surface. On the land surface, it can go over the land surface or in the shallow subsurface, or it can flow down to rivers and streams. Precipitation adds water to our rivers and may cause flooding… Some of the water can percolate into the ground and become ground water. All this water eventually flows back into the oceans and repeats.

4 key things to know about hydrogeology

1. What is the water table?



The saturated zone has 2 things: soil or rock and water. It is saturated with water (completely filled with water).

Unsaturated zone has 3 things: soil grains or rock grains, water, and air. So it is not completely saturated with water.

The boundary between the saturated and unsaturated zone is called the ground water table or water table.

How thick is the water table? It has no thickness, it is a line/boundary. It is a "marker"…. Trick question.

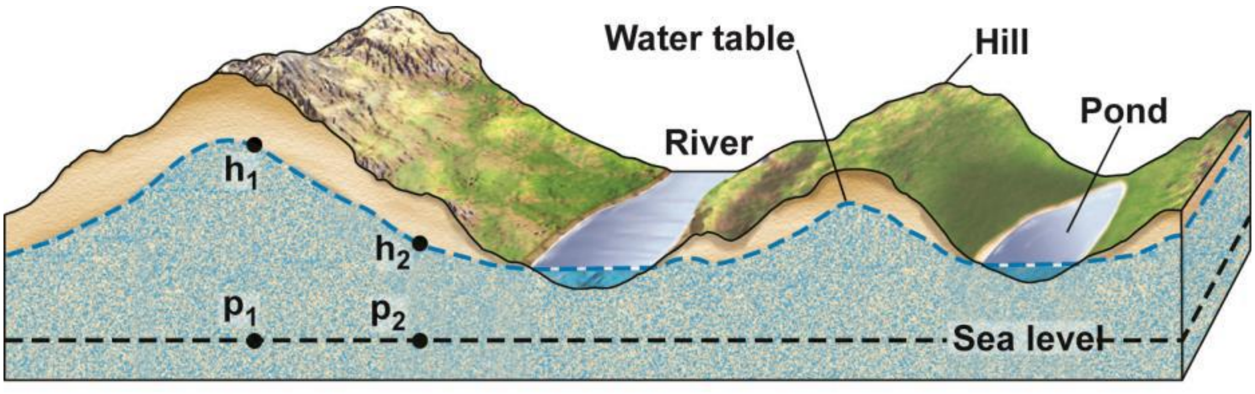
Water table topography

The water table is the boundary between the unsaturated and saturated zone.

The water table is not flat; it is a sloping surface.

The water table is a subdued replica of the topography.

- The water table is high where the land is high
- The water is low where the land is low



The water table usually follows what the topography is doing… dotted line is the water table. Everything below the water table is saturated (no air, only water).

2. Porosity is where water is stored.

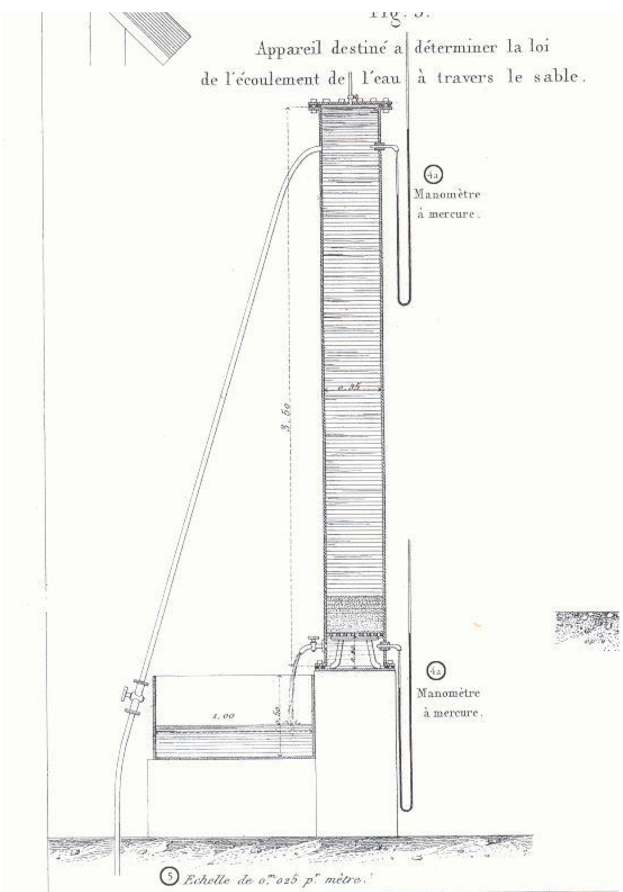
Imagine we have a beaker filled with gravel or sand and we turn on the tap and fill the beaker with water. All the space where the water goes is our porosity – where there are pores basically. Pores are holes/spaces between the rocks.

$$\frac{Volume\ of\ pores}{Volume\ of\ rock} = Porosity$$

Different conditions control the porosity

- if you have big grains or small grains, well-sorted vs. poorly-sorted sandstone → Small pores vs. big pores.
- Unfractured vs. fractured shale – layered rock (difficult for water to move through but there can be a fair amount of pores)
  -Very small amounts of pore space between clays and silt grains
  -Small amounts of pore space along cracks

3. Groundwater can move – Below the groundwater table, the ground is saturated, the water that is there can actually move. Groundwater can go from one place to another place.



Henry Darcy

- Birth 1803, died 1858
- Built completely enclosed, pressurized water distribution system for Dijon, France (fountain system)
- Chief director for Water and Pavements in Paris
- Darcy's Law – 1855/6
- Died of pneumonia

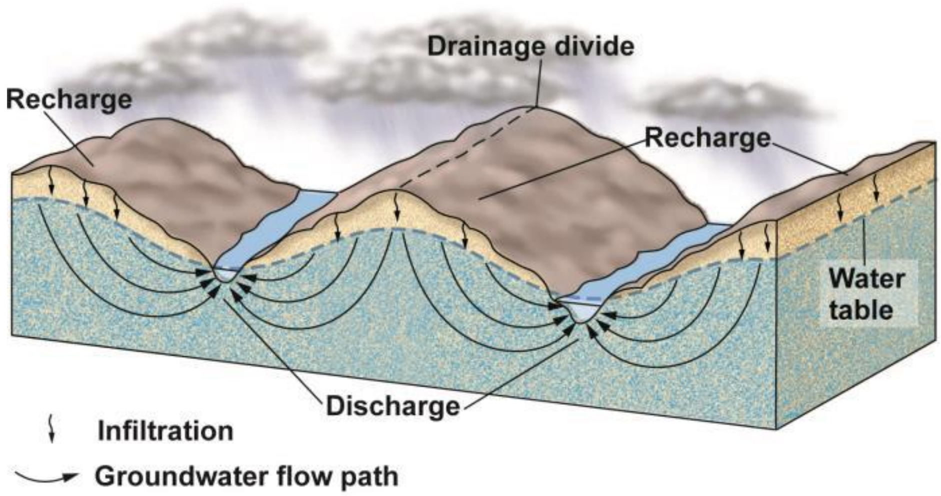
The Darcy Experiment: He had a giant tube which he filled with sand or gravel. Then he would add water which would flow through this tube. He could basically look at how much water could go through this tube and what controls how fast water goes through the tube - What is the pressure, the materials, etc?

Darcy's Law: Q=KiA
Q = discharge of water
K = Hydraulic Conductivity (permeability)
i = Hydraulic gradient (factors causing water to move, difference in pressure, elevation, etc)
A = cross sectional area (size of place)

Darcy figured out what controls how much water flows through the subsurface. We can actually measure "i" due to pressure or gravity. "K" is more difficult to measure – how readily can water flow through the subsurface. Say we went from gravel to granite, K can range from many orders of magnitude. Error bars in these types of analyses are in orders of magnitude…

Groundwater Flow

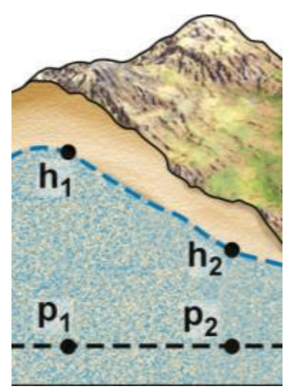
- Groundwater flows slowly
- Flow in the unsaturated zone flow is straight downward – percolates downwards until it reaches the water surface
- In the saturated zone, flow is more complicated – governed by gravity (from high elevation to lower elevation) and pressure.



Recharge areas: hill tops, rain is falling on the land surface. Then water flows down and discharges into rivers, streams, lakes.

Hydraulic head, potential energy driving flow, is due to:

- Elevation above sea level
- Pressure exerted by weight of overlying water



In the illustration below, the hydraulic head at $p_1 > p_2$

- The have the same elevation
- The weight of water over p_1 is greater than that over p_2

A piezometer is used to measure hydraulic head

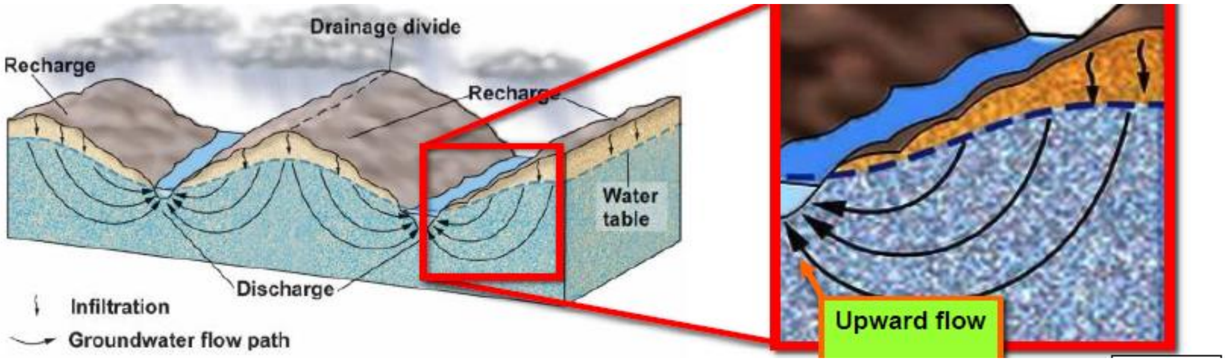
- Open-ended pipe
- Installed below the water table
- Water level is the hydraulic head

Hydraulic head, potential energy driving flow, is due to:

- Elevation above sea-level
- Pressure exerted by weight of overlying water
- Flow ALWAYS moves from a high to a low hydraulic head

Flow paths are not straight lines

- Flow follows a curved, concave-up path
- Water can flow upward as it moves to a lower hydraulic head



We can get situations where water flows down due to gravity but it also depends on how the pressure gradients are set up, resulting in water flowing upwards also.

Groundwater flow occurs on a variety of scales (from meters to continental in size):

- Local – shallow flow over short times and distances
- Intermediate – flow of moderate depth, time, and distance
- Regional – deep, long-distance, long-duration flow

Groundwater infiltrates through recharge areas (higher areas):

- Flow is directed downward
- Commonly found in topographic uplands

Groundwater exits at the subsurface at discharge areas (lower areas):

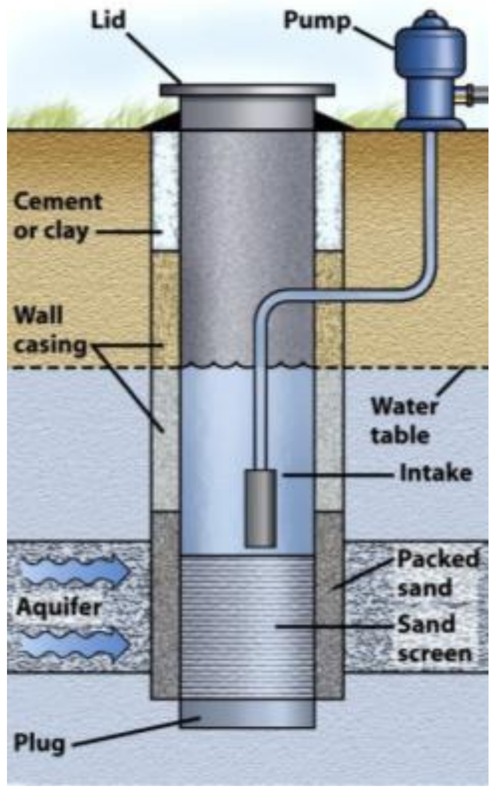
- Flow is directed upward
- Usually observed in topographic lows

4. Permeability mainly controls groundwater speed – how readily water can move through the subsurface, dependent on the type of material water is flowing through

Permeability is the ease of water flow due to pore interconnectedness. Highly permeable material allows water to flow readily. Larger values mean that water can move readily.

Aquifers

An aquifer is a hydrogeologic unit that is… saturated and sufficiently permeable to transmit economic quantities of water to wells and springs. But how much is an economic quantity? Therefore, the definition of aquifer will vary from person to person based on their economic quantity...



Aquifers have 5 key components:

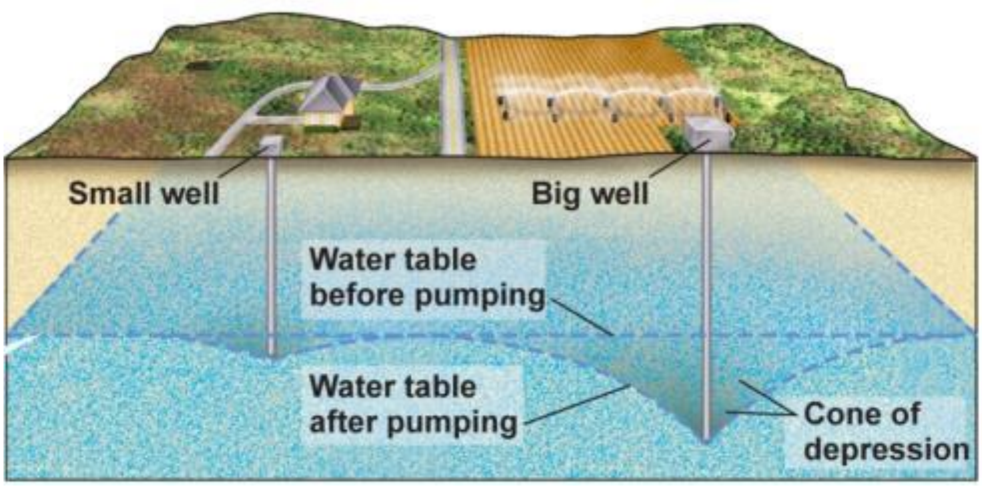
- 1. Groundwater
- 2. Permeable material – water can flow through it
- 3. Good porosity (granite is not a good material)
- 4. Drinkable water – water quality, whether it is polluted or not
- 5. Economic quantities

Tapping groundwater supplies

Wells are holes drilled or dug into the saturated zone

- Water is recovered by lifting or pumping
- Water flows from the aquifer into the well

Water is used for people, irrigation, industry, etc.



With drawdown, the water table near the well drops. In the image above, the original water table is the flat dotted line.

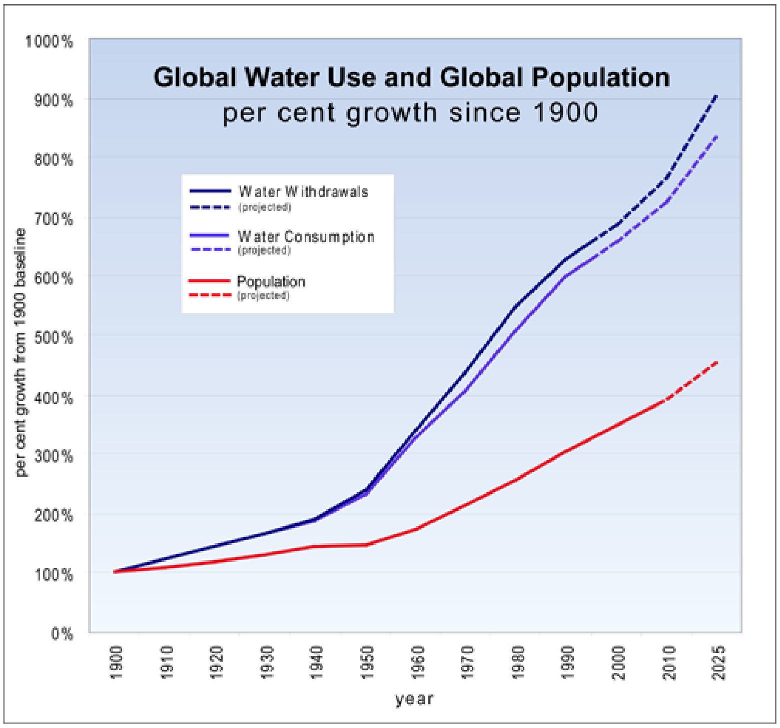
Water-table decline forms a cone-depression

- A downward-pointed conical-shaped surface
- Steepest near the well; flattens with distance
- The cone may expand outward with continues pumping
- The idea is that water will continue flowing to this area through groundwater flow.

There are aquifers all around the world… Lower aquifers usually have problems with contamination. Norther Interior Great Planes aquifer in Mid US provides a lot of water for US and Canada.

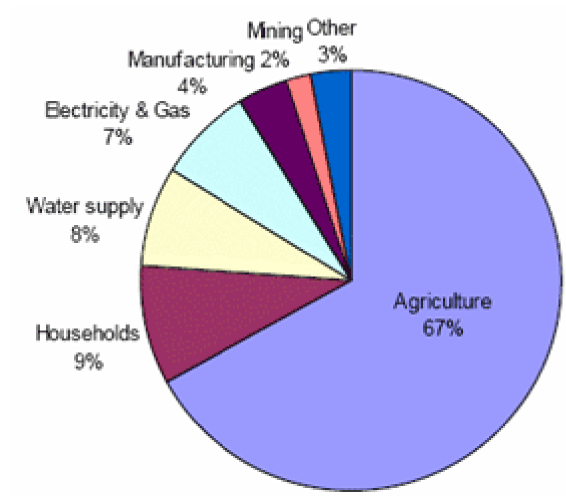
Is groundwater important?

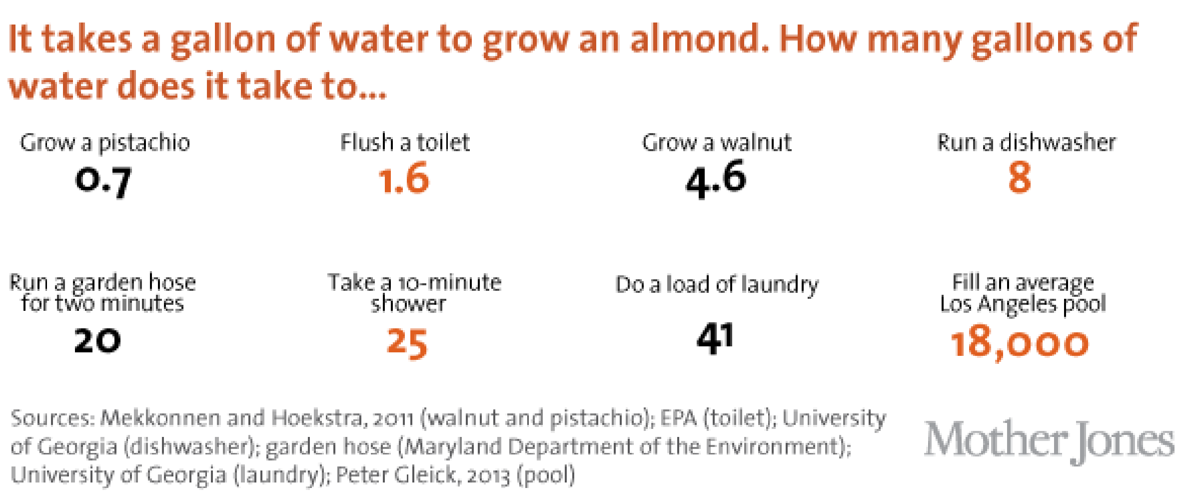
Globally we have increasing water demand.



Our water consumption is rapidly increasing. We use water for:

Farming animals, farming in general, feed livestock, agriculture is the big thing…

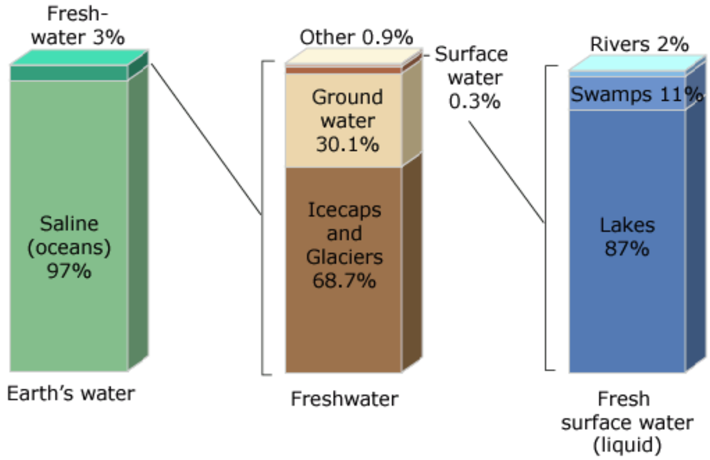




1 gallon = 4L of water

California grows the most almonds in the world.. therefore requires a lot of water. Where does California get their water to produce their almonds? Groundwater. They are extracting huge amounts of groundwater from Central Valley. They had no laws governing the extraction of ground water.

Distribution of water – not equal



On Earth, 97% of the water is sea water. 3% if fresh water. In the fresh water, there are ice caps and glaciers (2/3 of fresh water). 30% of the water that is left is groundwater. One third of the left over percent is surface water.

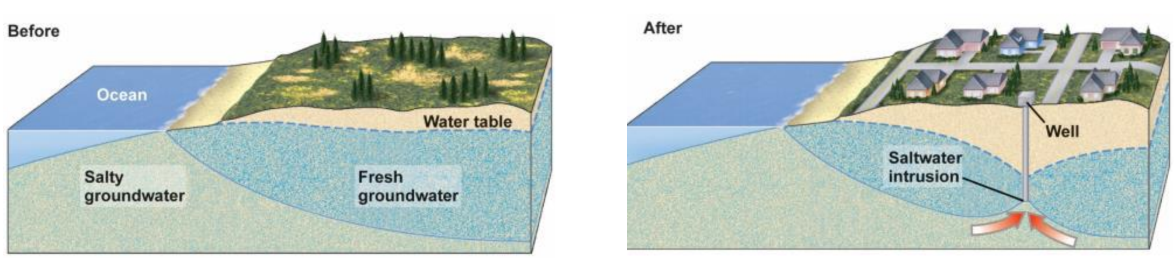
In terms of fresh water, 30% of it is groundwater. In Canada, we do have a lot of surface water. 25% of Canadians use groundwater as their main source of water. Therefore, we are using mostly surface water for the general population.

What are groundwater problems?

<u>Saline Intrusion</u>

Saltwater intrusion renders water unpotable. It only takes 1-2% of saltwater to make fresh water undrinkable.

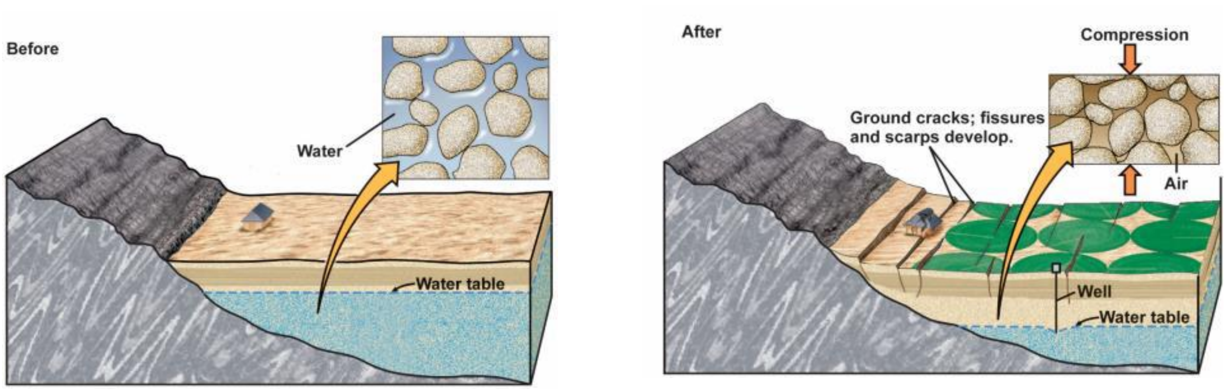
- Beneath coastal land, freshwater "floats" on saltwater due to density differences
- Pumping causes the fresh/salt boundary to rise
- Eventually, saltwater may enter the pumping well, contaminating the well



<u>Pore Collapse and Land Subsidence</u>

- Water in pore space holds grains apart

- When groundwater is removed:
  -Sediment grains compress; pore spaces collapse
  -The land surface cracks and sinks
- Subsidence is mostly irreversible



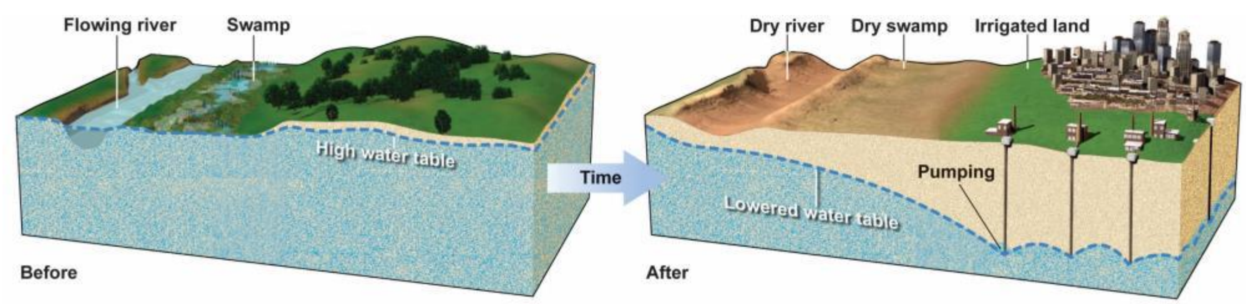
Initially, all the pores are surrounded by water. After pumping water out, and removing the water, the whole system compacts. This is not a good situation and is due to over-pumping.

Dramatic examples of subsidence:

- The leaning tower of Pisa, Italy
- Sinking buildings in Venice, Italy
- The San Joaquin Valley, California

<u>Ground water depletion</u>

As you are removing water from the ground, you are lowing the groundwater table. Severe water-table decline can alter surface water flow. By capturing flow, wells may drain streams and lakes.



It will take a long time for the water to flow back into the system.

How long does it take for that water to be replaced when we pump it out?

Is groundwater recharge equal? This depends on how much is rains = high recharge rate. Dry regions have low recharge rates, which means if the water is pumped out, it is not readily replaced.

Groundwater footprint

Map of different aquifers globally. How much water are we extracting from these aquifers versus their rate of recharge. Our extraction is larger than the recharge rate – we do huge extractions. We are over-extracting water at a rate which is not sustainable.