GY 111 Lecture Note Series  
Groundwater and Hydrogeology

Lecture Goals  
A) The hydrologic cycle  
B) Groundwater dynamics  
C) Mapping groundwater (done in class not on the web notes)

A) The hydrologic cycle  
At the time I am writing these notes (early October 2008), the economy of the world is in major trouble. Banks are failing, money is drying up and even profitable geological ventures like oil, gold and base metal exploration are starting to lose their appeal. No mention of job losses in these geology professions yet, but if no one (including businesses) has any capital to buy stuff, it will be difficult for geological companies to sell copper or zinc or even oil. But you know, there is one other commodity that geologists explore for that is unlikely to be impacted by any economic slowdown. It’s just too important…. water. Water is vital for most life forms on the planet and there is a lot of it. It is one of the most mobile substances on the planet and it is constantly being recycled from one form to another through the hydrologic (or hydrological) cycle. The hydrological cycle is a bit like the rock cycle, but instead of relating rocks and processes to one another, it relates water and processes. It is defined as all of the water on, over and in the Earth, and the processes by which that water moves between reservoirs. As they say, a picture is worth 1000 words, and the picture below saves me a lot of letters:

The hydrologic cycle consists of 5 main reservoirs (storage places for water). In order of descending volume, they are:  
1) Oceans (98% of all water)  
2) Ice caps (1.8%)  
3) Groundwater (0.6%)  
4) Lakes and rivers (0.01%)  
5) Atmosphere (0.001%)
Most people understand that the oceans and ice caps contain most of the planet’s water, but they are usually surprised that groundwater not river/lake water is the 3rd most important reservoir in the hydrologic cycle. Truth be told, groundwater contains 40x as much water as all the rivers and lakes on the surface of the Earth which is the reason why it is so important to much of the world’s population (including the good old US of A).

Anyone that has ever walked in Mobile in the summer knows that the volume of the reservoirs is not fixed (i.e., summer humidity in Mobile is extreme and it sometimes feels like there is more water in our atmosphere than in the oceans). Water is recycled between each of the reservoirs via the processes of:

1) evaporation (water to gas)
2) condensation (gas to liquid; e.g., clouds)
3) runoff (liquid water flowing over the land; e.g., rivers)
4) infiltration liquid water flows into the ground (groundwater)

The cartoon above shows the hydrologic cycle budget. A staggering 100 million billion gallons of water a year are cycled through all of the reservoirs (1/1000th of the total water on the planet!). Note that the majority of evaporation and condensation occurs over the oceans (especially in the tropics). Only 3% of the condensation falls on land where is joins moisture evaporated from lakes, rivers and wet soil. Rivers are the products of runoff which is defined as water flowing on the surface of the Earth. Infiltration occurs when water sinks into the soil to become groundwater. It too can also flow back toward the sea, but it is much, much slower than river water.

Groundwater is one of the most important resources that we have. In many parts of the world (including a surprisingly large percentage of the USA), groundwater is the only viable supply of water (e.g., Baldwin County). In the United States, 50% of Americans depend on groundwater for their drinking water (more if you include all...
those bottled water thingies we drink). Forty percent of irrigation water and 26% or industry-supplied water comes from underground…. And these numbers are increasing daily¹.

So how does groundwater get into the ground? The first thing you need is water (rainwater, river water, lake water etc). Then you need surface materials that are both porous (i.e., have lots of void spaces between grains) and permeable (i.e., all of the void spaces are connected). Well sorted beach sand is an excellent porous material, but broken up, fractured and mechanically weathered bedrock will all allow infiltration. Water that enters the voids is called pore water and it tends to move downward. The mechanism driving infiltration is gravity and it’s the same reason that water flows downhill in rivers. So as water infiltrates the subsurface, it is moving “downhill”, that is, straight down. The actual path that the water takes is tortuous because it has to flow through the pores between grains (see previous cartoon), and it is a relatively slow process. But if the material at the surface of the Earth is both porous and permeable, eventually, a lot of the water that falls during rain storms will infiltrate the soil. If all of the pore spaces get filled up with water, the excess runs off into streams and rivers. Water that passes into the ground will continue to percolate downward until it hits a barrier (e.g., a non-porous layer or the bedrock), or it simply fills up all of the available pore space. You can actually identify two separate layers or horizons below the surface of the Earth that are distinguished by the amount of water that fills pore spaces. The layer where water only partially fills pore space is called the Zone of Aeration (or vadose zone) and the layer below this where water entirely fills pore space is called the Zone of Saturation (or phreatic zone). The two layers are separated by an important plane called the water table. More on this shortly, but first. Let’s reconsider the whole infiltration/runoff concept a bit more particularly as it applies to rivers and lakes.

Some lakes and rivers, particularly in arid and desert areas, lose considerable amounts of water to infiltration. Some eventually dry up entirely. These rivers and lakes are said to be influent. Others actually receive a lot of water from groundwater draining into them (this happens a lot in our area and explains why rivers still have flowing water in the middle of prolonged droughts). These rivers and lakes are said to be effluent. (adjacent diagram from http://www.kgs.ku.edu).

¹ The data I gave you here is really old (1970’s), and I can assure you, all of these numbers are up considerably for 2007-08.
Back to the concept of the water table separating the zones of aeration and saturation. In order to actually get water out of the ground, it is necessary to penetrate below the water table. This sometimes occurs where the topography dips down deep enough (i.e., below the water table) resulting in natural springs.

However, most of the time if you want to access groundwater, you have to dig down to it (e.g., dig a well). Groundwater will rise up to the level of the water table in the well because it leaks in laterally from the pores (see adjacent image from www.epa.gov). This is the basic working process of all shallow wells. Any subsurface rock unit that is capable of producing water is called an *aquifer*. The example discussed here is known as an unconfined aquifer because it is open to direct infiltration from rainwater. The filling of an aquifer is technically called recharge.

Unconfined aquifers are usually close to the surface of the Earth but there are deeper aquifers that might lay underneath non-porous intervals (also called *aquicludes*). The diagram below shows one such type of confined aquifer. Unlike unconfined aquifers which need to have the water physically pumped to the surface, confined aquifers are commonly pressurized; water flows on its own up to the surface.

---

2 But not always. In Australia, some wells go down 100’s of feet in order to tap the water supply available in unconfined aquifers.

3 Annoying terminology time. As previously mentioned, we refer to the boundary between the zone of saturation and the zone of aeration in unconfined aquifers as the water table. The two zones are also distinguished within confined aquifers but in these cases, the boundary is called a *potentiometric surface*. 
surface. These free-flowing wells are called **artesian wells** (see figure at the bottom of the previous page from http://www.geosurvey.state.co.us) and along with springs, are important sources of water even in the driest deserts. Artesian wells are pressurized because of topographic differences between the area where recharge is occurring (conveniently called the **recharge area**) and the location of the well. If the recharge area is at a higher topographic area (e.g., mountains) than the well site (e.g., a valley), water will feel the pressure difference and attempt to flow up to the equivalent level of the water table (see diagram below). This pressure gradient is called the **hydraulic head** (or just **head** for short). Hydrologists and hydrogeologists have formulated an important mathematical relationship that determines the rate of water discharge from wells given the hydraulic head and lateral distance between the recharge and discharge points of a groundwater loop. It’s called **Darcy’s Law** and fortunately, you don’t have to worry about it in GY 111. If, however, you are interested in modeling groundwater, Google Darcy’s Law and see what you get.

There are two things that remain to be discussed about groundwater before we call it a day. The first is that groundwater can flow laterally within the zone of saturation if the water table is inclined (i.e., not horizontal). Simply put, groundwater flows from areas where the water table is high (high head) to areas where it is low (low head). The rate of movement is rather slow, commonly less than a few meters a day. In contrast, even slow moving rivers flow a few meters a second. Once again, it is the job of hydrologists and hydrogeologists to model how, where and how fast groundwater flows. This is an important job because of the rate of groundwater flow and water recharge are both normally much, much, much lower that the rate of water extraction. Or to put it bluntly, we suck water out of the ground a lot faster than it flows back into the ground. This is why the water table is locally depressed in the immediate vicinity of the water well (**cone of depression**). The diagram to the right is from www.kgs.ku.edu)

This is normal and in most cases, not a problem. But if water pumping is too extensive, the water table can drop below the bottom level of the well making it **go dry**. If water is being pumped from a lot of separate wells, the combine cones of depression can locally drop the water table over a much large area. This is what is happening to the water supply of Dothan, Alabama. Excessive water use⁴ has dropped the “water table”⁵ down well below sea level and scientists at the Geological Survey of Alabama in Tuscaloosa worry that their water supply wells will run dry within the next 15 to 20 years. This is a major issue; without a supply of water, cities can not function.

---

⁴ Dothan’s water supply is entirely groundwater based. In comparison, Mobile is in pretty good shape. We have a large surface reservoir (Big Creek Lake in Semmes) and several large capacity wells to draw on if we have a prolonged draught. Many US cities including Atlanta, Las Vegas, and La La Land have more demand for water than they have supply.

⁵ Potentiometric surface again.
If you are interested in water, at least as far as geology is concerned, I invite you to talk to me about how it all works. Even better, go see Dr. Jim Connors. He is a professional hydrogeologist and is always interested in talking about his work.

Depending upon the semester and time constraints, the last part of this class may involve a discussion about a groundwater assignment.

**Important terms/concepts from today’s lecture**  
*Google any terms that you are not familiar with*

- Hydrologic cycle
- Reservoir
- Infiltration
- Permeable (permeability)
- Porosity (pores)
- porewater
- Groundwater
- Zone of Aeration
- Zone of Saturation
- Recharge (recharge area)

- Aquifer
- Aquiclude
- Influent, effluent
- Confined aquifer
- unconfined aquifer
- Artesian well
- Spring
- Potentiometric surface
- Hydraulic head (head)
- Cone of depression