1 **Groundwater**

**Earth – Chapter 17**

2 ***Chapter 17 – Groundwater***

3 **Importance of Groundwater**

- Groundwater is water found in the pores of soil and sediment, plus narrow fractures in bedrock
- Groundwater and the Hydrosphere
  - Sixth-tenth of 1 percent of the hydrosphere is groundwater
  - Groundwater is the largest reservoir of freshwater that is readily available to humans
    - Groundwater makes up 14 percent of all freshwater reservoirs (most occurs as glacial ice)
    - Groundwater actually makes up 94 percent of all liquid freshwater reservoirs

4 **Earth's Freshwater**

5 **Importance of Groundwater**

- Geological Importance of Groundwater
  - As an erosional agent
    - Dissolving soluble bedrock such as limestone
      - Formation of caves and *sinkholes*
  - Equalizer of stream flow
    - Storage that sustains streams during dry periods

6 **Carlsbad Caverns, New Mexico**

7 **A Basic Resource**

- Every day in the United States we use ~350 billion gallons of freshwater
  - ~23 percent comes from groundwater
  - Groundwater exists almost everywhere—an advantage in places that lack available surface water sources
- Used primarily for irrigation

8 **A Basic Resource**

9 **Distribution of Groundwater**

- Most Groundwater Soaks into the Ground from Precipitation
  - Zone of soil moisture is a zone where water is held by molecular attraction on soil particles in the near-surface zone
    - Used by plants
    - Evaporates directly back to the atmosphere
  - Water not held in this zone percolates further downward

10 **Distribution of Groundwater**

  - Zone of saturation is a zone where all of the pore spaces are completely filled with water
    - Also called the phreatic zone
    - Water in the zone of saturation is *groundwater*
    - The water table is the upper limit of the zone of saturation
    - Extending upward from the water table is the capillary fringe
  - The unsaturated zone (vadose zone) is the area above the zone of saturation
    - Pore spaces include both air and water
    - Includes the zone of soil moisture
    - Includes the capillary fringe—a region where groundwater is held in pore spaces by surface tension

11 **Water Beneath Earth's Surface**

12 **The Water Table**

- Variations in the Water Table
  - Depth is highly variable
  - Varies seasonally and from year to year

- Precipitation variations affect the depth of the water table
  - Shape is usually a subdued replica of the surface topography
  - Except where it is at the surface, it cannot be observed directly

13 **Monitoring the Water Table**

14 **Mapping the Water Table**

15 **The Water Table**

- Interaction Between Groundwater and Streams
  - Constitutes a basic link in the hydrologic cycle
    - Gaining streams
      - Gain water from the inflow of groundwater through the streambed
      - Water table is higher than the stream surface
    - Losing streams
      - Lose water to the groundwater system by outflow through the streambed
      - Water table is lower than the stream surface
    - Combination streams
      - A stream can gain in some sections and lose in others

16 **Interactions Between Groundwater System and Streams**

17 **Factors Influencing the Storage and Movement of Groundwater**

- Porosity
  - The percentage of pore (open) spaces in a rock or sediment is called porosity
    - Depends on the size and shape of the grains, how well they are sorted, and how tightly they are packed
      - Poorly sorted sediments have a low porosity
      - Most crystalline rocks only gain porosity through fractures
  - Determines how much groundwater can be stored

18 **Porosity Demonstration**

19 **Factors Influencing the Storage and Movement of Groundwater**

- Permeability, Aquitards, and Aquifers
  - Permeability is the ability of a material to *transmit* a fluid
    - Depends on the connectivity between pores
  - An aquitard is an impermeable layer that hinders or prevents water movement
    - Example: Clay
  - An aquifer is permeable rock strata or sediment that transmits groundwater freely
    - Example: sands and gravels

20 **How Groundwater Moves**

- Groundwater moves very slowly
  - Average rate is 4 cm per day
- Underground rivers are rare, and a common misconception
- A Simple Groundwater Flow System
  - The force of gravity and pressure differences move groundwater
    - Groundwater is replenished in recharge areas
    - Groundwater flows back to the surface in discharge areas

21 **Underground Rivers: A Misconception**

22 **Groundwater Movement**

23 **How Groundwater Moves**

- Measuring Groundwater Movement
  - Darcy's law is a measure of the volume of water that flows through an aquifer
    - Uses the hydraulic gradient, conductivity, and cross-sectional area
    - Hydraulic gradient is the water table slope
    - Hydraulic conductivity takes into account the permeability of the aquifer and viscosity of the liquid to determine how fast water will flow through a medium

24 **Hydraulic Gradient**

25 **How Groundwater Moves**

- Different Scales of Movement
  - The area of groundwater flow systems vary from a few square kilometers to tens of thousands of square kilometers
  - Regional groundwater systems interact with deeper, larger groundwater systems

26 **Hypothetical Groundwater Flow System**

27 **Wells**

- A well is a hole bored into the zone of saturation—significantly below the water table
  - Most common methods for removing groundwater
    - More than 16 million water wells in the United States
    - More than 13 million belong to private households
  - Drawdown—As water is withdrawn from the well, the surrounding water table is lowered
    - A cone of depression (cone-shaped depression in the water table) forms around a well
    - Hydraulic gradient increases near wells with a cone of depression

28 **Cone of Depression**

29 **Perched Water Table**

- Perched Water Table
  - Forms where an aquitard is situated above the main water table

30 **Artesian Systems**

- An artesian well or spring is a system where groundwater under pressure rises above the level of the aquifer
- Two conditions must be met to form an artesian system:
  - Water must be confined to an inclined aquifer
  - Aquitards must exist above and below the aquifer to confine the aquifer
    - An aquifer confined by aquitards is called a confined aquifer

31 **Artesian Systems**

- Types of Artesian Wells
  - Nonflowing artesian well—Pressure surface is below ground level
  - Flowing artesian well—Pressure surface is above the ground
- Not all artesian systems are wells; *artesian springs* also exist
  - Groundwater may reach the surface through a fracture
  - Sometimes responsible for forming desert oases

32 **Artesian Systems**

33 **Artesian Systems**

- Some artesian systems transmit water a great distance
  - Example: South Dakota
- Municipal water towers create artificial artesian systems
  - Tower acts as a recharge area
  - Pipes confine the “aquifer”
  - Faucets are the flowing artesian wells

34 **A Classic Artesian System**

35 **City Water Systems**

36 **Springs, Hot Springs, and Geysers**

- Springs
  - A natural outflow of water from the intersection of the water table and the ground surface is called a spring
  - Many geologic situations lead to the formation of springs, not just perched water tables
    - Permeable zones exist as fractures or solution channels

37 **Thunder Spring (Muav Limestone, GCNP)**

38 **Thousand Springs**

39 **Vasey’s Paradise, Redwall Limestone (GCNP)**

40 **Springs, Hot Springs, and Geysers**

- Hot Springs
  - Water in a hot spring is 6˚C to 9˚C warmer than the mean annual air temperature of the locality
    - More than a 1000 in the United States!
  - The water for most hot springs is heated by the cooling of igneous rock
    - Most hot springs (more than 95%) are heated this way
  - Some hot spring water is warmed by the geothermal gradient
    - Example: Warm Springs, GA

41 **Distribution of hot springs and geysers in the U.S.**

42 **Hot Springs**

43 **Springs, Hot Springs, and Geysers**

- Geysers
  - Geysers are intermittent hot springs in which columns of water erupt with force
  - How Geysers Work
    - These occur where extensive underground chambers exist within hot igneous rock
    - Groundwater heats under great pressure from overlying water (but does not boil)
    - The super heated water expands, and some is forced to the surface reducing the pressure on water below
    - Water in the chamber then changes to steam, and erupts

44 **Yellowstone's Old Faithful**

45 **How a Geyser Works**

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49 **Springs, Hot Springs, and Geysers**

- Geysers
  - Geyser deposits
    - Chemical sedimentary rock accumulates at the surface, precipitated from minerals dissolved in the groundwater
    - The type of precipitate reflects the chemical makeup of the bedrock that the groundwater interacted with
      - *Siliceous sinter* or *geyserite* form from dissolved silica
      - *Travertine* or *calcareous tufa* forms from dissolved calcium carbonate
        - »Example: Mammoth Hot Springs, Yellowstone

50 **Yellowstone's Mammoth Hot Springs**

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52 **Environmental Problems**

- Mining Groundwater
  - We should be treating groundwater as a *nonrenewable* resource
    - In many places, the water available to recharge the aquifer is significantly short of the amount being withdrawn
    - Example: High Plains Aquifer
      - Underlies 111 million acres
      - One of the largest and most agriculturally significant aquifer
      - Accounts for 30 percent of all groundwater used for irrigation in the United States

53 **High Plains Aquifer (aka 'Ogallala' Aquifer)**

54

55 **Environmental Problems**

- Subsidence
  - The ground sinks when water is pumped from aquifers faster than natural recharge processes can replace it

- Particularly pronounced in areas underlain by thick layers of unconsolidated sediments
  - Example: San Joaquin Valley of California
    - Subsidence approached 9 m!
  - Other examples: Southern Arizona, Las Vegas, New Orleans, Baton Rouge, Houston and Galveston
  - Outside the United States: Mexico City
    - Subsided as much as 7 m!
    - Entrance to some buildings is now at second floor!

56 **That Sinking Feeling!**

57 **Environmental Problems**

- Saltwater Intrusion
  - Excessive groundwater withdrawal causes saltwater to be drawn into wells, thus contaminating the freshwater supply
  - Fresh water is less dense than salt water, so it naturally floats as a “lens” shaped body above it
  - The base of a fresh water body can extend well below sea level
  - Pumping out the fresh water faster than it recharges can result in salt water being drawn up with it
    - Primarily a problem in coastal areas
    - Can correct the problem with recharge wells

58 **Saltwater Contamination**

59 **Saltwater Contamination**

60 **Environmental Problems**

- Groundwater Contamination
  - One common source is sewage
    - Extremely permeable aquifers (coarse gravel) have such large openings that groundwater may travel long distances without being cleaned
    - Sewage often becomes purified as it passes through a few dozen meters of an aquifer composed of sand or permeable sandstone

61 **Comparing Two Aquifers**

62 **Environmental Problems**

- Groundwater Contamination
  - Sinking a well can lead to groundwater pollution problems
    - Cone of depression will locally increase or reverse the slope of the water table
    - Contributing to contamination of other nearby wells that had no been polluted prior to drawdown
  - Other sources and types of contamination include highway salt, fertilizers, pesticides, chemicals, and industrial materials
    - Similarly, contamination from leaking holding ponds can enter the groundwater supply

63 **Changing Direction**

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66 **Potential Sources of Contamination**

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69 **The Geologic Work of Groundwater**

- Groundwater Dissolves Rock
  - Most groundwater is often mildly acidic
    - Contains weak carbonic acid
      - Forms when rainwater dissolves carbon dioxide from the air and from decaying plants
  - Carbonic acid reacts with calcite in limestone to form calcium bicarbonate, a soluble

material that can be carried away in solution as dissolved load

70 **The Geologic Work of Groundwater**

- Caverns
  - The most spectacular results of erosion by groundwater
  - Most caverns are created by acidic groundwater dissolving soluble rock
  - About 17,000 caves have been discovered in the United States
    - Famously large examples: Mammoth Cave in Kentucky and Carlsbad Caverns in New Mexico

71 **Mammoth Cave**

72 **The Geologic Work of Groundwater**

- Cavern development
  - Developed as acidic groundwater dissolves limestone bedrock
  - Development occurs at several levels
    - Most active erosion is at or just below the zone of saturation
- How dripstone forms
  - Calcium carbonate deposited as dripping water evaporates is called travertine
- Dripstone features—speleothems
  - Speleothem is the general name for all dripstone features
    - Includes stalactites (hanging from the ceiling) and stalagmites (form on the floor of a cavern)
    - These may join together to form a *column*

73 **Cave Decorations ("speleothems")**

74 **Speleothems in Carlsbad Caverns National Park**

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77 ***"Soda straws" in Carlsbad Caverns National Park***

78 ***Halite "Soda straws"***

***(Grand Canyon National Park)***

79 ***Lewis & Clark Caverns State Park, Montana***

80 **The Geologic Work of Groundwater**

- Karst Topography
  - Karst topography is a landscape that has been shaped mainly by the dissolving power of groundwater
  - Occur in moist regions underlain by limestone
  - Some common features include:
    - Irregular terrain
    - Sinkholes or sinks (formed by groundwater slowly dissolving the bedrock often accompanied by collapse)
    - Striking lack of surface drainage (streams)
    - Tower karst: forms where thick limestone is highly fractured and jointed, groundwater dissolves along these fractures and leaves behind residual towers

81 **Development of a Karst Landscape**

82 **Sinkholes**

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84

85 **Tower Karst**

86 **End of Chapter**