

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**46 47 48 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**51 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**

83 

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85  **Tower Karst**

86  **End of Chapter**