1

2 ***Chapter 16 – Running Water***

3 **The Earth as a System: The Hydrologic Cycle**

- Earth is unique in the solar system
  - Right size and distance from the Sun to have liquid water
  - Mantle convection brings water to Earth's surface through volcanism
- The hydrologic cycle describes the movement of water through Earth's four spheres
  - *Geosphere*, *hydrosphere*, *atmosphere*, *biosphere*

4 **Distribution of Earth's Water**

5 **The Earth as a System: The Hydrologic Cycle**

- Movement Through the Hydrologic Cycle
  - Water evaporates from the oceans, plants, and soil and moves through the atmosphere
  - Water leaves the atmosphere via precipitation
  - Precipitation either
    - Soaks into the ground (infiltration),
    - Runs over the surface (runoff),
    - Evaporates, or
    - Is stored as part of a snowfield or glacier
  - The Hydrologic Cycle is balanced:
    - water is constantly moving from one reservoir to another, but the total amount on earth remains the same

6 **The Hydrologic Cycle**

7 **The Earth as a System: The Hydrologic Cycle**

- Movement Through the Hydrologic Cycle
  - Transpiration involves water absorbed by plants and later transferred to the atmosphere
  - As evaporation and transpiration both move water from the surface to the atmosphere, they are often considered a combined process called evapotranspiration

8 **Running Water**

- The difference between runoff and infiltration depends on
  - Intensity and duration of rainfall
  - The amount of water already in the soil
  - The type of soil
  - Slope of the land
  - Nature of the vegetative cover
- When the surface is impermeable or saturated, runoff is dominant
  - Runoff is high in urban areas due to buildings, roads and parking lots

9 **Running Water**

- Runoff Will Start as Sheet Flow
  - *Sheet flow* develops into tiny channels called rills
  - *Rills* meet to form *gullies*
  - Gullies join to form brooks, creeks, or streams
    - A stream is any water the flows in a channel, regardless of size
    - A river carries a substantial amount of water and has many tributaries

10 **Running Water**

- Drainage Basins
  - A stream drains an area of land called a drainage basin or watershed
  - The imaginary line separating one basin from another is called a divide
    - Sometimes visible as a high ridge in a mountainous region
    - Sometimes hard to determine in subdued topography
  - A *continental divide* splits a continent into different drainage basins
  - If you observed streams over several years, you would see many lengthen their courses

by headward erosion

11 **Drainage Basin and Divide**

12 **Mississippi River Drainage Basin**

13 **Headward Erosion**

14 **Running Water**

- River Systems
  - Rivers drain much of the land area
    - Exceptions: extremely arid or polar regions
  - The variety of rivers that exist is a reflection of the different environments they are found in
  - Climate differences and human intervention influence the character of a river
  - River systems can be divided into three zones
    - *Sediment production* (erosion dominates)
    - *Sediment transportation*
    - *Sediment deposition*

15 **Running Water**

- River Systems
  - Sediment production
    - Zone where most sediment is derived
    - Located in the headwater region of a river system
    - Sediment generated by
      - Bedrock broken into smaller pieces
      - Bank erosion
      - Scouring of the channel bed

16 **Running Water**

- River Systems
  - Sediment transport
    - Sediment is transported in *trunk streams*
      - In balance, the amount of sediment being eroded equals the amount of sediment being deposited
  - Sediment deposition
    - When a river reaches a large body of water, the energy decreases and the river deposits sediments
    - Typically only fine sediments are deposited in oceans

17 **Zones of a River**

18 **Drainage Patterns**

- Drainage systems are patterns of the interconnected network of streams in an area
  - Common drainage patterns
    - Dendritic
      - The most common
      - Uniform underlying material
    - Radial
      - Typically forms on volcanic cones or domes
    - Rectangular
      - Bedrock is jointed or faulted
    - Trellis
      - Bedrock consists of alternating bands of resistant and weak strata

19 **Drainage Patterns**

20 **Drainage Patterns**

- Formation of a Water Gap
  - A water gap is a notch where a river cuts through a ridge that lies in its path
  - Two possible methods of formation:

- Antecedent stream
  - –Stream existed before the ridge was uplifted
- Superposed stream
  - –Stream was eroded into a preexisting structure buried beneath layers of relatively flat lying strata

21 **Superposed Stream**

22 **Streamflow**

- Water Moves in a River Channel Under the Influence of Gravity
  - – Water slowly flowing in a nearly straight path is called laminar flow
  - – Water moving quickly in an erratic fashion (both horizontal and vertical movement) is called turbulent flow
  - – Streams typically exhibit turbulent flow

23 **Streamflow**

24 **Streamflow**

- Factors Affecting Flow Velocity
  - – The slope, or gradient, of the stream
    - A steeper gradient has more gravitational energy to drive channel flow
  - – Channel shape
    - The wetted perimeter is the area where the river is in contact with the channel
    - The most efficient channel has a small wetted perimeter compared to its *cross-sectional area*
      - –A narrow, deep channel has a small wetted perimeter, less frictional drag, and will flow more efficiently

25 **Influence of Channel Shape on Stream Velocity**

26 **Streamflow**

- Factors Affecting Flow Velocity
  - – Channel size and roughness
    - Water depth affects frictional resistance
      - –Maximum flow velocity occurs when a stream is *bankfull*
    - An *increase in channel* size will increase the cross-sectional area to wetted perimeter ratio, thus increasing channel efficiency
    - Rough channels (boulders, etc.) create turbulence and decreased velocity

27 **Streamflow**

- Factors Affecting Flow Velocity
  - – Discharge
    - Discharge is the volume of water flowing past a certain point in a given unit of time
      - –When discharge increases, the width, depth, and flow velocity increase predictably
  - – Monitoring streamflow
    - The U.S. Geological Survey (USGS) measures *flow velocity*, *discharge*, and *river stage* (height of water surface relative to a fixed point)
      - –USGS network of 7500 stream gaging stations
      - –These data are useful for resource management

28 **Streamflow**

29 **Streamflow**

- Changes Downstream
  - – A longitudinal profile is a cross-sectional view of a stream
    - Head or headwater is the source of the stream
    - Mouth is the downstream point where the stream empties into a larger body of water
  - – Most longitudinal profiles have a concave shape
    - Discharge increases toward the mouth
    - Channel size and velocity also increase toward the mouth
    - Slope decreases downstream

- Volume increases downstream

30 **Longitudinal Profile**

31 **Channel Changes from Head to Mouth**

32 **The Work of Running Water**

- Stream Erosion
  - Erosion related to slope, discharge, and bed/bank sediments
    - Sand-sized particles are easily eroded
    - Silt/clay-sized particles and gravels are harder to erode
      - Channels with cohesive silty bottoms are typically narrower than sandy channels
  - Streams cut channels by *quarrying*, *abrasion,* and *corrosion*
  - Quarrying involves removing large blocks from the channel bed
    - Aided by fracturing of bedrock

33 **The Work of Running Water**

- Stream Erosion
  - By scraping, bumping, and rubbing, abrasion both erodes sediments and polishes them while cutting a bedrock channel
    - Potholes form when fast moving, swirling sediment in eddies abrades a hole by acting like a drill into the streambed
  - Corrosion (rocks gradually dissolving in flowing water)
    - can occur in limestone bedrock channels

34 **Potholes**

35 **The Work of Running Water**

- Transport of Sediment by Streams
  - All streams transport some sediment
  - Sediment load is transported in three ways:
    - Dissolved load (in solution)
    - Suspended load (in suspension)
    - Bed load (sliding, skipping, or rolling along the bottom)

36 **Transport of Sediments**

37 **The Work of Running Water**

- Transport of Sediment by Streams
  - Dissolved load
    - Most of the dissolved load is brought to a stream via groundwater
    - Dissolved load is not affected by stream velocity
    - Dissolved minerals precipitate when water chemistry changes
      - When organisms create hard parts
      - When water enters an inland “sea” where the evaporation rate is high

38 **The Work of Running Water**

- Transport of Sediment by Streams
  - Suspended load
    - The largest part of a stream’s load is carried in *suspension*
      - Usually only fine sand, silt, and clay are carried this way
        - »During a flood stage, larger particles can also be carried in suspension
    - Amount of material carried in suspension is controlled by stream velocity and settling velocity of sediments
      - Settling velocity is the speed at which a particle falls through a still liquid

39 **Suspended Load**

40 **The Work of Running Water**

- Transport of Sediment by Streams
  - Bed load
    - Coarse sands, gravel, and boulders move along the stream bed by saltation (skipping or jumping)

- Larger particles slide or roll along the bottom
- Less rapid and more localized than transport via suspended load
- Coarse gravels may only be moved during times of high flow while boulders move only during exceptional floods

41 **The Work of Running Water**

- Capacity and competence
  - Describes a stream's ability to carry solid particles
  - Capacity is the maximum load of solid particles a stream can carry per unit time
    - The greater the discharge, the greater the capacity
  - Competence is the maximum particle size a stream can transport
    - Streams with a faster velocity have a higher competence

42 **The Work of Running Water**

- Deposition of Sediment by a Stream
  - Deposition occurs when a stream's velocity is less than the settling velocity
  - Particles of the same size are deposited at the same time in a process called sorting
    - Larger particles settle out first
  - Sediments deposited by streams are called alluvium

43 **Stream Channels**

- Bedrock Channels
  - Bedrock channels are cut into the underlying strata
    - Typically form in the headwater region where streams have a steep slope
    - Energetic flow tends to transport coarse particles that actively abrade the bedrock channel
    - *Steps* and *pools* are common features of bedrock channels
    - Channel pattern is controlled by the underlying geology

44 **Stream Channels**

- Alluvial Channels
  - Alluvial channels form in sediment previously deposited in the valley
    - Typically associated with a *floodplain*
    - Channels can change shape as material is eroded and transported
    - Channel shape is affected by the average size of sediment, gradient, and discharge
    - Channel patterns reflect the stream's ability to transport load at a uniform rate while expending the least amount of energy

45 **Stream Channels**

- Alluvial Channels
  - Meandering Channels
    - Streams transport suspended sediment in broad, sweeping bends called meanders
    - Relatively deep, smooth channels, primarily transporting mud
    - Meandering channels *evolve over time*
      - The outside of a meander (cutbank) is a zone of active erosion
      - The inside of a meander (point bar) is a zone of deposition
      - Through time, the bends in a channel can also migrate and eventually join together
        - »A meander that has been cut off from joined bends is called a cutoff oxbow lake

46 **Formation of Cut Banks and Point Bars**

47 **Formation of an Oxbow Lake**

48 **Stream Channels**

- Alluvial Channels
  - Braided channels
    - A braided channel is a complex network of converging and diverging channels that thread among numerous islands or gravel bars
    - A large portion of the load is coarse material
      - Bank material is easily eroded and reworked

- Stream has a highly variable discharge
  - –Commonly form at the toe of a glacier

49 **Braided Stream**

50 **Shaping Stream Valleys**

- A stream valley is the channel and the surrounding terrain that directs water to the stream
  - Alluvial channels have wide valley floors
  - Bedrock channels have narrow V-shaped valleys
    - In arid climates, narrow valleys have nearly vertical walls—called *slot canyons*

51 **Slot Canyon**

52 **Shaping Stream Valleys**

- Base Level and Graded Streams
  - The base level is the lowest point to which a stream can erode
    - Ultimate base level is sea level
    - Local or temporary base level includes lakes, resistant layers of rock, and large rivers
    - All limit a stream's ability to downcut its channel
  - Changing conditions causes readjustment of stream activities
    - Raising base level causes deposition
    - Lowering base level causes erosion

53 **Building a Dam**

54 **Shaping Stream Valleys**

- Base Level and Graded Streams
  - A graded stream only transports sediment
    - Has the necessary slope and other channel characteristics to maintain the minimum velocity required to transport the sediment supplied to it
    - No net erosion or deposition of sediment
  - Consider displacement by a fault along a graded stream:
    - Raises a layer of resistant rock
    - Forms a waterfall—concentrates energy here
    - Serves as a temporary base level
    - Called a *knickpoint*

55 **Changes in Base Level**

56 **Shaping Stream Valleys**

- Valley Deepening
  - A steep gradient and channel far above base level leads to downcutting of the channel
    - Lowering of the streambed toward base level
    - V-shaped valleys with steep sides are the result of severe downcutting
    - *Rapids* and *waterfalls* are prominent features in V-shaped valleys
      - –Occur where the stream's gradient increases significantly

57 **Yellowstone River**

58 **The Retreat of Niagara Falls**

59 **Shaping Stream Valleys**

- Valley Widening
  - As a stream approaches a graded condition, the shape changes to a meandering pattern
    - Downcutting is less dominant
    - More energy is directed laterally (side to side)
  - Continuous erosion from moving meanders produces a floodplain (flat valley floor)
  - The floodplain will be inundated when the stream overflows its banks
    - *Erosional floodplain* (floodplain is being formed)
    - *Depositional floodplain* (produced by major fluctuations in base level or climate conditions)

60 **Development of an Erosional Floodplain**

61 **Shaping Stream Valleys**

- Incised Meanders and Stream Terraces
  - Incised meanders are meanders flowing through steep, narrow bedrock valleys
    - Meanders first develop on a floodplain
    - Base level drops causing the meanders to start downcutting
    - Once the river has adjusted to the new base level, it will produce a new floodplain below the old one
      - The flat remnants of the old flood plain are called terraces

62 **Incised Meanders**

63 **Stream Terraces**

64 **Depositional Landforms**

- Deltas
  - Deltas form when sediment-charged streams reach a temporary or ultimate base level and enter a relatively still body of water
    - The stream's forward velocity decreases, lowering its carrying capacity
    - Sediments are deposited by the dying current and produce three types of beds
      - *Foreset beds*
      - *Topset beds*
      - *Bottomset beds*

65 **Depositional Landforms**

- Deltas
  - Size of sediment varies in the delta
    - Coarse sediments are deposited close to the river mouth (foreset beds)
    - Fine sediments are deposited at the outer edge of the delta (bottomset beds)
  - As a delta grows outward, the stream's gradient continually decreases
    - The channel becomes choked with sediment
    - River seeks shorter, steeper routes to base level
    - The main channel divides into several smaller channels in the delta called distributaries

66 **Formation of a Delta**

67 **Depositional Landforms**

- The Mississippi River Delta
  - History and Structure
    - The Mississippi River Delta is actually a series of seven coalescing deltas
    - Present delta, called a bird-foot delta, formed over the past 500 years
    - The river is trying to cut through to the Atchafalaya River
      - The river would abandon its current course through New Orleans and the lowermost 500 km of its channel
      - Engineering structures currently keep the river from migrating

68 **Growth of the Mississippi River Delta**

69 **Depositional Landforms**

- Natural Levees
  - Natural levees are raised areas adjacent to the channel formed during flood events
    - Water overtops banks and flows out like a flat sheet, loses velocity instantly and drops coarse material near the banks
    - Fine material is laid out on the valley floor
  - Following a flood event, levees prevent water from returning to the stream channel
    - Poorly drained back swamps form in the flood plain
    - Yazoo tributaries flow in the back swamp area before reaching the main stream channel

70 **Formation of a Natural Levee**

71 **Depositional Landforms**

- Alluvial Fans
  - Alluvial fans are fan-shaped deposits of sediments at the base of mountain fronts

        - The stream emerges onto a flat lowland, the gradient drops, and sediment is deposited
        - More prevalent in arid climates
        - Mountain streams carry mostly sand and gravel, thus alluvial fans are composed of the same material
        - Fan shape is produced in much the same way as a delta—the flow divides into distributary channels

72 **Alluvial Fan in Death Valley**

73 **Floods and Flood Control**

- A flood occurs when the stream exceeds the capacity of its channel
    - The most common and most destructive geologic hazard
- Common types of floods:
    - *Regional floods*
    - *Flash floods*
    - *Ice-jam floods*
    - *Dam-failure floods*

74 **Floods and Flood Control**

- Regional floods
    - Seasonal floods that typically result from spring rains or rapid melting of snow
        - Example: 2011 in the Mississippi River

75 **Floods and Flood Control**

- Flash floods
    - Occur with little to no warning
    - Produce rapid rises in water levels and can have devastating flow velocities
    - Mountainous areas are extremely susceptible due to steep slopes
        - Example: August 2011 flash floods in upstate New York and Vermont from Hurricane Irene

76 **Flash Floods in Vermont**

77 **Floods and Flood Control**

- Ice-jam floods
    - Ice forms in rivers creating dams that will break when temperatures rise
        - Common problem with north-flowing rivers in the northern hemisphere
- Dam-failure floods
    - Dams designed to contain small or moderate floods face a larger volume flood event
    - Dams fail and release large amounts of water as a flash flood
        - Example: Johnstown Flood of 1889

78 **North Flowing Siberian Rivers**

79 **Floods and Flood Control**

- Flood Recurrent Intervals
    - An estimate of how often a flood of a given size can be expected to occur
        - A “25-year event” would be much smaller but four times more likely to occur than a “100-year flood”
    - “100-year flood” means that there is a 1 percent probability in a given year for a flood of that size
        - Stream gage data must be collected for 20–30 years to make a reasonable calculation

80 **Floods and Flood Control**

- Flood Control
    - *Artificial levees*
        - Most commonly used stream-containment structures
        - Earth mounds built on river banks to increase the capacity of the channel
            - Not built to withstand, and often fail in floods
            - When exceptional floods threaten, openings are created to divert water out of the channel and into floodways

- *Channelization*
  - Altering a stream channel to make flow more efficient
  - Can make the stream straighter or deeper
    - Accelerates erosion

81 **Birds Point-New Madrid Floodway**

82 **Floods and Flood Control**

- Flood Control
  - *Flood-control dams*
    - Built to store floodwater and release it slowly (in a controlled manner)
    - Typically provide water for irrigation and hydroelectric power
  - Nonstructural approach
    - Best approach to flood control is to *limit development* within floodplains of high-risk flood areas

83

End of Chapter 16