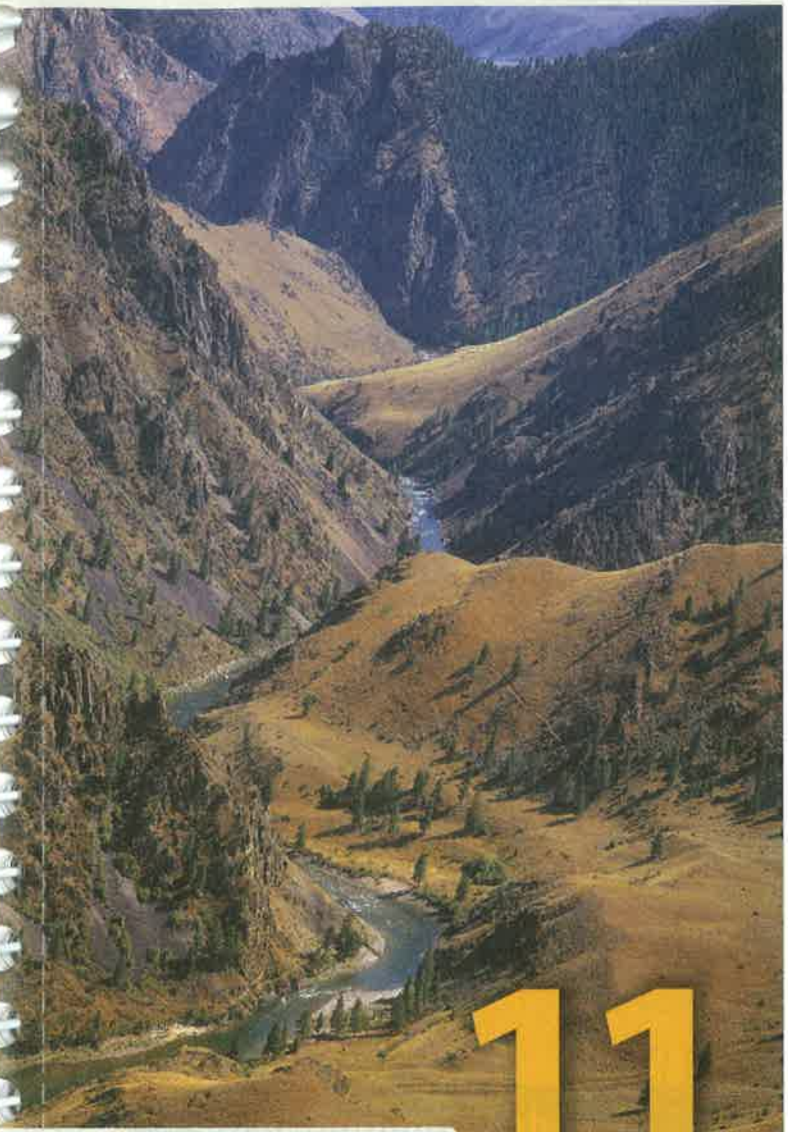


LABORATORY 11

Stream Processes, Landscapes, Mass Wastage, and Flood Hazards

CONTRIBUTING AUTHORS

Pamela J.W. Gore • *Georgia Perimeter College*

Richard W. Macomber • *Long Island University–Brooklyn*

Cherukupalli E. Nehru • *Brooklyn College (CUNY)*

The Middle Fork of the Salmon River flows for about 175 kilometers (110 miles) through a wilderness area in central Idaho. (Michael Collier)

BIG IDEAS

Streams shape the landscape and provide water to communities and agricultural systems. Flood hazards and mass wasting are also associated with streams. Tools and methods for determining flood hazards are provided by the Federal Emergency Management Agency (FEMA).

FOCUS YOUR INQUIRY

Introduction

It all starts with a single raindrop, then another, and another. As water drenches the landscape, some soaks into the ground and becomes *groundwater*. Some flows over the ground and into streams and ponds of *surface water*. The streams will continue to flow for as long as they receive a water supply from additional rain, melting snow, or *base flow* (groundwater that seeps into a stream via porous rocks, fractures, and springs).

Perennial streams flow continuously throughout the year and are represented on topographic maps as blue lines. *Intermittent streams* flow only at certain times of the year, such as rainy seasons or when snow melts in the spring. They are represented on topographic maps as blue line segments separated by blue dots (three blue dots between each line segment). All streams, perennial and intermittent, have the potential to flood (overflow their banks). Floods damage more human property in the United States than any other natural hazard.

Streams are also the single most important natural agent of *land erosion* (wearing away of the land). They erode more sediment from the land than wind, glaciers, or ocean waves. The sediment is transported and eventually deposited, whereupon it is called *alluvium*. Alluvium consists of gravel, sand, silt, and clay deposited in floodplains, point bars, channel bars, deltas, and alluvial fans (**FIGURE 11.1**).

Therefore, stream processes (or *fluvial processes*) are among the most important agents that shape Earth's surface and cause damage to humans and their property.

ACTIVITY 11.1 Streamer Inquiry

THINK About It **Where does a stream near your community come from, where does it go, and why does it matter?**

OBJECTIVE Analyze where a community's stream water comes from and where it goes, then infer how a community may benefit from such knowledge.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   ____ computer with Internet access
   ____ Activity 11.1 Worksheets (pp. 297–298) and pencil

2. **Complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet**, be prepared to discuss your observations and ideas with others.

ACTIVITY 11.2 Introduction to Stream Processes and Landscapes

THINK About It **How does stream erosion shape the landscape?**

OBJECTIVE Analyze and interpret stream valley features using maps and an orthoimage, stream profile, and graph.

PROCEDURES

1. **Before you begin**, read Stream Processes and Landscapes below. Also, this is **what you will need:**

   ___ calculator
   ___ 15-inch (40 cm) piece of thin string or thread
   ___ Activity 11.2 Worksheets (pp. 299–303) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.

ACTIVITY 11.3 Escarpments and Stream Terraces

THINK About It **How does stream erosion shape the landscape?**

OBJECTIVE Analyze and interpret escarpments and terraces along the Souris River using an orthoimage with topographic contours and a sketch of the river valley profile.

PROCEDURES

1. **Before you begin**, read Stream Processes and Landscapes below. Also, this is **what you will need:**

   ___ Activity 11.3 Worksheet (p. 304) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.

ACTIVITY 11.4 Meander Evolution on the Rio Grande

THINK About It **How does stream erosion shape the landscape?**

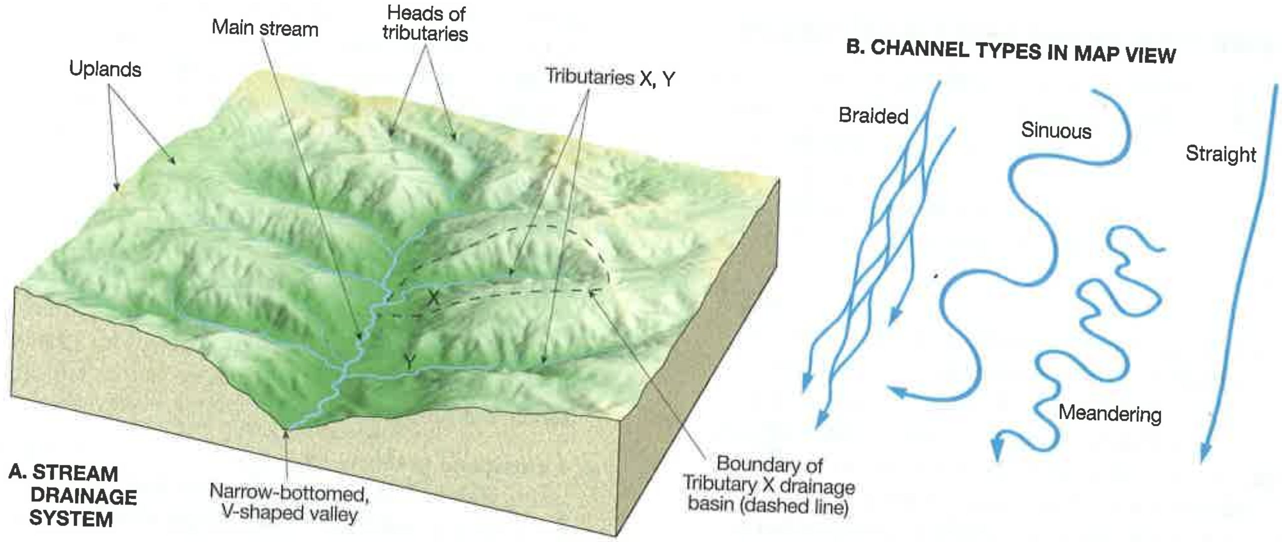
OBJECTIVE Analyze a map of changes in the course of the Rio Grande to interpret the evolution of meanders.

PROCEDURES

1. **Before you begin**, read Stream Processes and Landscapes below. Also, this is **what you will need:**

   ___ calculator, ruler
   ___ Activity 11.4 Worksheet (p. 305) and pencil

2. **Then follow your instructor's directions** for completing the worksheet.



Sinuosity is a measure, below, of how much a stream channel meanders side-to-side.

$$\text{Sinuosity} = \frac{\text{Length A-B of stream channel measured along the path of water flow (blue arrows in drawing C, below)}}{\text{Length A-B measured along a straight line distance between A and B (red line in drawing C, below)}}$$

Straight channels have sinuosities less than 1.3, sinuous channels have sinuosities of 1.3 to 1.5, and meandering streams have sinuosities greater than 1.5.

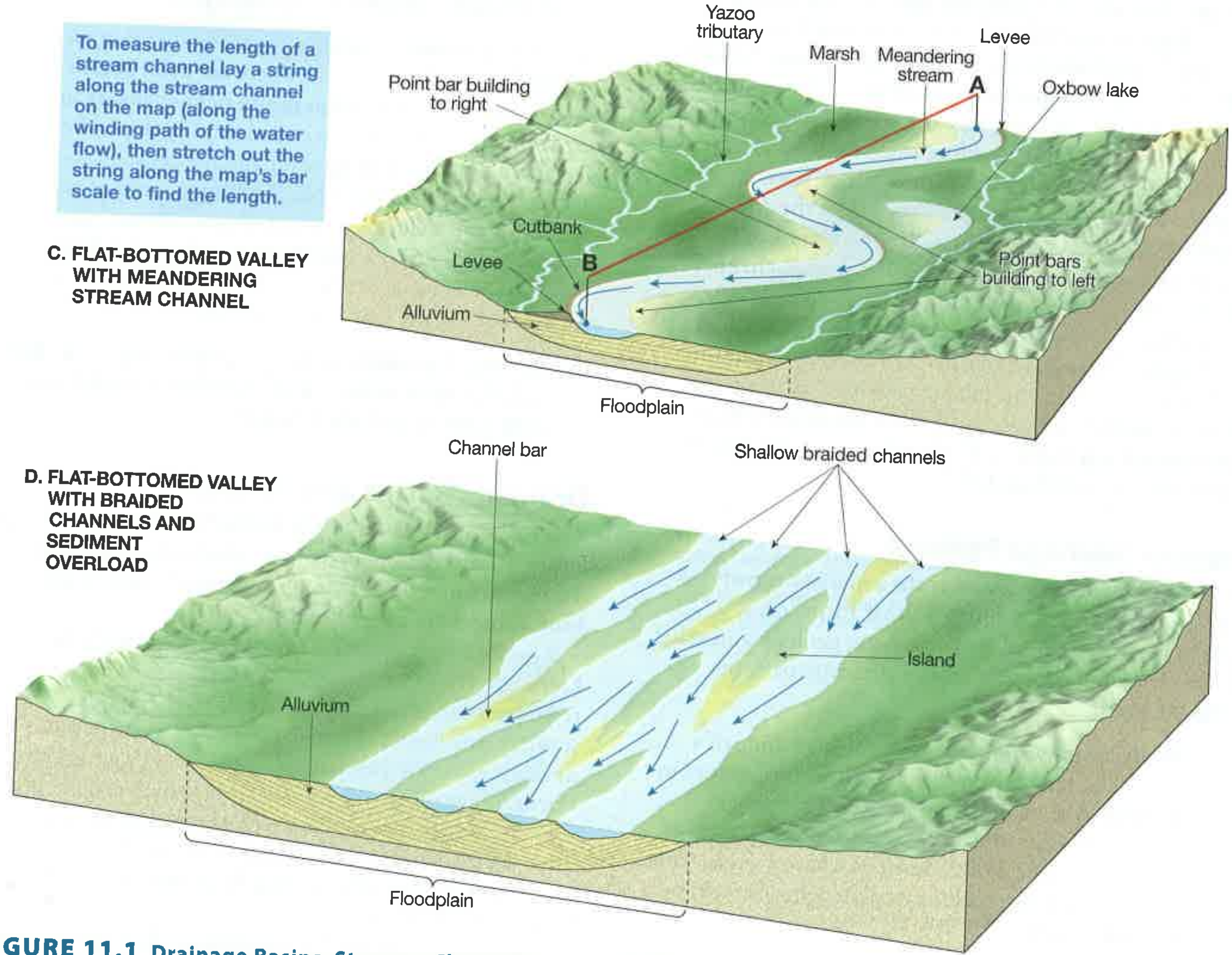


FIGURE 11.1 Drainage Basins, Streams, Channel Types, and Sinuosity. Arrows indicate current flow in the main channels of streams. A. Features of a stream drainage basin. B. Stream channel types as observed in map view. C. Features of a meandering stream valley. D. Features of a typical braided stream. Braided streams develop in sediment-choked streams. **To measure the length of a stream channel**, lay a string along the stream channel on the map (along the winding path of water flow), then stretch out the string along the bar scale to find the length.

Stream Processes and Landscapes

Recall the last time you experienced a drenching rainstorm. Where did all the water go? During drenching rainstorms, some of the water seeps slowly into the ground. But most of the water flows over the ground before it can seep in. It flows over fields, streets, and sidewalks as sheets of water several millimeters or centimeters deep. This is called *sheet flow.*

Sheet flow moves downslope in response to the pull of gravity, so the sheets of water flow from streets and sidewalks to ditches and street gutters. There, the water is channelized. It flows into small stream channels that eventually merge to form larger streams. Larger streams merge to form rivers, and rivers flow into and outlet waterbody (lake or ocean). This entire drainage network, from the smallest *upland* tributaries to larger streams, to the largest river (*main stream* or *main river*), is called a **stream drainage system** (FIGURE 11.1A).

Stream Channel Types and Their Sinuosity

Stream channels have different forms when viewed from above (map view). They may be straight, sinuous, or meandering, and they may become braided (FIGURE 11.1B). **Sinuosity** is a measure of how much a stream meanders side-to-side, the way a snake crawls. It can be calculated by dividing the length of a stream channel (along the winding path of water flow) by the straight-line distance from start to end of the stream segment (FIGURE 11.1). To measure the length of a stream channel, lay a string along the stream channel on the map (along the winding path of water flow), then stretch out the string along the bar scale to find the length. Perfectly straight channels have a sinuosity of 1, but streams in this lab are classified as straight if their sinuosity is less than 1.3. Sinuous streams have sinuosities from 1.3 to 1.5. Meandering streams have sinuosities greater than 1.5.

Stream Drainage Patterns

A **stream drainage pattern** is the arrangement of stream channels and tributaries that forms on a landscape as a result of its underlying geology and relief. These are some common stream drainage patterns (FIGURE 11.2):

- **Dendritic pattern**—resembles the branching of a tree. Water flow is from the branch-like tributaries to the trunk-like main stream or river. This pattern is common where a stream cuts into flat lying layers of rock or sediment. It also develops where a stream cuts into homogeneous rock (crystalline igneous rock) or sediment (sand).
- **Rectangular pattern**—a network of channels with right-angle bends that form a pattern of interconnected rectangles and squares. This pattern often develops over rocks that are fractured or faulted in two main directions that are perpendicular (at nearly right angles) and break the bedrock into rectangular or square blocks. The streams erode channels along the perpendicular fractures and faults.
- **Radial pattern**—channel flow outward from a central area, resembling the spokes of a wheel. Water drains from the inside of the pattern, where the "spokes" nearly meet, to the outside of the pattern (where the "spokes" are farthest apart). This pattern develops on conical hills, such as volcanoes and some structural domes.
- **Centripetal pattern**—channels converge on a central point, often a lake or playa (dry lake bed), at the center of a closed basin (a basin from which surface water cannot drain because there is no outlet valley).
- **Annular pattern**—a set of incomplete, concentric rings of streams connected by short radial channels. This pattern commonly develops on eroding structural domes and folds that contain alternating folded layers of resistant and nonresistant rock types.
- **Trellis pattern**—resembles a vine or climbing rose bush growing on a trellis, where the main stream is long and intersected at nearly right angles by its tributaries. This pattern commonly develops where alternating layers of resistant and nonresistant rocks have been tilted and eroded to form a series of parallel ridges and valleys. The main stream channel cuts through the ridges, and the main tributaries flow perpendicular to the main stream and along the valleys (parallel to and between the ridges).
- **Deranged pattern**—a random pattern of stream channels that seem to have no relationship to underlying rock types or geologic structures.

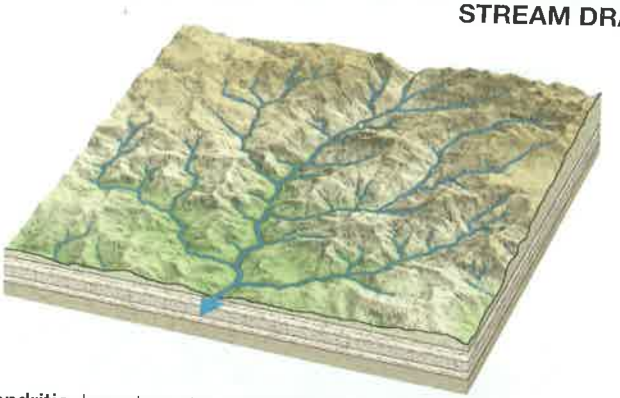
Drainage Basins and Divides

The entire area of land that is drained by one stream, or an entire stream drainage system, is called a **drainage basin.** The linear boundaries that separate one drainage basin from another are called **divides.**

Some divides are easy to recognize on maps as knife-edge ridge crests (FIGURE 11.3). However, in regions of lower relief or rolling hills, the divides separate one gentle slope from another and are more difficult to locate precisely (FIGURE 11.1A, dashed line surrounding the Tributary X drainage basin). For this reason, divides cannot always be mapped as distinct lines. In the absence of detailed elevation data, they must be represented by dashed lines that signify their most probable locations.

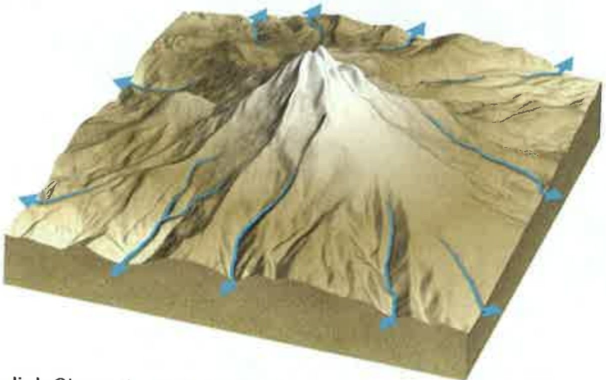
You may have heard of something called a *continental divide,* which is a narrow strip of land dividing surface waters that drain in opposite directions across the

STREAM DRAINAGE PATTERNS

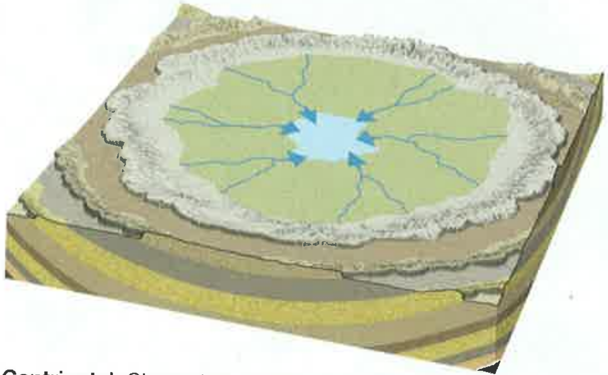


Dendritic: Irregular pattern of channels that branch like a tree. Develops on flat lying or homogeneous rock.

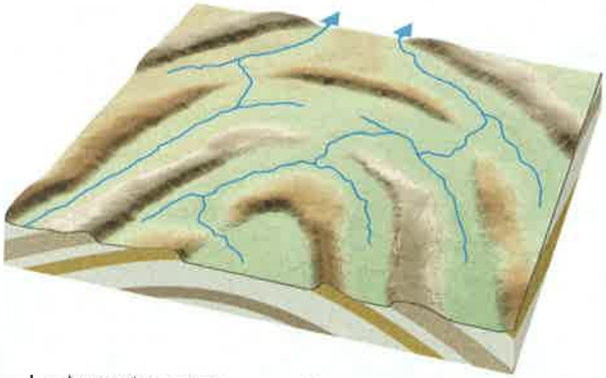
Rectangular: Channels have right-angle bends developed along perpendicular sets of rock fractures or joints.



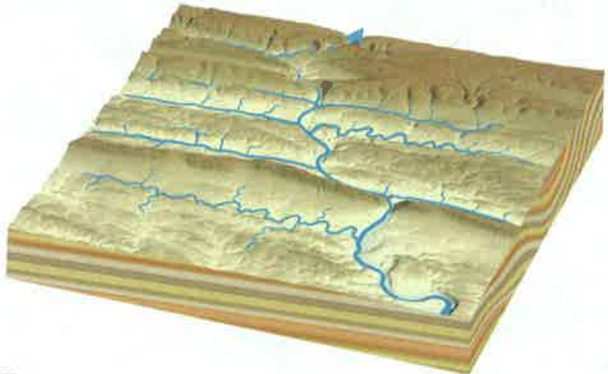
Radial: Channels radiate outward like spokes of a wheel from a high point.



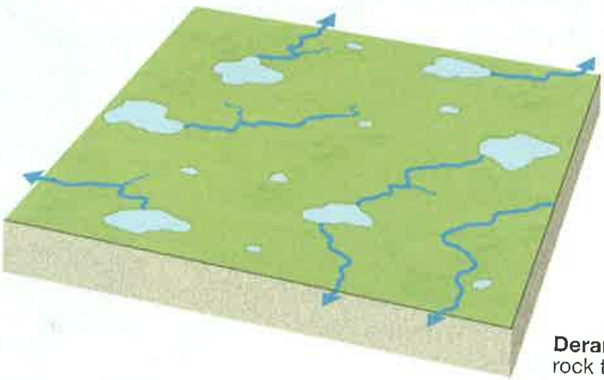
Centripetal: Channels converge on the lowest point in a closed basin from which water cannot drain.



Annular: Long channels form a pattern of concentric circles connected by short radial channels. Develops on eroded domes or folds with resistant and nonresistant rock types.



Trellis: A pattern of channels resembling a vine growing on a trellis. Develops where tilted layers of resistant and nonresistant rock form parallel ridges and valleys. The main stream channel cuts through the ridges, and the main tributaries flow along the valleys parallel to the ridges and at right angles to the main stream.



Deranged: Channels flow randomly with no relation to underlying rock types or structures.

FIGURE 11.2 Some stream drainage patterns. Note their relationship to bedrock geology.

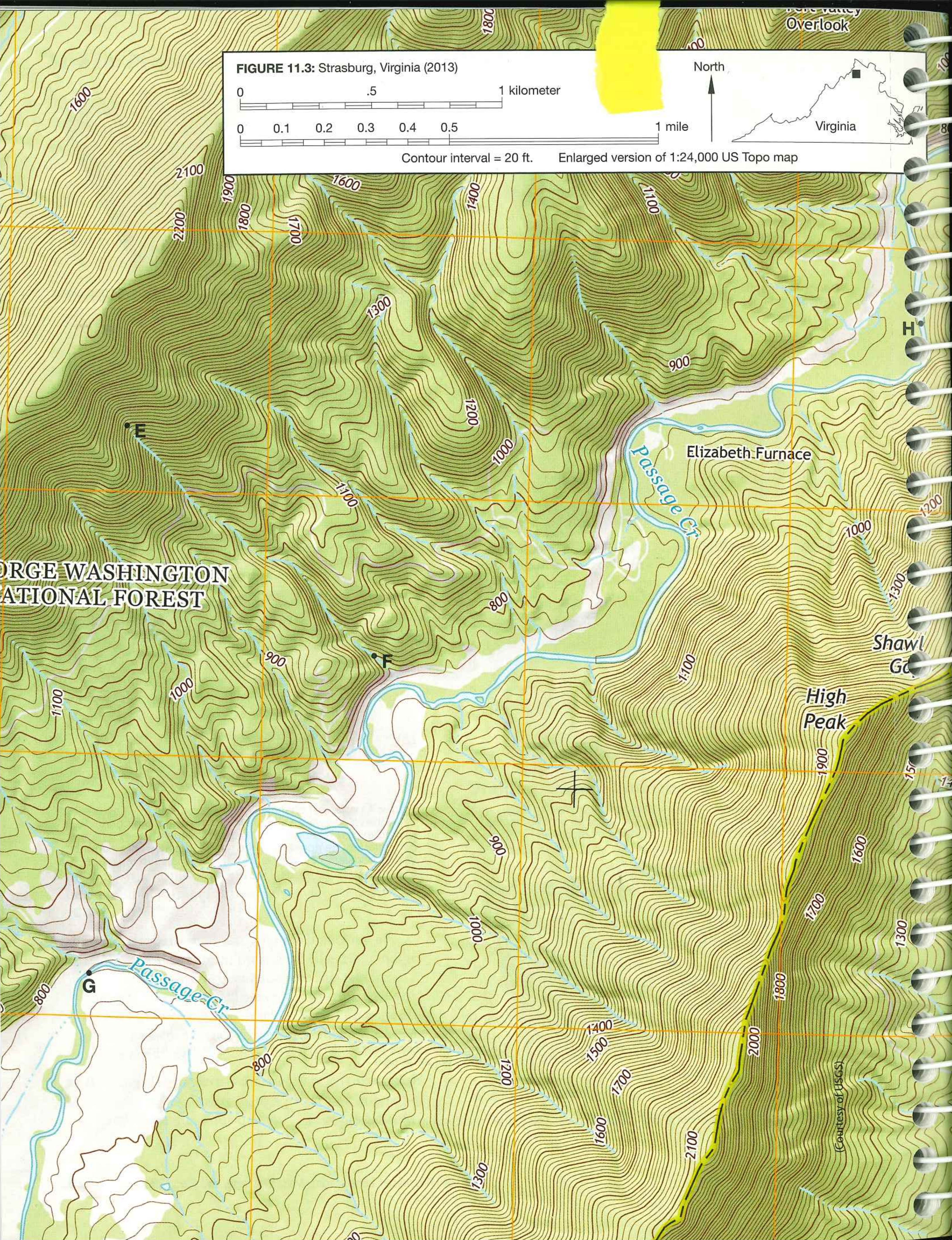


FIGURE 11.3: Strasburg, Virginia (2013)

continent. The [illegible]al divide in North America is an imaginary [illegible] the crest of the Rocky Mountains (see [illegible]n small map in FIGURE 11.4). Rainwater that falls east of the line drains eastward into the Atlantic Ocean, and rainwater that falls west of the line drains westward into the Pacific Ocean. Therefore, North America's continental divide is sometimes called "The Great Divide."

Stream Weathering, Transportation, and Deposition

Three main processes are at work in every stream. *Weathering* occurs where the stream physically erodes and disintegrates Earth materials and where it chemically decomposes or dissolves Earth materials to form sediment and aqueous chemical solutions. *Transportation* of these weathered materials occurs when they are dragged, bounced, and carried downstream (as suspended grains or chemicals in the water). *Deposition* occurs if the velocity of the stream drops (allowing sediments to settle out of the water) or if parts of the stream evaporate (allowing mineral crystals and oxide residues to form).

The smallest valleys in a drainage basin occur at its highest elevations, called **uplands** (FIGURE 11.1). In the uplands, a stream's (tributary's) point of origin, or **head**, may be at a spring or at the start of narrow runoff channels developed during rainstorms. Erosion (wearing away rock and sediment) is the dominant process here, and the stream channels deepen and erode their V-shaped channels uphill through time—a process called **headward erosion.** Eroded sediment is transported downstream by the tributaries.

Streams also weather and erode their own valleys along weaknesses in the rocks (fractures, faults), soluble nonresistant layers of rock (salt layers, limestone), and where there is the least resistance to erosion (see FIGURE 11.2). Rocks composed of hard, chemically resistant minerals are generally more resistant to erosion and form ridges or other hilltops. Rocks composed of soft and more easily weathered minerals are generally less resistant to erosion and form valleys. This is commonly called *differential erosion* of rock.

Headward tributary valleys merge into larger stream valleys, and these eventually merge into a larger river valley. Along the way, some new materials are eroded, and deposits (gravel, sand, mud) may form temporarily, but the main processes at work over the years in uplands are erosion (headward erosion and cutting V-shaped valleys) and transportation of sediment.

The end of a river valley is the **mouth** of the river, where it enters an outlet waterbody (lake, gulf, ocean) or a dry basin. At this location, the river water is dispersed into a wider area, its velocity decreases, and sediment settles out of suspension to form an alluvial deposit such as a delta (in water) or an alluvial fan (FIGURE 11.5). If the river water enters a dry basin, then it will evaporate and precipitate layers of mineral crystals and oxide residues (in a playa).

River Valley Forms and Processes

The form or shape of a river valley varies with these main factors:

- **Geology**—the bedrock geology over which the stream flows affects the stream's ability to find or erode its course (FIGURE 11.2).
- **Gradient**—the steepness of a slope—either the slope of a valley wall or the slope of a stream along a selected length (segment) of its channel (FIGURE 11.6). Gradient is generally expressed in *meters per kilometer* or *feet per mile*. This is determined by dividing the vertical rise or fall between two points on the slope (in meters or feet) by the horizontal distance (run) between them (in kilometers or miles). For example, if a stream descends 20 meters over a distance of 40 km, then its gradient is 20 m/40 km, or 0.5 m/km. You can estimate the gradient of a stream by studying the spacing of contours on a topographic map. Or, you can precisely calculate the exact gradient by measuring how much a stream descends along a measured segment of its course. Learn more about calculating slope (gradient) at this site featuring *The Math You Need, When You Need* It math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/slope/index.html**
- **Base level**—the lowest level to which a stream can theoretically erode. For example, base level is achieved where a stream enters a lake or ocean. At that point, the erosional (cutting) power of the stream is zero and depositional (sediment accumulation) processes occur.
- **Discharge**—the rate of stream flow at a given time and location. Discharge is measured in water volume per unit of time, commonly *cubic feet per second* (ft^3/sec).
- **Load**—the amount of material (mostly alluvium, but also plants, trash, and dissolved material) that is transported by a stream. In the uplands, most streams have relatively steep gradients, so the streams cut narrow, V-shaped valleys. Near their heads, tributaries are quick to transport their load downstream, where it combines with the loads of other tributaries.

Therefore, the load of the tributaries is transferred to the larger streams and, eventually, to the main river. The load is eventually deposited at the mouth of the river, where it enters a lake, ocean, or dry basin.

From a stream's headwaters to its mouth, the gradient decreases, discharge generally increases, and valleys generally widen. Along the way, the stream's load may exceed the water's ability to carry it, so the solid particles accumulate as sedimentary deposits

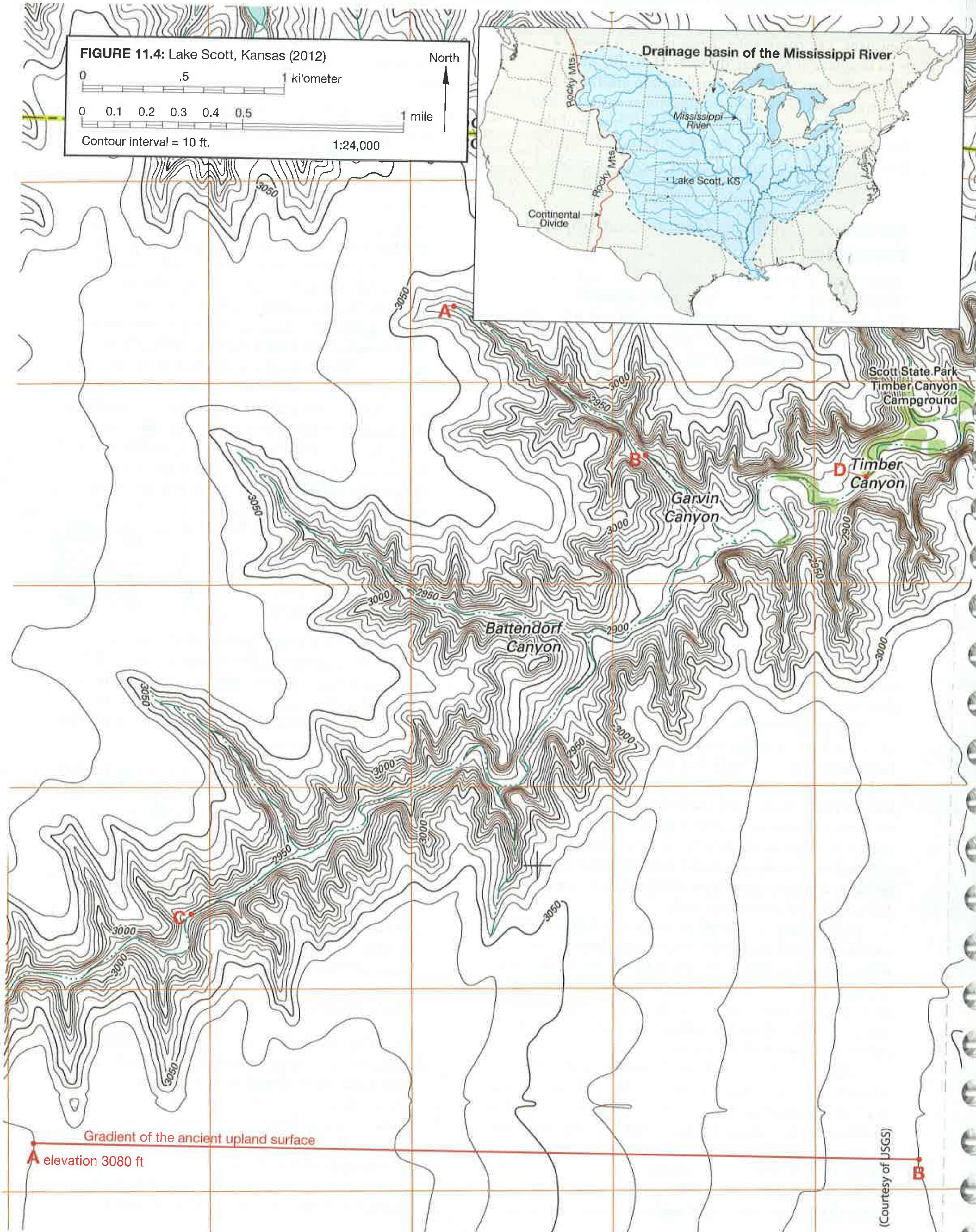


FIGURE 11.4: Lake Scott, Kansas (2012)

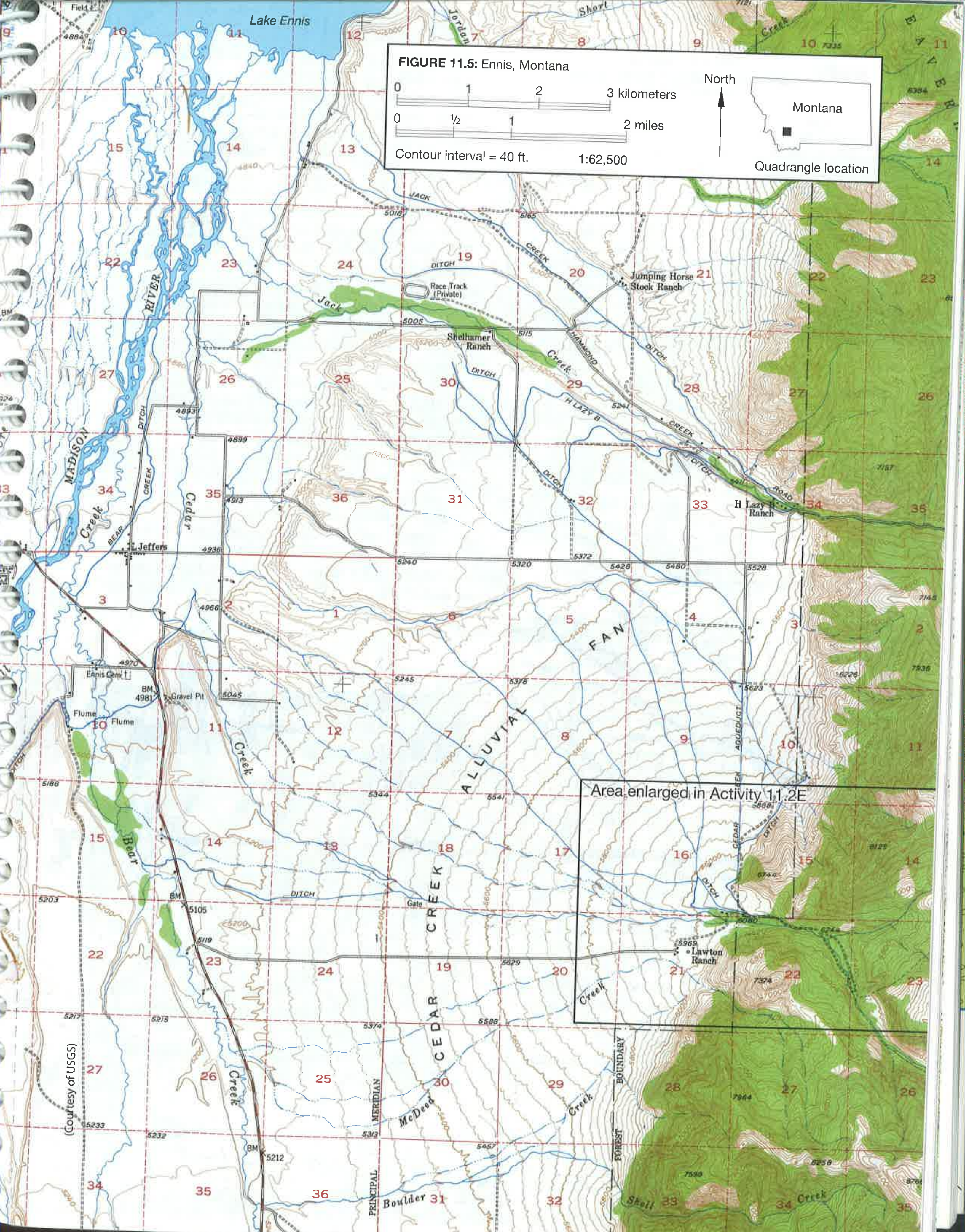


FIGURE 11.5: Ennis, Montana

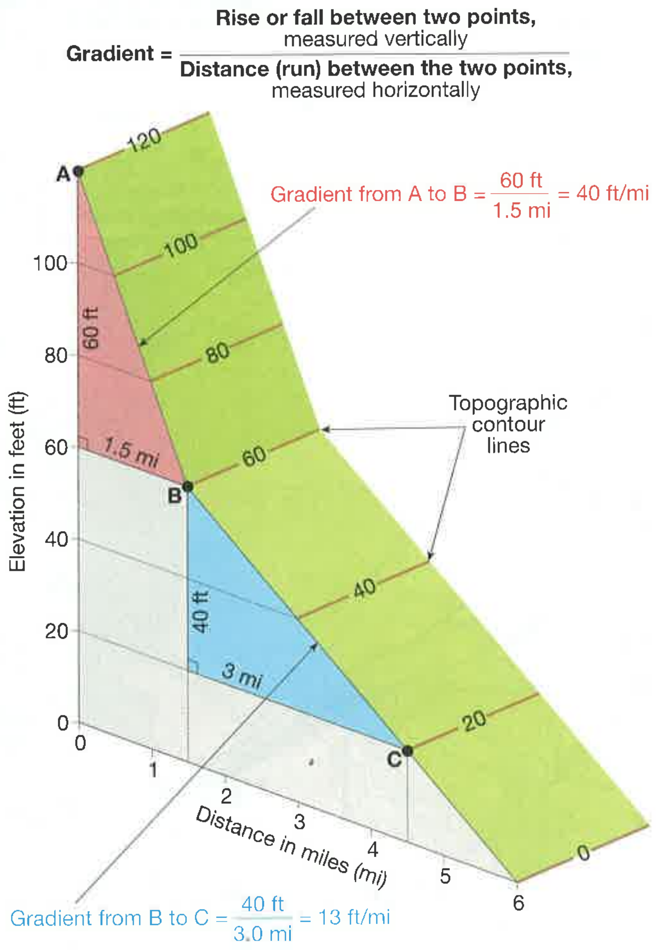


FIGURE 11.6 Stream gradient (slope). The gradient of a stream is a measure of the steepness of its slope. As above, gradient is usually determined by dividing the rise or fall (vertical relief) between two points on the map by the distance (run) between them. It is usually expressed as a fraction in feet per mile (as above) or meters per kilometer.

A second way to determine and express the gradient of a slope is by measuring its steepness in degrees relative to horizontal. Thirdly, gradient can be expressed as a percentage (also called *grade* of a slope). For example, a grade of 10% would mean a grade of 10 units of rise divided by (per) 100 units of distance (i.e., 10 in. per 100 in., 10 m per 100 m).

along the river margins, or banks. **Floodplains** develop when alluvium accumulates landward of the river banks, during floods (**FIGURES 11.1C** and **11.1D**). However, most flooding events do not submerge the entire floodplain. The more abundant minor flooding events deposit sediment only where the water barely overflows the river's banks. Over time, this creates natural **levees** (**FIGURE 11.1C**) that are higher than the rest of the floodplain. If a tributary cannot breach a river's levee, then it will become a **yazoo tributary** that flows parallel to the river (**FIGURE 11.1C**).

Still farther downstream, the gradient decreases even more as discharge and load increase. The stream valleys develop very wide, flat floodplains with sinuous channels. These channels may become highly sinuous, or **meandering** (see **FIGURES 11.1B, 11.7, 11.8**). Erosion occurs on the outer edge of meanders, which are called **cutbanks**. At the same time, **point bar** deposits (mostly gravel and sand) accumulate along the inner edge of meanders. Progressive erosion of cutbanks and deposition of point bars makes meanders "migrate" over time.

Channels may cut new paths during floods. This can cut off the outer edge of a meander, abandoning it to become a crescent-shaped **oxbow lake** (see **FIGURE 11.1C**). When low gradient/high discharge streams become overloaded with sediment, they may form **braided stream** patterns. These consist of braided channels with linear, underwater sandbars (**channel bars**) and islands (see **FIGURES 11.1B** and **11.1D**).

Some stream valleys have level surfaces that are higher than the present floodplain. These are remnants of older floodplains that have been dissected (cut by younger streams) and are called **stream terraces**. Sometimes several levels of stream terraces may be developed along a stream, resembling steps. The steep slopes or cliffs separating the relatively horizontal stream terraces are **escarpments**.

Where a stream enters a lake, ocean, or dry basin, its velocity decreases dramatically. The stream drops its sediment load, which accumulates as a triangular or fan-shaped deposit. In a lake or ocean, such a deposit is called a **delta**. A similar fan-shaped deposit of stream sediment also occurs where a steep-gradient stream abruptly enters a wide, dry plain, creating an **alluvial fan**.

ACTIVITY

11.5 Mass Wastage at Niagara Falls

THINK About It | **How does stream erosion shape the landscape?**

OBJECTIVE Describe erosional and mass wastage processes at Niagara Falls and calculate the rate at which the falls is retreating upstream.

PROCEDURES

1. **Before you begin**, read about Mass Wastage at Niagara Falls. Also, this is **what you will need**:
   ___ ruler, calculator
   ___ 30-cm (12-inch) length of string
   ___ Activity 11.5 Worksheet (p. 306) and pencil with eraser
2. **Then follow your instructor's directions** for completing the worksheet.

FIGURE 11.7: Voltaire, North Dakota (2011)

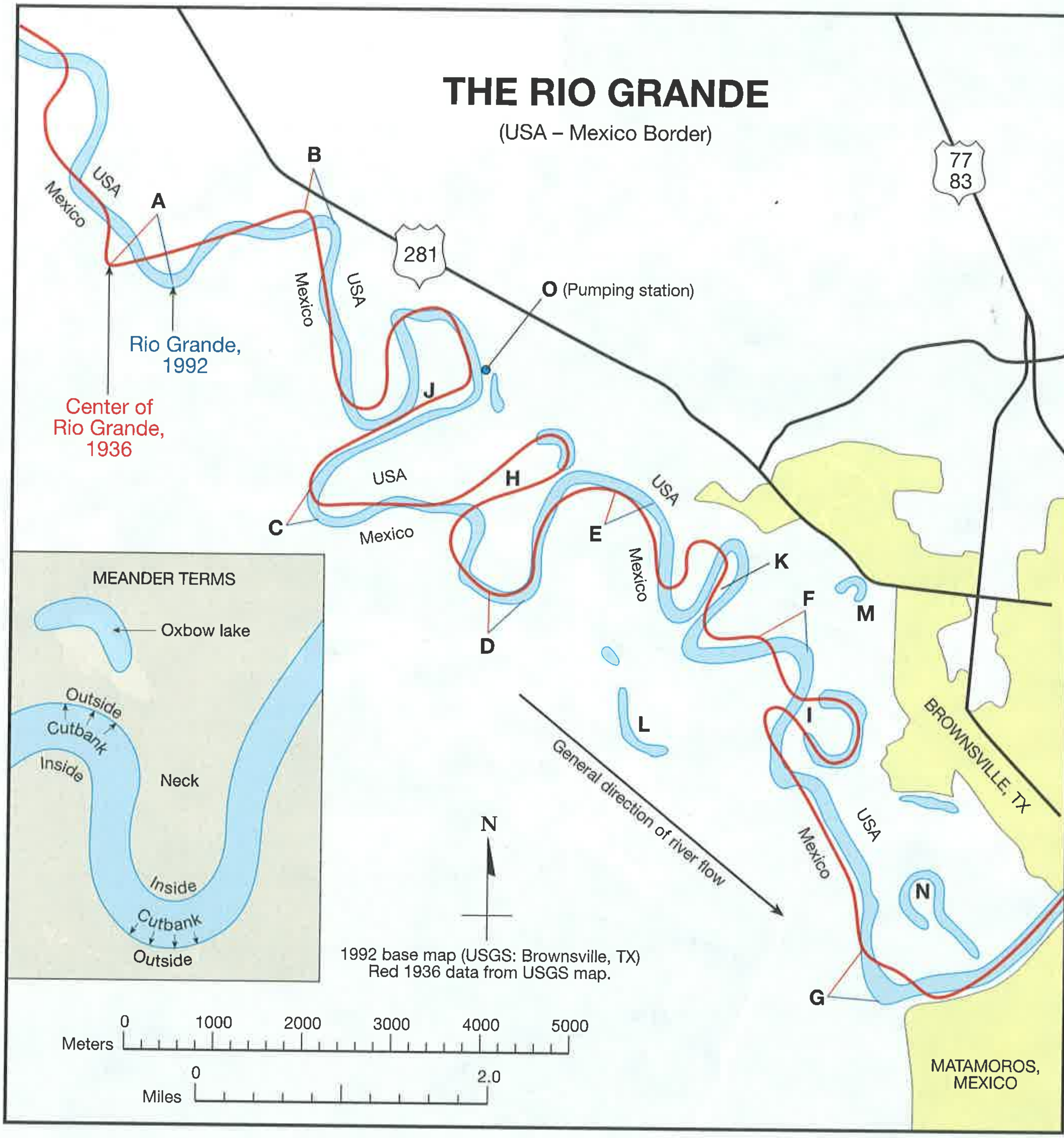


FIGURE 11.8 The Rio Grande. This map shows where the Rio Grande was located in 1992 (blue) and its former position in 1936 (red). The map is based on U.S. Geological Survey topographic maps (Brownsville, Texas, 1992; West Brownsville, Texas, 1936). The river flows east-southeast. Note the inset box of meander terms used to describe features of meandering streams.

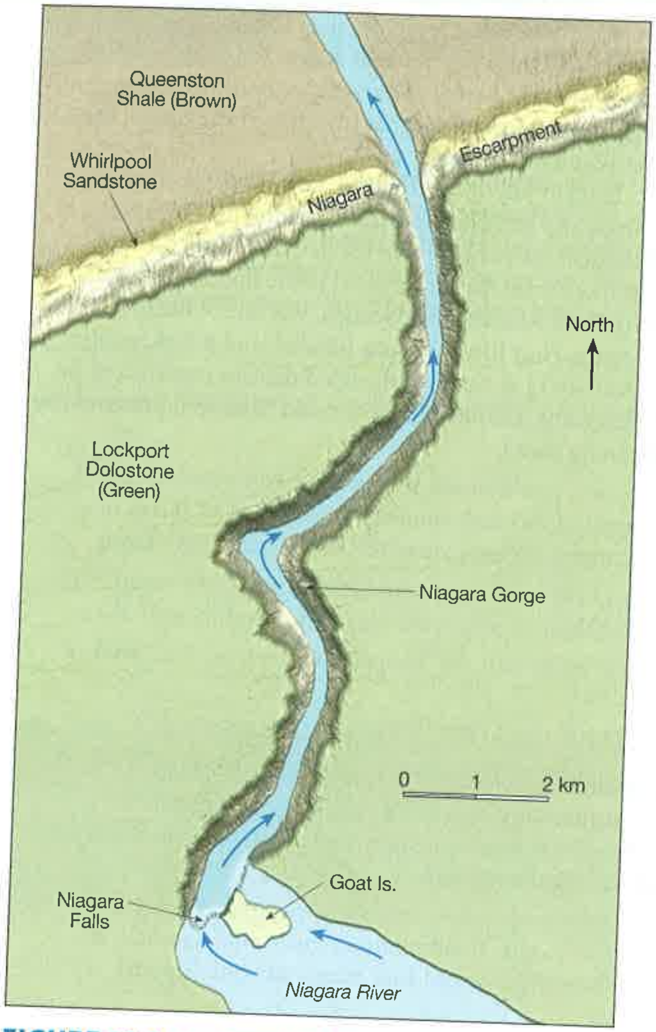


FIGURE 11.9 Geology of the Niagara Gorge Region. The Niagara River flows from Lake Erie north to Lake Ontario and forms the border between the United States and Canada. Niagara Falls is located on the Niagara River at the head of Niagara Gorge, about half way between the two lakes.

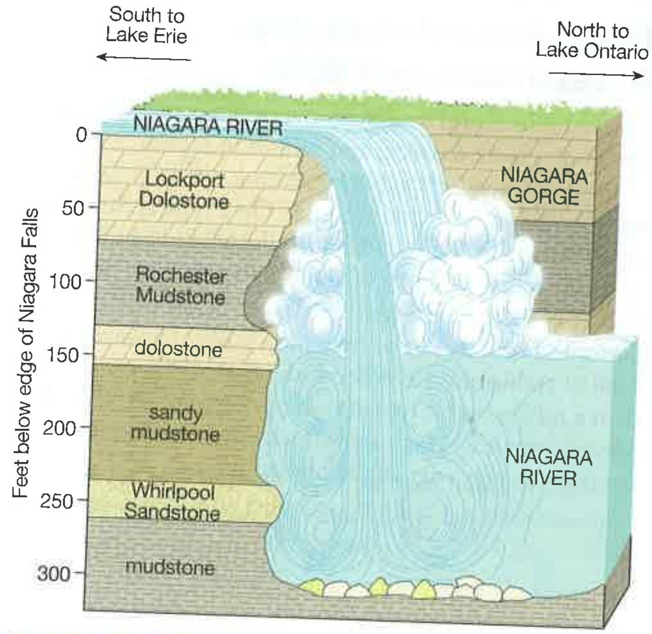


FIGURE 11.10 Cross Section of Niagara Falls. Niagara Falls exists because the named rock units beneath the falls vary in their hardness (resistance to erosion). As the hard dolostone caprock is undercut by erosion of the softer mudstone beneath it, pieces of the caprock break off and the falls moves upstream.

Mass Wastage at Niagara Falls

Mass wastage is the downslope movement of Earth materials such as soil, rock, and other debris. It is common along steep slopes, such as those created where rivers cut into the land. Some mass wastage occurs along the steep slopes of the river valleys. However, mass wastage can also occur in the bed of the river itself, as it does at Niagara Falls.

The Niagara River flows from Lake Erie to Lake Ontario (FIGURE 11.9). The gorge of the Niagara presents good evidence of the erosion of a caprock falls, Niagara Falls (FIGURE 11.10).

ACTIVITY 11.6 Flood Hazard Mapping, Assessment, and Risk

THINK About It How do geologists determine the risk of flooding along rivers and streams?

OBJECTIVE Construct a flood magnitude/frequency graph, map floods, and flood hazard zones, and assess flood hazards along the Flint River, Georgia.

PROCEDURES

1. **Before you begin**, read Flood Hazard Mapping, Assessment, and Risks below. Also, this is **what you will need**:
   ___ calculator
   ___ Activity 11.6 Worksheets (pp. 307–310) and pencil with eraser
2. **Then follow your instructor's directions** for completing the worksheet.

Flood Hazard Mapping, Assessment, and Risks

The water level and discharge of a river fluctuates from day to day, week to week, and month to month. These changes are measured at *gaging stations,* with a permanent water-level indicator and recorder. On a typical August day in downtown St. Louis, Missouri, the Mississippi River normally has a discharge of about 130,000 cubic feet of water per second and water levels well below the boat docks and concrete *levees* (retaining walls). However, at the peak of an historic 1993 flood, the river discharged more than a million cubic feet of water per second (8 times the normal amount), swept away docks, and reached water levels at the very edge of the highest levees.

When the water level of a river is below the river's banks, the river is at a **normal stage**. When the water level is even with the banks, the river is at **bankfull stage**. And when the water level exceeds (overflows) the banks, the river is at a **flood stage.**

Early in July 1994, Tropical Storm Alberto entered Georgia and remained in a fixed position for several days. More than 20 inches of rain fell in west-central Georgia over those three days and caused severe flooding along the Flint River. Montezuma, Georgia, was one of the towns along the Flint River that was flooded, and it is the subject of Activity 11.6. Some of the flood damage experienced by Montezuma, Georgia, in 1994 could have been prevented by planning ahead.

ACTIVITY 11.1 Streamer Inquiry

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

Have you ever stood beside a stream and wondered where the water comes from or where it goes? *Streamer* is a map-based database of stream maps and information that allows you to find out. It is a new component of the U.S. National Atlas project, managed by the U.S. Geological Survey, that allows you to trace streams upstream to their sources or downstream to where they empty into larger streams or the ocean. To use Streamer, go to **http://nationalatlas.gov/streamer/Streamer/welcome.html** and click on the "Go to Map" panel. Then proceed below.

A. Where does the water come from?

1. Pick a community in the United States. What is the name of your community?

2. Locate your community on the *Streamer* map. You can double-click on the map to zoom in, or use your mouse to scroll in or out, to find your community. You can also type the location of the community (city, state) in the "Location Search" panel, then press "Enter," to locate your community.

3. Choose the largest stream located in or near your community to study as "**your stream**." Click on the "Trace Upstream" tab, then click on a point on the stream to display, in red, all of the streams that supply water to that point on the stream.

4. Now click on the "Trace Report" tab, and select "Detailed Report" to get a Stream Trace Detailed Report.

a. What stream did you study (Trace Origin Stream Name)?

b. What is the elevation [Trace Origin Elevation (feet)] and coordinates [Trace Origin (latitude, longitude)] of the point on the stream that you selected?

Elevation: ____________ feet above sea level. Latitude: ______________ Longitude: ______________

c. Through how many communities [Cities (count)] does the stream flow before it gets to this point? ______________________________

d. In how many named streams [Stream Names (count)] does the water flow to this point in the stream? ______________________________

e. What is the total length of the stream(s) named in Part **4d** [Total Length of Traced U.S. Streams (miles)]? ______________________________

f. Close the Stream trace Detailed Report (**not the map**) by clicking on the small gray "x" of the righthand tab at the top of the screen (it will say "National Atlas Streamer Detailed Trace Report" when you hover over it with your mouse), and proceed to part B below.

B. Where does the water go?

1. Click on the "Trace Downstream" tab. Then click on approximately the same point of the same stream that you studied in part A. to display, in red, where the water goes after that point on the stream.

2. Click on the "Identify" tab. Now when you click on any part of the red downstream trace of the water, it will identify the name of the stream at that point of the trace. List the names of all of the streams in the downstream trace of the water, from upstream (the starting red point in your map) to where it enters the "Outlet Waterbody" (downstream end of the red line on your map).

3. Click on the "Trace Report" tab, and select "Detailed Report" to get a new Stream Trace Detailed Report.

a. In how many named streams [Stream Names (count)] does the water flow downstream from this point? ______________________________

b. Through how many communities [Cities (count)] does the water flow downstream from this point? ______________________________

c. What is the total length of the stream(s) named in Part **3b** [Total Length of Traced U.S. Streams (miles)]? ______________________________

d. Into what "Outlet Waterbody" does the stream's water eventually empty? ____________________

e. What is the name of the last community or feature that the stream passes through before it enters the "Outlet Waterbody"? ____________________

f. Close the Stream trace Detailed Report (**not the map**), and proceed to part C below.

C. Your Stream Drainage System.

1. Click on the "Trace Downstream" tab again. Then click on the downstream end of the downstream trace that you identified in part B. It will be located near the place you identified in part B3e. This will display an entire stream drainage network, from the smallest upland tributaries to the largest river (main stream or main river). What do you think happens to the amount of water in the stream drainiange system, the width of the streams, and the slope of the streams as the water drains from small tributaries to the largest river?

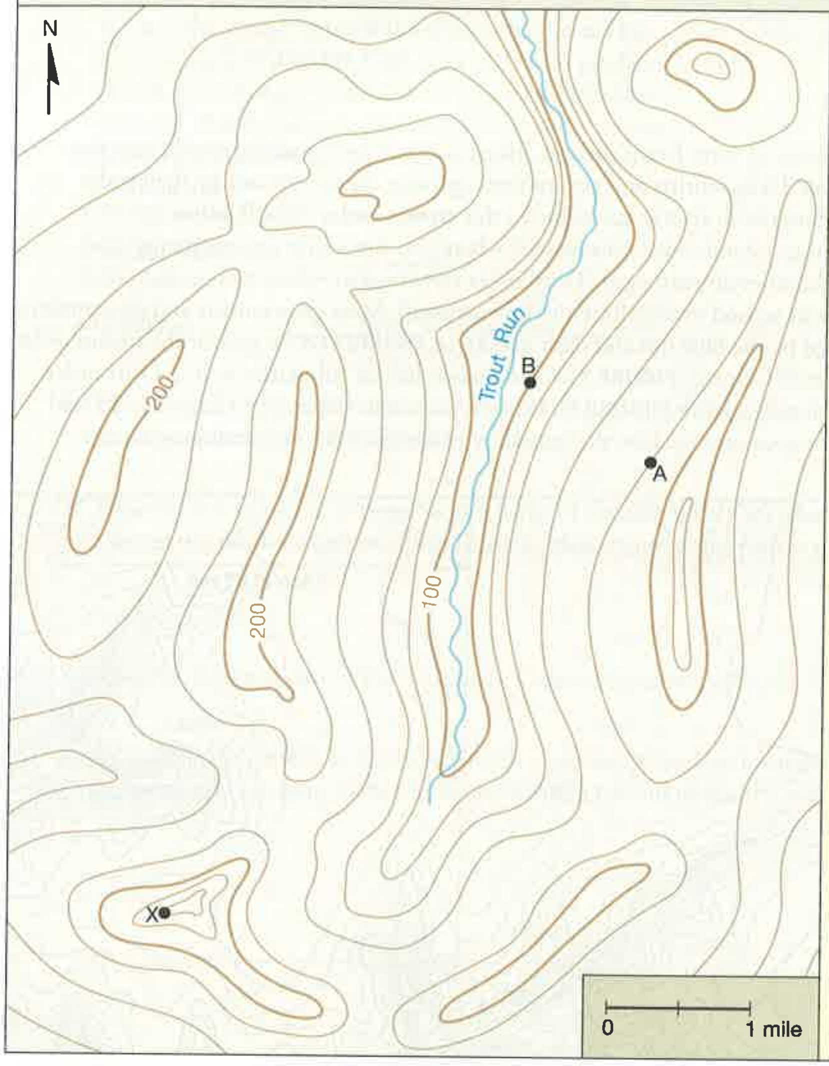
D. **REFLECT & DISCUSS** Why would a community located on or near a stream want to know where its stream water comes from, and what else might they want to know about the water?

E. **REFLECT & DISCUSS** Why would a community located on or near a stream want to know where its stream water goes after passing their community?

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Trout Run Drainage Basin: **1.** Complete items **a** through **h** below.

TOPOGRAPHIC MAP REVIEW FOR DRAINAGE BASIN MAPPING



a. This map is contoured in feet. The contour interval is: ____________ feet.

b. The elevation of point X is: ____________ feet.

c. The elevation of point B is: ____________ feet.

d. The elevation of point A is: ____________ feet.

e. The distance from A to B is: ____________ mile(s).

f. The gradient from A to B is: ____________ feet per mile.

g. Lightly shade or color the area inside each closed contour that represents a hilltop, then draw a dashed line to indicate the drainage divide that surrounds Trout Run drainage basin.

h. Trout Run flows (drains down hill) in what direction? ____________

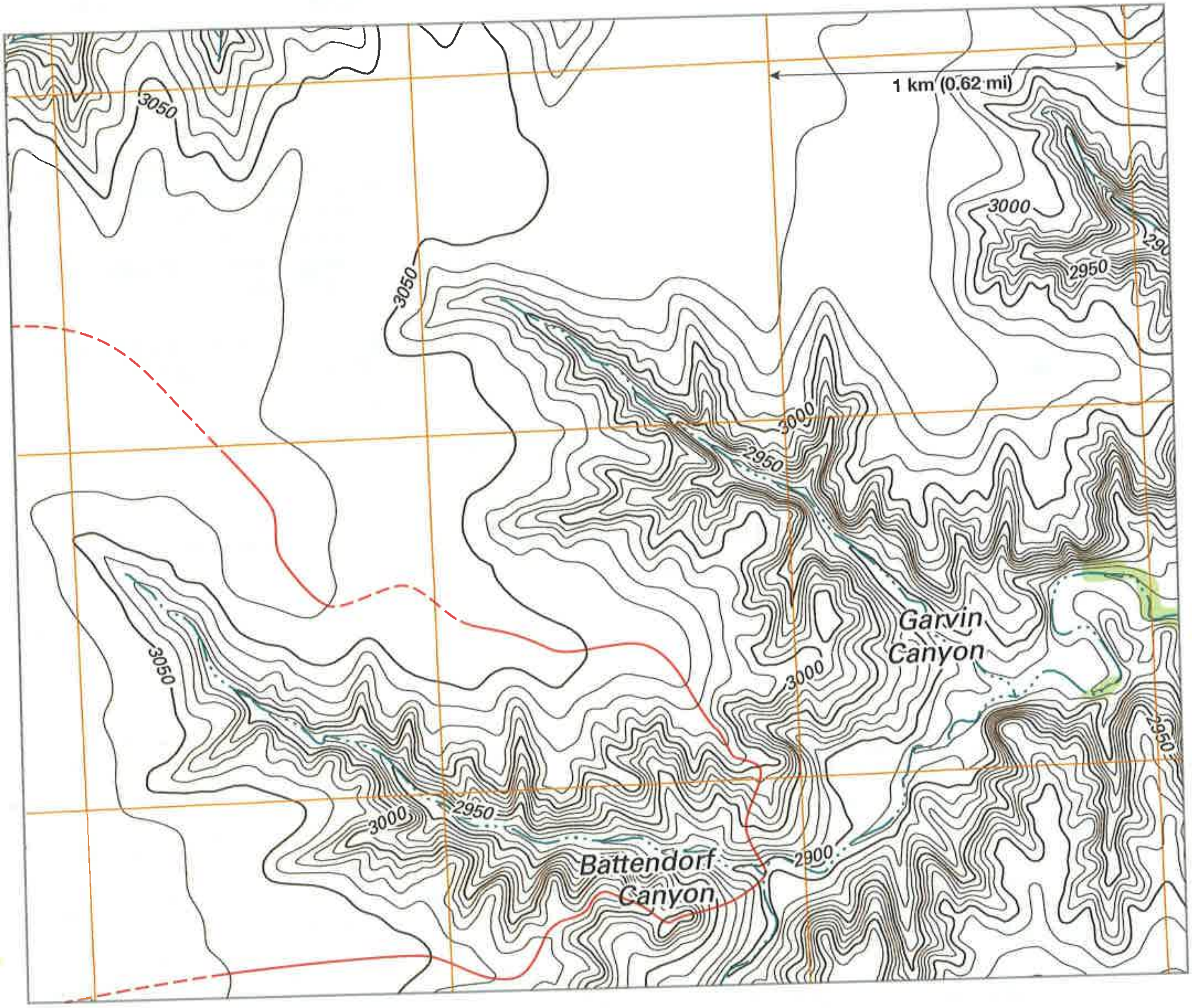
2. Imagine that drums of oil were emptied (illegally) at location **X** above. Is it likely that the oil would wash downhill into Trout Run? Explain your reasoning.

B. Refer to the topographic map of the Lake Scott quadrangle, Kansas (**FIGURE 11.4**). This area is located within the Great Plains physiographic province and the Mississippi River Drainage Basin. The Great Plains is a relatively flat grassland that extends from the Rocky Mountains to the Interior Lowlands of North America. It is an ancient upland surface that tilts eastward from an elevation of about 5500 feet along its western boundary with the Rocky Mountains to about 2000 feet above sea level in western Kansas. The upland is the top of a wedge of sediment that was weathered and carried eastward from the Rocky Mountains by a braided stream system that existed from Late Cretaceous to Pliocene time (65–2.6 Ma). Modern streams in western Kansas drain eastward across the Great Plains and cut channels into the ancient upland surface. Tiny modern tributaries merge to form larger streams that eventually flow into the Mississippi River. You can view this in *Streamer*: go to **http://nationalatlas.gov/streamer/Streamer/welcome.html** and click on the "Go to Map" panel. Then click on the "Trace Downstream" tab, zoom in to any stream in western Kansas (KS), and click on the stream. The red line will show how the stream is part of a stream drainage system the flows east across Kansas, on the ancient upland surface.

1. What is the gradient of the ancient upland surface in **FIGURE 11.4**? Show your work.

2. What is the name of the modern stream drainage pattern from **FIGURE 11.2** that is developed in the Lake Scott quadrangle (**FIGURE 11.4**), and what does this drainage pattern suggest about the attitude of bedrock layers (the sediment layers beneath the ancient upland surface) in this area?

3. Notice in **FIGURE 11.4** that tiny tributaries merge to form larger streams. These larger streams become small rivers that eventually merge to form the Mississippi River. Geoscientists and government agencies classify streams by their order within this hierarchy of stream sizes from tributaries to rivers. According to this **stream order classification**, streams with no tributaries are called first order streams. Second order streams start where two first order streams merge (and may have additional first order streams as tributaries downstream). Third order streams start where two second order streams merge (and may have additional first or second order tributaries downstream). Most geoscientists and government agencies include intermittent streams (marked by the blue dot and dash pattern in **FIGURE 11.4**) as part of the stream order classification. The intermittent stream in Garvin Canyon (**FIGURE 11.4** and below) has no tributaries so it is a first order stream. Notice, on the map below, how the drainage basin (**FIGURE 11.1**) of the stream in Battendorf Canyon is defined by a red line. Draw a similar line, as exactly as youi can, to show the boundary of the Garvin Canyon drainage basin.



(Courtesy of USGS)

4. What is the gradient (ft/mi) and sinuosity, from A to B on **FIGURE 11.4**, of the first order stream in Garvin Canyon? (Refer to **FIGURES 11.1** and **11.6** for help measuring gradient and sinuosity.) Show your calculations. You will graph this data later in the activity.

   Gradient: ____________ft/mi   Sinuosity: ____________

5. What is the stream order of the stream that occurs in Timber Canyon (**FIGURE 11.4**), and what is its gradient (ft/mi) and sinuosity from C to D? (Refer to **FIGURES 11.1** and **11.6** for help measuring gradient and sinuosity.) Show your calculations. You will graph this data later in the activity.

   Stream order: ________________

   Gradient: ____________ft/mi   Sinuosity: ____________

6. The Mississippi River is a tenth order stream. Based on your answers to the two questions above, state what happens to the gradient of streams as they increase in order.

7. What do you think happens to the discharge of streams as they increase in order, and what effect do you think this would have on the relative number of fish living in each stream order within a basin?

C. Examine the enlarged part of the Strasburg, Virginia, quadrangle map in **FIGURE 11.3**.

1. What drainage pattern is developed in this area, and what does it suggest about the attitude of bedrock layers in this area? Explain your reasoning. (*Hint:* Refer to **FIGURE 11.2** and notice the stream pattern in relation to ridges and valleys.)

2. What is the gradient (ft/mi) and sinuosity of the small stream, from E to F? (Refer to **FIGURES 11.1** and **11.6** for help measuring gradient and sinuosity.) Show your calculations. You will graph this data later in the activity.

   Gradient: ____________ft/mi   Sinuosity: ____________

3. What is the gradient (ft/mi) and sinuosity of Passage Creek from G to H? (Refer to **FIGURES 11.1** and **11.6** for help measuring gradient and sinuosity.) Show your calculations. You will graph this data later in the activity.

   Gradient: ____________ft/mi   Sinuosity: ____________

D. Refer to the Ennis Montana 15' quadrangle in **FIGURE 11.5**. Some rivers are subject to large floods, either seasonal or periodic. In mountains, this flooding is due to snow melt. In drylands, it is caused by thunderstorms. During such times, rivers transport exceptionally large volumes of sediment. This causes characteristic features, two of which are braided channels and alluvial fans. Both features are relatively common in arid mountainous regions, such as the Ennis, Montana, area in **FIGURE 11.5**. (Both features also can occur wherever conditions are right, even at construction sites!)

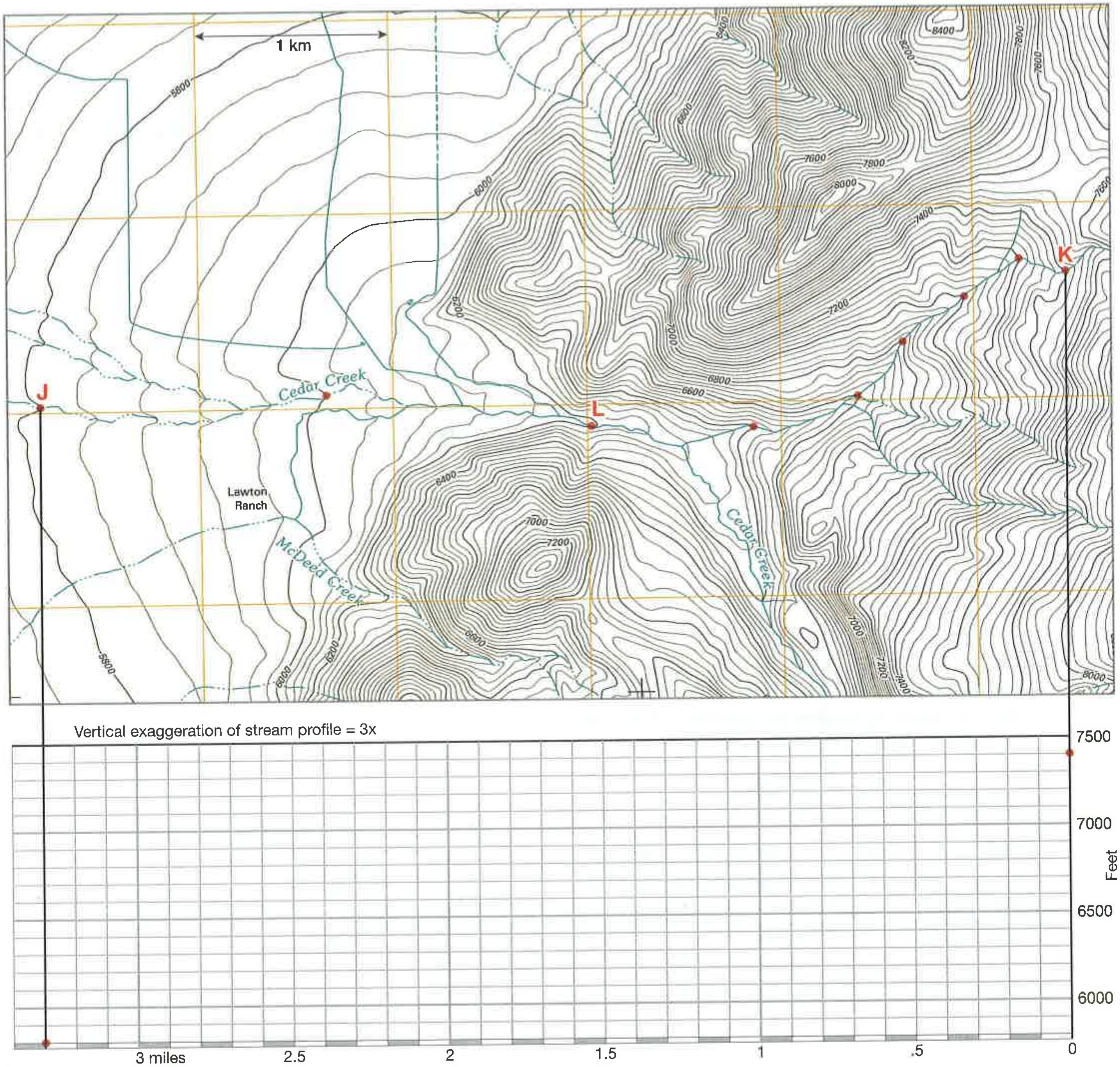
1. What main stream channel types (shown in **FIGURE 11.1B**) are present on:

   a. the streams in the forested southeastern corner of this map?

   b. the Cedar Creek Alluvial Fan?

   c. the valley of the Madison River (northwestern portion of **FIGURE 11.5**)?

2. Notice on **FIGURE 11.5** and the portion of that map enlarged below that Cedar Creek is the source of water that transports sediment onto Cedar Creek Alluvial Fan. Below, complete profile J-K of Cedar Creek by plotting and connecting the nine red elevation points (notice how points J and K have already been plotted).



(Courtesy of USGS)

deposited from Cedar Creek."

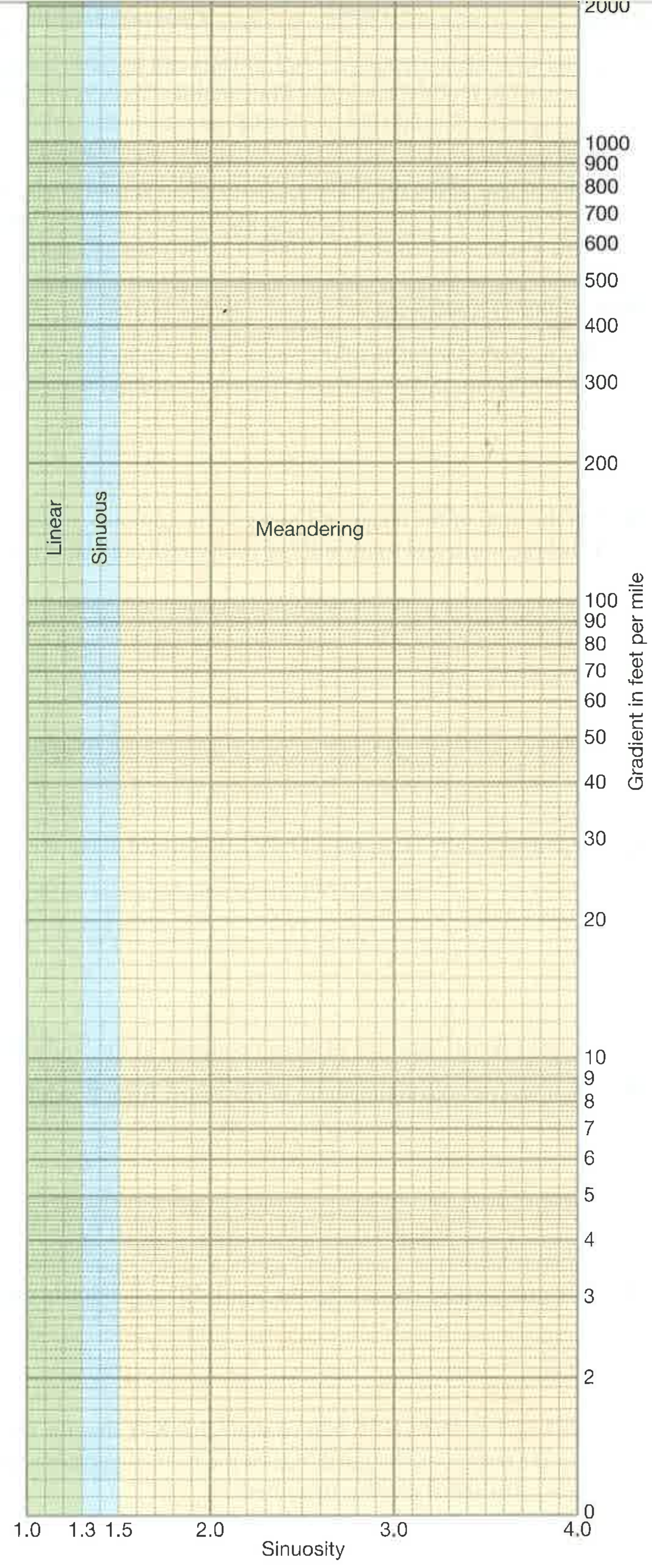
4. Observe Cedar Creek on the map in part D2.
   a. What is its stream order classification at point L?

   b. What happens to that stream's gradient and order downstream, as it enters the alluvial fan, and how does this contribute to the formation of the alluvial fan?

E. On the semi-logarithmic graph paper provided at right, you can determine if a stream is linear, sinuous, or meandering by plotting a point based on the stream's gradient and sinuosity.

1. Plot points for the following streams, and draw a best-fit line through the points:
   - Stream segment A-B (Garvin Canyon stream) from part B4 of this activity
   - Stream segment C-D (Timber Canyon stream) from part B5 of this activity
   - Stream segment E-F (tributary of Passage Creek) from part C2
   - Stream segment G-H (Passage Creek) from part C3
2. Based on the summary graph that you just completed, is there a relationship between a stream's gradient and whether its channel is straight, sinuous, or meandering? If yes, then what is that relationship?

F. **REFLECT & DISCUSS** Compare the four landscapes that you studied in this activity. What factors determine the kind of drainage pattern that develops on a landscape and whether a stream is eroding bedrock or depositing sediment?



ACTIVITY 11.3 Escarpments and Stream Terraces

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

Associated with many streams are escarpments and terraces. Escarpments are long cliffs or steep narrow slopes that separate one relatively level part of the landscape from another. Terraces are long, narrow or broad, level surfaces bounded on one or both sides by an escarpment. Stream terraces parallel the stream The difference in elevation between two terraces can range from centimeters to tens of meters.

Refer to part of the the Voltaire, North Dakota quadrangle (orthoimage with topographic contours) in **FIGURE 11.7**. Glaciers (composed of a mixture of ice, gravel, sand, and mud) were present in this region at the end of the Pleistocene Ice Age. When the glaciers melted about 11,000–12,000 years ago, a thick layer of sand and gravel was deposited on top of the bedrock, and streams began forming from the glacial meltwater. Therefore, streams have been eroding and shaping this landscape for about 11,000–12,000 years.

A. The modern floodplain of the Souris River can be identified by its lush, dark green vegetation and blue meandering river. What other meandering stream features named in Figure 11.1C do you recognize in this image?

B. On the basis of the image and topographic contours, make a sketch, below, of a cross section of the landscape from **X** to **Y**. Label the north and south sides of your sketch, and label terraces with a "T" and escarpments with an "E."

C. Describe how the escarpments may have formed along the Souris River.

D. On your sketch, label the modern floodplain of the Souris River and record its width along line **X–Y**.

E. What was the maximum width of the Souris River floodplain in the past (measured along line **X–Y**) and how can you tell?

F. Give one possible reason why the Souris River floodplain was wider in the past.

G. **REFLECT & DISCUSS** Notice along line **X–Y** that the terrace on the south side of the Souris River is 30–40 feet higher than the terrace on the north side of the river. Suggest how these two different levels of terraces may have formed and which one is older based on your hypothesis.

ACTIVITY 11.4 Meander Evolution on the Rio Grande

Name: ______________________________ **Course/Section:** ______________________________ **Date:** __________

Refer to **FIGURE 11.8** showing the meandering Rio Grande, the river that forms the national border between Mexico and the United States. Notice that the position of the river changed in many places between 1936 (red line and leaders by lettered features) and 1992 (blue water bodies and leaders by lettered features). Study the meander terms provided in **FIGURE 11.8**, and then proceed to the questions below.

A. Study the meander cutbanks labeled **A** through **G.** The red leader from each letter points to the cutbank's location in 1936. The blue leader from each letter points to the cutbank's location in 1992. In what two general directions (relative to the meander, relative to the direction of river flow) have these cutbanks moved?

B. Study locations **H** and **I.**

1. In what country were **H** and **I** located in 1936?

2. In what country were **H** and **I** located in 1992?

3. Explain a process that probably caused locations **H** and **I** to change from meanders to oxbow lakes.

C. Based on your answer in item B3, predict how the river will change in the future at locations **J** and **K.**

D. What are features **L, M,** and **N,** and what do they indicate about the historical path of the Rio Grande?

E. What is the average rate at which meanders like **A** through **G** migrated here (in meters per year) from 1936 to 1992? Explain your reasoning and calculations.

F. **REFLECT & DISCUSS** Explain in steps how a meander evolves from the earliest stage of its history as a broad slightly sinuous meander to the stage when an oxbow lake forms.

ACTIVITY 11.5 Mass Wastage at Niagara Falls

Name: ____________________ **Course/Section:** ____________________ **Date:** __________

A. Geologic evidence indicates that the Niagara River began to cut its gorge (Niagara Gorge) about 11,000 years ago as the Laurentide Ice Sheet retreated from the area. The ice started at the Niagara Escarpment shown in **FIGURE 11.9** and receded (melted back) north to form the basin of Lake Ontario. The Niagara Gorge started at the Niagara Escarpment and retreated south to its present location. Based on this geochronology and the length of Niagara Gorge, calculate the average rate of falls retreat in cm/year. Show your calculations.

B. Name as many factors as you can that could cause the falls to retreat at a faster rate.

C. Name as many factors as you can that could cause the falls to retreat more slowly.

D. Niagara Falls is about 35 km north of Lake Erie, and it is retreating southward. If the falls was to continue its retreat at the average rate calculated in **A,** then how many years from now would the falls reach Lake Erie?

E. **REFLECT & DISCUSS** Look at the cross section of Niagara Falls in **FIGURE 11.10**. Describe how the process that formed the falls could have begun. (Hint: Use your knowledge of stream erosion and the effects of stream gradient.)

ACTIVITY 11.6 Flood Hazard Mapping, Assessment, and Risk

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. On the Montezuma, Georgia topographic map below, locate the gaging station on Flint River in the map center. The gaging station is located at an elevation of 255.83 feet above sea level, and the river is considered to be at flood stage when it is 20 feet above this level (275.83 feet). A July 1994 flood established a record at 35.11 feet above the gaging station, or 289.94 feet above sea level. This corresponds to the 290-foot contour line on the map. Trace the 290-foot contour line on both sides of the Flint River and label the area within these contours (land lower than 290 feet) as "1994 Flood Hazard Zone."

(Courtesy of USGS)

B. Name two human structures that were submerged by the flood and tell what effect that would have had on the environment and human quality of life after the flood.

C. Notice line **X–Y** near the top center part of the topographic map in part A.

1. The map shows the Flint River at its normal stage. What is the width (in km) of the Flint River at its normal stage along line **X–Y?**

2. What was the width of the river (in km) along this line when it was at maximum flood stage (290 feet) during the July 1994 flood?

D. Notice the floodplain of the Flint River along line X–Y on the map in part A. It is the relatively flat (as indicated by widely spaced contour lines) marshy land between the river and the steep (as indicated by more closely spaced contour lines) walls of the valley (escarpments) that are created by erosion during floods.

1. What is the elevation (in feet above sea level) of the floodplain at point Z near line **X–Y?**

2. How deep (in feet above sea level) was the water that covered that floodplain at point Z during the 1994 flood? (Explain your reasoning or show your mathematical calculation.)

3. Did the 1994 flood (i.e., the highest river level ever recorded here) stay within the floodplain and its bounding valley slopes? Does this suggest that the 1994 flood was of normal or abnormal magnitude (severity) for this river? Explain your reasoning.

E. The USGS recorded annual high stages (elevation of water level) of the Flint River at the Montezuma gaging station for 99 years (1897 and 1905–2002). Parts of the data have been summarized in the Flood Data Table ahead on the next page.

1. The annual highest stages of the Flint River (S) were ranked in severity from S = 1 (highest annual high stage ever recorded; i.e., the 1994 flood) to S = 99 (lowest annual high stage). Data for 14 of these ranked years are provided in the Flood Data Table and can be used to calculate recurrence interval for each magnitude (rank, S). **Recurrence interval** (or **return period**) is the average number of years between occurrences of a flood of a given rank (S) or greater than that given rank. Recurrence interval for a rank of flood can be calculated as: $RI = (n + 1)/S$. Calculate the recurrence interval for ranks 1–5 and write them in the table. This has already been done for ranks of 20, 30, 40, 50, 60, 70, 80, 90, and 99.
2. Notice that a recurrence interval of 5.0 means that there is a 1-in-5 probability (or 20% chance) that an event of that magnitude will occur in any given year. This is known as a *5-year flood*. What is a *100-year flood?*

3. Plot (as exactly as you can) points on the flood magnitude/frequency graph (below the Flood Data Table) for all 14 ranks of annual high river stage in the Flood Data Table. Then use a ruler to draw a line through the points (and on to the right edge of the graph) so the number of, or distance to, points above and below the line is similar.
4. Your completed flood magnitude/frequency graph can now be used to estimate the probability of future floods of a given magnitude and frequency. A 10-year flood on the Flint River is the point where the line in your graph crosses the flood frequency (RI, return period) of 10 years. What is the probability that a future 10-year flood will occur in any given year, and what will be its magnitude (river elevation in feet above sea level)?

5. What is the probability for any given year that a flood on the Flint River at Montezuma, GA will reach an elevation of 275 feet above sea level?

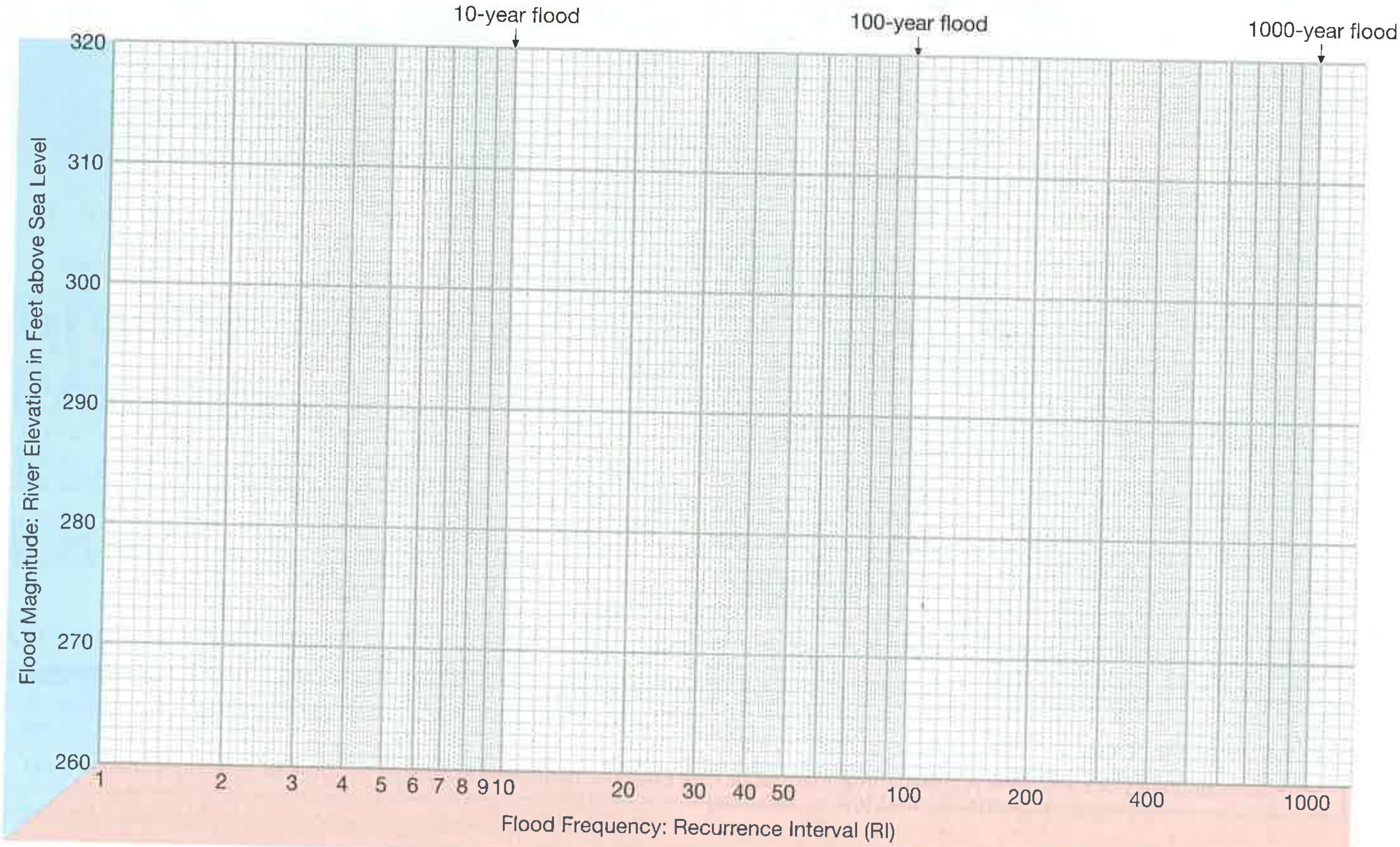
F. Most homeowners insurance policies do not insure against floods, even though floods cause more damage than any other natural hazard. Homeowners must obtain private or federal flood insurance in addition to their base homeowners policy. The National Flood Insurance Program (NFIP), a Division of the Federal Emergency Management Agency (FEMA), helps communities develop corrective and preventative measures for reducing future flood damage. The program centers on floodplain identification, mapping, and management. In return, members of these communities are eligible for discounts on federal flood insurance. The rates are determined on the basis of a community's FIRM (Flood Insurance Rate Map), an official map of the community on which FEMA has delineated flood *hazard areas* and *risk premium zones* (with discount rates). The hazard areas on a FIRM are defined on a *base flood elevation* (BFE)—the computed elevation to which flood water is estimated to rise during a *base flood.* The regulatory-standard base flood elevation is the 100-year flood elevation. Based on your graph, what is the BFE for Montezuma, GA?

Flood Data Table

Recurrence Intervals for Selected, Ranked, Annual Highest Stages of the Flint River over 99 Years of Observation (1897 and 1905–2002) at Montezuma, Georgia (USGS Station 02349500, data from USGS)

Rank of annual highest river stage (S)	Year (*n = 99)	River elevation above gage, in feet	Gage elevation above sea level, in feet	River elevation above sea level, in feet	Recurrence interval** (RI), in years	Probability of occurring in any given year	Percent chance of occurring in any given year***
1 (highest)	1994	34.11	255.83	289.9		1 in 100	1%
2	1929	27.40	255.83	283.2		1 in 50	2%
3	1990	26.05	255.83	281.9		1 in 33.3	3%
4	1897	26.00	255.83	281.8		1 in 25	4%
5	1949	25.20	255.83	281.0		1 in 20	5%
20	1928	21.30	255.83	277.1	5.0	1 in 5	20%
30	1912	20.60	255.83	276.4	3.4	1 in 3.4	29%
40	1959	19.30	255.83	275.1	2.3	1 in 2.3	43%
50	1960	18.50	255.83	274.3	2.0	1 in 2	50%
60	1934	17.70	255.83	273.5	1.8	1 in 1.8	56%
70	1974	17.25	255.83	273.1	1.5	1 in 1.5	67%
80	1967	14.76	255.83	270.6	1.3	1 in 1.3	77%
90	1907	13.00	255.83	268.8	1.1	1 in 1.1	91%
99 (lowest)	2002	8.99	255.83	264.7	1.0	1 in 1	100%

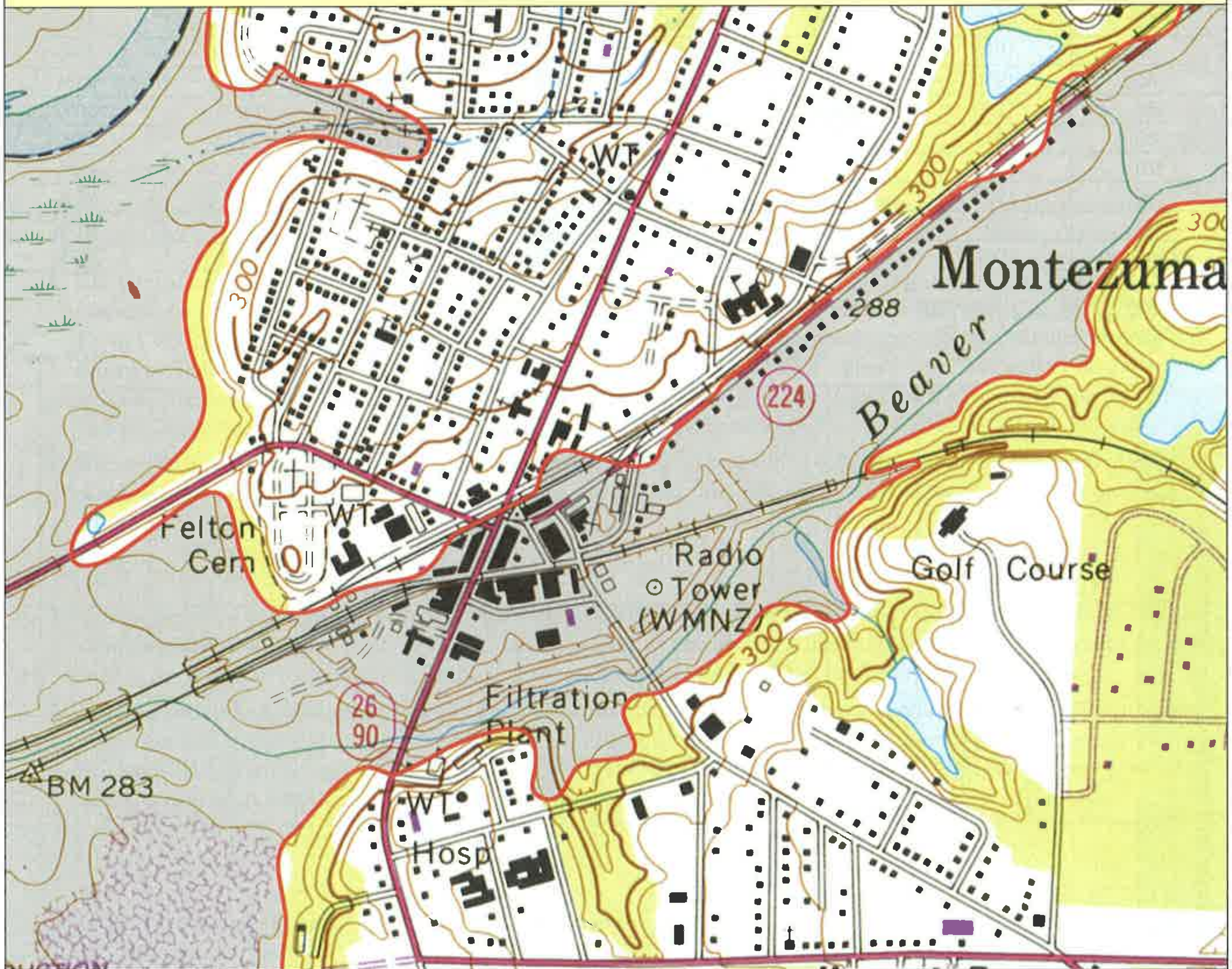
*n = number of years of annual observations = 99
**Recurrence Interval (RI) = (n + 1) / S = average number of years between occurrences of an event of this magnitude or greater.
***Percent chance of occurrence = 1 / RI x 100.



G. **REFLECT & DISCUSS** The 1996 FEMA FIRM for Montezuma, Georgia, shows hazard areas designated *zone A*. Zone A is the official designation for areas expected to be inundated by 100-year flooding even though no BFEs have been determined. The location of zone A (shaded gray) is shown on the Flood Hazard Map of a portion of the Montezuma, GA 7.5 minute map below. Your work above can be used to revise the flood hazard area. Place a dark line on this map (as exactly as you can) to show the elevation contour of the BFE for this community (your answer in item **F**). Your revised map reflects more accurately what area will be inundated by a 100-year flood. In general, how is the BFE line that you have plotted different from the boundary of zone A plotted by FEMA on its 1996 FIRM?

Flood Hazard Map

Portion of Montezuma, Georgia U.S.G.S. 7 1/2 Minute Topographic Quadrange Map Shaded Gray to Show FEMA FIRM Zone A (area inundated by 100-year flooding) as Adapted From FEMA FIRM # 13193C0275D (1996)



Scale 1:12,000
Contour Interval = 10 feet

0 — 1 km

= Boundary of FIRM Zone A (FEMA FIRM #13193C0275D; Effective 1996) (area inundated by 100-year flooding is shaded gray)

ACTIVITY

14.4 Dryland Lakes of Utah

THINK About It **How can topographic maps and aerial photographs of drylands be used to interpret how their environments have changed?**

OBJECTIVE Analyze a stereogram and topographic map of the Utah desert to evaluate the history of Lake Bonneville.

PROCEDURES

1. **Before you begin**, read Dryland Lakes below. Also, this is **what you will need:**
   ____ colored pencils
   ____ Activity 14.4 Worksheet (p. 373) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.

raises the level of the lake. Therefore, the level of Great Salt Lake has varied significantly in historic times over periods of months, years, and decades. During one dry period of many years, people ignored the dryland hazard of fluctuating lake levels and constructed homes, roads, farms, and even a 2.5-million-dollar resort, the Saltair, near the shores of Great Salt Lake. When a wet period occurred from 1982–87, many of these structures (including the resort) were submerged. The State of Utah installed huge pumps in 1987 to pump lake water into another valley, but the pumps were left high and dry during a brief dry period that lasted for 2 years (1988–89) after they were installed.

Geologic studies now suggest that the historic fluctuations of Great Salt Lake are minor in comparison to those that have occurred over millennia. Great Salt Lake is actually all that remains of a much larger lake that covered 20,000 square miles of Utah—Lake Bonneville. Lake Bonneville reached its maximum depth and geographic extent about 17,000 years ago as glaciers were melting near the end of the last Ice Age. One arm of the lake at that time extended into Wah Wah Valley, Utah, which is now a dryland (**FIGURE 14.8**).

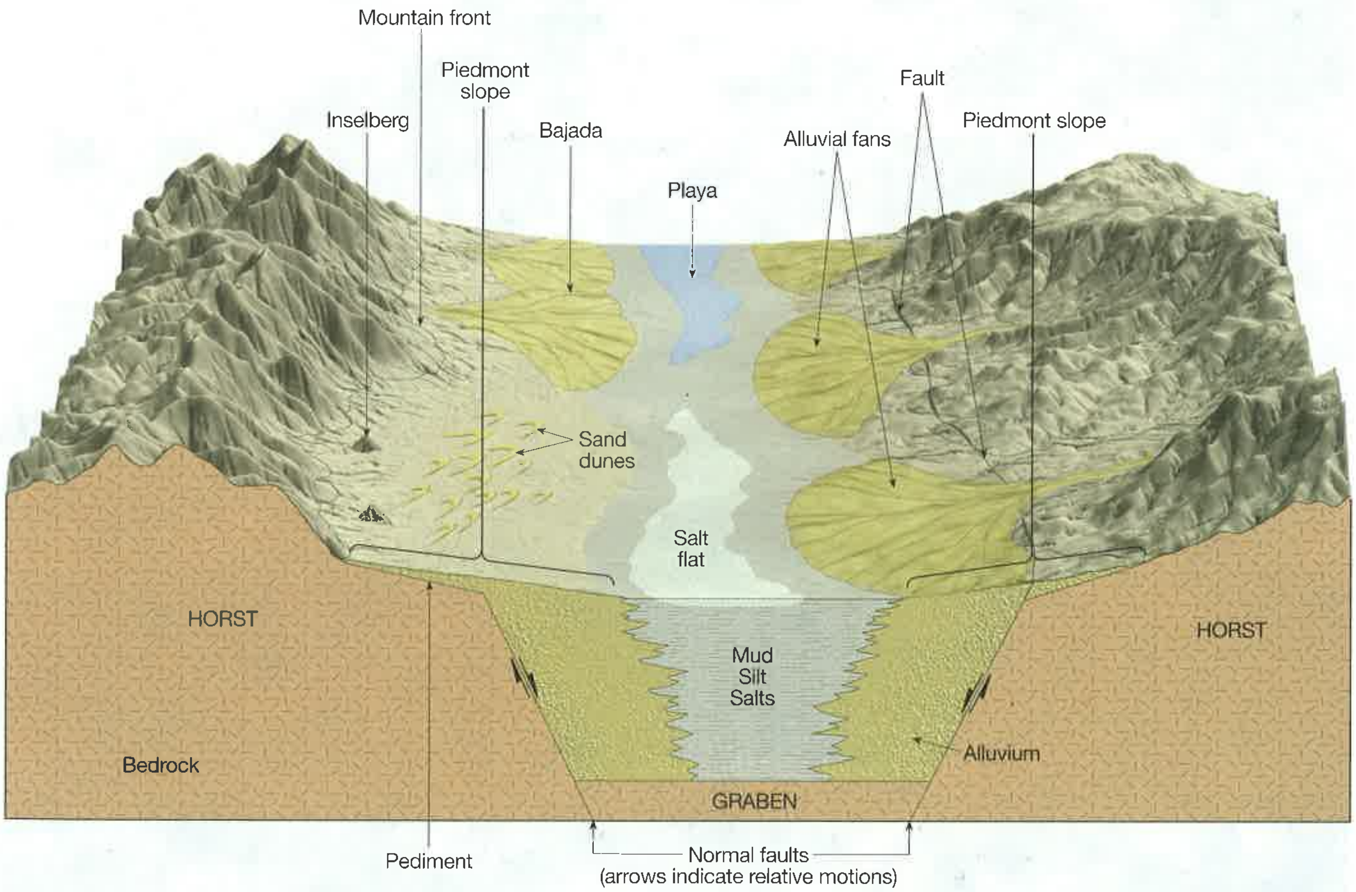


FIGURE 14.7 Landforms of mountainous drylands. These landforms are typical of arid mountainous deserts in regions of the southewestern United States, where Earth's crust has been lengthened by tensional forces (pulled apart). Mountain ranges and basins develop by **block faulting**—a type of regional rock deformation where Earth's crust is broken into fault-bounded blocks of different elevations. The higher blocks form mountains called *horsts* and the lower blocks form valleys called *grabens*. Note that the boundaries between horsts and grabens are typically normal faults. Sediment eroded from the horsts is transported into the grabens by wind and water. **Alluvial fans** develop from the mountain fronts to the valley floors. They may surround outlying portions of the **mountain fronts** to create **inselbergs** (island-mountains). The fans may also coalesce to form a **bajada.** In cases where there is no drainage outlet from the valley, the valley is a closed basin from which water can escape only by evaporation. Because rain is infrequent in drylands, the lakes that form are temporary (**playas**). When they evaporate, all that is left is a **salt flat** (a patch of level land that is encrusted with salt.). Wind blowing over the valleys can form **sand dunes** made of salt crystals or muineral grains eroded from bedrock (usually quartz sand).