ES 473 – Environmental Geology

Dr. Taylor
Spring 2013
Midterm Digital Lab Report

Prepared By: Kathryn Roberts
May 9, 2013

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Task 1-1

Registration for Association of Engineering and Environmental Geologists

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Task 1-2

Review Questions for Introductory Video on Hanford

Kathryn Roberts April 2, 2013
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Video 1: La Loma Prieta Earthquake

1. Where was the earthquake and how large was it?
2. The tectonics of what two plates was the Loma Prieta Quake a result of?
3. What was the magnitude of the Earthquake?
4. Where was the epicenter of the earthquake located?
5. How far below the ground was the fault movement?
6. How far was the damage felt from the epicenter?
7. Why must geologists get out and explore the surrounding areas of land quickly after an earthquake?
8. What is the most important information to get out to the public after an earthquake?
9. Describe the movement of the plates that caused the earthquakes.
10. Why was the shaking in the "marina area" much worse than other places?
11. Why was the Bay Area so susceptible to damage from an earthquake?
12. What can we do to make old and new buildings safe?
13. What can we do to prepare for earthquakes?

Video 2: Hanford Nuclear Cleanup

1. What was the nuclear plant built for?
    a. Making plutonium for atomic bombs
2. Why was Hanford such an ideal place to build this nuclear facility?
    a. It was a secure location, isolated, had an abundant supply of water, and had a low population
3. What does the "Deadly Mile" refer to?
    a. Area of farms that is downwind of Handford
4. Did the government know what the long term effects would be to the area?
    a. They knew how much they were dumping, but did not anticipate the duration of production after WWII (through Korean, Vietnam, Cold Wars)
5. How many radioactive reactors are there?
    a. 9
6. How many tons of possibly lethal fuel is sitting in the basins?
    a. 2,000 metric tons
7. What is the major issue that still poses a threat to the water table?
    a. Leaks in the tanks that contain the most dangerous (both hazardous and radioactive) material that sit approximately 200ft above the water table
8. What are downwinders?
    a. Those who live east or downwind of Handford and are at higher likelihood for radiation poisoning
9. Describe the Hanford site. Include the 100 zone, 200 zone, and buffer zones.
    a. 100 area = eastern bend of Columbia, border of Handford site
    b. 200 area = high ground where plutonium was actually extracted (2% of total site), toughest cleanup problems, with both waste and contaminated soil
    c. Buffer area = security areas that are virtually pristine and untouched as preserves
10. Are there effects on the Columbia River ¼ mile away from the plant? Explain.
    a. Yes, the lethal fuel is stored near it, which is stored in open containers that are subject to corrosion and leaking

  b. After WWII, radiation showed in fish as far as caught in the Pacific Ocean, since 1970s, monitoring shows much lower (and safe) levels of radiation
  c. Some radiation enters the river indirectly in a lower flow
11. Why can’t we just leave the waste there and lock up the area?
  a. The tanks may leak and will eventually seep into the air, soil, or water
12. Who is involved in the decision of cleaning up? What are researchers doing in order to attempt to clean up this highly contaminated area?
  a. Fed EPA
  b. Fed DOE
  c. Washington State Dept. of Ecology

Long Answer Essay Questions

A. How do each of the video presentations relate to humans, and their respective ecosystem, to geologic principles and processes?

The second video is an example of how humans can influence the environment at an extreme scale. The Hanford Nuclear Site represents some of the most intense environmental degradation done by humans. Though not directly intentioned to harm the environment, Hanford represents an example of what happens when humans do not directly consider their environment as part of normal planning routines. Hanford was distinctly planned without regard to the potential environmental impacts (not all impacts were even fully understood or even anticipated). As a result, the severity of the environmental degradation was significantly heightened and was allowed to be magnified as the problem was subsequently ignored for a long time even after degradation began, and successful remediation is still elusive as even after active contamination has ceased, full understanding is not known.

B. Compare and contrast the video clips to one another. How are humans and the Earth interacting with one another in each case study?

N/A

Task 1-3

Summary of DOGAM Special Paper 32
Geologic Hazards in Oregon

Kathryn Roberts April 5, 2013
ES 473 – Environmental Geology

Summary – "Geologic Hazards: Reducing Oregon's Risks"

In Special Paper 32, authors Beaulieu and Olmstead provide a summary of Special Paper 31, a technical resource manual which details the geologic hazards of Oregon and how the risks associated with each of these hazards can be reduced. Oregon encompasses some of the most varied terrains and includes among the widest variety of geologic hazards of any US state. The Oregon Department of Geology and Mineral Industries (DOGAMI) serves as the state's primary agency for technical information on Oregon's geologic hazards and risk management strategies. Through technical study, planning, and coordination, risks from geologic hazards can be reduced to acceptable levels relative to cost/benefit calculations.

Oregon Hazards and How to Reduce Their Risk

The tectonic and geologic setting of Oregon allows for an array of hazards, including: floods, landslides, debris flows, erosion, volcanic eruptions, earthquakes, and tsunamis. Each hazard is unique in target area (i.e. some regions are more prone to flooding than others), frequency, and scope of impact. Thus different strategies of risk management are needed for each type of hazard and each region dealing with a hazard. However, Beaulieu and Olmstead note that despite the variance in hazards, there are several key components to risk management that are universal. Core steps for reducing risk of hazards includes: "Properly characterizing the hazard; constructing a team to develop strategies; considering a range of strategies to address the risk; making an informed selection of strategies from a broad range of choices; and permanently integrating the strategies to assure ongoing success" (p. 2).

History of Geologic Hazards in Oregon

In Appendices 1-3, Beaulieu and Olmstead document the range of hazard types, the specific disasters in recent Oregon history, and the damage assessment and cost for each of the disasters.

Oregon's geologic hazards are significant and have been clearly evidenced through a number of natural disasters going back approximately 200 years including landslides, debris flows, earthquakes, tsunamis, volcanic eruptions, and coastal erosion. In tabulated form, the appendices also note the range of frequency (from ongoing with coastal erosion, to 300-600 years with subduction zone earthquake) that is an important factor when considering risk management strategies. Also crucial in deciding risk management strategies is a comparable impact in terms of lives and cost (which ranges from no loss of life and minimal cost for stream bank erosion, to major loss of life and tens of millions annually cost for landslides).

How Hazards are Studied and Who is Responsible

The next step for proper risk reduction is adequate hazard characterization and study. Beaulieu and Olmstead itemize the various methodologies that are commonly used to assess each hazard and its associated risk and also delineate the various agencies and groups that may be put in charge of each characterization based on their relative strengths and weaknesses. Each type of hazard is assessed in a unique way that is specifically applicable. For example, regional evacuation maps are a needed tool for tsunamis, but serve little purpose for hazards like earthquakes. Similarly, each invested group holds specific advantages in some areas of study, but are lacking in adequacy for all areas. For example, local cities and councils are considered central for planning, and have the strengths of access to special funding from the federal government and the desire to address the local problem with having to live with the risk, but suffer from the lack of technical experience that other agencies have in abundance. By assessing each group's strengths and weaknesses, the core step of an effective team assemblage can be carried out.

Range of Risk Reduction Strategies

Beaulieu and Olmstead conclude their summary with an itemized table of the range of potential strategies that can be undertaken to reduce the risk of geologic hazards, which group would need to lead the specific strategy, and how the strategy would work to reduce the risk. The authors note that these strategies are generalized policy approaches which may be adapted for any of several hazards, but is likely more applicable to some than others. Additionally, the range of strategies varies from non-action (which may be appropriate for hazards of low frequency and impact) to mandatory action enforced by government policy (which may be necessary for high risk and high frequency hazards). Each strategy comes with a trade-off of risk reduction to cost (both in terms of implementation and limitation or restriction of personal freedoms like property rights), which must be balanced by an informed consensus agreement.

Though Oregon has many geologic hazards, through the core steps outlined by DOGAMI, the risk of each of these hazards can be successfully managed to acceptable levels.

Task 1-4

Hydrology problems 1-5 / isohyet map exercise p.14

1-5 and map on back 04/04/13

PROBLEMS

Answers to odd-numbered problems will appear at the end of the book.

See attached page

1. A farmer has a reservoir with vertical sides and a surface area of 2.5 ac. Following the rainy season, the reservoir is filled to a depth of 3.0 m. During the dry season the reservoir loses 2.5 in. of water per week (wk) to evaporation. If the average irrigation demand during the dry season is 0.23 ac-ft per day, for how many weeks can the farmer irrigate from the reservoir?
2. How long must a pump with a capacity of 12 gal/min pump to fill a tank with a capacity of 37 m^3?
3. A circular water transmission pipe has a diameter of 1.0 ft and is 8.3 mi long. How much water does it take to fill the pipe?
4. If the water is flowing into the pipe of Problem 3 at a velocity of 1.3 feet per second (ft/s), what is the rate at which the pipe is transmitting water?
5. A small urban watershed has an area of 16.34 mi^2. A summer storm drops an average of 1.50 in. of rain over the entire watershed. If 50% of the rainfall runs off the watershed into surface-water bodies, what is the volume of runoff:
   A. In cubic inches?
   B. In cubic feet?
   C. In cubic meters?

1.1. The annual evaporation from a lake, with a surface area of 1600 hectares, is 3 meters. Determine the average daily evaporation rate in hectare-centimeters per day during the year.

1.2. Rainfall takes place at an average intensity of 1 cm/h over a 250-hectare area for 3 days. Determine the average rate of rainfall in cubic meters per second (m^3/s). Determine the 3-day volume of rainfall in hectare-cm and hectare-meters. Also determine the 3-day volume of rainfall in centimeters of equivalent depth over the 250-hectare area.

1.3. Water is to be supplied from a reservoir fed by a stream with a discharge of 2 m^3/s to meet domestic requirements of an area with a population of 150,000. The average daily consumption is 300 liters per person. The lowest discharge of the stream is 0.25 m^3/s for a period of 15 days. Determine the reservoir size in km^3 and the rate of outflow when the reservoir is full.

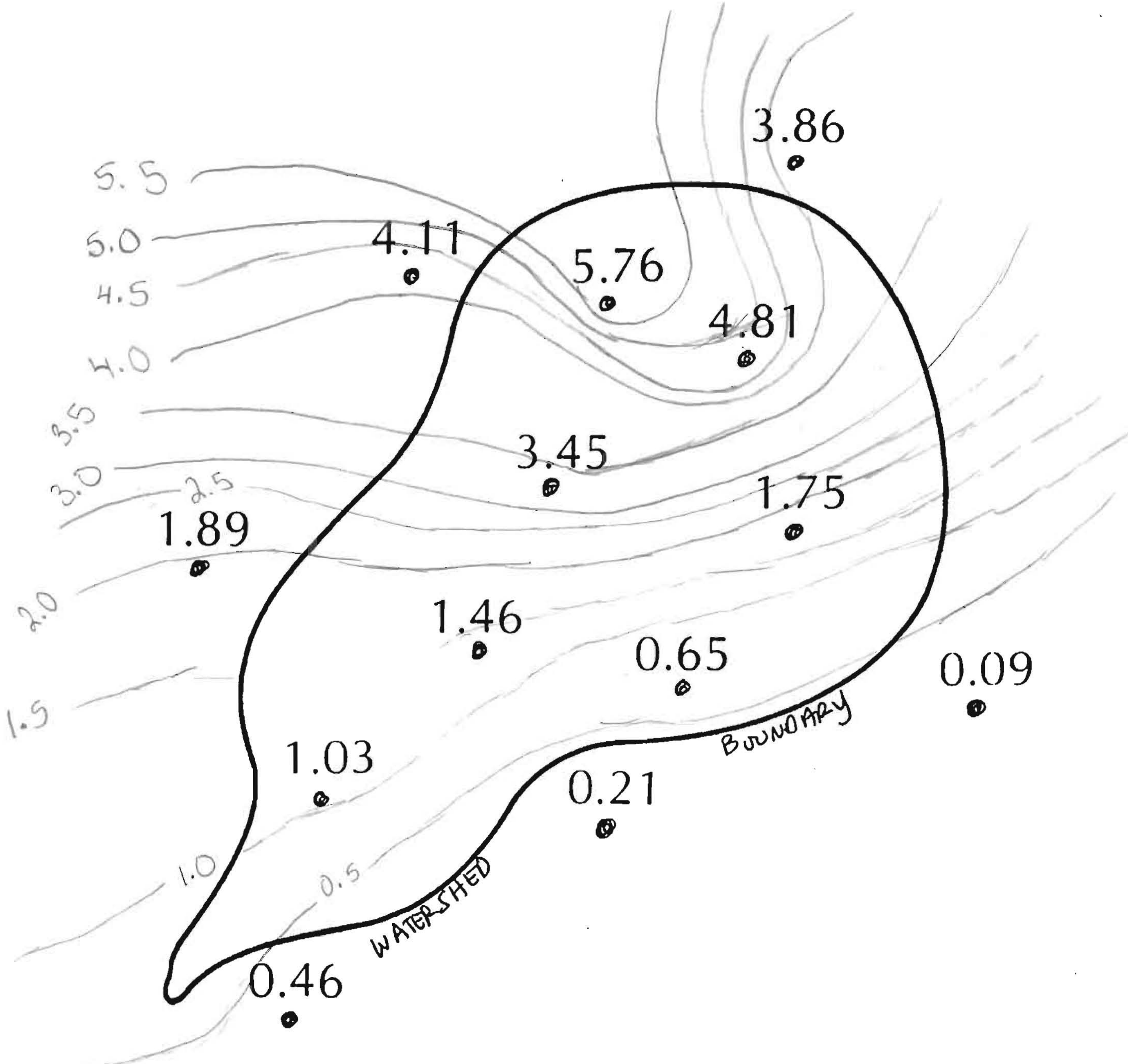
1.4. Compute the time required to fill the reservoir in Exercise 1.3 when the demand of the population is being simultaneously fed by the stream and the reservoir is empty after a drought period. The stream discharge is 1.75 m^3/s.

1.5. An area is being irrigated by a stream with a drainage area of 300 km^2. The drainage area contribution is 0.1 $m^3/s/km^2$. Determine the discharge of the channel and the area irrigated if 0.37 m^3/s are required per 1000 hectares.

1.6. The average monthly precipitation in a watershed of 4500 km^2 is 46 cm. If the cumulative losses are 20% of precipitation, determine the area of Exercise 1.5 that can be irrigated with the remaining water. Also calculate the channel discharge.

1.7. Estimate the storage capacity of a reservoir for Exercise 1.6 when the average precipitation is 28 cm for a period of 20 days. The area calculated above is to be continuously supplied with its full demand.

1.8. Water is to be supplied to an area for both domestic and agricultural purposes. The population is 200,000 and the area to be irrigated is 3600 hectares. Water is to be pumped from the river. If the average daily consumption is 320 liters per person and the agricultural demand 0.33 $m^3/s/1000$ hectares, find the number of pumps required when 30% of the pumps are required to be standby. Also calculate the minimum discharge in the river to meet the above demand. The individual pump capacity is 0.1 m^3/s.



The map above shows an outline of a drainage basin or watershed. The data points represent locations of rain gage stations. The numbers show the total 24-hour rainfall amounts (inches) for each station. Draw an isohyetal contour map (contour map with lines connecting points of equal rainfall) using a contour interval of 0.5 inches (i.e. draw contour lines for the following isohyets: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5). Remember to follow the rules of contour and to interpolate the lines between data points as necessary.

Calculate the following data parameters for the watershed:

Maximum 24-hour Rainfall Recorded	5.76 in
Minimum 24-hour Rainfall Recorded	0.65 in
Average 24-hour Rainfall Recorded	2.70 in
Standard Deviation of 24-hour Rainfall Rec'd	1.99 in
Median of 24-hour Rainfall Recorded	1.75 in
Total Number of Gage Stations	7 stations

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ES473 Problems #1-5

1. SA = 2.5 ac → depth of 3.0 m

   loss rate = 2.5 in/week = .208 ft/week = .0298 ft/day

   demand = 0.23 ac-ft/day

   weeks = ?

   Volume of reservoir: $3.0\,m\left(\frac{3.28\,ft}{m}\right) = 9.84\,ft$ = depth

   depth × SA = Volume

   9.84 ft × 2.5 ac = 24.6 ac-ft

   time til dried from loss: $\frac{\text{depth}}{\text{loss rate}}$ $\frac{9.84\,ft}{.208\,ft/week}$ = 47.3 weeks = 331.1 days

   time til dried from demand: $\frac{\text{Volume}}{\text{demand}}$ $\frac{24.6\,ac\text{-}ft}{0.23\,ac\text{-}ft/day}$ = 106.9 days

   time = volume ÷ (demand + loss)

   day = $ac\text{-}ft \div \left(\frac{ac\text{-}ft}{day} + \frac{ft}{day}\right)$

   $= \frac{24.6\,ac\text{-}ft}{(.0298\,ft/day + 0.23\,ac\text{-}ft/day)} = \frac{24.6\,ac\text{-}ft}{.2598\,ac\text{-}ft/day} = \boxed{94.6\text{ days}}$

---

2. pump = 12 gal/min   1 gal = $3.78 \times 10^{-3}\,m^3$

   Capacity = 37 m^3 pump: $\frac{12\,gal}{min}\left(\frac{3.78\times10^{-3}\,m^3}{1\,gal}\right) = .04536\,m^3/min$

   time = $\frac{\text{capcity}}{\text{pump}}$

   $= \frac{37\,m^3}{.04536\,m^3/min} = 815.69\,min\left(\frac{hr}{60\,min}\right) = \boxed{13.6\,hr}$

---

3. diameter = 1.0 ft   length = 8.3 mi

   volume = $\pi r^2 l$ r = ½ diameter = 0.5 ft

   $l = 8.3\,mi\left(\frac{5280\,ft}{mi}\right) = 43824\,ft$

   volume = $\pi(0.5)^2 \cdot (43{,}824\,ft) = \boxed{34{,}419.3\,ft^3}$

---

4. velocity = 1.3 ft/sec $\frac{\text{volume}}{\text{time}} = \pi r^2 \cdot h$ r = .5 h = 1.3 ft/sec

   volume = 34,419.3 ft^3 $= \boxed{1.02\,ft^3/sec}$

   rate: ?

5. area = $16.34\ mi^2$

rain = 1.5 in over whole area, 50% runoff

area of rain fall = 1.5 in x 16.4 mi

$16.4\ mi^2 \left(\frac{5280\ ft}{mi}\right)^2 \left(\frac{12\ in}{1\ ft}\right)^2 = 6.5 \times 10^{10}$

A. area in^3 = $1.5\ in \times 6.5 \times 10^{10}\ in^2 = \boxed{9.88 \times 10^{10}\ in^3}$

B. area ft^3 = $9.88 \times 10^{10}\ in^3 \left(\frac{1\ ft^3}{12\ in^3}\right) = \boxed{5.67 \times 10^{7}\ ft^3}$

C. area m^3 = $5.67 \times 10^{7}\ ft^3 \left(\frac{0.02832\ m^3}{1\ ft^3}\right) = \boxed{1.61 \times 10^{6}\ m^3}$

Task 2-1

Review Questions for Mass Wasting Video

Part 16 - Earth Revealed - Mass Wasting

11. How many lives were taken as a result of the eruption and lahar at the volcano in Columbia? What types of hazards to human health and economy are associated with mass wasting processes?

21,000 people died

12. What is "mass wasting"? How does it relate to weathering?

downslope mov't earth material under gravity

13. List and discuss three factors that control mass wasting processes.

gravity, angle of slope, presence of water

14. What mass wasting process may transport material at greater velocities than debris flow?

fall/avalanche

15. What type of mass wasting causes the most annual economic damage in the U.S.?

Creep

7. List, discuss and summarize the 4 main types of mass wasting covered in the video. Explain what they are and how they work. Drawings are helpful.

types of mass wasting
- creep, slump (flow), slide, fall (avalanche)
  ↳ based on speed of movement from lowest to fastest

how mass wasting impacts humans/economics -

successful mitigation strategies
- releveling, de watering, buttressing, flood channels

8. Give three examples of how human land-use can enhance mass wasting processes.

Road building (putting fill dirt upslope of a landslide) in Portugese Bend, CA

building load weight on top of slide-prone land

not researching/ignoring geologic hazards when planning land use

9. What are the economic and social implications of mass wasting in urban and developed areas. Key your answer to how these factors might relate to Coastal Oregon.

Increased risk to society and increased cost of mitigation and/or emergency services/long-term cleanup

In coastal Oregon, after a major mass wasting event, the coastal community may be isolated from emergency crews as roads to/from the coast are likely to be impacted

Task 2-2

Landslide Lab Exercise Parts A and B

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Landslides and Avalanches Lab Part A and B

Part A

1. Yes, homes were damaged, evidenced by contours and scar from the mass wasting event.
2.

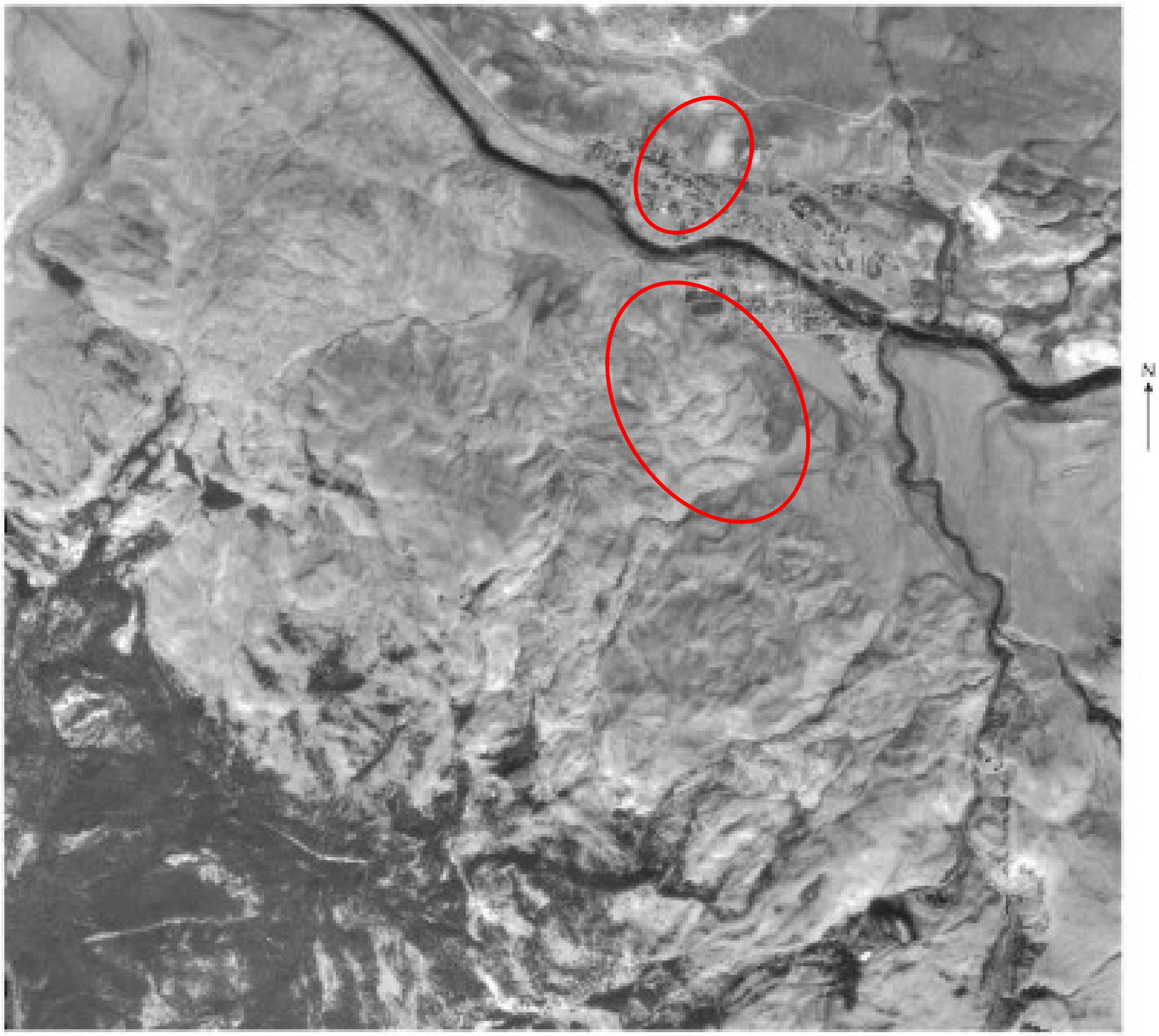

FIGURE 8.7 Landslides southwest of Gardiner, MT. See Figure 8.8. (USGS Digital Ortho Quarter Quad downloaded August 11, 2008, from http://nris.state.mt.us/nsdi/doq.asp?Srch24=4511016)

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3.

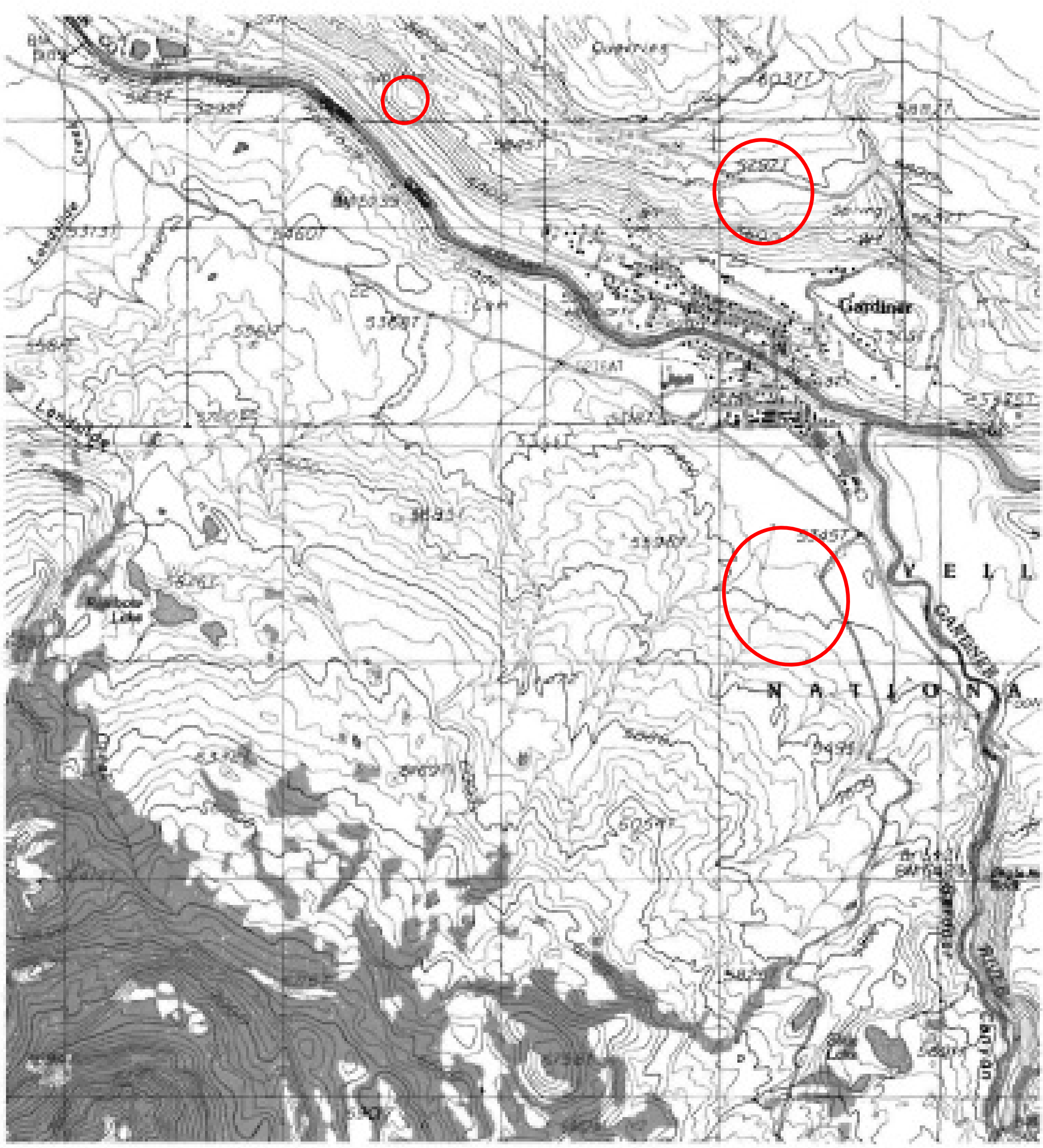

FIGURE 8.8 Gardiner, MT. Topographic map. Contour Interval = 40 ft. See Figure 8.7.

4. Features include crenulated contours, hummocky terrain, and landslide scaring (seen with lack of vegetation)

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5. Some features include lack of vegetation and slide scars

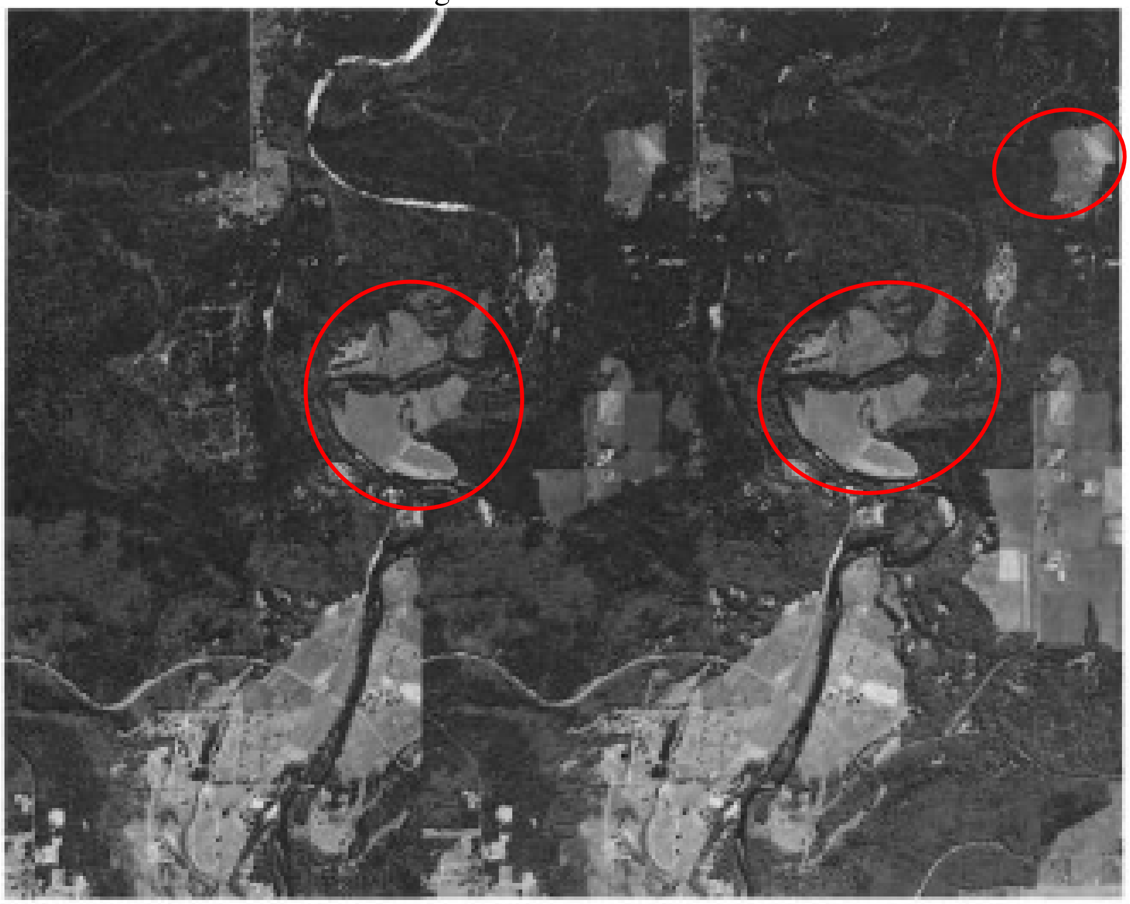

FIGURE 8.9 Stereo aerial photos of Green River Gorge, Washington. Photos courtesy of Washington Department of Transportation.

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6. Other indicators include steepness of topography and lobate topography

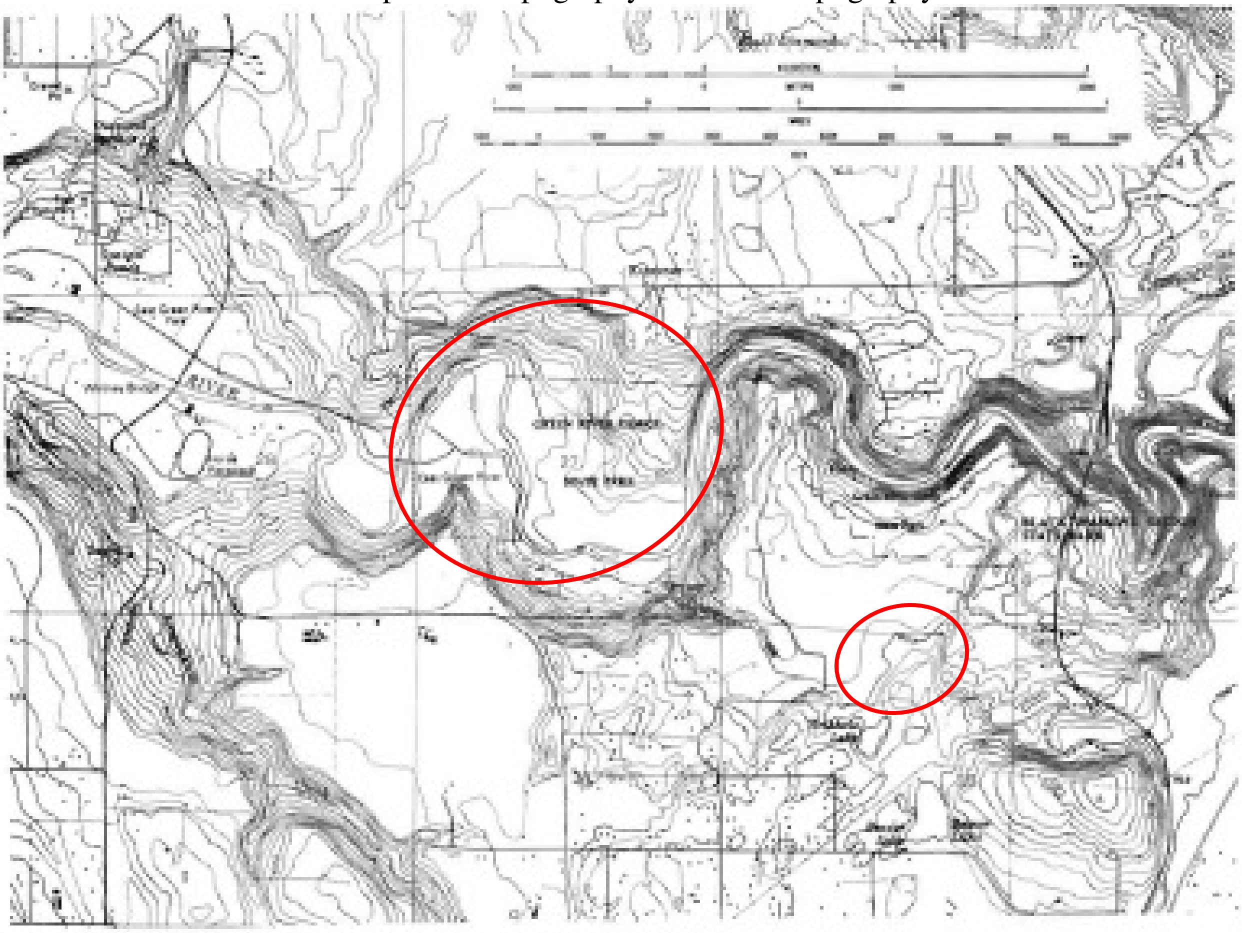
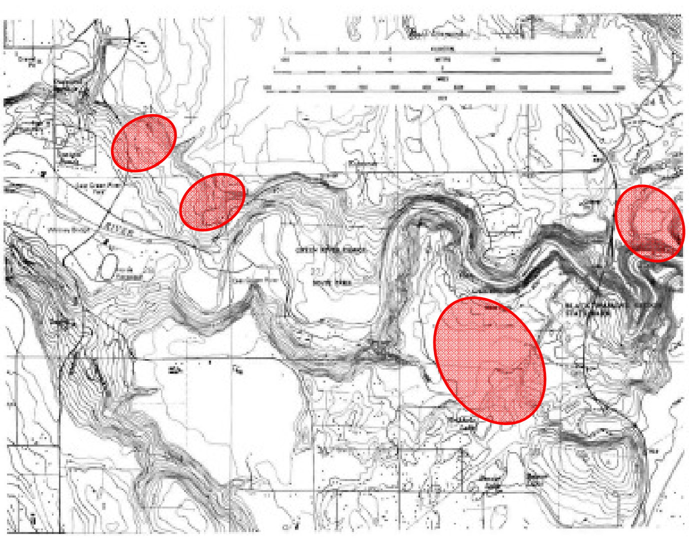


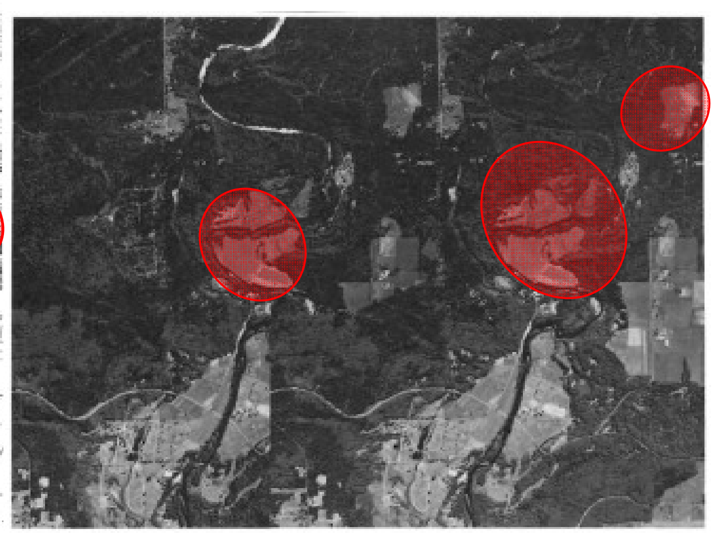
FIGURE 8.40 Topographic map, Green River Gorge. Contour interval = 25 ft.

7. Virtually removing vegetation allows for a clearer view of land scars that indicate a landslide. However, some vegetation trends (i.e. areas that show vegetation abruptly ending around one region) can also help indicate a landslide area.

FIGURE 8.11 Green River Gorge Lidar Image. (Courtesy of King County, Washington, GIS Center)

8. The landslides are easiest to see on LIDAR, next easiest on a topographic map and most difficult to interpret on an aerial photograph.





Part B

1. Contour intervals show lines of equal elevation across the terrain. Different contour intervals are used on different maps of the same area depending on the scale and the amount of detail shown on the map. (40 feet and 20 feet are the intervals on this map)

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2. M

FIGURE 8.12 Landslide and other surficial deposits in northeastern San Jose, California.
(Nilsen and Brabb, 1972).

3. The landslide material is primarily Qal, or alluvial deposits
4. Point A = 440ft. Point B = 280ft.   Difference = 160ft.

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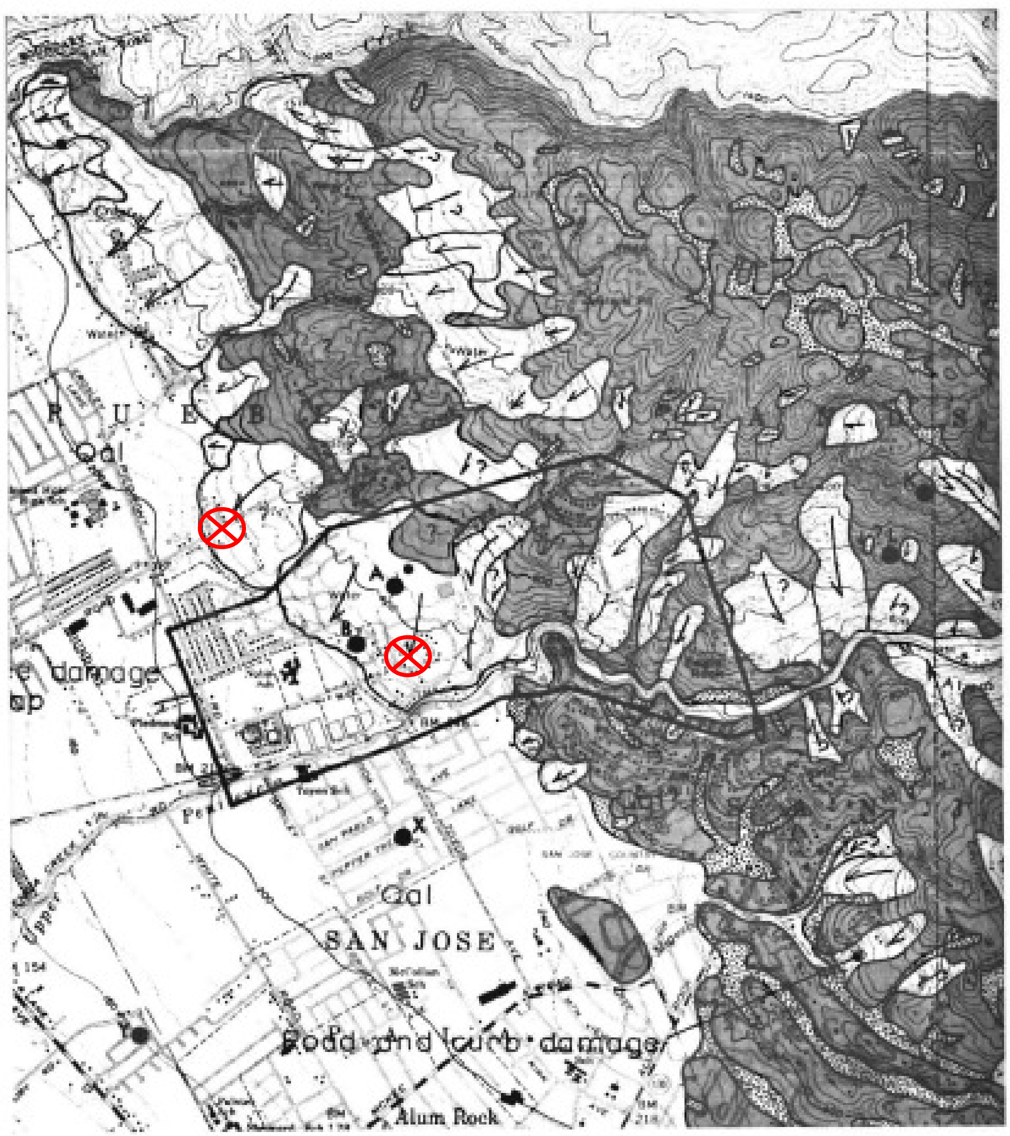
5. The distance between Point A and B is 0.2 miles.
6. Average gradient = 160ft. / 0.2 miles = 800ft./mile
7. Total Relief, X-Y = 70 ft. Total distance = 0.9 miles, Average gradient = 70ft./0.9miles = 77.8 ft./mile
8. The potential for landslides is greater at point X, because the slope is greater than at point K, which increases the likelihood of a landslide
9. QAL is Quaternary Alluvium, which is water transported sediments (primarily mud, silt, and sand) from the Quaternary time frame.
10. QAL is deposited by either directly fluvial processes (i.e. river or stream deposition) or by subsequent alluvial fan depositions.
11. QAF are man-made fills for highways, canals or other structural purposes, with the fill being generated from nearby cuts or quarries.
12. Areas with larger amounts of colluvial deposits are likely the result of mudflows



13. ~ 4000 feet
14. No, it is on the other side of the lobate toe of landslide deposits and is not sitting on a high enough relief area to have a landslide
15. Penetencia Creek Ave.
16. San Jose Highlands
17. No, it is on active landslide terrain

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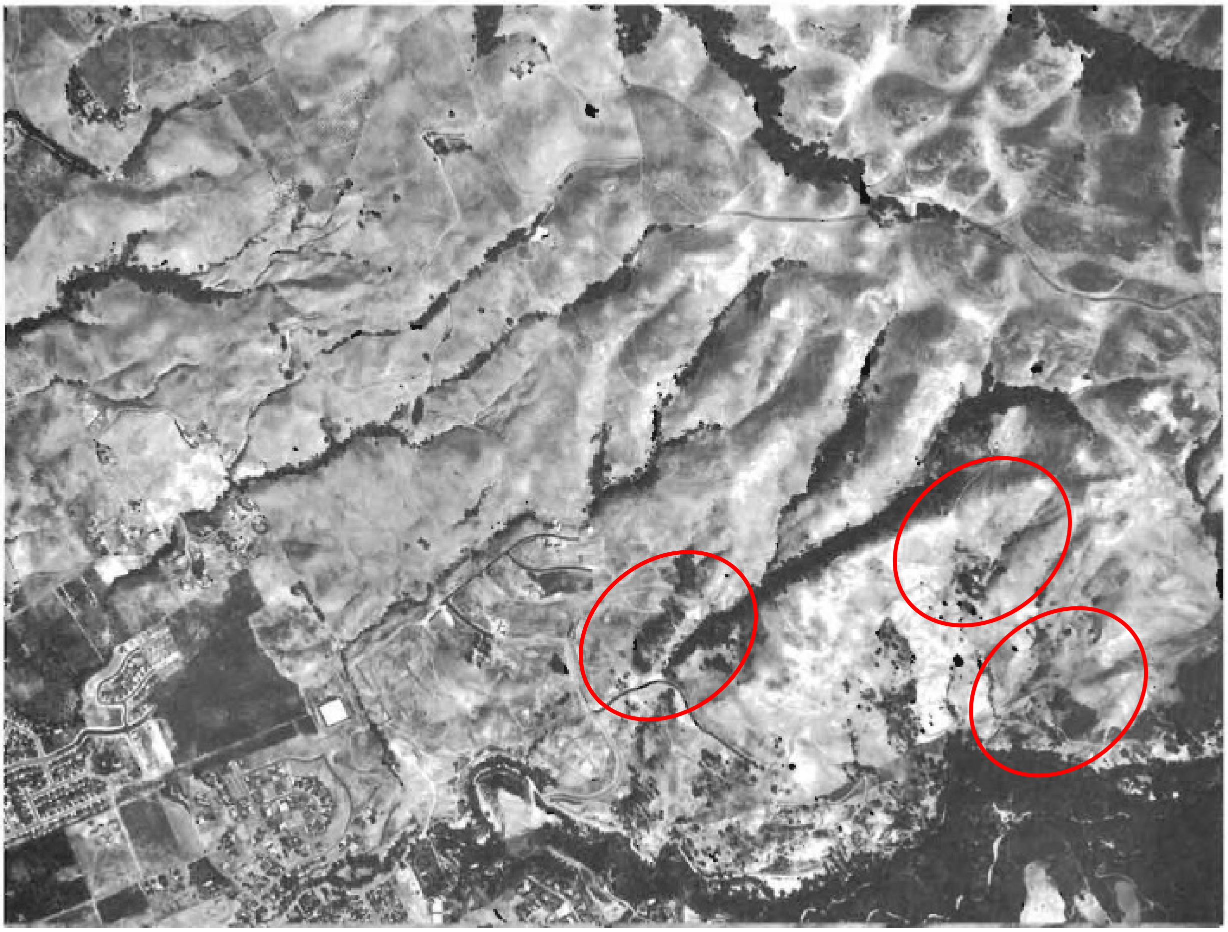
18. Because the land is not stable enough to permit underground utility lines

19. De-watering and perhaps building retaining walls may help stabilize the hillsides

20. 

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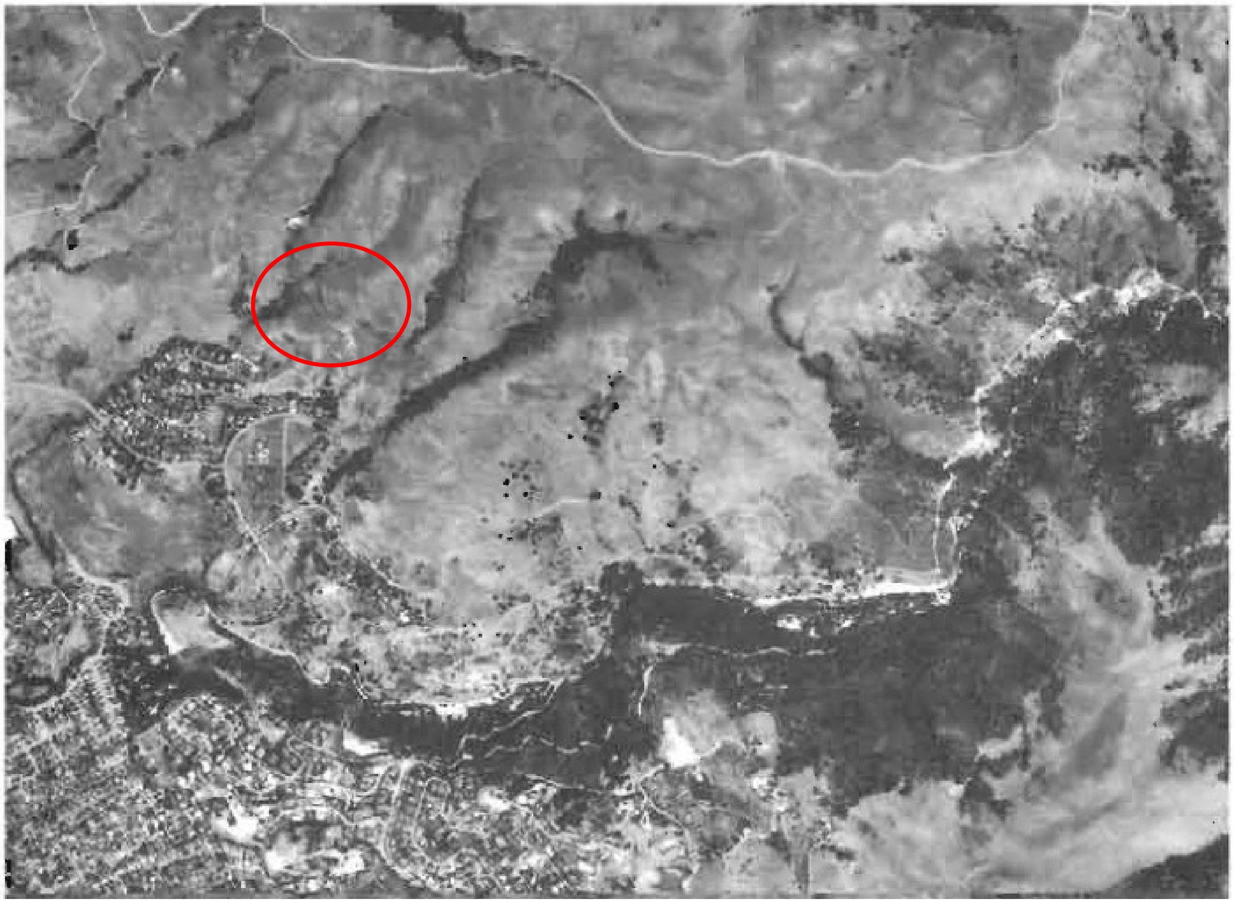
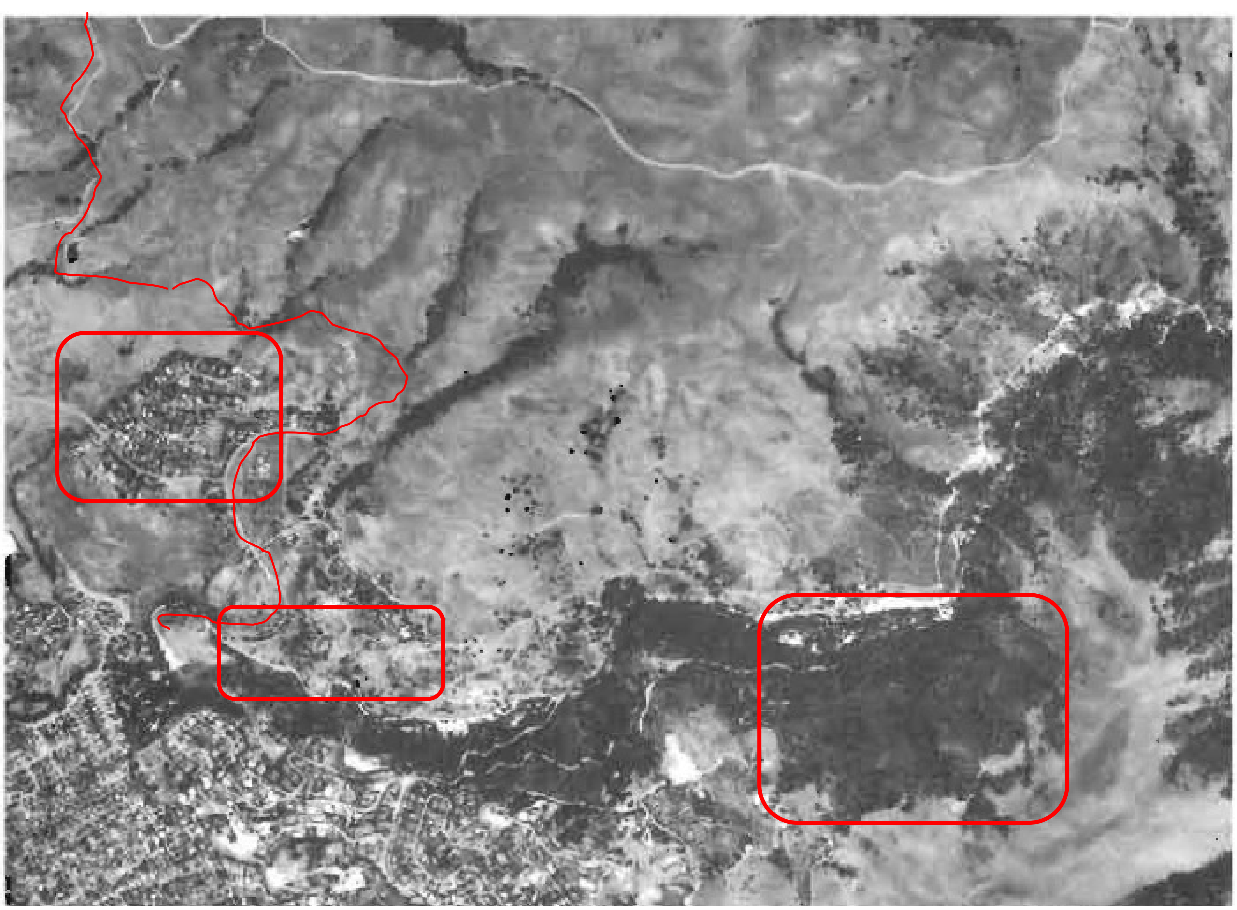


21.



22.

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23. See Figure Above

24. a. I would advise against building on a mountain site that has active landslides

    b. I would advise the local zoning commission to put significant barriers against building any residential or commercial buildings that would likely be difficult to insure and costly in a landslide disaster.

Task 2-3

Topographic Profile / Refresher Exercise

Exercise 7. Drawing Profiles from Topographic Maps

1. Draw a profile along line A–B of the topographic map in figure 2.8.
2. Refer to the Delaware Map of figure 2.12. Three north-south red lines and three east-west red lines intersect at approximately one-mile intervals. These north-south and east-west lines define the boundaries of *sections*. Each section is numbered, and the number is printed in red in the center of each section.

   On the grid of figure 2.11, draw a north-south profile (in pencil) along the red line that defines the western boundary of sections 10, 3, and 34. The beginning point of the profile is the southwest corner of section 10, and the ending point is the shore of Lake Superior, which has an elevation of 602 feet above sea level. (Part of Lake Superior is indicated along the northern part of the Delaware Map.) The vertical scale has been established as 0.1 inch = 40 feet. The horizontal scale is the same as the map scale. Significant features along the line of profile have already been labeled.
3. What is the horizontal scale of the profile in feet per inch?
4. What is the vertical scale of the profile you have drawn in feet per inch?
5. By what factor is the vertical scale exaggerated?
6. In order to visualize more clearly the effect of vertical exaggeration, redraw the profile using a vertical scale of 0.1 inch = 80 feet. Use the grid in figure 2.11 and label the horizontal lines (according to the new scale) on the right-hand margin of the grid. The horizontal line now labeled 600 feet will be labeled 800, and the line now labeled 800 will be 1,200 on the new scale.

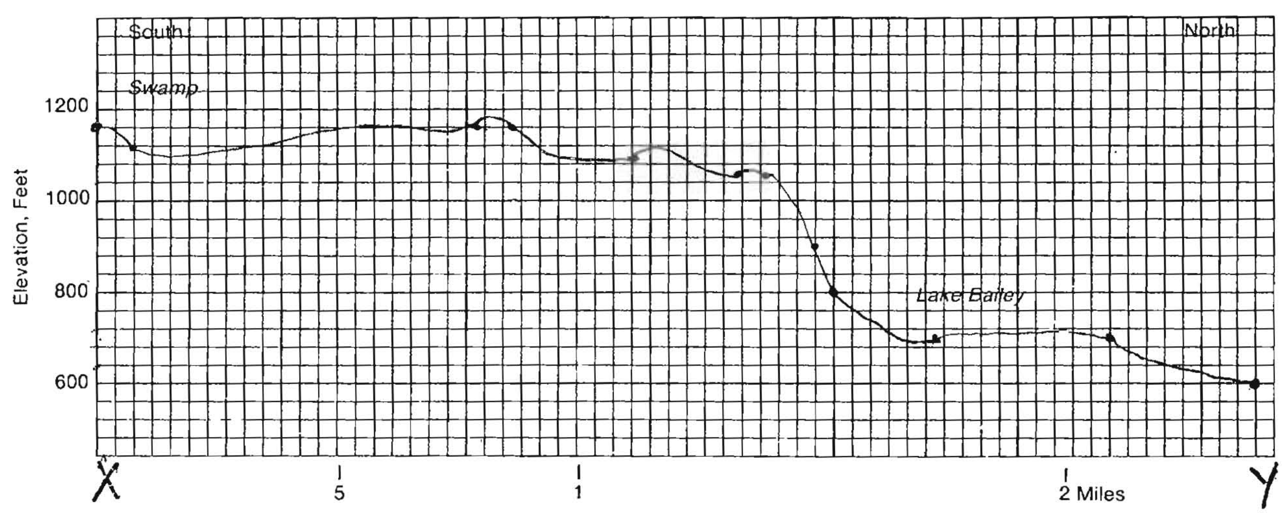


Figure 2.11 Grid to be used in drawing a north-south topographic profile from the Delaware Map (fig. 2.12). The south end of the profile is the southwest corner of section 10, and the north end is the shore of Lake Superior. The line of profile is coincident with the western boundaries of sections 3, 10, and 24.

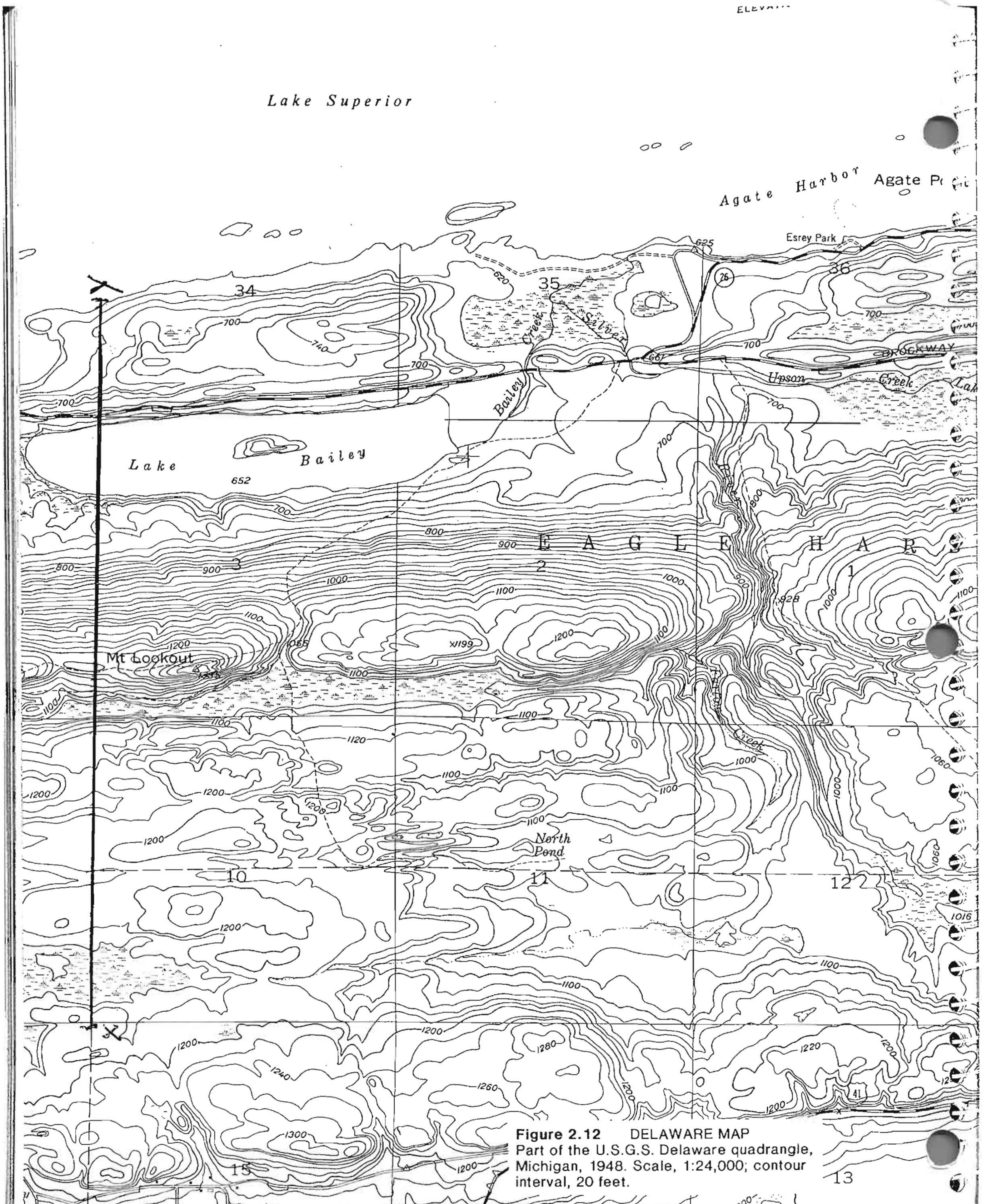


Figure 2.12 DELAWARE MAP
Part of the U.S.G.S. Delaware quadrangle, Michigan, 1948. Scale, 1:24,000; contour interval, 20 feet.

Task 3-1

Slope Stability Problem Set

3-1 04/16/13

Environmental Geology Mass Wasting / Slope Stability Problem Set

(1) A block of rock is perched on a cliff with 5000 joules of potential energy. The cliff is 200 feet high, calculate the mass of the block of rock (show all of your work, answer in kg).

(2) A block of rock is perched on a cliff 500 feet high and weighs 5000 pounds. Calculate the amount of potential energy in the system (show all of your work, answer in joules).

(3) A mass of rock material is sliding down a bedrock slope at a velocity of 2 mi/hr. The total kinetic energy in the system is 10,000 joules. Determine the mass of the sliding rock material (show all of your work, answer in kg).

(4) A boulder that weighs 5 tons has rolled onto a bridge that measures 200 ft long and 50 ft wide. What is the stress load of the boulder on the bridge (answer in N per sq. meter).

(5) A block of rock (better known as a "BFR") is pushed off of a cliff and has a density of 3.0 gm/cm^3. The dimensions of the block are roughly 5 m x 6.2 m x 3.2 m. The cliff is 300 ft high. Calculate the amount of work expended by the time the rock hits the ground beneath.

(6) A block of rock is sitting on a slope of 35 degrees. The density of the block is 4.0 gm/cm^3. The dimensions of the block are roughly 3.0 m x 2.1 m x 7.0 m. Calculate the normal force and shear force exerted on the block of rock. (show all of your work, answer in N per sq. meter).

(7) A block of rock is sitting on an inclined slope. The shear force is 10 kN and it's mass is 5000 kg. Determine the slope angle. Calculate the normal force (answer in N)

(8) A mass of colluvium measures 0.4 km (width) x 0.2 km (length) x 0.15 km (thickness). The bulk density of the colluvium is 2.1 Mg/m^3 (that's "megagram" per cubic meter). Calculate the following for the mass: (a) specific weight (N per cubic meter) (b) normal stress (kN per sq. m) (c) shear stress (kN per sq. m). Show all of your work.

$\theta = 12^\circ$

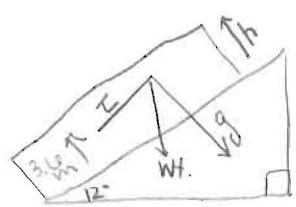
(9) A 3.6 m thick mass of regolith rests on top of a sloping bedrock surface. The hillslope is 12 degrees and the factor of safety is 1.2. A geotechnical engineering firm conducted an in-situ slope stability analysis with the following results:

Area = 50m x 50m

* Assume that the total shear strength is equal to the total shear force acting on the material

c regolith cohesion = 3245 N/m^2
σ' effective normal stress = 45789 N/m^2
density = 2.3 gm/cm^3
γ specific wt. = 25921 N/m^3

ϕ Determine the angle of internal friction of the material. (degrees)



S Determine the shear force acting on the material. (N)

σ Determine the normal force acting on the material. (N)

Calculate the total weight of material (N).

$S = c \cdot \sigma' \tan(\phi)$ $S = wt.(\sin\theta)$

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ES473 - Environmental Geology Slope Stability Prblms 1-9

1. PE = 5,000 J, Cliff = 200 ft Mass = ? $g = 9.8 m/sec^2$

$ep = m \cdot g \cdot h$

$5{,}000 J = m \cdot 9.8 m/sec^2 \cdot 60.98 m$

$200 ft \left(\frac{m}{3.28 ft}\right) = 60.98 m$

$J = Kg\, m^2/sec^2$

$5{,}000 J = m \cdot 597.56 \frac{m^2}{sec^2}$

m = 8.37 Kg

---

2. Cliff = 500 ft block = 5,000 lbs. PE = ?

$ep = m \cdot g \cdot h$

$500 ft \left(\frac{m}{3.28 ft}\right) = 152.44 m$

$5{,}000 lbs \left(\frac{Kg}{2.2 lbs}\right) = 2272.727 kg$

$ep = 2272.727 kg \cdot 9.8 m/sec^2 \cdot 152.44 m$

$ep = 3395232.816 Kg\text{-}m^2/sec^2$

= **3,395,232.8 J**

---

3. velocity = 2 mi/hr KE = 10,000 J Mass = ?

$ek = \frac{1}{2} m \cdot v^2$ $m = 2 \cdot \frac{ek}{v^2}$

$\frac{2 mi}{hr}\left(\frac{5280 ft}{mi}\right)\left(\frac{m}{3.28 ft}\right)\left(\frac{hr}{60 min}\right)\left(\frac{min}{60 sec}\right) = .8943 m/sec$

$= .79978 m^2/sec^2$

$m = 2\left(\frac{10{,}000 J}{.79978 m^2/sec^2}\right)$

m = 25,006.6 Kg

---

4. wt = 5 tons bridge = 200 ft × 50 ft Stress load = ? N/m^2

Stress = F/A $F = m \cdot g = wt$

$F = 5 tons \left(\frac{2{,}000 lbs}{1 ton}\right)\left(\frac{4.448 N}{1 lb}\right) = 44{,}480 N$

$A = \left(200 ft \left(\frac{m}{3.28 ft}\right) = 60.98 m\right) \times \left(50 ft \left(\frac{m}{3.28 ft}\right) = 15.24 m\right) = 929.51 m^2$

Stress = $\frac{44{,}480 N}{929.51 m^2}$ = **47.85 N/m^2**

5. D = $3.0 g/cm^3$, rock = 5 m × 6.2 m × 3.2 m Cliff = 300 ft Work = ? Work = F/d

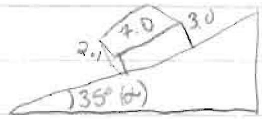
$V = 99.2 m^3 \left(\frac{100 cm}{m}\right)^3 = 9.92 \times 10^7 cm^3$

mass = D·V = $3.0 g/cm^3 \times (9.92 \times 10^7 cm^3) = 2.976 \times 10^8 g \left(\frac{kg}{1000 g}\right) = 2.976 \times 10^5 kg$

$F = m \times g = 2.976 \times 10^5 kg \times 9.8 m/sec^2 = 2.91648 \times 10^6 N$

$d = 300 ft \left(\frac{m}{3.28 ft}\right) = 91.46 m$ Work = $\frac{2.91648 \times 10^6 N}{91.46 m}$ = **3.19 N/m**

6. Slope = 35°   D = 4.0 g/cm³, rock: 3.0m x 2.1m x 7.0m   Shear F = ? Norm F = ?



Normal Force = W(cos α)   Shear Force = W (sin α)

mass = volume x density   volume: $3.0\times2.1\times7.0 = 44.1m^3 \left(\frac{100cm}{m}\right)^3 = 4.41\times10^7 cm^3$

mass = $4.41\times10^7 cm^3 \times 4.0 \frac{g}{cm^3} = 1.764\times10^8 g \left(\frac{kg}{1000g}\right) = 1.764\times10^5 kg$

W = mass x g = $1.764\times10^5 kg \times 9.8 m/sec^2 = 1.7287\times10^6 N$

Normal Force = W(cos α) = $1.7287\times10^6 N \times \cos(35) = 1.416\times10^6 N$

Shear Force = W(sin α) = $1.7287\times10^6 N \times \sin(35) = 9.916\times10^5 N$

7. Shear Force = 10kN   Mass = 5,000 kg   α = ?   Normal F = ?

W = 5,000 kg x 9.8 m/sec² = $4.9\times10^4 N$

Shear Force = W(sin α)

$\sin\alpha = \frac{\text{Shear Force}}{W} = \frac{10\times10^3 N}{4.9\times10^4 N} = .204$ $\alpha = \sin^{-1}(.204) =$ **11.78°**

Normal Force = W(cos α) = $4.9\times10^4 N \times 11.78°$ = **577,011.5 N**

8. colluvium = 0.4 km x 0.2 km x 0.15 km (thickness, h)   D = 2.1 Mg/m³   Specific Wt (γ) = ? (a)

Normal Stress (σ) (b) = ?   Shear Stress (τ) = ? (c)   θ = 12°

volume = .4 x .2 x .15 = $.012 Km^3 \left(\frac{1000m}{km}\right)^3 = 12,000,000 m^3$

mass = d · V = 2.1 Mg/m³ · 12,000,000 m³ = 25,200,000 Mg $\left(\frac{1000kg}{Mg}\right) = 2.52\times10^{10} kg$

W = $2.52\times10^{10} kg \times 9.8 m/sec^2 = 2.469\times10^{11} N$

a. specific wt. = $\frac{wt}{volume} = \frac{2.469\times10^{11}N}{12,000,000 m^3} =$ **20,580 N/m³**

b. Normal stress = $\gamma\cdot h(\cos^2\theta) = 20,580 N/m^3 \cdot 150m(\cos(12)\times\cos(12)) =$ **$2.954\times10^6 N/m^2$**

c. Shear stress = $\gamma\cdot h(\cos\theta)(\sin\theta) = 20,580 \frac{N}{m^3} \cdot 150m(\cos(12)\times\sin(12)) =$ **627798.0 N/m²**

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9. thickress = 3.6m Slope (θ) = 12°, Safety Factor = 1.2

Factor of Safety = $\frac{\text{Normal stress}}{\text{shear stress}}$ = σ / τ D = 2.3 g/cm³ Spec. wt = 25921 N/m³

a. ∡ of Interna Friction = ? $2.3 \frac{g}{cm^3} \left(\frac{100\,cm}{m}\right)^3 \left(\frac{kg}{1000g}\right) = 2300\ kg/m^3$

b. Shear Force = ?

c. Normal Force = ?

d. Wt = ?

Wt = Spec. Wt × Volume Wt = mass × g vol. = $\frac{m}{d}$ D = $\frac{m}{V}$

Shear Stress = $\tau = \gamma \cdot h\,(\cos\theta)(\sin\theta) = 25921\ N/m^3 \cdot 3.6m \cdot (\cos 12)(\sin 12) = 18977.44\ N/m^2$

$wt = \sqrt{\tau^2 - g^2} = \sqrt{18977.44^2 - 9.8^2} = 18977.44$

$N/m^2 - m/sec^2$

$\frac{N}{m^2} - \frac{m}{sec^2} =$

volume = 50m × 50m × 3.6m = 9,000 m³

d. wt = spec. wt. × vol = $25921 \frac{N}{m^3} \times 9{,}000\,m^3$ = **233,289,000 N**

b. **S = wt (sin θ) = 233,289,000 N (sin 12°) = 48503510.44 N**

c. **σ = wt. (cos θ) = 233,289,000 N (cos 12°) = 228,191,075.6 N**

a. $S = c \cdot \sigma' \tan(\phi)$

$48503510.44\,N = 3245 \frac{N}{m^2} \cdot 45789 \frac{N}{m^2} \cdot \tan(\phi)$

$48503510.44 = 148585305 \frac{N}{m^2} \cdot \tan(\phi)$

$.3264 = \tan(\phi)$

a. **18.1° = ϕ**

Task 3-2

OSU Paired Watershed Field Trip Reading and Summary

Kathryn Roberts April 22, 2013
ES 473 – Environmental Geology

Summary Assignment: WRC Paired Watershed Conference 2013

On April 18, 2013 Oregon State University (OSU) hosted the 2013 Watersheds Research Cooperative (WRC) Paired Watershed Conference. The afternoon session of the conference included presentations on the ongoing paired watershed studies done at Hinkle Creek, OR. The Hinkle Creek Paired Watershed Study was designed as to assess the impact of current forest management practices on watershed hydrology, stream chemistry, and biology, especially salmonids. Although paired watershed studies have been conducted in the past, the Hinkle Creek study was designed to address the lack of significant research done for more modern forestry practices on harvest-regenerated forest area. The study took place in the Hinkle Creek Watershed, near Roseburg, OR, on approximately $19km^2$ of land owned and actively managed by Roseburg Forest Products. The study started (informally) in August, 2001 and is still ongoing. Presentations of findings thus far were given at the WRC Conference on the impact of forest practices on watershed hydrology, stream chemistry/nutrients, and salmonid habitability.

Hydrology Presentation – Nicolas Zègre

The first presentation of the afternoon session of the 2013 WRC conference was "Local & Downstream Impacts of Contemporary Forest Harvesting Practices on Watershed Hydrology" by Dr. Nicolas Zègre. The study design included both a paired watershed and nested watershed observation. The North Fork basin served as the control and the South Fork basin the treated watershed. Two treatments of clear-cutting were done in the treated shed consisting of multiple units around both non-fish bearing streams (2005) and fish bearing streams (2008). The hydrologic impact was measured at a basin scale and at a stream scale, with focus on instant maximum peak flow, storm quick flow, and the mean monthly stream flow. The results of the study showed that at both headwater catchments and downstream mean stream flow measurably increased post-harvest, though not always in direct correlation to the amount of harvesting done adjacent to a specific stream. At all headwater catchments quickflow and peak flow also measurably increased. However, at downstream catchments there was no statistically significant increase in peakflow and actually a decrease in quickflow. Additional analysis of data is still being done on the hydrology within the study and further future studies are in the proposal stage to better understand the unexpected results of decreasing quickflow in third order streams post timber harvest.

Sediment Yield Presentation – Arne Skaugset

The second conference of the afternoon was by Dr. Arne Skaugset on "Local and downstream impacts of contemporary forest practices on sediment yield." The treated watershed was analyzed relative to the control watershed for turbidity and suspended sediment to assess the influence of timber harvest. For the experiment turbidity measures were calculated to suspended sediment and graphed against the stream discharge to determine a sediment concentration rate. The hypothesis was that at treated watersheds the sediment concentration rate would increase in correlation to increased stream discharge. The findings were that sediment yield rates increased by 20-40% over the control watershed, which is significantly less than the average from other similar paired watershed studies in the past. However, the results do correlate with the increased discharge (which is somewhat resulting from the calculation being discharge-dependent). Proposed explanations for the lower average include more modern foresting practices including the use of buffer strips, site preparation practices, yarding practices (like skyline cables), and connectivity of roads.

Stream Chemistry Presentation – Scott Meininger

Scott Meininger's presentation on "The Influence of Contemporary Forest Management on Stream Nutrient Concentrations in an Industrialized Forest in the Oregon Cascades," was the third presentation session. The study focused on the soil nutrient content (primarily cations of Na, Ca, Mg, K, P, N, and SO_3). The results of the study showed that most nutrients measured did not show statistically significant results, with the exception of NO_3. NO_3 increases were found to correlate better to individual streambed slope than to the magnitude of adjacent timber harvest. Additionally, the increase in NO_3 measured was comparable to the increase seen in timber harvests of old growth trees, which allowed for the conclusion that the harvest regenerated timber in Hinkle Creek had sufficient time for restoration.

Cutthroat Trout Presentation – Robert E. Gresswell

The final presentation for the Hinkle Creek Paired Watershed was "Effects of stream adjacent logging on downstream populations of coastal cutthroat trout." The habitat and biomass of coastal trout were measured pre and post timber harvest at an individual tributary and catchment scale to assess the impact of the harvest on the population. The results from both timber harvesting treatments (both without buffer strips in non-fish bearing streams and with buffer strips in fish bearing streams) showed no statistical change in the overall fish population or in habitat. The results led to the inferred conclusion that current forest management practices are sufficient to ensure protection of fish population.

Task 4-1

Flood Analysis Lab Exercise (Exercise 27, Exercise 28, Exercise 30)

4-1

Name Kathryn Roberts

Exercise 27: The Stream Channel Cross Section

Introduction

A stream flows in a channel, often bordered by a floodplain, both measurable features.

Question Set 47: Plotting a Channel Cross Section

Measurements were made at the Seneca Creek **gaging station** near Dawsonville, Maryland, located on Figure 60. The east–west cross-sectional data of the stream at that station are given in Table 3.

i. On Figure 61, plot these data to show the Seneca Creek cross-channel section. The east point has been plotted.

ii. What is the vertical exaggeration (see Exercise 4) of your cross section? Vertical exaggeration = 10

iii. On the cross section, label the following features: a. The main channel; b. The **floodplain**; and c. The natural **levee**. (Note: The west bank is very steep.)

iv. The **bankfull stage** of a channel is reached when waters fill the channel to its brim before spilling over its banks onto the floodplain.

a. Draw a line and label it at the bankfull stage on your plot (Figure 61).

b. What is the bankfull width of the channel at this location? 90 ft

c. What is the elevation of the bankfull stage? 226.2 ft

v. Determine the average depth of the bankfull channel by measuring the depth at 10-foot intervals across the channel. Begin on the west bank of the bankfull channel. Record your measurements below. The first value is given.

Distance from West Bank of Bankfull Channel	Depth (ft)
10	4.5
20	5.6
30	6.0
40	6.2
50	6.8
60	7.2
70	6.0
80	1.0
Average depth (ft)	5.4 ft

vi. The bankfull cross-sectional area of the Seneca channel is its bankfull stage width multiplied by the average depth. Determine the bankfull cross-sectional area.

Width (ft) × avg depth (ft) = area (ft^2)

90ft × 5.4ft = 487ft²

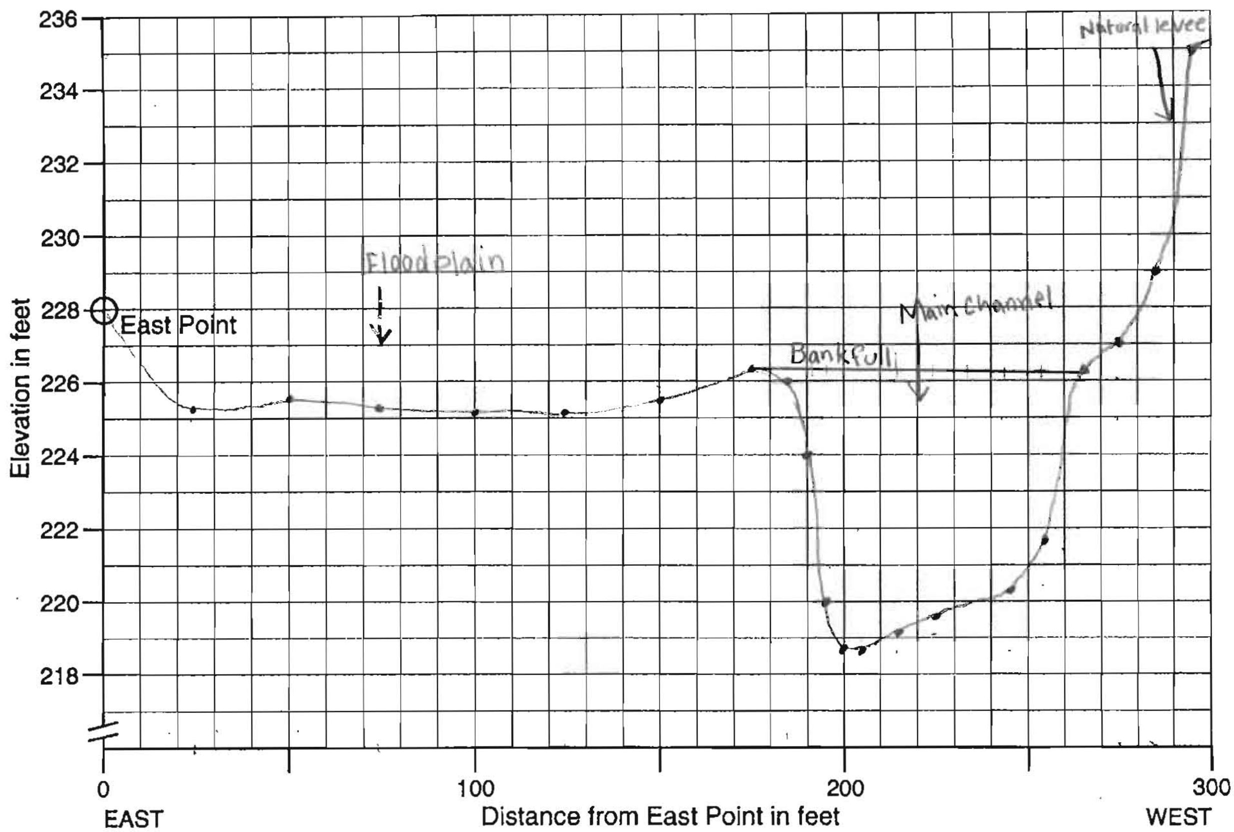


Figure 61. **Graph for plotting cross-channel section, Seneca Creek Gaging Station, Dawsonville, MD.**

Table 3 Valley Cross Section Survey Data, Seneca Creek Gaging Station, Dawsonville, Maryland

Distance from the East Point (ft)	*Elevation (ft)*	*Distance from the East Point (ft)*	*Elevation (ft)*
0	228.0	200	218.8
25	225.3	205	218.8
50	225.5	215	219.1
75	225.3	225	219.6
100	225.1	245	220.2
125	225.1	255	221.7
150	225.5	265	226.2
175	226.2	275	227.0
185	226.0	285	229.0
190	224.0	295	235.0
195	220.0		

Name ____________

Exercise 28: Calculation of Stream Discharge

Introduction

Virtually all river flow is ultimately derived from precipitation. Rain falling on the surface may drain directly into river channels or may soak into the ground and later be delivered to the river as ground water. The rest of the precipitation is evaporated into the atmosphere (**evaporation**), or is transpired, which occurs when water is released by plants into the atmosphere (**transpiration**). The formula can be written

$$P_{\text{(precipitation)}} = R_{\text{(runoff and infiltration)}} + ET_{\text{(evaporation and transpiration)}}$$

The amounts and percentages in this formula vary widely in both time and place. However, the average percentage values for the United States are sometimes used in a National Average Formula:

$$P_{100\%} = R_{30\%} + ET_{70\%}$$

Remember, also, that this is only an average, and the percentages will change with climate, topography, vegetation, and geology.

The stream's **discharge** is the volume of water flowing through a stream channel in unit time, usually expressed in cubic meters per second or cubic feet per second (**cfs**). To determine the stream discharge we need to know the width, depth, and velocity of the stream. The formula is

$$\text{Discharge} = \text{width} \times \text{depth} \times \text{velocity}$$

Question Set 48: Calculating Stream Discharge in Seneca Creek

You determined the bankfull cross-sectional area (width × depth) of the Seneca Creek channel in Question Set 47 vi, in the preceding question set. In order to calculate the stream discharge, we need to know the velocity of the stream when it is bankfull. This requires a field measurement. Here we assume a reasonable value of 4.47 ft/sec.

i. What is the bankfull discharge in cubic feet per second (cfs)?

Area (ft^2) × avg velocity (ft/sec) = discharge (cfs)

$487\ ft^2$ × 4.47 ft/sec = 2176.89 cfs

ii. Under what conditions will Seneca Creek begin to flood?

at discharge of >2176.89 cfs

iii. The area drained by Seneca Creek at the gaging station is 101 mi^2. The average yearly rainfall is 42 in/yr.

a. Using the National Average Formula, calculate the approximate annual discharge of Seneca Creek in cubic feet per year. Show calculations.

area = 101 mi^2
rainfall = 42 in/yr
42 in/yr = 30% R
R = 12.6 in/yr
$101\ mi^2 \left(\frac{5280 ft}{mi}\right)^2 = 2815718400\ ft^2$
$12.6 \frac{in}{yr}\left(\frac{ft}{12\ in}\right) = 1.05\ ft/yr$
$D = 2815718400\ ft^2 \times 1.05\ ft/yr = 2956504320\ ft^3/yr$

Discharge of Seneca Creek 2.96×10^9 ft^3/yr

b. Using the relation 1 ft^3 = 7.48 gallons, give the discharge in gallons. Show calculations.

$2.96\times10^8 \frac{ft^3}{yr}\left(\frac{7.48\ gal}{1\ ft^3}\right) = 2.21\times10^9\ gal/yr$

2.21×10^9 gal/yr

iv. We can evaluate the National Average Formula figure computed above by using data from the Seneca Gaging Station itself. The U.S. Geological Survey reports that the average annual flow of Seneca Creek at the gaging station over a 49-year period is 102 cfs.

a. Using the USGS average of 102 cfs, what is the annual discharge in cubic feet per year at the gaging station? Show calculations.

$102 \frac{ft^3}{sec}\left(\frac{3600\ sec}{hr}\right)\left(\frac{24\ hr}{day}\right)\left(\frac{365\ day}{yr}\right) = 3.2167\times10^9\ ft^3/yr$

3.217×10^9 ft^3/yr

b. What is the discharge in gallons? Show calculations.

$3.217\times10^9 \frac{ft^3}{yr}\left(\frac{7.48\ gal}{1\ ft^3}\right) = 2.406\times10^{10}\ gal/yr$

2.406×10^{10} gal/yr

v. By what percentage is the USGS average annual discharge higher or lower than that determined by using the National Average Formula for discharge? +9 %

$3.217\times10^9 = x\%$ of 2.96×10^9

$\frac{3.217\times10^9}{2.96\times10^9} = 1.099 = 109\%$

Table 4 **Annual Flood Series from 1928 to 1987 Recorded at Seneca Creek Gaging Station, Dawsonville, Maryland.** *U.S. Geological Survey*

Year	*Discharge (cfs)*	*Year*	*Discharge (cfs)*	*Year*	*Discharge (cfs)*
1928	3,800	1948	1,990	1968	1,640
1929	1,600	1949	2,240	1969	3,490
1930	1,450	1950	2,280	1970	2,200
1931	1,730	1951	2,420	1971	25,900
1932	1,380	1952	2,810	1972	26,100
1933	9,300	1953	7,330	1973	3,020
1934	2,410	1954	1,240	1974	3,160
1935	1,420	1955	2,620	1975	16,000
1936	2,020	1956	15,000	1976	4,900
1937	2,610	1957	959	1977	3,770
1938	2,280	1958	3,640	1978	7,850
1939	2,150	1959	1,970	1979	16,000
1940	1,240	1960	1,600	1980	10,800
1941	1,300	1961	3,070	1981	1,340
1942	1,460	1962	1,920	1982	3,160
1943	3,620	1963	1,480	1983	3,260
1944	2,660	1964	2,520	1984	3,010
1945	2,110	1965	2,640	1985	3,620
1946	2,940	1966	3,270	1986	1,070
1947	1,990	1967	2,660	1987	4,950

Exercise 30: Flood Frequency

Introduction

One type of flood frequency analysis is the annual flood series, which is based on the largest flow in each calendar year of record. The first step in the analysis is to rearrange the annual floods in order from the largest to the smallest (Table 5). A magnitude M is then assigned to each flood, with the largest flood assigned M = 1, the next largest M = 2, and so on. The **recurrence interval, RI**, is then calculated with the formula

$$RI = \frac{N + 1}{M}$$

where N is the number of years of record.

The recurrence interval is a statistical estimate of how often a flood of a particular size is likely to recur. A flood with an RI = 50 yr, for example, is likely to happen at least once in a 50-year period. Remember, however, that this is only an estimate. Furthermore, the recurrence interval indicates nothing about *when* a flood of a particular size might occur. A 50-year flood might be followed the next year, or the next month, by a 100-year flood.

Name Kathryn Roberts

Question Set 50: Flood Recurrence Intervals

The annual flood record for Seneca Creek at Dawsonville, Maryland, has been ordered by magnitude in Table 5 and the recurrence interval (RI) for most of the record has been computed.

i. Complete Table 5 by calculating the RI value for the first 10 and the last 5 years. For the Seneca Creek data, N = 60.

ii. After recurrence intervals are calculated, the data are usually graphed so they can be interpreted more easily. Figure 62 is a graph of the Seneca Creek data. Notice that the axes of the graph are both logarithmic. If you are unfamiliar with logarithmic plots, you should ask your instructor how to read them. A "best-fit" line has been drawn through the data points. This line can be used to estimate the sizes of floods of various recurrence intervals. For example, the 10-year flood would be 9,000 cfs (Figure 62). Use Figure 62 to estimate the approximate sizes for floods of the following recurrence intervals:

5-year 5,000 cfs
50-year 35,000 cfs
100-year 60,000 cfs

iii. If you were on the zoning commission of the county government, what land use would you think should be permitted on the Seneca Creek floodplain, and why?

Given a 5,000 cfs flood with a 5yr recurrence interval, I would recomend against any major/important infastructure on the flood plain at Seneca Creek. I would zone the area for agricultural usage, that can better handle frequent floods.

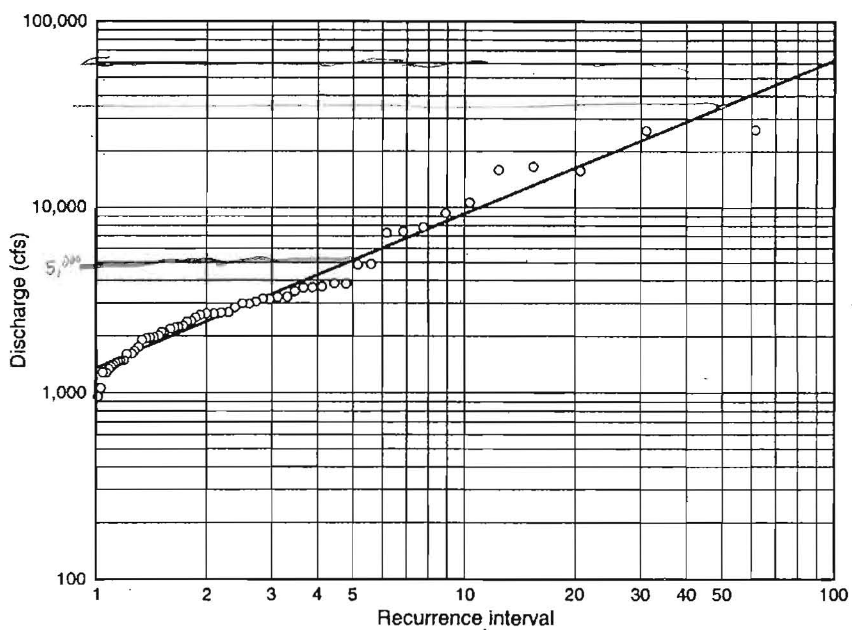


Figure 62. **Plot of annual flood series ordered by magniture as recorded at the Seneca Creek Gaging Station.** *U.S. Geological Survey.*

Name ____________________

Table 5 Annual Flood Series Recorded at Seneca Creek Gaging Station, Dawsonville, Maryland (ordered by magnitude). *U.S. Geological Survey*

Year	*Discharge (cfs)*	*Magnitude (M)*	*Recurrence Interval (RI) (yr)*	*Year*	*Discharge (cfs)*	*Magnitude (M)*	*Recurrence Interval (RI) (yr)*
1972	26,100	1	61	1937	2,610	31	1.97
1971	25,900	2	30.5	1964	2,520	32	1.91
1975	16,000	3	20.33	1951	2,420	33	1.85
1979	16,000	4	15.25	1934	2,410	34	1.79
1956	15,000	5	12.2	1938	2,280	35	1.74
1980	10,800	6	10.17	1950	2,280	36	1.69
1933	9,300	7	8.71	1949	2,240	37	1.65
1978	7,850	8	7.62	1970	2,200	38	1.61
1953	7,330	9	6.78	1939	2,150	39	1.56
1987	4,950	10	6.1	1945	2,110	40	1.53
1976	4,900	11	5.55	1936	2,020	41	1.49
1928	3,800	12	5.08	1947	1,990	42	1.45
1977	3,770	13	4.69	1948	1,990	43	1.42
1958	3,640	14	4.36	1959	1,970	44	1.39
1943	3,620	15	4.07	1962	1,920	45	1.36
1985	3,620	16	3.81	1931	1,730	46	1.33
1969	3,490	17	3.59	1968	1,640	47	1.30
1966	3,270	18	3.39	1929	1,600	48	1.27
1983	3,260	19	3.21	1960	1,600	49	1.24
1974	3,160	20	3.05	1963	1,480	50	1.22
1982	3,160	21	2.90	1942	1,460	51	1.20
1961	3,070	22	2.77	1930	1,450	52	1.17
1973	3,020	23	2.65	1935	1,420	53	1.15
1984	3,010	24	2.54	1932	1,380	54	1.13
1946	2,940	25	2.44	1981	1,340	55	1.11
1952	2,810	26	2.35	1941	1,300	56	1.09
1944	2,660	27	2.26	1940	1,240	57	1.07
1967	2,660	28	2.18	1954	1,240	58	1.05
1965	2,640	29	2.10	1986	1,070	59	1.03
1955	2,620	30	2.03	1957	959	60	1.01

$RI = \frac{N+1}{M}$ $N=60$

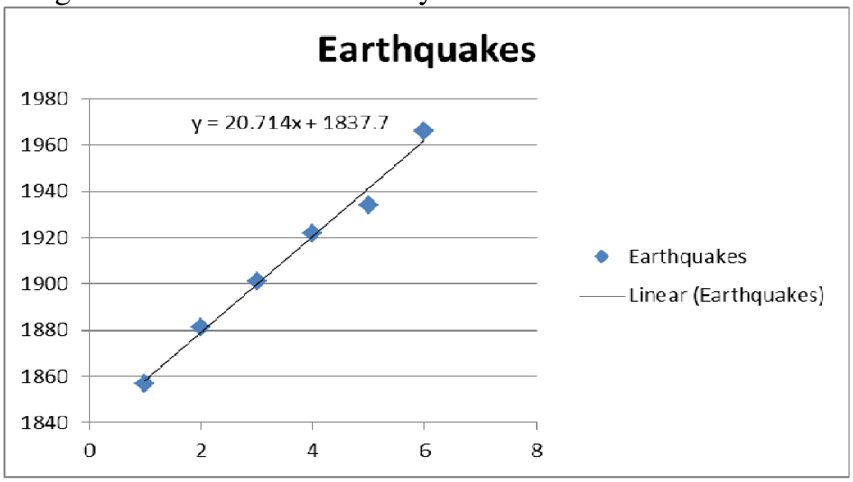
Task 5-1

Earthquake Recurrence Interval Exercise

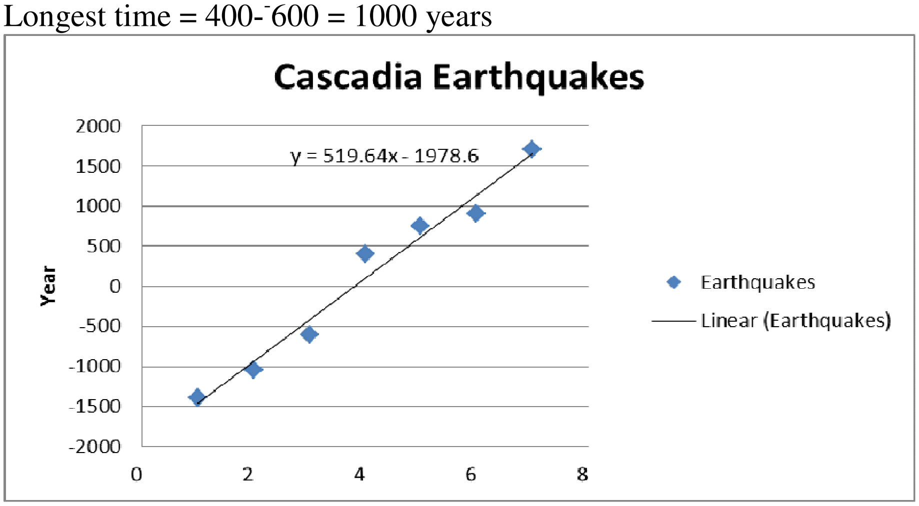
Kathryn Roberts
ES 473 – Environmental Geology

April 30, 2013

In-Class Activity: Earthquake Cycles

1. Shortest time = 1934-1922 = 12 years
2. Longest time = 1966-1934 = 32 years
3. 

4. Y = 20.714(7) + 1837.7 y= 1983
5. Average = 21.8 years
6. a. least predictable earthquake – 1934 quake
   b. should have occurred 1944
7. No, this recurrence interval is only based on just over 100 years of data (completely insignificant in geologic time) and could be a coincidence

1. Shortest time = 900-750 = 150 years
2. Longest time = 400-¯600 = 1000 years
3. 

4. Y = 519.64(8) – 1978.6 Y = 2178.52
5. Average = 516.7 years
6. This is more significant than the Parkfield data, as it relies on just over 3000 years of data rather than 100.
7. Do to the less precise trend line over a longer period of time, predicting an earthquake is more difficult. According to this data, an earthquake could occur at any time between tomorrow and 2700.

Task 5-2

Reading Summary – Combined Rip 9 & Goldfinger et al Articles

Kathryn Roberts May 1, 2013
ES 473 – Environmental Geology

Reading Summary – OR Earthquake Hazard Articles (USGS & Outside Mag)

As part of an ongoing effort to better understand and track the earthquake hazards of the Cascadia subduction zone, the USGS conducted a study in coordination with multiple experts in the region to measure and correlate the presence of turbidite sequences within the Cascadia Basin to paleoseismic records. Their paper, "Turbidite Event History—Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone," outlines the methodology of analyzing and correlating turbidite sequences as well as the earthquake recurrence interval results that were derived from the data (Goldfinger, et. al., 2012). The Cascadia Basin was chosen for this study for a variety of factors, including that the system is a single fault subduction zone, has an abundance of turbidite sequences, and has easily distinguishable stratigraphic indicators like faunal changes at the Pleistocene-Holocene boundary and Mazama ash. Turbidite sequences were tested using a variety of methods including swath bathymetry, accelerated mass spectrometry (AMS), and piston, gravity, kasten, and box cores. Previous work on the subject includes a 1990 study that first hypothesized the synchronous triggering of Cascadia basin turbidites from large earthquakes. As this original study used only core descriptions, the new study proposed to test the hypothesis in greater depth using both AMS radiocarbon dating and more modern sedimentological techniques that include testing tests for synchroneity of turbidite events along strike on convergent and transform margins (pg.3). Results of this testing are interpreted with implications of earthquake recurrence interval and can be applied to other similar tectonic environments like the San Andreas Fault or Sundra subduction regions. The results of the study allowed more than 10 new correlations of turbidites to be drawn within the Cascadia Basin. These combined with radio-carbon dated on-shore data were used to create space-time diagrams for the Cascadia Basin. Earthquake indicators correlated by both on and off shore data are considered much more reliable as the previously available on-shore only data can be biased over time by younger, overlying vegetation and/or sediments. When correlated to either tsunamis or localized storms, the data shows clear mismatches, which further suggest that the turbidites are the result of earthquakes. Data collected in the study can be used to establish probability estimates for another earthquake along that fault. The northern Cascadia has a seven to eleven percent probability of rupture in the next fifty years, while the southern segment has an eighteen percent probability of rupture in the next fifty years.

Scientific studies like the one above can provide the scientific basis for looking at how a major earthquake like those correlated through the study would impact Oregon. Looking at the historical on-shore data in the Pacific Northwest, including tree-ring ages from ancient down-dropped forests and road uplift rates across Oregon and Washington, scientists can tell not only that megaquakes (those 9.0 or higher on the Richter scale) happen, but that the Pacific Northwest is currently due (or maybe overdue) for another one. Megaquakes occur on an interval of once every 500 years. Significant (8.0-8.5 magnitude) quakes occur more often, or about once every 244 years. The last quake in the Pacific Northwest was in 1700, more than 300 years ago. Using that scientific data as a guide, *Outside Magazine's* "Totally Psyched for the Full-Rip 9" details a minute-by-minute guide of what it would be like to live through a 9.0 earthquake and resulting tsunami in the Pacific Northwest. The quake would cause a 5 foot down-dropping of the coast, move North America approximately 60 feet west and would be powerful enough to shift the tilt of the earth about 8-20 inches on its axis. The first impact felt would be the P waves (assuming a five minute quake, the S wave won't hit until one minute later). At the one minute mark is probably when the official earthquake warning will come in to first responders, government officials and media. Major downtown areas like Portland and Seattle are likely to have major damage or collapse of skyscrapers from the effects of liquefaction. By the five minute mark, the quake stops moving the ground, but more damage is yet to come, especially for the coast. At this point the wall of displaced water from the down dropping of the plate is 35 miles offshore, half headed west toward Japan and half headed east, where it will hit the Oregon and Washington coast in 15 minutes. When the wave is 25 miles offshore, the coastline visibly starts to recede, but for many who aren't prepared getting to the safe-zone of 50 feet above sea level will be a challenge, especially with collapsed bridges and roads that have buckled under liquefaction. 18 minutes after the start of the earthquake, the tsunami hits. It eventually will go as far as six miles inland. When the whole disaster is over, more than 7,000 people are dead, and another 27,000 were injured. Costs of the damage will be in the range of 5-15 billion dollars. Those this scenario seems extreme, it points out the general unpreparedness of the region in the light of scientific data. The disaster is that much worse because it seems so unlikely in the Pacific Northwest, which has never had a large earthquake in recorded history. However, the Pacific Northwest is within the tectonically unstable Ring of Fire, and the Cascadia Subduction Zone is still pushing the Juan de Fuca Plate underneath the North American Plate, building up more and more strain, which will eventually release in a massive earthquake.

Task 5-3

Earthquake Hazards Lab Exercise (Part A)

EXERCISE 6

5-3

Earthquake Epicenters, Intensities, Risks, Faults, Nonstructural Hazards and Preparation

INTRODUCTION

Zachary Grey, writing in 1750, said "An earthquake is a vehement shake or agitation of some considerable place or part of the Earth, from natural causes, attended with a huge noise, like thunder; and frequently with an eruption of water, fire, smoke or wind. They are looked upon to be the greatest and most formidable phenomena of nature." Although our present understanding of earthquakes is much more refined, they are still considered to be formidable phenomena. An earthquake is the ground shaking caused by elastic waves propagating in the Earth generated by a sudden release of stored strain energy. The sudden release of stored strain energy is the result of an abrupt slip of rock masses along a break in the Earth called a *fault*. Most fault slip occurs below the Earth's surface without leaving any surface evidence. The place where this slippage occurs is known as the *hypocenter* or *focus* of the earthquake, and the point on the surface vertically above the focus is the *epicenter*.

In this exercise we review earthquake wave types, locate an earthquake epicenter, determine earthquake intensities, assess seismic risk, examine fault types, and study fault zone characteristics.

Earthquake Waves

The energy released at the focus of an earthquake sets up several types of vibrations or waves that are transmitted through the Earth in all directions. Some waves travel through the Earth to the surface and are known as body waves. Others travel along the Earth's surface and are known as surface waves (Figure 6.1).

One type of body wave is a compressional wave in which the particles of rock vibrate back and forth in the direction of wave travel; the motion is similar to that of sound waves that alternately compress and dilate the medium—solid, liquid, or gas—through which they travel. Compressional waves are also called longitudinal or *primary* waves (P waves); the latter name is given because these waves appear first on seismograms (Figure 6.2) that record earthquake waves. Another type of wave is the shear or transverse wave, in which the particles vibrate at right angles to the direction of wave progress, in the same manner as a wave moving along a stretched string that is plucked. Because these waves are the second waves to appear on the seismogram, they are called *secondary* waves (S waves).

After the body waves, another class of seismic waves, the surface waves, arrive. They have frequencies of less than 1 cycle per second and often approximate the natural frequency of vibration in tall buildings. Surface waves in general decrease in amplitude more slowly than body waves. The surface waves consist of *Love* waves (horizontal lateral vibrations perpendicular to direction of transmission; they travel forwards but shake sideways) and *Rayleigh* waves (rotational displacement of particles to produce a wavy or undulating surface; they travel up and down in small circles).

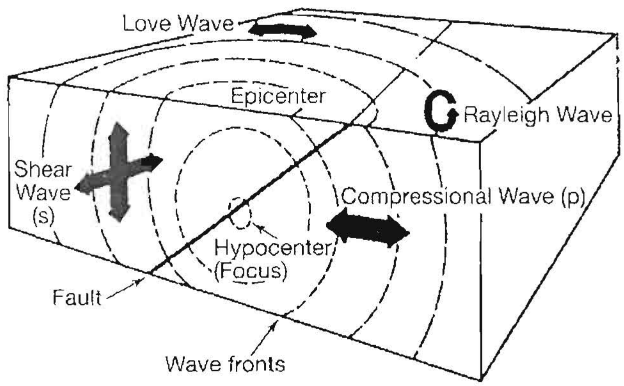


FIGURE 6.1 Diagram of directions of vibrations of body (P and S) and surface (Love and Rayleigh) waves (Hays, 1981).

PART A. EPICENTER, INTENSITY, AND SEISMIC RISK

Epicenter (6, Part A1)

After an earthquake, seismologists are faced with the task of finding when and where the shaking began. They do this by examining the *seismograms* from several seismograph stations. Because the P and S waves travel at different rates, the difference in arrival times varies from station to station depending on the distance from the source.

The average travel times of P and S waves compiled from many earthquake records are used to make travel-time graphs and tables showing the time required for waves to travel various distances from a hypocenter. These records show that P waves travel more rapidly than S waves. Therefore, travel-time curves will show P and S waves as separate curves. Surface waves travel at about 90 percent of the velocity of S waves because the surface waves are traveling through lower velocity materials located at the Earth's surface.

If arrival times are available from several seismograph stations, the distances given by the travel-time curves may be used to determine the earthquake's location. The distance provides the radius of a circle about the seismograph station. The *epicenter* is located somewhere on that circle. With at least three stations, the location of the epicenter may be determined as the point where the three circles intersect.

We can also arrive at the distance to the epicenter by using simple subtraction and a proportional relationship. Because of their different velocities, there is a time lag between arrival of the first P and first S wave at a seismograph station. The time lag (time of S minus time of P) can be determined from seismograms. This time lag can be used to compute the distance to the epicenter, provided the average velocity of each wave type is known. In the first part of the exercise, we will use seismograms from four different stations to locate the epicenter and time of an earthquake.

QUESTIONS (6, PART A1)

Epicenter

1. In Figure 6.2, use the time scale to determine the lag in arrival time between the P and S waves at four stations: St. Louis, Missouri (SLM); Bloomington, Indiana (BLO); Minneapolis, Minnesota (MNM); and Bowling Green, Ohio (BGO). The first major impulse on the left in the seismogram indicates the arrival of the first P wave at the station, the second impulse, the arrival of the first S wave. The lag time, T, is given by the difference between S and P times. Enter the lag time value for each station below:

SLM: 21 sec	BLO: 31 sec
MNM: 81.5 sec	BGO: 58 sec

2. To determine the distance from the earthquake to each seismograph station we must first determine the time lag between P and S wave arrivals at a given distance from an earthquake, say 100 km, knowing the average velocities of the P and S waves. If the average velocity of the P wave is 6.1 km/sec and the average velocity of the S wave is 4.1 km/sec, what is the time required for each wave to travel 100 km? (It may help to think of this problem like a very fast driving trip: if you want to go 100 km, and you drive at a rate of 6.1 km/sec, how long, in seconds, will it take you to get to your destination?)

P waves (6.1 km/sec) travel 100 km in 16.4 seconds.
S waves (4.1 km/sec) travel 100 km in 24.4 seconds.
Thus the time lag between the arrival of P and S waves at a distance 100 km from the hypocenter (T_{100}) is 8.0 seconds.

3. Remembering that for longer distances there is a proportionally longer lag time, we can construct a simple equation to calculate the unknown distance x to each station:

$$\frac{x}{T_x} = \frac{100\text{km}}{T_{100}}$$

where x = unknown distance in km; Tx = lag time for distance x; T_{100} = lag time at 100 km

Since values for Tx are known from Question 1 and the value of T_{100} is known from Question 2, the equation can be solved for x for each station. More than one station is needed to determine the epicenter since the information from one station can only give the distance to the earthquake and not the direction. The minimum number of stations needed to locate an epicenter is three.

Using the data from Figure 6.2 and the equation above, determine the distance to the earthquake epicenter from each station and enter below.

SLM: $\frac{x}{21} = \frac{100\text{km}}{8\text{sec}}$ = 262.5 km
MNM: $\frac{x}{81.5\text{sec}} = \frac{100\text{km}}{8\text{sec}}$ = 1018.75 km
BLO: $\frac{x}{31} = \frac{100}{8}$ = 387.5 km
BGO: $\frac{x}{58} = \frac{100}{8}$ = 725 km

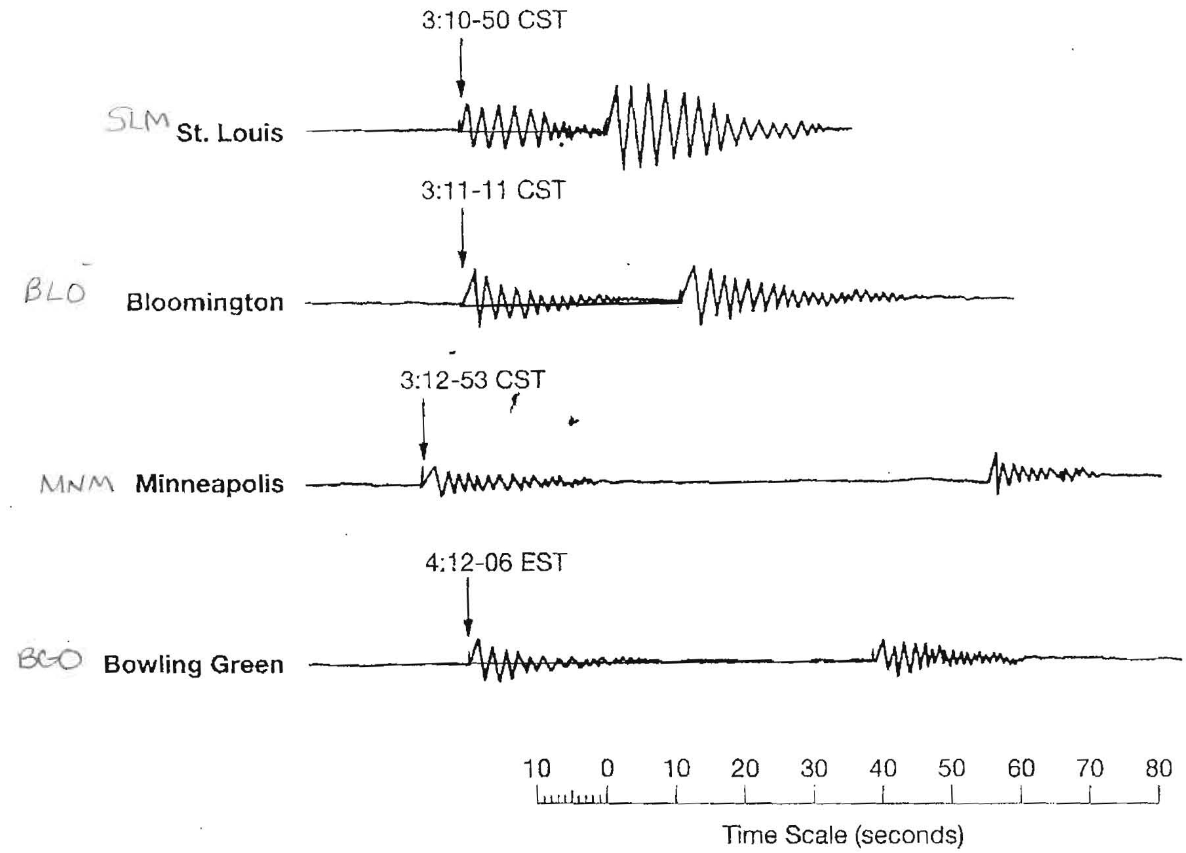


FIGURE 6.2 Partial seismograms for an earthquake. The P wave arrived at the St. Louis seismograph at 10 minutes and 50 seconds after 3:00 P.M. CST. The second disturbance on the seismogram represents the arrival of the S waves.

4. a. The epicenter of the earthquake can be pinpointed by drawing compass arcs from three of the stations with radii corresponding to the distances calculated in Question 3. The intersection of these radii marks the epicenter. Do this in Figure 6.3.

b. Where is the epicenter? (Give location within a state.)

Western tennessee

c. Label it on the map (Figure 6.3).

d. At what time did the earthquake occur? (Refer to Figure 6.2.)

262.5km (1sec / 6.1km) = 43.0sec
3:10.50 = 3:10.7 CST

Intensity (6, Part A2)

The *intensity* of an earthquake at a site is based on the observations of individuals during and after the earthquake. It represents the severity of the shaking, as perceived by those who experienced it. It is also based on observations of damage to structures, movement of furniture, and changes in the Earth's surface as a result of geologic processes during the earthquake. The Modified Mercalli Intensity Scale is commonly used to quantify intensity descriptions. It ranges from I to XII (Table 6.1).

An *isoseismal* map shows the distribution of seismic intensities associated with an earthquake. The greatest impact of an earthquake is usually in the epicentral region, with lower intensities occurring in nearly concentric zones outward from this region. The quality of construction and variation of geologic conditions affect the distribution of intensity.

Seismic risk maps have been based on the distribution and intensities of past earthquakes or on the probability of future earthquake occurrences (of a given ground motion in a given time period). In this exercise the first type of map is adequate for our examination of seismic risk in middle North America; however, maps based on the probabilistic approach may be needed in other investigations. The latter maps do not express intensity. Rather, they show probability of occurrence of ground shaking that has a 10 percent probability of being exceeded in 50 years.

Note that we also use the term *magnitude* to describe an earthquake. The magnitude of an earthquake is a measure of the amplitude of an earthquake wave on a seismograph (Bolt, 1988). The Richter magnitude scale is a commonly used standardized system of amplitude measurement, and allows for comparison of different

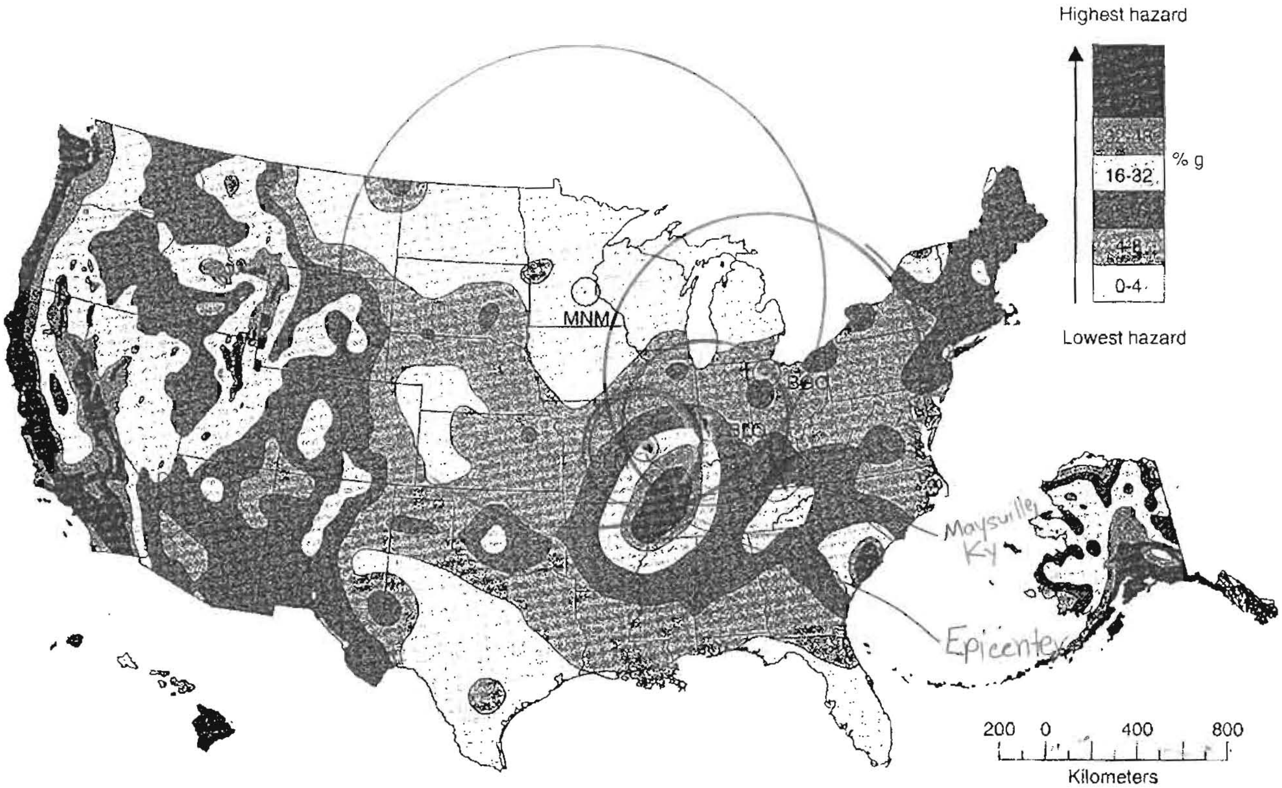


FIGURE 6.3 Seismic acceleration, expressed as a percent of gravity, that can be expected during a 50 year period. Higher numbers indicate greater potential for shaking (From Peterson and others, 2008).

earthquakes around the world. The Richter scale is a logarithmic scale, which means that each increase in number, for example from M5 to M6, represents a 10-fold increase in amplitude (and about a 30-fold increase in actual energy released by the earthquake).

QUESTIONS (6, PART A2)

1. Following are some historical descriptions of earthquakes (a–d). Such statements, made to scientists or reporters or recorded in diaries or on survey forms distributed by government agencies, allow scientists to determine the intensity of an earthquake. Using the Modified Mercalli Intensity Scale (Table 6.1), assign each of the quakes an intensity number. Pick the lowest number exhibiting the characteristics given. The first quotation describes the observations of an eyewitness to a California earthquake around 1913. The second, third, and part of the fourth descriptions are from data gathered by the U.S. Coast and Geodetic Survey after the Daly City, California, earthquake of 1957 (Richter magnitude 5.3).

a. "There was a keen frost, and when we reached the water-hole a thin film of ice was seen upon the water. I dismounted and led my horse by the bridle, and walked to the edge of the water. Just as I reached it, the ground seemed to be violently swayed from east to west. The water splashed up to my knees; the trees whipped about and limbs fell on and all around me. I was affected by a fearful nausea, my horse snorted and in terror struggled violently to get away from me, but I hung to him, having as great a fear as he had himself. The lake commenced to roar like the ocean in a storm, and, staggering and bewildered, I vaulted into the saddle and my terrified horse started, as eager as I was to get out of the vicinity." (Eisman, 1972)

Intensity: VII

b. "The shock seemed to be a sort of gentle swaying back and forth, causing hanging fixtures to swing, but doing no damage." (Iacopi, 1971)

Intensity: IV

c. "The earthquake was very intense . . . a heavy oak china cabinet and massive table moved 2 to 3 inches away from original positions; kitchen stove moved 2 inches; furnace in basement moved two inches off base and water heater tilted off base." (Iacopi, 1971)

Intensity: VI

TABLE 6.1 Modified Mercalli Intensity Scale of 1931.

Intensity	Description of Effects
I	Not felt by people, except under especially favorable circumstances. Sometimes birds and animals are disturbed. Trees, structures, liquids, and bodies of water may sway gently, and doors may swing slowly.
II	Felt indoors by a few people, especially on upper floors of multistory buildings. Birds and animals are disturbed, and trees, structures, liquids, and bodies of water may sway. Hanging objects may swing.
III	Felt indoors, usually as a rapid vibration that may not be recognized as an earthquake at first, similar to that of a light truck passing nearby. Movements may be appreciable on upper levels of tall structures.
IV	Felt indoors by many, outdoors by few. Awakens a few individuals. Characterized by vibration like that due to passing of heavy or heavily loaded trucks, a heavy body striking building, or the falling of heavy objects inside. Dishes, windows, and doors rattle. Walls and house frames creak. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeably.
V	Felt indoors by practically everyone, outdoors by most people. Awakens many or most sleepers. Frightens a few people; some persons run outdoors. Buildings tremble throughout. Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances. Hanging objects and doors swing generally. Pictures knock against walls, or swing out of place. Pendulum clocks stop, or run fast or slow. Doors and shutters open or close abruptly. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled containers.
VI	Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; there is general excitement, and some persons run outdoors. Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Plaster cracks or falls in small amounts. Many dishes and glasses, and a few windows, break. Books and pictures fall. Furniture may overturn or heavy furnishings move.
VII	Frightens everyone. There is general alarm, and everyone runs outdoors. People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes, and streams. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns.
VIII	There is general fright, and alarm approaches panic. Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off. Sand and mud erupt in small amounts. Flow of springs and wells is changed. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Walls fall. Solid stone walls crack and break seriously. Chimneys twist and fall. Very heavy furniture moves conspicuously or overturns.
IX	There is general panic. Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings, with some collapsing in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged, and underground pipes sometimes break.
X	Most masonry and frame structures and their foundations are destroyed. Ground, especially where loose and wet, cracks up to widths of several inches. Landsliding is considerable from riverbanks and steep coasts. Sand and mud shift horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, and embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Railroad rails bend slightly. Pipelines tear apart or are crushed endwise. Open cracks in cement pavements and asphalt road surfaces.
XI	Few if any masonry structures remain standing. Broad fissures, earth slumps, and land slips develop in soft wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes, and embankments, even at long distances. Supporting piers or pillars of large, well-built bridges are wrecked. Railroad rails bend greatly and some thrust endwise. Pipelines are put out of service.

TABLE 6.1 Modified Mercalli Intensity Scale of 1931. (Continued)

Intensity	Description of Effects
XII	Damage is nearly total. Practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rockfalls, and slumps in riverbanks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

(Modified from Cluff and Bolt, 1969, p. 9)

d. "It was as if giant hands took the house and shook it . . . the pea soup jumped out of the pot and the grandfather clock was silenced." (modified from Iacopi, 1971)

Intensity: V

2. Not all earthquakes occur in areas where high levels of risk have been identified. On July 27, 1980, an earthquake of Richter magnitude 5.1 shook Kentucky, Ohio, and adjacent states. The earthquake epicenter was determined to be at latitude 38.2° N, longitude 83.9° W, near Sharpsburg, Kentucky (approximately 30 miles southwest of the Ohio River town of Maysville, Kentucky). It had a focal depth of 13 km. Damage to structures along the Ohio River in Maysville, Kentucky, and in the Ohio communities of Aberdeen, Manchester, Ripley, and West Union, consisted of chimneys being knocked down, cracks in plaster and concrete blocks, and merchandise being toppled from store shelves. In Cincinnati a cornice reportedly fell from city hall.

a. Based on the reported damage, what was the intensity of this earthquake along the Ohio River?

VII

b. Locate the earthquake epicenter with an X on Figure 6.3.

Isoseismal Maps (6, Part AB)

Large earthquakes have the potential for significant damage. This damage varies with the geologic nature of the earthquake and the rocks between the focus and the site, types and properties of the materials at a site, and the nature of the buildings. In this part of the exercise we use data from 1949 and 1965 earthquakes in western Washington to construct isoseismal maps.

QUESTIONS (6, PART A3)

1. The intensity of an earthquake is a measure of the impact of seismic shaking on the ground, structures, and people. It is described on a scale of I to XII (in Roman numerals), where I is only rarely felt and XII is total destruction. Use the Modified Mercalli Intensity Scale (Table 6.1) and the descriptions of site damage for the April 13, 1949, earthquake (Table 6.2) to determine the intensity at each site. Record the intensity and the primary evidence used in determining the intensity for each site, beside the names of the sites in Table 6.3. Several intensities, with evidence, are given.

2. Place the intensity values from Table 6.3 on the map of Washington (Figure 6.4). Then draw boundaries between these intensities to produce an isoseismal map.

3. What was the maximum intensity from the 1949 earthquake?

XI

4. Where does the epicenter for the 1949 earthquake appear to have been?

Puyallup

5. What observation in Table 6.2 was the most interesting or surprising to you? Why?

The reports of subterrainian noise

6. Using intensity numbers from the April 29, 1965, western Washington earthquake shown in Table 6.4, enter the intensity values on the map of Washington (Figure 6.5).

7. Draw the approximate boundaries of the intensity zones as determined by the values you entered for each locality. Part of one boundary is given for you in Figure 6.5.

TABLE 6.2 Impact of the 1949 Earthquake in Western Washington at Various Sites.

Aberdeen	One death. Scores of chimneys tumbled at roof level. Broken dishes and windows.
Bellingham	Hanging objects swung. Swaying of buildings. Pendulum clocks stopped or ran fast or slow.
Bremerton	One death. Considerable falls of plaster. Elevator counterweights pulled out of guides. Swaying of buildings. Trees shaken moderately to strongly.
Buckley	Part of high school building fell. Most chimneys in town toppled at roofline. Cracked plaster and ground.
Centralia	One death; 10 persons hospitalized. Very heavy damage. Collapse of building walls and many chimneys. Water mains broken; Water and sand spouted from ground. Violent swaying of buildings and trees. Many objects moved, including pianos. Objects fell from shelves. Pendulums swinging east–west stopped. Many persons panic-stricken. Four miles southwest of town, water spouted 18 in. high in middle of field, leaving a very fine sand formation around each hole (1–3 in. in diameter). Gas or air boiling up through river.
Cle Elum	Pendulum clocks stopped. Small objects and furnishings shifted. Trees and bushes shaken moderately.
Eatonville	Chimneys toppled. Plaster fell in large pieces in schoolhouse. People had difficulty in maintaining balance.
Hyak	Few windows broke. Trees and bushes shaken moderately. Furnishings shifted.
Longview	Two minor injuries. Gable of community church fell. Water main broke, beams cracked in school. Extensive but scattered damage to business buildings, industrial properties, and residences. Considerable damage to irrigation ditches. Landslides on cuts along highway. Objects fell in all directions. Some heavy furniture overturned. Glass figurine on mantle thrown 12 ft.
Olympia	Two deaths; many persons injured. Conspicuous cracks in ground and damage in masonry structures. Capitol buildings damaged. Nearly all large buildings had cracked or fallen walls and plaster. Two large smokestacks and many chimneys fell. Streets damaged extensively; many water and gas mains broken. Portion of a sandy spit in Puget Sound disappeared during the earthquake.
Port Townsend	Pendulum clocks facing northeast stopped. Hanging objects swung. Slight damage in poorly built buildings. Subterranean sounds heard. Bells rang in a small church.
Puyallup	Many injured. High school stage collapsed. Nearly every house chimney toppled at roof line. Several houses were jarred off foundations. Minor landslides blocked roads. Water mains broke. Multiple-story brick buildings most severely damaged. Some basement floors raised several feet, driving supports through floor above. Plaster badly damaged. Water spouted in fields, bringing up sand.
Randle	Twisting and falling of chimneys; about one-fourth of all chimneys fell. Damage considerable. Water spilled from containers and tanks. Plaster and walls fell; dishes and windows broke. Lights went out.
Satsop	Cracked ground. Pendulum clocks stopped. Trees and bushes shaken strongly. Furnishings overturned.
Seattle	One death; many seriously injured with scores reporting shock, bruises, and cuts. Many houses on filled ground demolished; many old buildings on soft ground damaged considerably. Collapse of top of one radio tower and one wooden water tank with damage to many tanks on weak buildings. Many chimneys toppled. Heavy damage to docks (fractures in decayed pilings). Several bridges damaged; many water mains in soft ground broken. Telephone and power service interrupted. Large cracks in filled ground; some cracking of pavement. Water spouted 6 ft or more from ground cracks. At the federal office building, bookcases thrown face down. Very heavy furniture overturned. Plaster badly cracked and broken with pieces 1–3 ft square thrown from walls. Pictures on north–south walls canted; those on east–west walls—little cant. Some doors did not fit after shock. Many old brick buildings partially destroyed.
Snoqualmie	Most damage confined to brick chimneys, windows, and plaster. Overturned vases and floor lamps. Coffee shaken out of cups. Rockslides on Mt. Si. Trees and bushes shaken strongly.
Tacoma	One death. Many buildings damaged and parts fell. Many chimneys toppled. Several houses slid into Puget Sound. One smokestack fell. One 23-ton cable saddle was thrown from the top of tower at Tacoma Narrows Bridge, causing considerable loss. Railroad bridges thrown out of line. Tremendous rockslide, a half-mile section of a 300-ft cliff, into Puget Sound. Considerable damage to brick; plaster, windows, walls, and ground cracked.

(Modified from Murphy and Ulrich, 1951)

TABLE 6.3 Intensities from the April 13, 1949, Earthquake

Location (symbol)	Intensity	Primary Evidence for 1949 Earthquake
Aberdeen (Ab)	IX	chimneys fall;
Bellingham (Be)	V	pendulum clocks stopped/slow
Bremerton (Br)	VIII	elevators off weight, tree striking
Buckley (Bu)	VIII	Walls and chimneys fall; cracked ground
Centralia (Ce)	VIII–IX	Sand and mud eruption: pipes break; damage considerable
Cle Elum (Cl)	V	pendulum clocks stop
Eatonville (Ea)	VII	Plaster falls in large pieces; difficulty maintaining balance
Hyak (Hy)	VI	Trees/bushes shake moderately; few windows break
Longview (Lo)	IX	water main breaks, heavy furniture moves
Olympia (Ol)	X	many buildings destroyed
Port Townsend (Po)	V	Subterranian sounds
Puyallup (Pu)	XI	earth moves
Randle (Ra)	VIII	Twisted and fallen chimneys; walls fall
Satsop (Sa)	VII	cracked ground
Seattle (Se)	IX	severe damage, mass hysteria
Snoqualmie (Sn)	VII	Damaged chimneys/windows; trees/bushes shaken strongly
Tacoma (Ta)	X	Houses off foundation

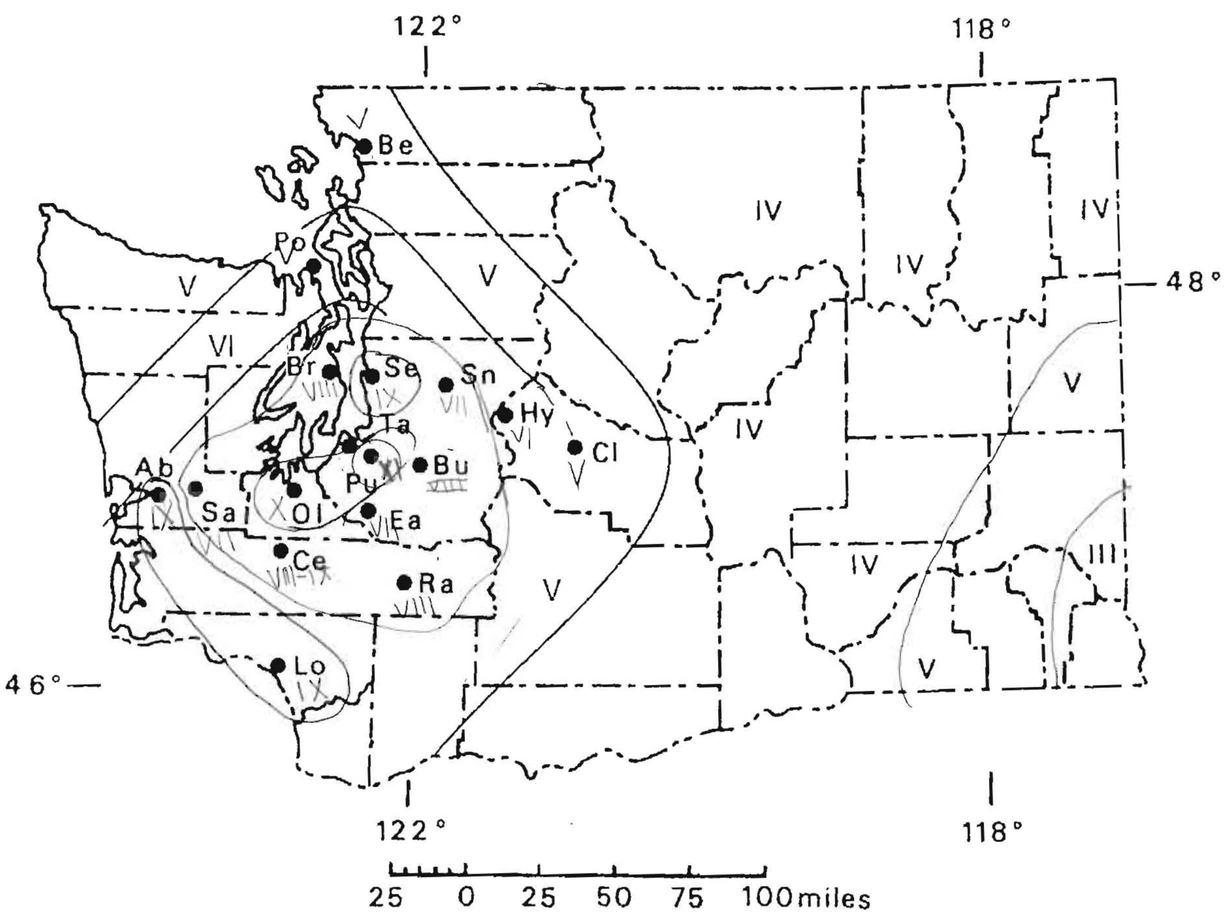


FIGURE 6.4 Index map of Washington showing locations of the sites listed in Table 6.3. Modified Mercalli Intensities for April 13, 1949, earthquake are given for eastern Washington. Some boundaries of intensity zones shown. Completed map is an isoseismal map.

TABLE 6.4 Locations and Intensity Data for the April 29, 1965, Western Washington Earthquake

Location	Intensity	Location	Intensity
Aberdeen (Ab)	V	Longview (Lo)	V
Arlington (Ar)	VI	Olympia (Ol)	VI
Bellingham (Be)	V	Port Angeles (Pa)	V
Bremerton (Br)	VI	Port Townsend (Po)	V
Buckley (Bu)	VI	Puyallup (Pu)	VII
Centralia (Ce)	VI	Randle (Ra)	V
Cle Elum (Cl)	V	Satsop (Sa)	VI
Concrete (Co)	VI	Seattle (Se)	VII
Eatonville (Ea)	VI	Snoqualmie (Sn)	VII
Forks (Fo)	IV	Tacoma (Ta)	VII
Hyak (Hy)	VI	Vancouver (Va)	V

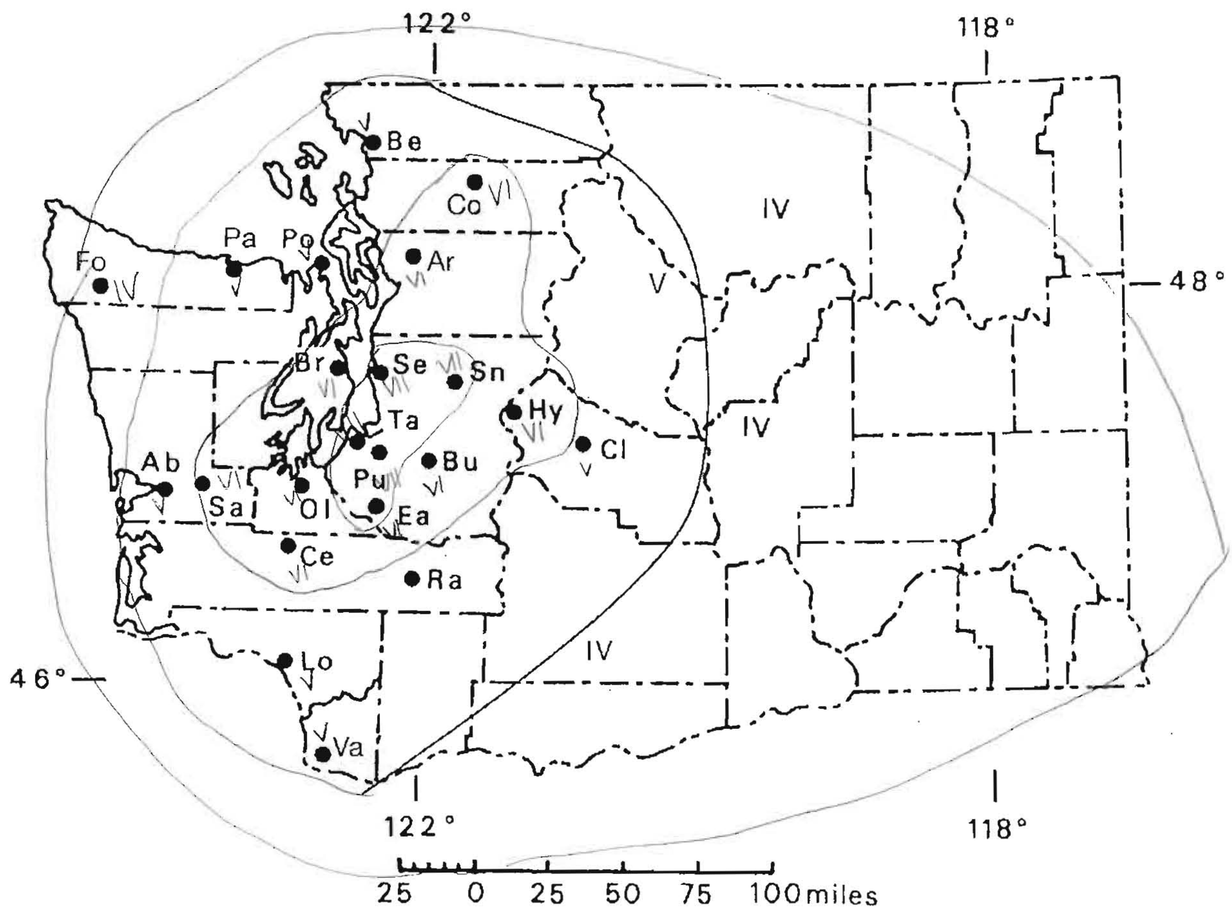


FIGURE 6.5 Index map of State of Washington showing the sites of intensity data from the 1965 western Washington earthquake.

8. a. What was the maximum intensity for the 1965 earthquake?

VII

b. Where does the epicenter for the 1965 earthquake appear to have been?

Tacoma

9. On the Web you will find additional information on these two earthquakes (and others) at http://earthquake.usgs.gov/eqcenter/dyfi.php. Complete the following blanks for these two western Washington earthquakes.

a.	1949 Earthquake	1965 Earthquake
Date	'49	'65
Maximum Intensity	XI	VII
Name (Earthquake)		
Magnitude		
Number of Reports		

b. You might still be curious about earthquake intensities. Below write a question for your TA or instructor about some aspect of the exercise that you don't understand.

Note: If you experience an earthquake you can report what you saw/felt during the earthquake and what damage you noted. It is useful to write your account of the event as soon as you are safe and can make notes. Then use those notes when completing the form at http://pasadena.wr.usgs.gov/shake/pnw/html/unknown_form.html.

Earthquake Shaking Hazard Maps (6, Part A4)

National maps of earthquake shaking hazards provide information that helps to save lives and property by providing data for building codes. Buildings designed to withstand severe shaking are less likely to injure occupants. These hazard maps are also used by insurance companies, FEMA (for support of earthquake preparedness), EPA (for landfill design), and engineers (for landslide potential).

The map shows the hazard by zones (or in some maps contour peak values) of the levels of horizontal shaking. The higher the number the stronger is the shaking. The number is % g or percent of acceleration due to gravity (in this case as horizontal acceleration). Acceleration is chosen, because building codes prescribe how much horizontal force a building should be able to withstand during an earthquake. 10% g is the approximate threshold for damage to older (pre-1965) structures. Additional information on these maps is available from Frankel et al. (1997) and from the USGS (Fact Sheet 183-96).

Figure 6.3 is a ground-shaking hazard map that shows a 10 percent probability of exceeding a given value in a 50-year period (Peterson and others, 2008). That is, over the next 50 years there is a 1 in 10 chance that the acceleration given for any area will be exceeded. Use information in Figure 6.3 to help answer the following questions.

QUESTIONS (6, PART A4)

1. Which areas of the country have the lowest hazard from earthquake shaking (where 4% g, or less, peak acceleration is expected)?

Florida, Southern Tx, Northern Plains

2. If damage to older (pre-1965) structures can be expected with horizontal accelerations of 10% g or more, which areas of your home state are:

a. at some risk? all of Ca

b. at greatest risk? Southern Ca

c. what is your home state? Ca

3. What three or four regions of the country have the highest accelerations?

Southern Ca (West Coast)
New England
Mississippi Valley

4. What geologic processes, other than shaking and fault displacement, could produce a hazard in an earthquake? List two.

Liquifaction
Landslide

5. The geologic material on which a building rests plays a role in the type of shaking that occurs during an earthquake. Weak materials amplify the shaking. Which of the following foundation materials would most likely result in less shaking and a safer building? (circle one)

artificial fill, poorly consolidated sediments, marine clays, unweathered bedrock

6. If the Internet is available, now or after class, determine and list (places and magnitudes) where the largest two earthquakes have occurred in the last 2 weeks. Also list what processes, other than shaking, contributed to the loss of structures and life. A possible source to begin the search is: http://earthquake.usgs.gov/recenteqs/

7. The Mississippi Valley is indicated as a high-risk area because of earthquake activity that is associated with stress within the continental lithospheric plate. Consider the types of plate margins in the plate tectonics model to answer the following questions. (See a geology text for basic details on plate margins.)

a. What is the tectonic explanation for the major shaking hazard in southern California? Form fault
San Andreas - transform fault

b. What is the tectonic explanation for the major shaking hazard around Seattle?
Convergent Boundary

PART B. FAULTS AND FAULT DETECTION

Earthquakes are related to movements along fault zones. Diagrams of several types of faults are shown in Figure 6.6. If necessary, the review questions in this portion of the exercise may be answered with the aid of a standard introductory geology textbook.

Fault zones can be recognized on aerial photographs, satellite and LIDAR images, geologic maps, and topographic maps, as well as by field observations. Features that might indicate a fault zone area are (1) scarps (cliff or break in slope) formed by horizontal or vertical movement; (2) steep mountain fronts; (3) offset streams and ridges; (4) sag ponds and lakes; (5) lineaments of vegetation; (6) valleys in fault zones; (7) changes in rock type, structure, moisture, and vegetation and (8) faceted spurs. These features are shown in Figure 6.7, which depicts a strike-slip fault (largely horizontal displacement). Normal faults also can have distinct features, which are illustrated in Figure 6.8.

QUESTIONS (6, PART B)

Fault Diagrams

1. The freshly exposed cliff of bedrock or regolith along a fault line is known as a fault ______________ ___.

2. Following an earthquake, the horizontal distance between two utility poles on opposite sides of a fault trace (not a strike-slip fault) had increased. Are the regolith (soils) and bedrock in this area in a region of compression (squeezing together) or tension (pulling apart)? Explain your reasoning.

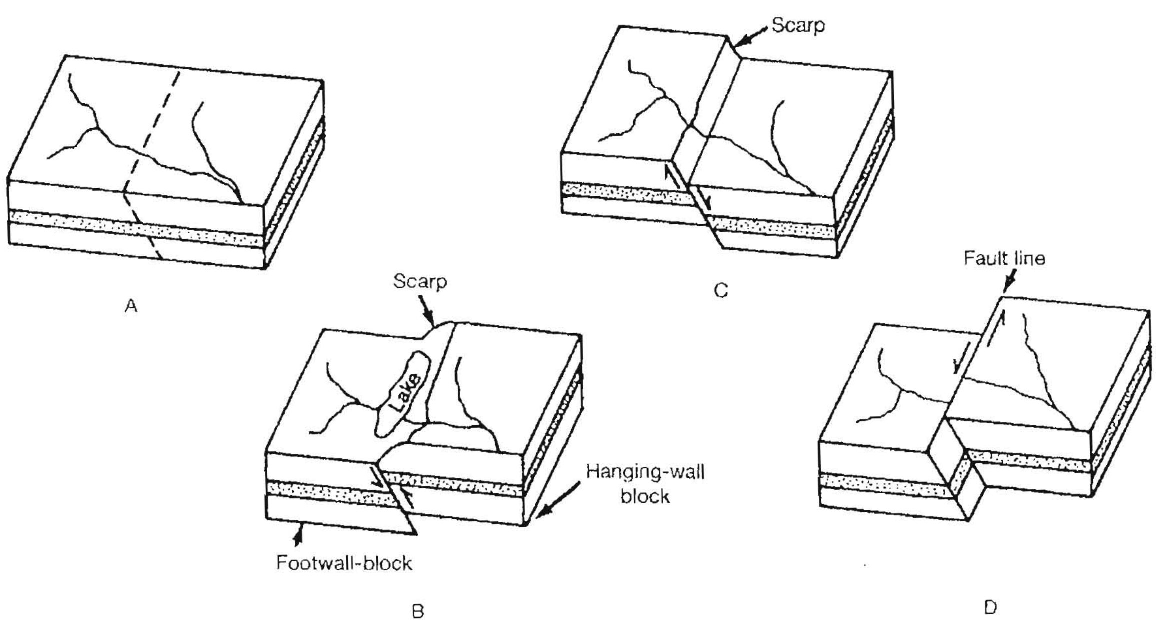


FIGURE 6.6 Types of fault movement: (a) block before movement; (b) reverse fault, or thrust fault, in which the hanging-wall block has moved up relative to the footwall block; (c) normal fault, in which the hanging-wall block has moved down relative to the footwall block; (d) strike-slip fault, in which the blocks on either side of the fault have moved sideways past each other. Arrows indicate relative motion of the blocks.

(Modified in part from McKenzie, Pettyjohn, and Utgard, 1975)

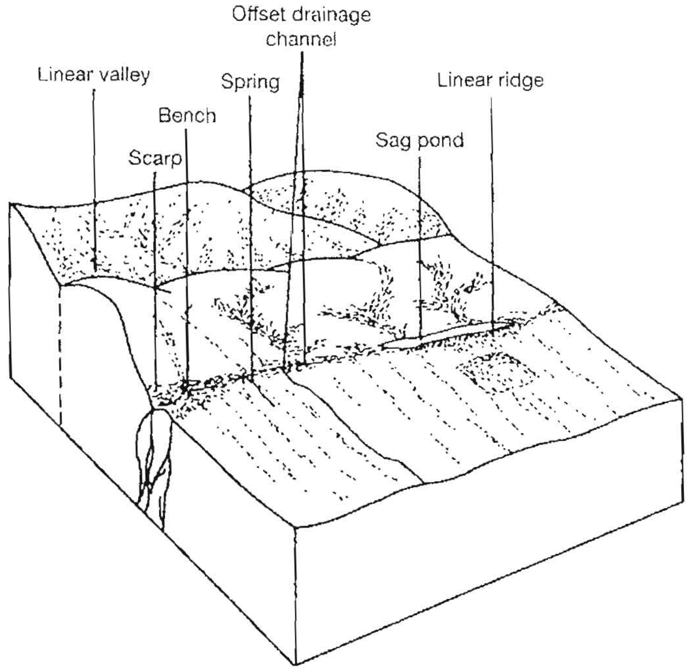


FIGURE 6.7 Distinctive landforms and drainage patterns aligned along a strike-slip fault are visible evidence that fault movement is recent enough to have interrupted the more gradual processes of erosion and deposition.
(Brown and Kockelman, 1983)

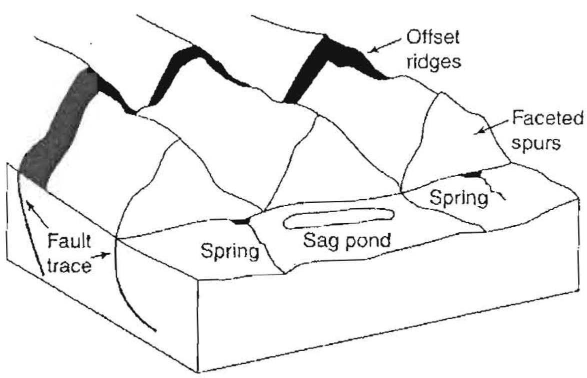


FIGURE 6.8 Typical geologic features found associated with a normal fault in mountainous terrain.

3. Sketch two utility poles on Figure 6.6a, placing one on each side of the fault. Use fault diagrams Figure 6.6b and c, and determine if the relative motion of the fault blocks in Question 2 indicates that it is a normal fault or reverse fault. Explain your reasoning.

San Andreas Fault

Study Figure 6.9, which is a photo of the San Andreas Fault, and then answer the questions below. It will help to review Figure 6.7.

4. What geological features can be used to identify the location of the fault? Outline the fault zone in Figure 6.9.

5. Does the fault zone consist of a single fracture or several parallel fractures? What is your evidence?

6. In addition to faults, what other natural or human-made features can create straight lines in topography? Are any of these features present in this photograph?

7. Indicate the direction of movement along the fault by drawing arrows on either side of the fault in Figure 6.9.