Lab 7: Fluvial Landforms

Geol 454 – Geomorphology

Objectives: To review drainage patterns and introduce fluvial landforms, as well as concepts of hydrographs and flood dynamics. Many of the exercises focus on the relationship between flood and channel characteristics.

Exercise: Answer the problems at the end of the handout. You may need to utilize the lecture text to supplement your answers (Chapter 4 in Bierman and Montgomery discusses basic hydrology, and Chapter 6 deals with floodplains and other fluvial landforms). This is an individual assignment; each person must submit his/her own worksheet and typed answers (where indicated).

Part One: Drainage Patterns

Drainage patterns often reveal useful information about the underlying structure and lithology. A search for a distinctive drainage network on a topographic map or aerial photograph is a logical first step in the study of regional geology and provides clues into these structural characteristics.

One of the most common drainage patterns is **dendritic**, which often develops on horizontally bedded sedimentary rocks or uniformly resistant crystalline rocks. Also possible are **parallel** patterns, indicating moderate to steep slopes or parallel elongate landforms, and **trellis**, which commonly occurs atop dipping or folded sedimentary, volcanic, or low-grade metasedimentary rocks. Trellis patterns may also be structurally controlled in areas of parallel fractures. Similar to trellis but lacking the orderly, repetitive quality is the **rectangular** drainage pattern. This pattern reflects jointing and/or faulting at right angles in the underlying bedrock. **Radial** patterns indicate volcanoes or domes of uniform lithology, while **annular** patterns suggest volcanoes or structural domes that expose sedimentary rocks of variable resistance. Inversely, a **centripetal** drainage pattern forms in structural basins, karst, or old lakebeds. Localized subsurface accommodation of drainage forms a **multibasinal** drainage pattern. Multibasinal patterns may reflect hummocky glacial deposits, differentially scoured or deflated bedrock, karst, or permafrost regions. Review the lecture text for specific guidelines in identifying drainage patterns.

Part Two: Fluvial Landforms

Fluvial landforms are landforms shaped dominantly by the action of running water, whether in the form of overland flow or stream flow. Even in arid and semi-arid environments like Colorado, features produced by fluvial processes often dominate landscapes.

The **piedmont** is a large, gently sloping surface that joins a mountain range to an adjacent basin or plain. A **pediment** is a portion of the piedmont that consists of a sloping, relatively smooth bedrock surface that may be covered by a thin veneer of sediment. Pediments are thought to be erosional in origin. **Alluvial fans** are stream deposits that accumulate on piedmonts at the base of mountain fronts. They are fan-shaped in plan-view and convex-up in a cross-section taken parallel to the mountain front. Fans are commonly **dissected** by distributary channels or washes, all of which are probably not active at any one time. The coalescing of several adjacent alluvial fans along a mountain front forms **Bajadas**. The transition from a series of single fans to a bajada is complete when the cone shape of each individual fan is lost.

Bolsons are extensive, flat basins or depressions, almost or completely surrounded by mountains and from which drainage has no surface outlet. These arid region features characteristically have centripetal drainage patterns and commonly have level plains in their center called **playas**. **Playa lakes** may form during heavy rainfall, but are usually short-lived, due to aridity and consequent infiltration and evaporation.

Recall that **channel planform** is a way to classify rivers, where channels that exhibit a **braided** planform have multiple, shifting threads of flow. These channel types tend to occur in very steep environments with abundant sediment supply. Rivers that maintain flow primarily within a single channel can be categorized by their sinuosity (P). These single thread channels can exhibit **straight** ($P < 1.5$) or **meandering** ($P > 1.5$) channel planform. The growth of a meander results from erosion of the outside bank of each bend and concurrent deposition of material on the inside of each curve. As the meander bend migrates laterally, the continued accretion of sediment on the inside of the meander curve forms a **point bar.**

Meanders migrate downstream because of more effective erosion occurring on the downstream side of the meander bend. Differential erosion causes these meander bends to become distorted and increasingly sinuous until a threshold of disequilibrium is reached. Periodically, a stream will form temporary cutoff channels during high discharge without permanently altering the channel pattern. This process, coupled with continued lateral migration of a meander and point bar deposition, forms a series of low ridges and shallow swales on the inside of meander bends called **ridge and swale topography** or **meander scroll topography.** Once unstable, the river cuts across the meander loop to follow a more direct course. Abandonment of the old meander loop produces a crescent-shaped lake called an **oxbow lake.** Migration of meandering channels over time result in relic topography that reveals the location of abandoned meanders and point-bars deposits called **scroll bars**.

Floodplains are formed by a number of processes, but lateral channel migration and vertical overbank deposition are believed to be the most important processes in operation. Most floodplains form by the interaction of a number of processes; the relative importance of these processes varies from situation to situation.

A **natural levee** forms when a river leaves the confines of its channel and deposits coarse-grained material adjacent to the bank edge. This coarse-grained material continues to accumulate, due to subsequent flooding, and a natural levee is formed. On topographic maps only large levees are visible. These levees are recognizable as elongate, narrow ridges adjacent to a channel. Occasionally, river flow breaches a levee, forming a gap in the levee called a **crevasse**. Sediment is deposited on the floodplain in a fan-shaped deposit of debris called a **crevasse splay**. These features tend to form on floodplains having well-developed levees which form barriers to surface drainage attempting to enter the river. These areas are called **backswamps**; they play an important role in reducing flood peaks downstream by trapping and temporarily storing floodwater, which has breached the levee.

Terraces are abandoned floodplains formed during a period when the river flowed at a topographically higher elevation. Terraces result when channel downcutting lowers a river's level, creating a new – lower and smaller – floodplain. Terrace surfaces represent relic features that are no longer directly related to current flood hydrology. Terraces form in response to changes in stream discharge or bedload sediment transport rates.

Many terraces classification systems based on different distinguishing criteria are currently in use. Genetic terms that explain the way in which terraces form include **erosional terraces**, which are created primarily by lateral erosion, and **depositional terraces**, which represent an uneroded surface of older channel fill. Another classification system divides terraces into **tectonic** and **climatic terraces**, based on the cause of terrace formation. More descriptive terms include **strath (bedrock)** and **alluvial (fill) terraces**. Similarly, **paired terraces** occur on both sides of the channel at equal elevations. These paired terraces are usually interpreted as former floodplain levels of similar age. **Unpaired terraces**, on the other hand, vary in elevation on either side of the channel. Unpaired terrace formation has been attributed to slow incision with slow lateral migration. Therefore, the unpaired terraces represent floodplain levels of different ages.

Part Three: Hydrologic Concepts

The **floodplain** is generally considered the flat surface adjacent to a channel. Floodplains are located at a slightly higher elevation than the channel and provide temporary storage of floodwaters. When water rises above the level of the banks, a portion of the discharge continues to flow downstream over the floodplain. Because the floodplain usually has many trees, bushes, houses, etc., the flow encounters more resistance than the water still flowing down the channel. Based on Manning's equation (Bierman and Montgomery, 2013; Chapter 6), we know that water velocity is proportional to the channel slope ($S^{1/2}$), hydraulic radius ($R^{2/3}$), and the channel resistance (Manning's n). Therefore, we can deduce that water traveling over the floodplain will generally travel more slowly than water traveling in the channel.

As a flood-wave moves downstream, resistance in the channel and on the floodplain tends to slow the release of a portion of the water (**flood attenuation**). Given an overall volume of storm runoff, resistance to flow tends to decrease flood peaks downstream and lengthens the period of time necessary for the flood to pass a given location. The more resistance offered by the channel and the floodplain, the more dramatic the effects of flood attenuation become.

To help demonstrate this process, you can picture all of your friends lining the side of a channel armed with buckets. As a flood-wave approaches, some of your friends fill their buckets from the channel and then pour the water back into the channel at a later point in time. If you are standing downstream from your friends, it will take a longer time for all of the flood water to reach you than it would have taken without the bucket storage (temporary floodplain storage). If more of your friends fill and empty their buckets (increased channel and floodplain resistance), then the flood-wave will take even longer to pass you (more attenuated flood-wave).

Analyzing Flood Hydrographs

The **flood hydrograph** is a plot of stream discharge versus time. The hydrograph illustrates the rate of increase of river stage, the flood peak magnitude, the duration of high flow, and the rate of descent of river stage. Similarly, **a hyetograph** depicts the depth of precipitation over time. The **storm hydrograph** has a plot of precipitation (i.e. hyetograph) superimposed on the discharge hydrograph. This information allows one to determine the relationship between storm precipitation and the resultant rate of discharge at a stream gaging station. A typical hydrograph is illustrated in Figure 1.

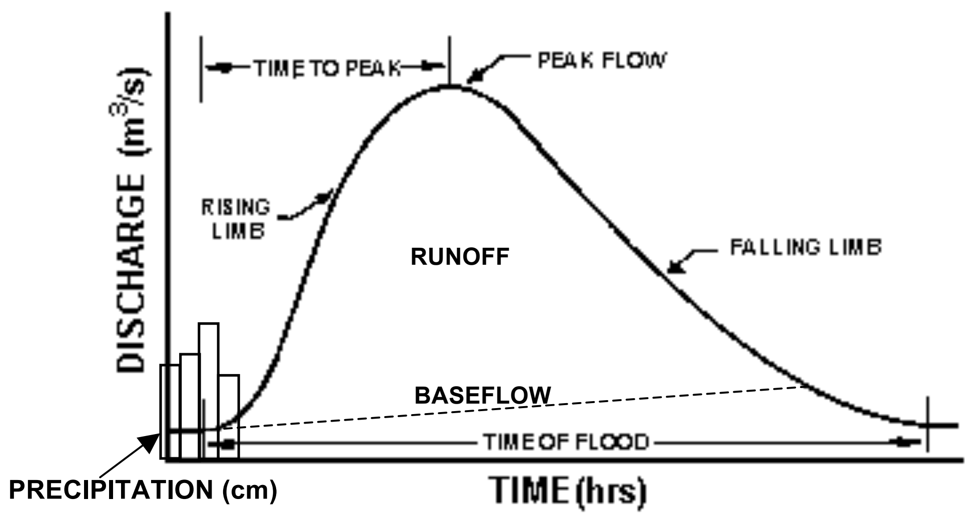


Figure 2. Storm hydrograph shows the relationship between precipitation and stream discharge.

The point of maximum discharge is called the **flood peak** or **peak flow** and corresponds with highest flood stage. The **rising limb** of the hydrograph is characteristically steeper than the **falling** or **recession limb**, reflecting the relatively rapid rate of transport of surface runoff to the channel and the relatively slow release of water held in storage and in groundwater storage.

Stream discharge can be separated into two general components: 1) **direct runoff** or quickflow and 2) **baseflow** or delayed flow. Baseflow, derived primarily from groundwater flow, sustains stream flow during periods of low precipitation. Because hydrographs represents stream discharge over time, they include both baseflow and storm runoff (or direct runoff) components. Various methods can be used to separate the hydrograph; the particular method chosen in a given situation is largely arbitrary.

The **lag time** is defined as the time interval between the center of mass of the storm precipitation and the center of mass of the flood hydrograph, represented by the peak (Figure 2). The precipitation hyetograph is usually plotted either on the left side of the hydrograph or in the upper left corner of the diagram to facilitate comparison between precipitation and discharge.

Streams with short lag times are called **flashy** and represent situations where precipitation is delivered rapidly to the stream channel, presumably as direct runoff. As the volume of direct runoff increases, the magnitude of the flood peak increases. Moreover, the groundwater component decreases when direct runoff is high because less water is available for groundwater recharge and baseflow discharge.

Estimations of storm runoff volume and stream discharge are essential in effective flood planning and design of engineering structures, such as dams and levees. These values can be easily determined from the storm hydrograph.

Rating Curves and Flood Frequencies

Statistical probability analysis of discharge records (collected by the U.S. Geological Survey and other federal, state, and private agencies) forms the basis for flood frequency studies. These discharge records contain mean daily discharge and the maximum instantaneous flow for the year, as well as the corresponding gauge height for each gaging station. These data can be used to construct a rating curve, which is the graphical relationship between stage and discharge at a particular gaging station, and a flood frequency curve, which is a plot of discharge versus statistical recurrence interval on logarithmic graph paper.

A **rating curve** is a plot on regular graph paper that relates stage to discharge for a given channel cross-section. The form of the rating curve is normally parabolic but may show some irregularities. A measure of the scatter of points about the best line fit determines the adequacy of a rating curve. Construction of a rating curve requires many discharge measurements, taken at a gaging site, that span a wide spectrum of discharge values. Naturally, the accuracy of the resultant rating curve is directly proportional to the number of available discharge and related stage measurements.

The **recurrence interval (RI)** is the time scale used for **flood frequency curves**, plotted along the abscissa. The recurrence interval is defined as the average interval of time within which a discharge of a given magnitude will be equaled or exceeded at least once. There are two commonly used methods to manipulate discharge data for studying flood frequency. The first method is the **annual-flood array**, in which only the highest instantaneous peak discharge in a water year is recorded. The list of yearly peak flows for the entire period of a record are then arranged in order of descending magnitude, forming an array. The recurrence interval of any given flow event for the period of record can be determined by using the equation:

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

where: RI = recurrence interval,
N = the total number of years in record, and
M = the rank or magnitude of the flow event.

Some hydrologists and geomorphologists object to the use of annual floods because this method uses only one flood in each year; occasionally, the second highest flood in a given year – which is omitted – may outrank many annual floods. The other method commonly used in flood frequency analysis is the **partial-duration series**. When using this method, all floods of greater magnitude than a pre-selected base are listed in an array, without regard to whether they occur within the same year. As you might expect, this method also draws criticism. The main problem with the partial-duration series is that each included flood may not be a truly independent event (*i.e.*, flood peaks counted as separate events may actually represent one period of flooding.) Because of the simplicity and general reliability of the annual-flood array, the U.S. Geological Survey has adopted this method.

It is critical to note that the flood array method of flood frequency analysis is a probabilistic approach in which flood occurrences are treated as random events. The method assumes that all floods occurring during a period of time constitute a sample of an infinitely large population in time. Specifically, if in a period of 30 years of record the largest flood recorded was of a certain magnitude, it is probable that a flood of equal magnitude will occur within the next 30 years. It therefore follows that the accuracy of flood prediction will depend to a large degree on the length of time for which discharge records are available. Predicting a flood of a certain magnitude is a calculated risk based upon a statistical probability. There is an element of chance involved.

Many times the flood record is much shorter than what we would desire. Often such records contain an individual flood whose recurrence interval is much greater than the total period of record. The point representing such an event will lie well off the general trend of the curve defined by the other points. Such an outlying point will cause the best-fit line to be shifted into a position that is unrepresentative of the actual scenario. This variability brings into question the validity of predicting rare flood events from a relatively short period of record. There is obviously a large degree of uncertainty in doing this, but frequently there are no alternatives. Despite these problems, flood frequency analysis remains the most accurate method of flood forecasting yet devised.

Even when flood probability is determined from long periods of record, the recurrence interval is only the average frequency with which a given discharge will occur. The 100-year flood is <u>not</u> necessarily an event that will occur at 100-year intervals. Rather, there is a one-percent chance that the 100-year flood will occur in any given year. If one occurred in a given year, there is still a one-percent chance that it will occur again the following year. The probability that a flood with a given recurrence interval will occur or be exceeded in any year can be determined using the following equation:

$$p = 1 - (1 - \frac{1}{RI})^n$$

where: p = probability of occurrence,
RI = recurrence interval of the event in question, and
n = the number of years in question.

For example, there is a four-percent chance that the 50-year flood will occur in the next two years because:

$$\mathrm{p} = \left[1 - (1 - \frac{1}{50})^2\right] * 100 = 3.96 \text{ or } 4\%$$

The **mean annual flood** is simply the arithmetic mean of all the maximum discharges in the annual array, and for most flood series distributions, it has been found to have a recurrence interval of 2.33 years. In fact, Dalrymple (1960) has defined the mean annual flood as the 2.33-year flood, as picked from the graphic flood frequency curve.

The uncertainty of extrapolating a flood frequency curve, as well as the possible error introduced by fitting a curve through the peak discharge point distribution, make flood forecasting a risky venture. Hydrologists and geomorphologists must be aware of the limitations inherent in flood forecasting methods before making predictions.

TABLE 5.1 Descriptions and Characteristics of Basic Drainage Patterns Illustrated in [illegible]

Pattern	Geological Significance
Dendritic	Horizontal sediments or beveled, uniformly resistant, crystalline rocks. Gentle regional slope at present or at time of drainage inception. Type pattern resembles spreading oak or chestnut tree.
Parallel	Generally indicates moderate to steep slopes but also found in areas of parallel, elongate landforms. All transitions possible between this pattern and dendritic and trellis patterns.
Trellis	Dipping or folded sedimentary, volcanic, or low-grade metasedimentary rocks; areas of parallel fractures; exposed lake or seafloors ribbed by beach ridges. All transitions to parallel pattern. Pattern is regarded here as one in which small tributaries are essentially same size on opposite sides of long parallel subsequent streams.
Rectangular	Joints and/or faults at right angles. Lacks orderly repetitive quality of trellis pattern; streams and divides lack regional continuity.
Radial	Volcanoes, domes, and erosion residuals. A complex of radial patterns in a volcanic field might be called multiradial.
Annular	Structural domes and basins, diatremes, and possibly stocks.
Multibasinal	Hummocky surficial deposits; differentially scoured or deflated bedrock; areas of recent volcanism, limestone solution, and permafrost. This descriptive term is suggested for all multiple-depression patterns whose exact origins are unknown.
Contorted	Contorted, coarsely layered metamorphic rocks. Dikes, veins, and migmatized bands provide the resistant layers in some areas. Pattern differs from recurved trellis in lack of regional orderliness, discontinuity of ridges and valleys, and generally smaller scale.

From Howard 1967, reprinted by permission.

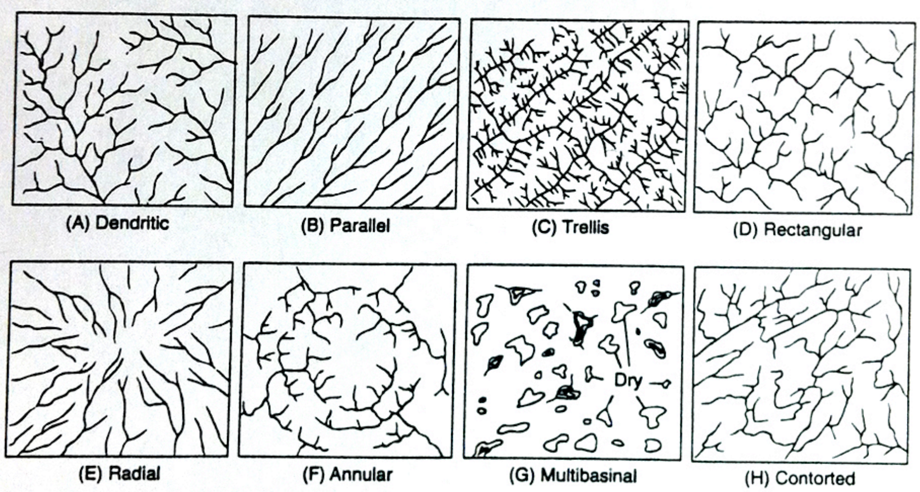


Figure 5.2A
Basic drainage patterns. Descriptions are given in table 5.1.
(Howard 1967, reprinted by permission)

Figure 2. Additional drainage patterns from Ritter, Kochel and Miller (2002) *Process Geomorphology* textbook.

Name __________________________ **Lab Day (circle one):** Monday Wednesday

Lab 7 Exercises

Fluvial Landforms - Refer to the attached visual depictions of drainage patterns (Ritter et al., 2002) for this portion of the lab (Figure 2).

Mount Rainier, Washington

1. (a) What drainage pattern is formed on Mount Rainier? (2 pts)

   (b) What does the drainage pattern indicate about the underlying structure and lithology of this mountain? (2 pts)

Lake Wales, Florida

2. What drainage pattern dominates this area? (2 pts)

Strasburg, Virginia

3. (a) What drainage pattern occurs in the center portion of the map depicting this region? (2 pts)

   (b) What do the erosional patterns of the channels indicate about the relative resistance of the ridges and valleys? (2 pts)

St. Paul, Arkansas

4. (a) What is the drainage pattern in this area? (2 pts)

Bright Angel, Arizona

5. (a) What drainage pattern occurs on the Kaibab Plateau? (2 pts)

   (b) What drainage pattern dominates Bright Angel Canyon? (2 pts)

   (c) What channel planform pattern best characterizes the Colorado River in Granite Gorge? (2 pts)

Bright Angel, Arizona & Manassa NE, Colorado

6. Compare the relative drainage density of the San Luis Hills at Manasa and Bright Angle Canyon and explain. (2 pts)

Manassa NE, Colorado

7. (a) What drainage pattern occurs around Flat Top Mountain (HINT: look at the entire map)? (2 pts)

   (b) What geomorphic landform name can be applied to the ponds in the northwest corner of the map? (2 pts)

Brandon, Vermont

8. (a) What is the fluvial landform represented by the wetlands along either side of Otter Creek? (2 pts)

   (b) What fluvial landform probably separates these wetlands from the river? (2 pts)

   (c) How do these features form? (2 pts)

Ennis, Montana

9. (a) What type of channel planform pattern does the Madison River exhibit upstream of Ennis Lake? (2 pts)

   (b) What type of channel planform pattern does the Madison River exhibit downstream of Ennis Lake? (2 pts)

   (c) The Cedar Creek Alluvial Fan represents a large deposit of material transported from the local mountains. How could this alluvial fan be affecting the Madison River channel pattern? (2 pts)

   (d) How would you describe the influence of Cedar Creek and Bear Creek on Cedar Creek alluvial fan? (HINT: see the notes at the beginning of this lab) (2 pts)

Guadalupe Peak, Texas

10. (a) Why might Salt Lake be salty? (2 pts)

(b) What type of geomorphic feature could you consider Salt Lake? (2 pts)

(c) What is the gently sloping area linking Salt Basin and Crow Flats to the Guadalupe Mountains? (2 pts)

Furnace Creek, California

11. (a) What is the geomorphic name for the gently sloping landform stretching from the northwestern corner of the quadrangle to the south central portion of the quadrangle near the San Bernardino Meridian? (2 pts)

(b) How could this landform have developed? (2 pts)

(c) What is the elevation at the base of this landform? (1 pts)

(c) Given your answer to part c) above, type of geomorphic feature could you consider Death Valley? (2 pts)

Menan Buttes, Idaho

12. (a) What are the fluvial landforms represented by the crescent shaped mounds along the inside of the meander bends? (2 pts)

(b) How do these features form? (2 pts)

Menan Buttes, Idaho and **Flaming Gorge Utah-Wyoming**

13. (a) The Snake River and Henry's Fork located on the Menan Buttes, Idaho, topographic map and the Green River located on the Flaming Gorge, Utah-Wyoming, topographic map represent what channel planform pattern? (2 pts)

(b) Based on the presence or lack of fluvial landforms and the relative incision of these channels, which of the above channels shows the most active lateral channel migration and why? (2 pts)

(d) Which of these channels would tend to form levees and why? (2 pts)

(e) What type of fluvial landforms do you see near Henry's River in the northeastern portion of the map? (2 pts)

Cumberland, Maryland-Pennsylvania-West Virginia

14. (a) What is the approximate average width of the floodplain (in kilometers) of Wills Creek between Lovers' Leap (The Narrows) and Eckert Junction? (2 pts)

(b) What is the approximate average width of the floodplain (in kilometers) of Wills Creek between Locus Grove and Mt. Savage Junction? (2 pts)

(c) How would flood attenuation vary between these two reaches? (2 pts)

Flood Hydrology and Channel Responses

Use your knowledge of flood processes and fluvial landforms to help you answer the questions that follow. Refer to your text and this handout for additional information and use figures 3-6 as prompted by each question.

Fig. 3 records a runoff event at streamflow gage A resulting from rain in the upper portion of the basin.

Fig. 4 is a flood frequency curve for streamflow gaging station A.

Fig. 5 is a rating curve for gaging station A.

Fig. 6 shows the plan-view map of this river with gage station A for part I, whereas gage B and levees are used in Part II.

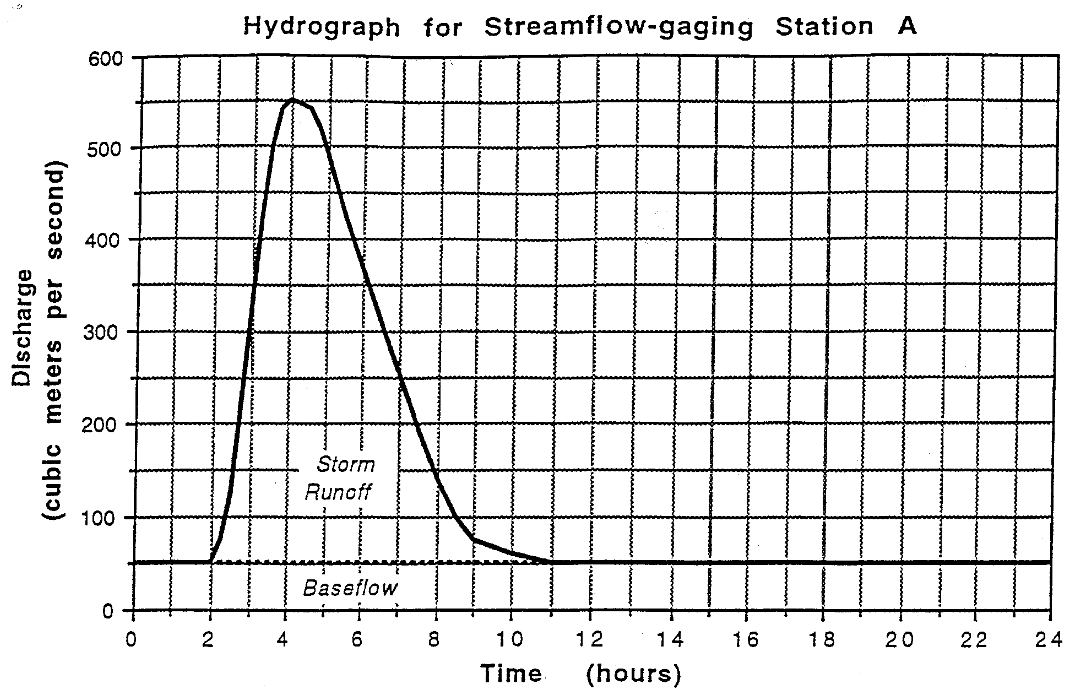


Figure 3: Runoff event at station A resulting from rain in the upper portion of the basin.

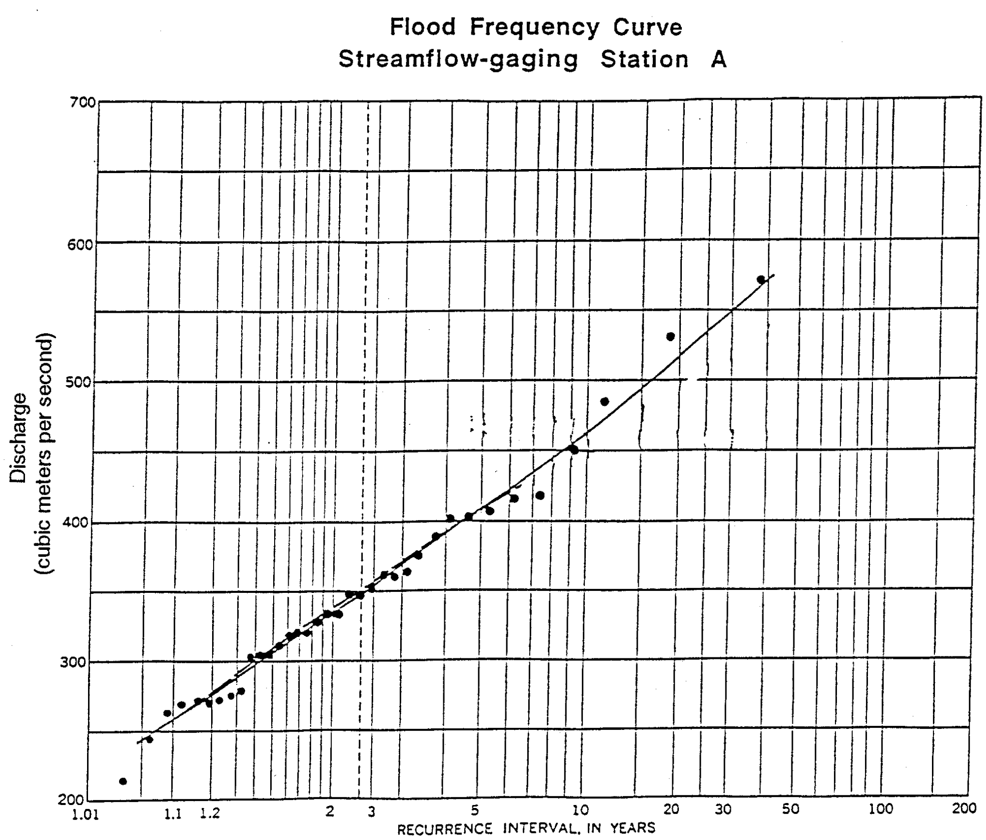


Figure 4: Flood frequency curve for streamflow gaging station A.

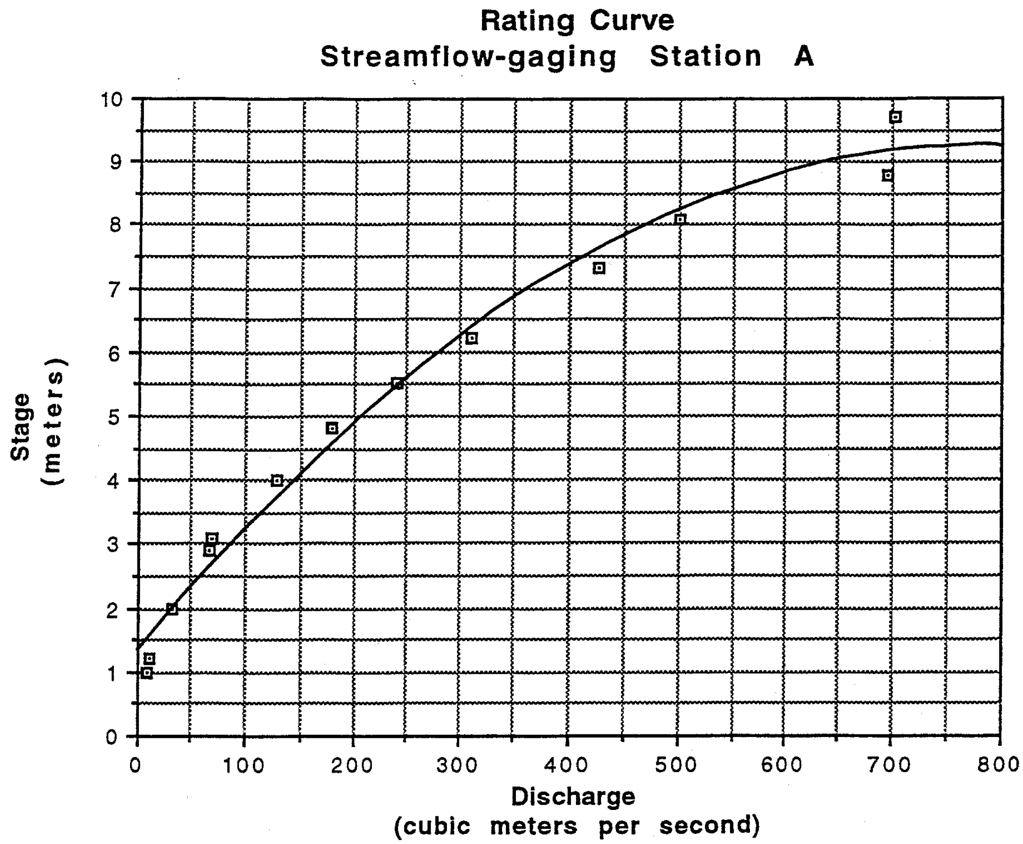


Figure 5: Rating curve for station A.

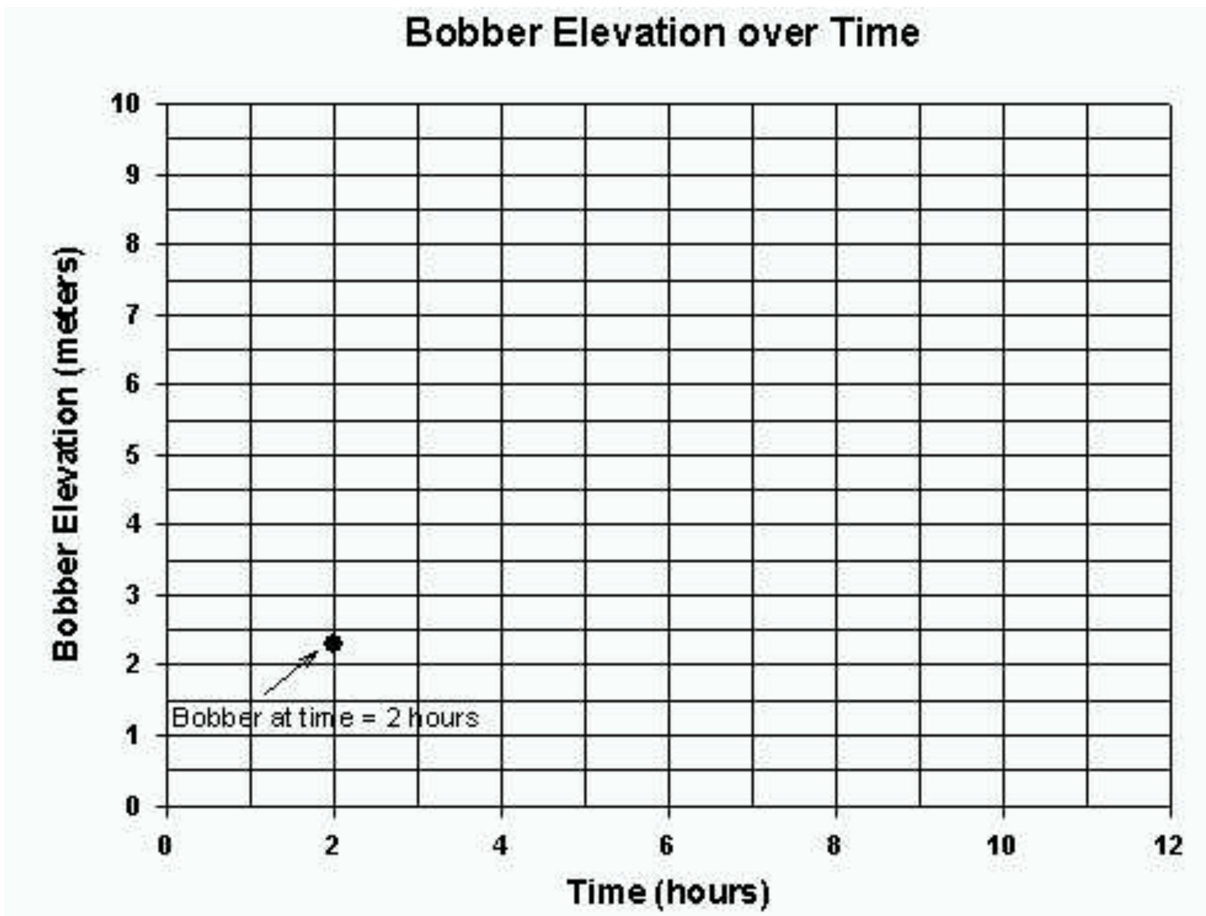
PART I

15. The streamflow-gaging station at point A records a runoff event for a short precipitation event occurring at time = 0 hours (Fig. 3).
    What is the lag-to-peak for this flow? (2 pts)

16. Determine the peak discharge from the hydrograph and determine the approximate recurrence interval for this flow from the attached flood frequency curve (Fig. 4). (2 pts)

17. What is the probability that a second flood of equal discharge will occur in the next 7 years? **Show your work (2 pts)**

18. You happen to be fishing at streamflow-gaging station A during this runoff event and you carefully observe the elevation of your fishing bobber during the runoff event. (The bobber remains at the same cross section and does not move downstream). Using the attached hydrograph (Fig. 3) and rating curve (Fig. 5) draw the elevation of the bobber at each one-hour increment from time = 2 hours until time = 11 hours. (Plot on the attached graph below). This plot is essentially the same graph that would be automatically recorded by the stage recorder inside the streamflow-gaging station. (4 pts)



19. Using your knowledge of flood attenuation, draw the approximate hydrograph that would be observed at streamflow-gaging station B for the same rainfall event recorded at streamflow-gaging station A before the levee is built (Fig. 6). Assume it takes approximately 3 hours for the first portion of the runoff to travel from gage A to gage B. Also assume there are no significant water losses or inputs between the two stations. (4 pts)

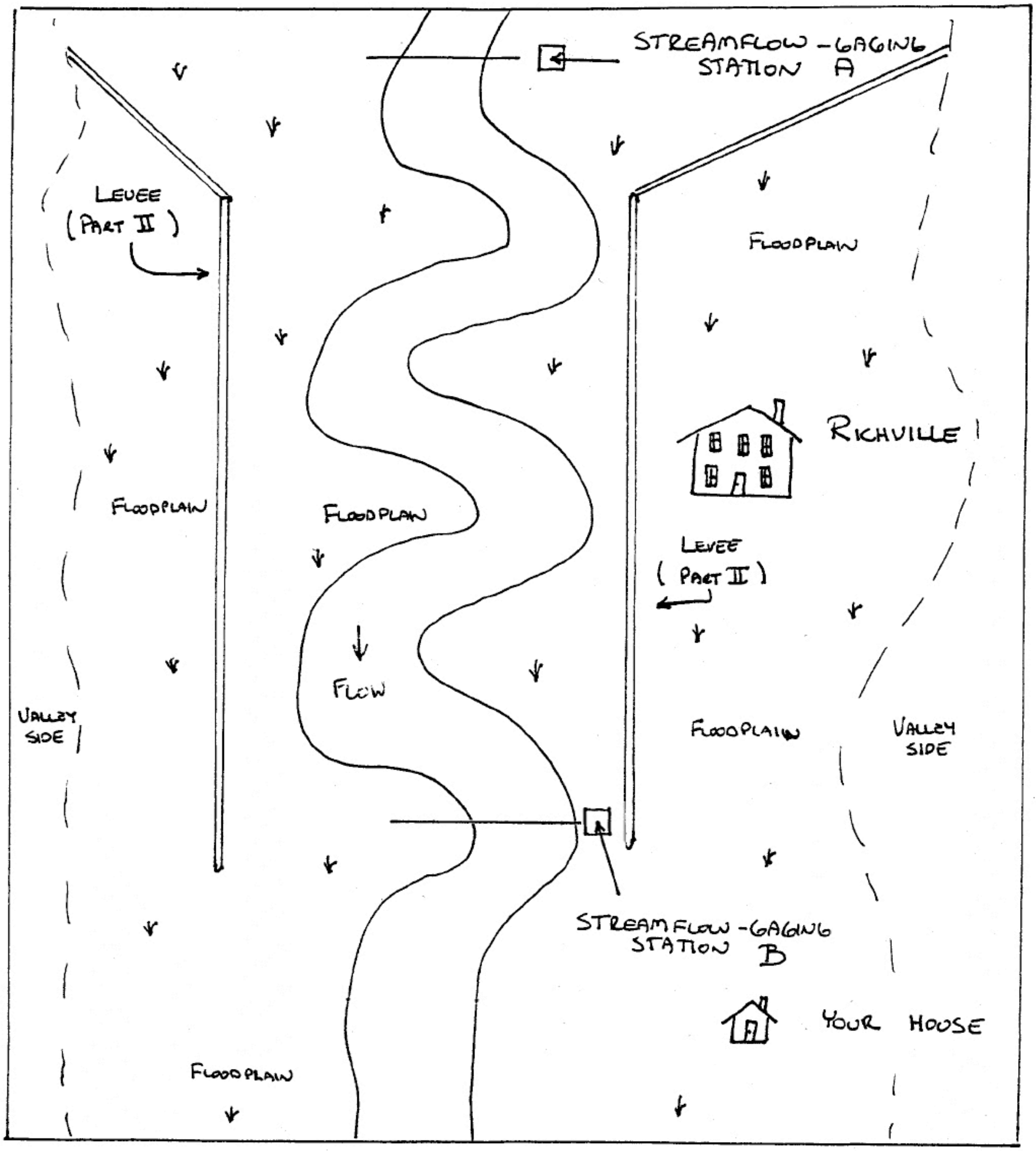
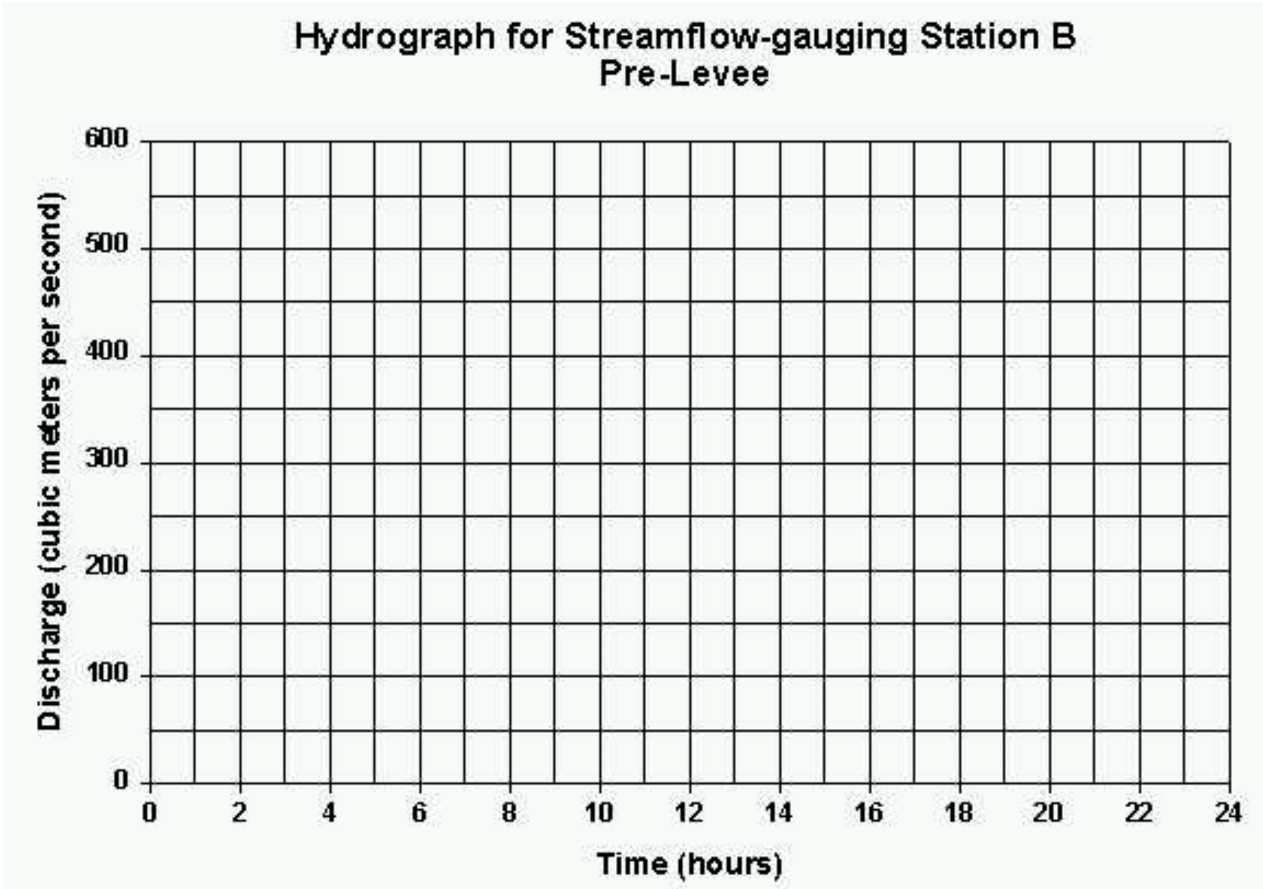


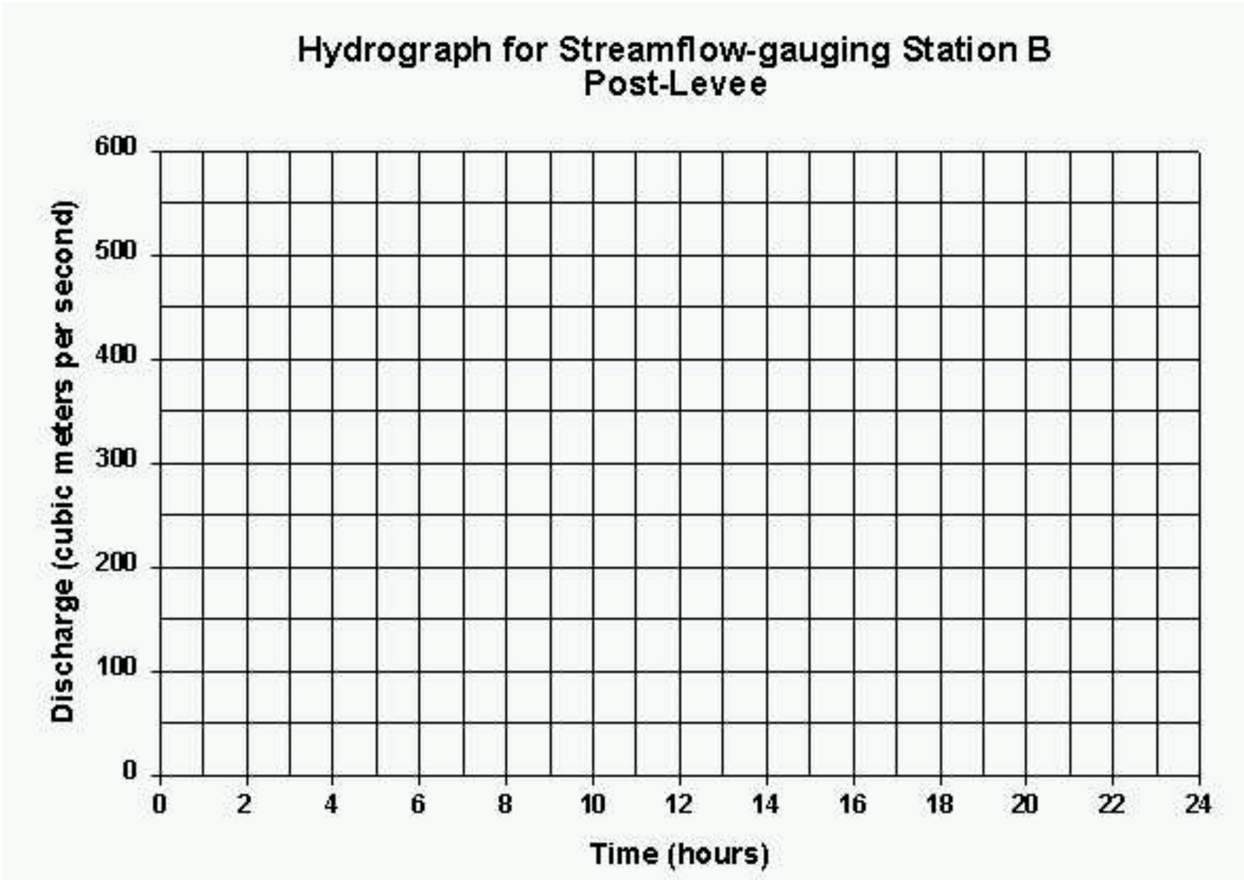
Figure 6: Plan-view map the river/floodplain system with gage A and gage B.



PART II

Now we will assume that the town of Richville constructs the levee indicated on the map above (Fig. 6) to protect their town from flooding.

20. Estimate and draw a new hydrograph (on the attached plot provided below) for streamflow-gaging station B using the same original hydrograph for streamflow-gaging station A after Richville builds the levee. Assume there are no significant water losses or inputs between the two stations. (4 pts)



21. In a **short <u>typed</u> paper** (i.e., one or two paragraphs not to exceed more than 300 words, about ½ a page) discuss what effects the levee will have on the flood hydrograph at streamflow-gaging station B. In particular, try to address the following questions: How will the levee affect the volume of storm runoff, flood peak and time-to-peak of the flood? (Describe qualitatively.) If there were no changes in the dimensions of the channel at streamflow-gaging station B, would a rating curve for this station need to be adjusted? (Indicate why or why not.) Would a pre-levee flood frequency curve for station B need to be adjusted? (Indicate why or why not.) If you lived a small elevation above the river downstream of station B, what long-term effects could the levee have on your property value? (Think about the elevation, relative stage of the river, and flooding.) (8 pts)

22. On the planform diagram used for questions 19 – 21 (Fig. 6), draw and label the following anatomy of a channel. Feel free to ignore the presence of the levee for this schematic. (5 pts)
    - Point bar
    - Cut bank
    - Crevasse splay
    - Oxbow lake
    - Scroll bars