STREAMS AND FLOODING

DEFINITIONS

Discharge (Q): The *volume of water per unit time* that passes a specified point on a stream. Discharge is conventionally measured in cubic feet per second (ft^3/sec or cfs) or cubic meters per second (m^3/sec or cms). Q = w d v where w = water width d = mean water depth v = mean water velocity

River stage or gage height: The elevation of the water surface in a stream.

Rating curve (or **stage-discharge curve**)**:** A graph relating *stage* (water height) to water discharge at a point on the stream channel.

Hydrograph: A graph showing how water discharge or stage varies with time at a point on a stream.

Water year: For hydrologic purposes, we use the *water year*, which runs from October of one year through September of the next. For example, water year 1990 extends from Oct. 1 1989 through Sept. 30 1990. The idea is to avoid splitting up winter storm flows between years.

Annual flood: The *annual flood* on a stream is the highest instantaneous peak discharge of the water year.

Flood magnitude: The size of a flood peak in discharge units (e.g., ft^3/sec or m^3/sec).

Flood recurrence interval (or **return period**)**:** The average time in years between flood events equal to or greater than a specified magnitude.

Flood-frequency curve: A graph showing the relationship between flood magnitude and their recurrence interval for a specified site.

Mean daily discharge: The average discharge of any specified calendar day (midnight to midnight). It is calculated by taking the total *volume* of water discharged during that day and dividing by 86400, the number of second in a day

Flow-duration curve: A graph showing the percentage of time specified mean daily discharges are equalled or exceeded.

Mean annual discharge (Q_{av}): The discharge that would have to flow constantly to equal the *volume* of water discharged by that stream over the entire period of years record. Q_{av} is the total volume of water discharged by the stream during the period of record divided by the number of seconds in that period. It is more easily calculated by averaging all the individual mean daily discharges.

Hydraulic geometry: The hydraulic geometry of a stream is the set of relations which show how width, depth, velocity, and cross-sectional area of flow vary with increasing discharge. These relations take the form of power functions (straight lines on logarithmic graph paper).

Floodplain: A level area near a river channel, constructed and maintained by the river in the present climate and overflowed during moderate flow events. The floodplain is largely built by the deposition of sediments on the inside of bends (*point bars*), and erosion on the outside, together with some overbank deposition. The floodplain is constantly reconstructed and maintained by the river. Not all streams have obvious floodplains, especially if the stream is 1) small; 2) incided in bedrock; or 3) has recently downcut.

River terrace: An abandoned floodplain, left behind as the river downcuts. Downcutting may be caused by tectonic uplift, or by climatic change. Terraces may be occasionally inundated by floods, but they are no longer actively maintained by the stream and are gradually consumed as the stream changes its course. Terraces that were cut across bedrock are called *strath terraces.; fill terraces* were formed by deposition of sediment in the valley bottom.

Bankfull discharge: The water discharge at which the water just starts to leave the channel and spill over onto the floodplain. On many streams bankfull discharge has a recurrence interval of about 1.5 years. Bankfull discharge is very important in maintaining the channel geometry and pattern -- it is large enough to transport appreciable sediment and to erode the banks, and it occurs frequently enough that it is effective in shaping the channel.

Point bar: A bar built on the inside of a bend where the water is slower and the sediment transported by the stream can settle out. The top of the upstream end point bar is approximately the elevation of the floodplain.

Riffle: A shallower, steeper part of the stream channel, typically of gravel. Riffles alternate with **pools,** which are deeper and have a flat water surface at low flow.

FLOOD-FREQUENCY COMPUTATION

INTRODUCTION

A *flood-frequency curve* at a point on a stream shows how often flood discharges of different sizes (magnitudes) will be equalled or exceeded. In combination with a rating curve and a topographic map, flood-frequency curves can be used to predict how often various areas are likely to be inundated.

The *recurrence interval* (T_r) of a flood is a *statistical* measure of how often a flood of a given magnitude is likely to be equalled or exceeded. Specifically, the "fifty-year flood" is one which will, *on the average*, be equalled or exceeded once in *any* fifty-year period. It does *not* mean that it occurs every fifty years.

The *probability* that a flood of specific size will be equalled or exceeded in any given year is given by:

$$P = \frac{1}{T_r}$$

The fifty-year flood has once chance in fifty of occurring in any specified year, that is, its probability is 1/50 (P = 0.02 or 2%).

Flood discharges of varying recurrence intervals are symbolized as $\mathbf{Q_{Tr}}$, where $\mathbf{T_r}$ is the appropriate recurrence interval. For example, the fifty-year recurrence interval flood (or simply the fifty-year flood) is written $\mathbf{Q_{50}}$.

There are three chief approaches to constructing a flood frequency curve at a gaged site:

a. Empirical (non-parametric) flood-frequency curve -- essentially an eyeball fit of the relation between estimated recurrence interval and flood magnitude.

b. Parametric flood-frequency curve -- a curve created by fitting the data to a specified probability distribution, such as the lognormal, extreme value, or log-Pearson Type III distribution

c. Flood-frequency curve derived from regional relations, e.g., from a regression on drainage area, mean annual discharge, mean annual rainfall, relief, mean annual flood, channel width, etc.

PROCEDURE FOR DEVELOPING AN EMPIRICAL FLOOD-FREQUENCY CURVE

1. Compile a list of *annual floods*.

   Set up a flood frequency computation table as follows:

Water Year	Date	Peak Q ft^3/s	Rank, M	T_r yr

   From published gaging data (e.g., USGS or DWR data publications) under "momentary maximum" or "annual maximum" find the largest flood (maximum instantaneous peak discharge) of each *water* year. Enter that value in ft^3/sec in the "Peak Q" column.

2. Rank the discharges

   When all the floods have been entered in the computation table--one for each year--rank the discharges in order from largest to smallest. Let the largest flood have rank M=1. The smallest flood will have rank M=N, where N is the number of years for which we have flood data. In the case of a tie, give the tied events different , but adjacent, ranks.

3. Compute the recurrence interval

   Compute the *recurrence interval* (or *return period*) of each flood using the formula:

$$T_r = \frac{(N+1)}{M}$$

   M = rank

   N = total number of floods

   The units of T_r are years.

4. Plot the discharges on flood-frequency paper

   Plot each flood discharge versus its T_r on either arithmetic or logarithmic extreme-value flood frequency paper. Fit a *smooth curve* through the points. Note that this is a best-fit-by-eye curve, *not* follow the dots. You are trying to extract a general trend from the data. Because we do not have much data to define the uppermost end of the curve, we should not try slavishly to fit the line through the uppermost points--instead, we need to look at the overall trend of the curve (c.f. Dunne & Leopold p. 305-313.) Note: In fitting the curve, don't give too much weight to the position of the largest 2 or 3 floods if the sample size is small ($n < 25$). They are probably plotting to the left of where they would correctly plot if we had a longer record.

   This graph is the flood-frequency relation for the gaging station, based on the N years of data available to us. The relation would change if we had more years of data available.

5. It is often a good idea to draw confidence bands around the flood-frequency curve. A procedure for doing this is described on p. 308-09 of Dunne & Leopold.

6. From this curve you can read off the estimated flood discharge corresponding to different recurrence intervals (e.g. 1.5-yr, 5-yr, 10-yr, 50-yr floods). To get the floods for larger recurrence intervals (ones beyond the limits of your plotted data), you will have to cautiously extrapolate the flood-frequency curve. There will be substantial error in these estimates when the period of record is short.

USEFUL WEB LINKS

Streamflow Data

Real-time water discharge at selected northern California gaging stations (USGS)
http://wwwdcascr.wr.usgs.gov/Sites/h1801.html

Real-time water discharge and rainfall at selected northern California stations (Calif Data Exchange Center)
http://cdec.water.ca.gov/queryQuick.html

California River Forecast Center
http://www.wrh.noaa.gov/cnrfc/

Weather Forecasts

Redwood Coast Weather Forecast
http://www.wrh.noaa.gov/cgi-bin/wrhq/TotalForecast.csh?TotalForecast+WR+CA+001+023+MAPCOORDS^41^198

Redwood Coast Forecast Discussion
http://www.wrh.noaa.gov/cgi-bin/Eureka/getproduct.pl?SFOAFDEKA

Weather Maps & Satellite Images

4km Weather Satellite Photo
http://defiant.wrh.noaa.gov/CURRENT/VIS4NW.GIF

1km Weather Satellite Photo
http://defiant.wrh.noaa.gov/CURRENT/VIS1EKA.GIF

Weather Radar Image
http://www.intellicast.com/LocalWeather/World/UnitedStates/Southwest/California/Eureka/BaseReflectivity

4km Water Vapor Image
http://www.wrh.noaa.gov/satellite/4km/WR/WV4.GIF

16km Water Vapor Image
http://www.wrh.noaa.gov/satellite/16km/WV16.GIF

Rainfall Map
http://www.intellicast.com/LocalWeather/World/UnitedStates/Southwest/California/Eureka/Precipitation/

California Precipitation Maps (CDEC)
http://cdec.water.ca.gov/precip_maps/pcpmaps.html

NOAA 24-hr Precip Map
http://nimbo.wrh.noaa.gov/cnrfc/prods/nc_pcp24.gif

Other Resources

EPA Surf Your Watershed
http://www.epa.gov/surf/

US Forest Service Redwood Sciences Lab
http://www.rsl.psw.fs.fed.us

US Forest Service Stream Team
http://www.stream.fs.fed.us/

Watershed Management Council
http://www.watershed.org

My own extensive browser-ready set of weather, water, and earth-science bookmarks is available at http://www.humboldt.edu/~geodept/geology700/geo700_akl_bookmarks.html

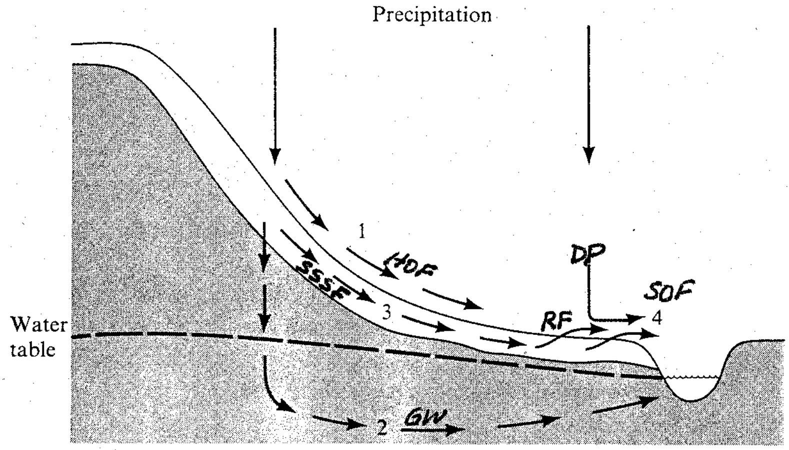

Figure 9-1 Possible paths of water moving downhill: path 1 is Horton overland flow; path 2 is groundwater flow; path 3 is shallow subsurface stormflow; path 4 is saturation overland flow, composed of direct precipitation on the saturated area plus infiltrated water that returns to the ground surface. The unshaded zone indicates highly permeable topsoil, and the shaded zone represents less permeable subsoil or rock.

HOF = HORTON OVERLAN
FLOW

SSSF = SUBSURFACE
STORMFLOW

SOF = SATURATION
OVERLAND FLOW

DP = DIRECT PRECIPITA
ON SATURATED
AREAS

RF = RETURN FLOW

GW = GROUNDWATE
FLOW

STORM HYDROGRAPH DEFINITION SKETCH

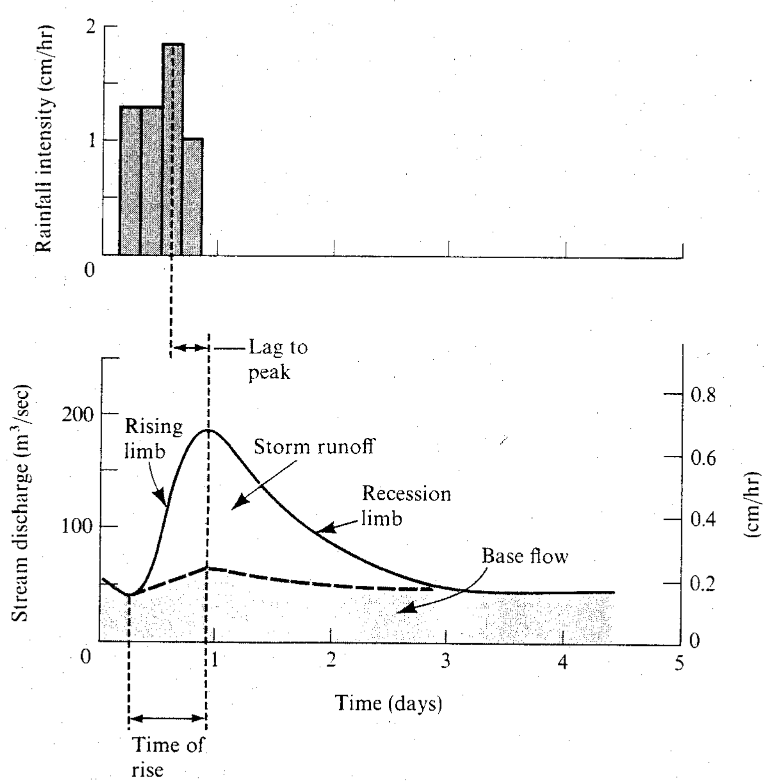

Figure 9-3 Hydrograph of streamflow in response to a rainstorm from a 100-square-kilometer basin. Methods of separating storm runoff and baseflow are described in Chapter 10.

DEFINITION SKETCH OF STREAM CHANNEL

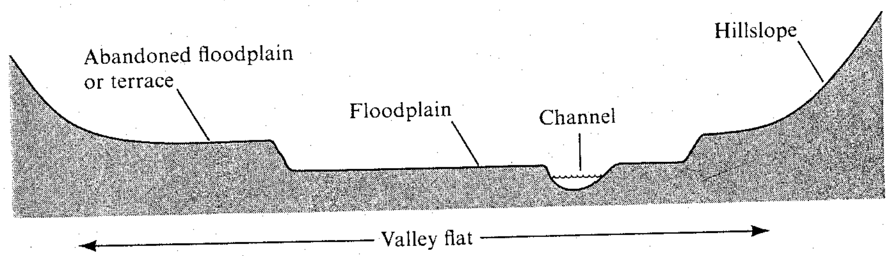

Figure 16-9 Diagrammatic cross section of a valley showing relation of present channel to the floodplain and to a terrace (abandoned floodplain).

BANKFULL DISCHARGE VS DRAINAGE AREA

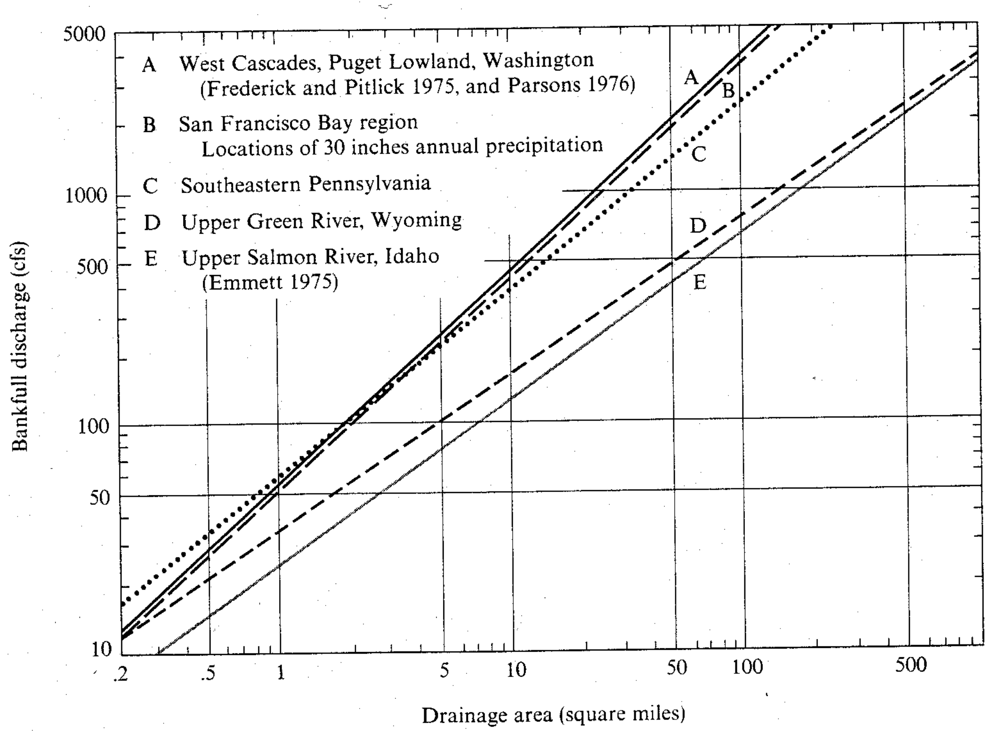

Figure 16-18 Bankfull discharge as a function of drainage area in the form of average relations for five regions.

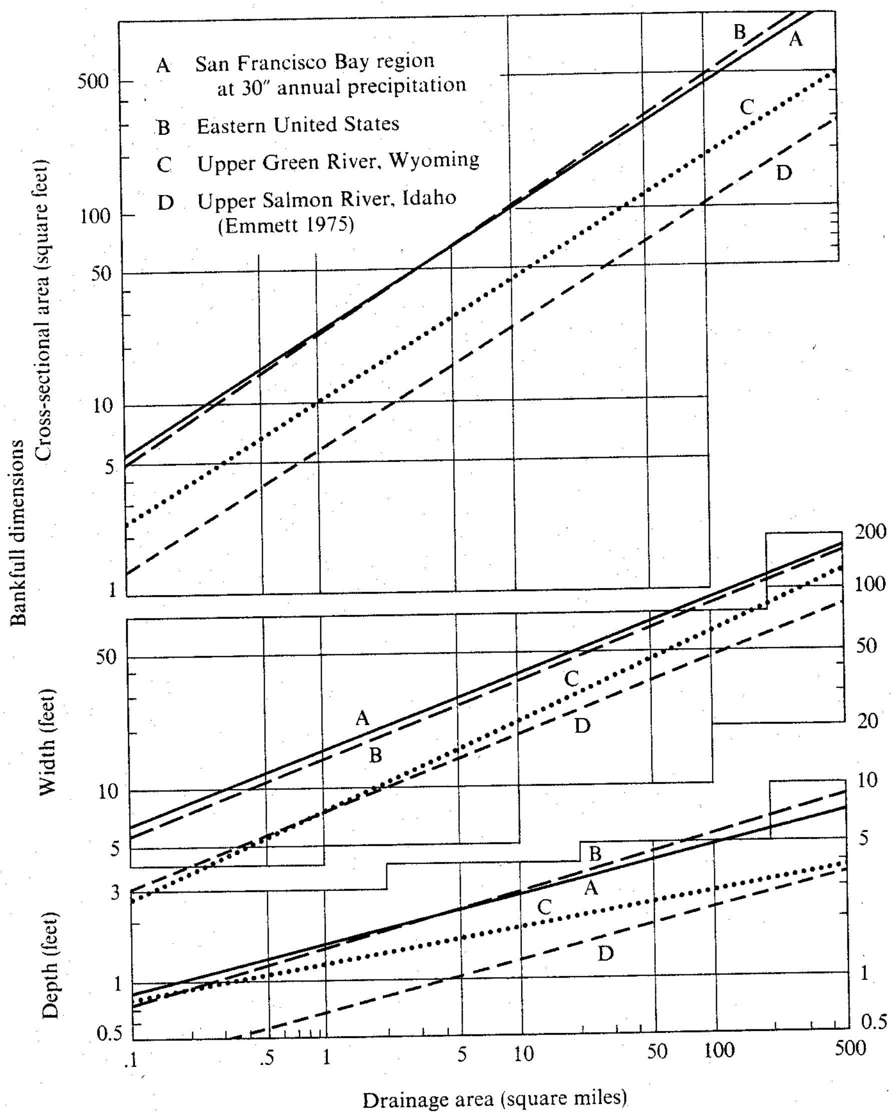

Figure 16-16 Average values of bankfull channel dimensions as functions of drainage area for four regions.

DIMENSIONLESS RATING CURVE

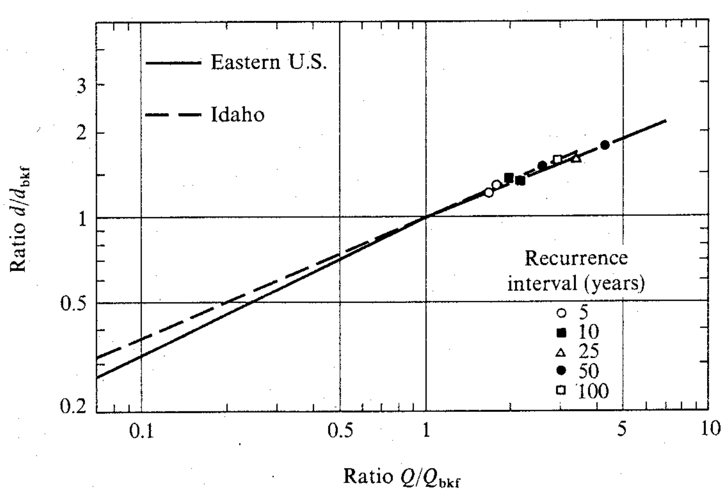

Figure 16-37 Dimensionless rating curve for two regions, eastern United States and Idaho. (Idaho data from Emmett 1975.)

d_{bf} = BANKFULL DEPTH

Q_{bf} = BANKFULL DISCHARGE

Criteria for Bankfull Stage in the Field

It is a nice generalization to draw a cross section of an average channel with an ideal shape and flat floodplain. In the field the situation is often far less clear. Every location along a channel reach is slightly different in shape, vegetation, location and form of bars, and nature of bank materials. Therefore it is important to have a set of criteria for identifying the bankfull level.

The first step is to ascertain the expected level of the floodplain, the bankfull level, for a river of given size in the region. To this end the curves in Figure 8.5 have been developed from a large number of field observations in various parts of the United States. The lines are drawn through data points for basins in (1) high-rainfall areas such as Pennsylvania, with average annual precipitation of 45 inches, (2) Mediterranean climates of winter rainfall such as the San Francisco area, and (3) mountain areas of the western states such as Idaho, Colorado, and Wyoming. The graphs show the mean channel width and mean depth at bankfull as functions of drainage area. The latter is particularly useful because if the drainage area is known, the mean height above the streambed can be read where the bankfull level is expected. This gives a first, important clue regarding where to look for indicators of bankfull. Terraces or remnants of abandoned floodplains are common, and these may be easily mistaken for currently building point bars or for the floodplain.

For example, to identify the bankfull level in a basin of 20 square miles area in a mountainous part of Utah for which no curve is shown, one would look at curves for the Green River, Wyoming, and the Salmon River, Idaho. Figure 8.5 shows that the bankfull depth might be expected at 1.5 to 1.9 feet above the bed. This knowledge would constrain the range of indicators sought in the field inspection. The principal indicators in order of usefulness are as follows.

1. The point bar is the sloping surface that extends into the channel from the convex bank of a curve, as shown in Figures 1.3 and 1.4. The top of the point bar is at the level of the floodplain because floodplains generally result from the extension of point bars as a channel moves laterally by erosion and deposition through time.

2. The bankfull level is usually marked by a change in vegetation, such as the change from bare gravel bar to forbs, herbs, or grass. Shrubs and willow clumps are sometimes useful but can be misleading. Willows may occur below bankfull stage, but alders are above bankfull. In Idaho the lichens on rocks changes species and thus color at bankfull level. In ephemeral channels the bankfull stage is marked by changes of plant species.

3. There is usually a topographic break at bankfull. The stream bank may change from a sloping bar to a vertical bank. It may change from a vertical bank to a horizontal plane on top of the floodplain. The change in topography may be as subtle as a change in slope of the bank.

4. Bankfull is often registered by a change in the size distribution of materials at the surface, from fine gravel to cobbles, from sand to gravel or even fine gravel material. It can change from fine to coarse or coarse to fine, but a change is common.

5. Even more subtle are changes in the debris deposited between rocks, such as the amount of leaves, seeds, needles, or organic debris. Such indicators are confirmation rather than primary evidence. Flood-deposited debris alone should not be trusted.

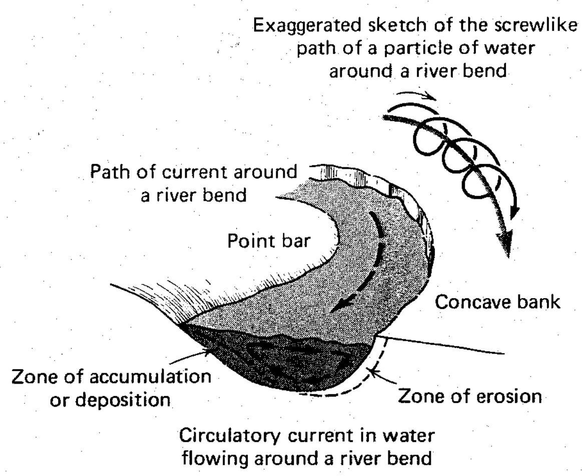

Figure 24
Effect of a curved channel on water flow. (U.S.G.S.)

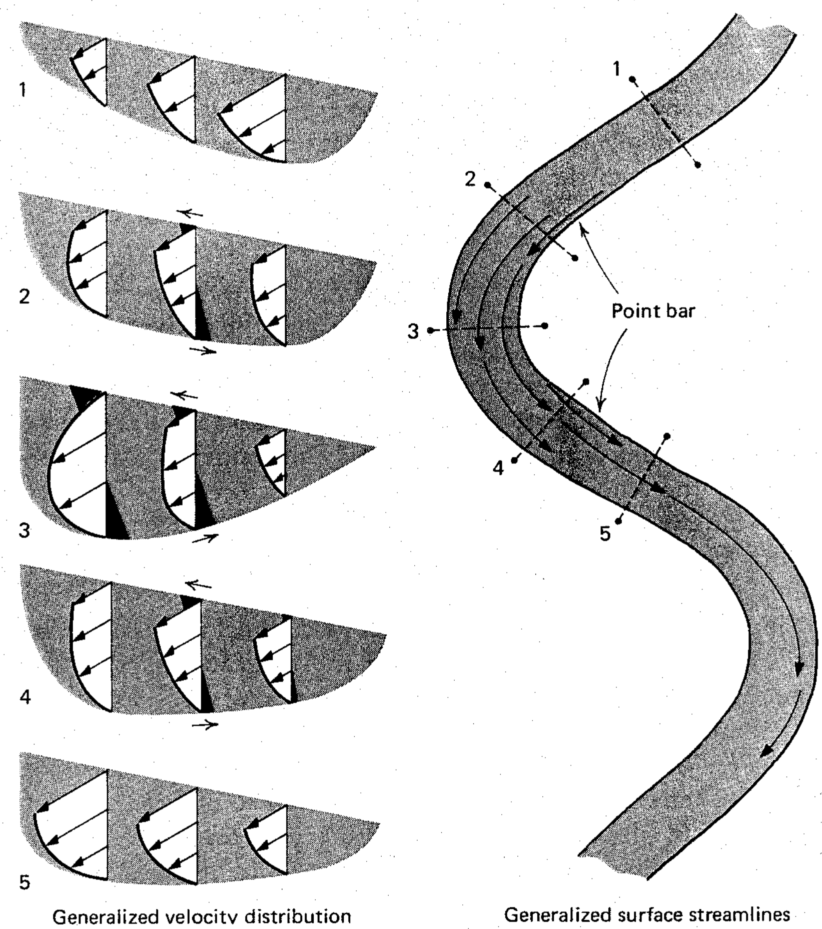

Figure 25
Isometric view of generalized diagram of flow distribution in a meander; open parabolas with arrows indicate downstream velocity vectors; lateral component of velocity is shown by gray areas; all sections are viewed from a changing position to the left of and above the individual section. (From *Fluvial processes in geomorphology*, by Leopold, Wolman, and Miller. W. H. Freeman and Company. Copyright © 1964.)

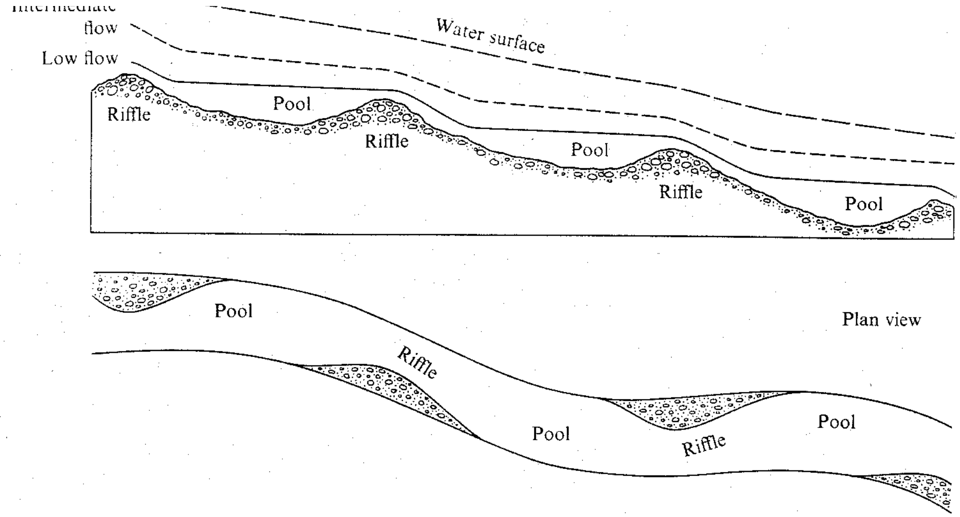

Figure 16-20 Diagram of longitudinal profile and plan view of a pool-riffle sequence. Water surface profiles in upper figure represent high, intermediate, and low flow conditions.

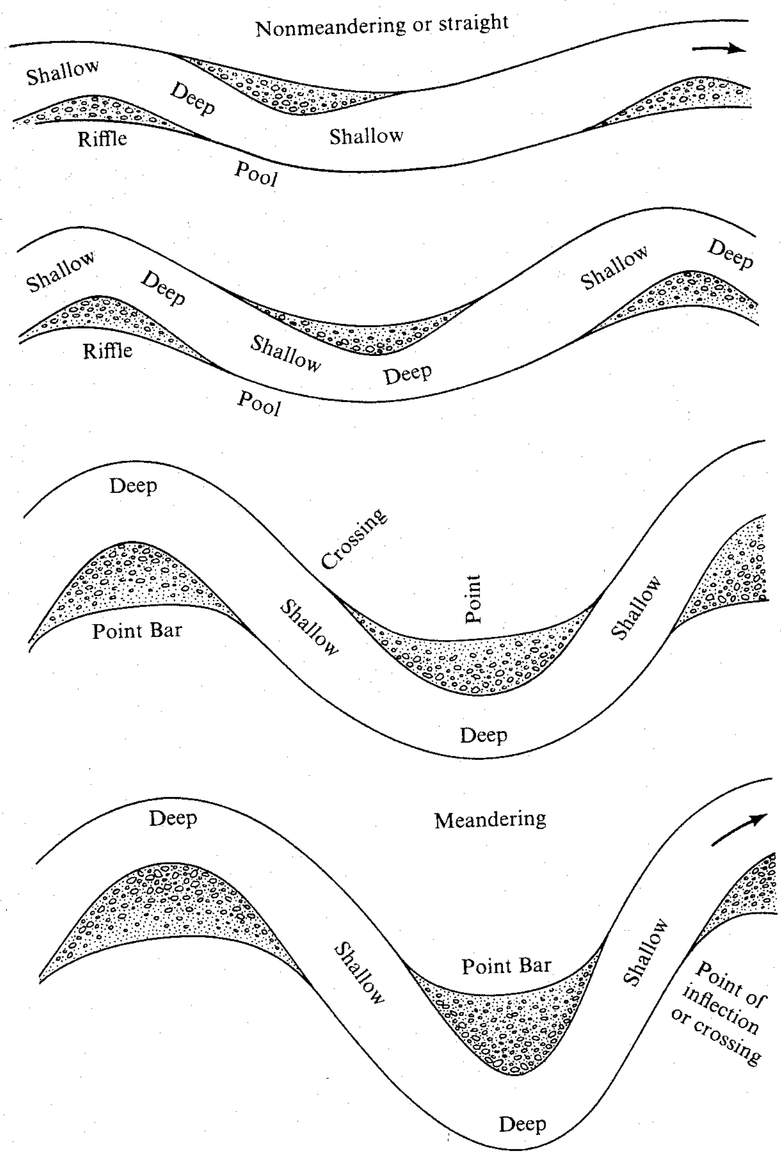

Figure 16-23 Locations of shallow and deep zones in channels of different sinuosity. Riffle bars on alternate banks characterize straight channels, but point bars on convex banks characterize meander bends.

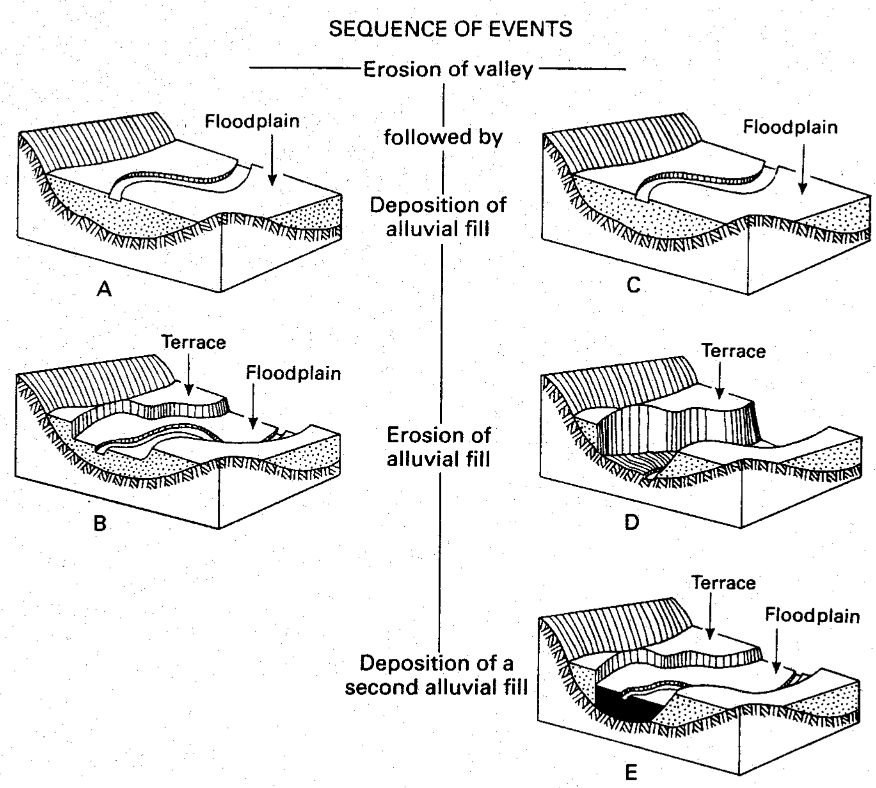

Figure 1.7 The stages in development of a terrace. Two sequences of events leading to the same surface geometry are shown in diagrams A-B and C-D-E.

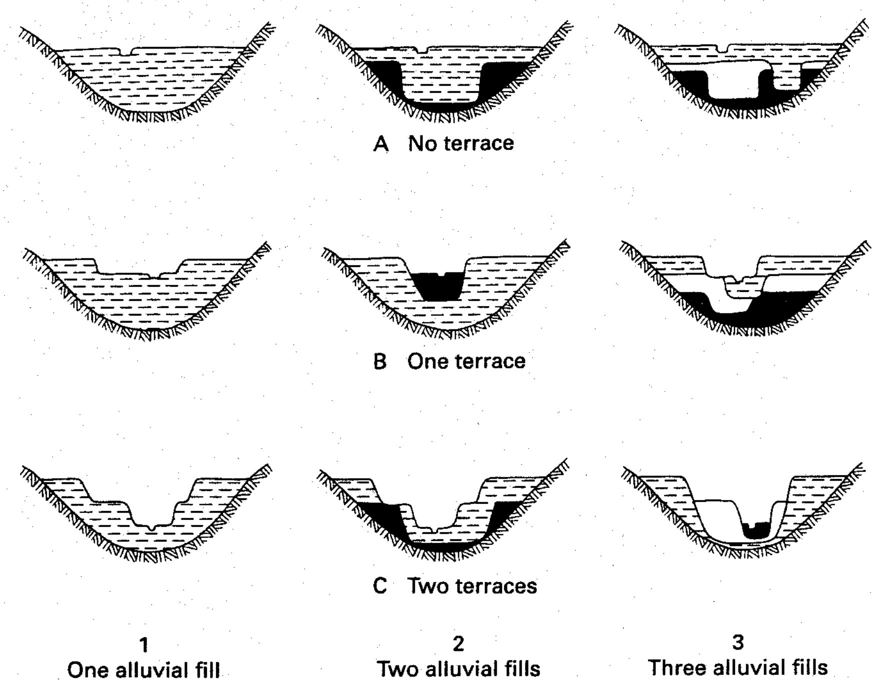

Figure 1.8 Valley cross sections showing some of the possible stratigraphic relations in valley alluvium.

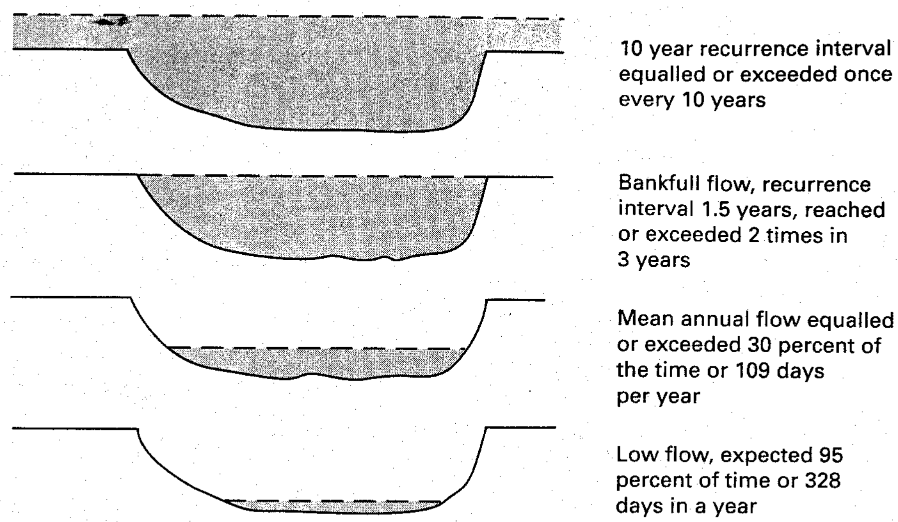

Figure 8.3 The amount of water in a river channel and the frequency with which such an amount occurs.

FROM L. B. LEOPOLD, 1994: A VIEW OF THE RIVER

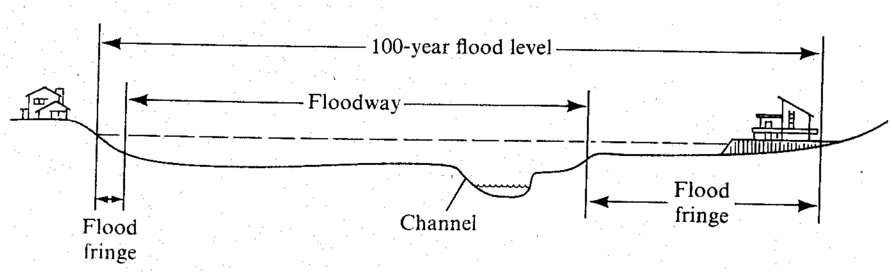

Figure 11-26 Division of the flood-prone area of a valley floor into the flood fringe and the floodway. The floodway is usually reserved for agriculture, recreation, or other uses that are not susceptible to heavy flood damage. In the flood fringe, houses can be built if special protection is installed.

FROM DUNNE + LEOPOLD, 1978: WATER IN ENVIRONMENTAL PLANNING

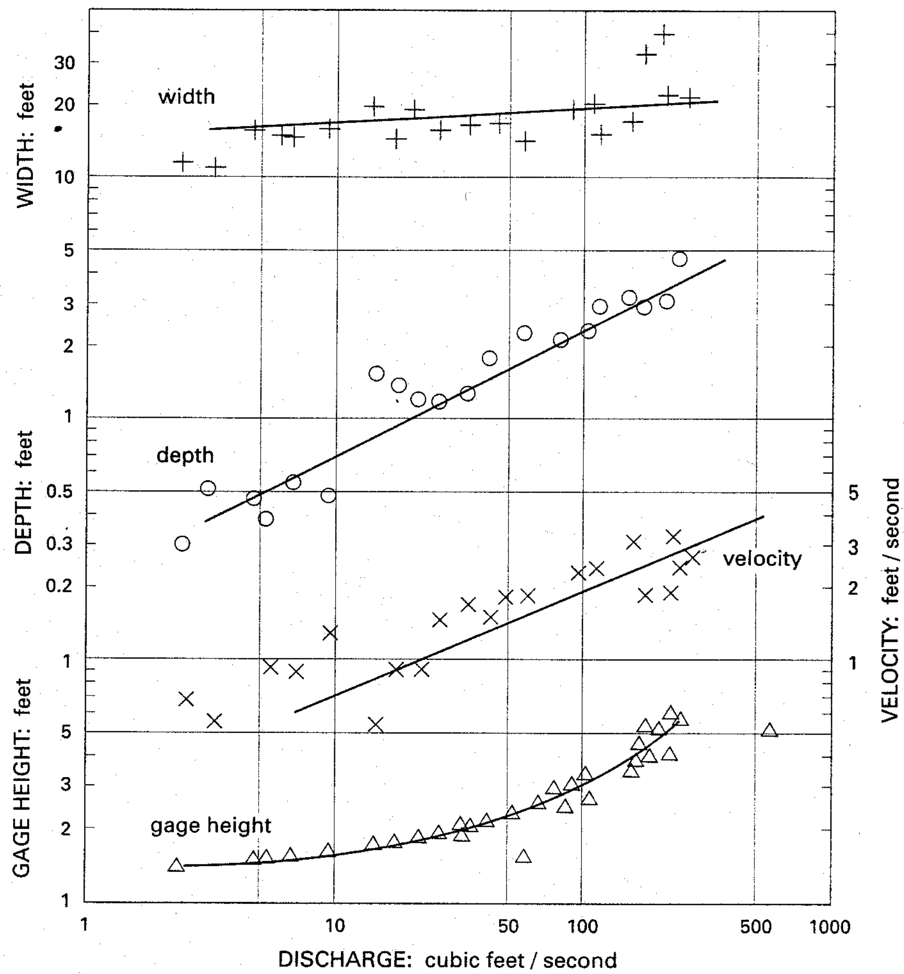

Figure 9.3 The hydraulic geometry of the natural channel of Watts Branch.

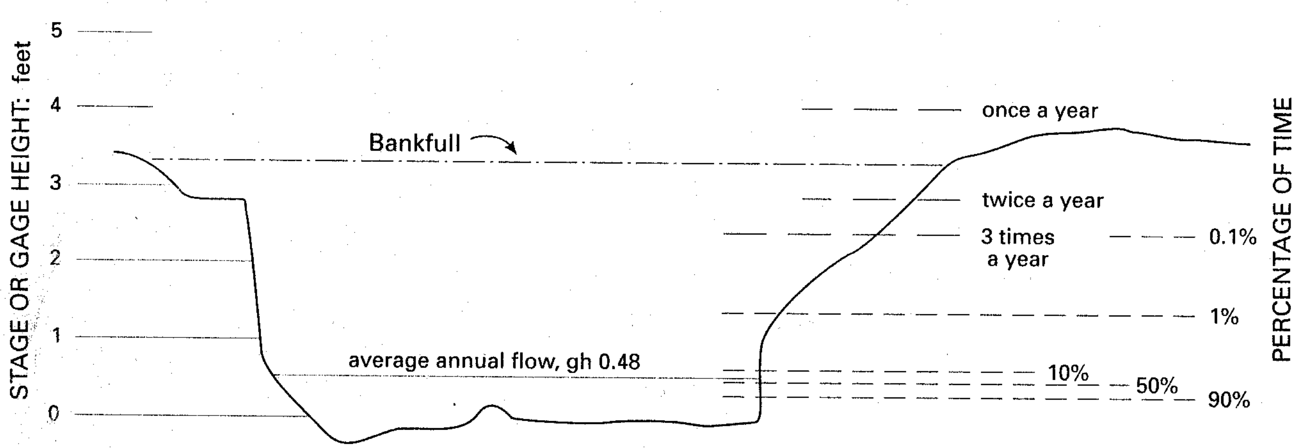

Figure 9.2 Cross section of the natural channel of Watts Branch. The scale near the right bank indicates the depth of water in the channel equaled or exceeded one or several times each year by flood peaks. The scale on the far right shows the percentage of time that the depth of water in the channel is equaled or exceeded.

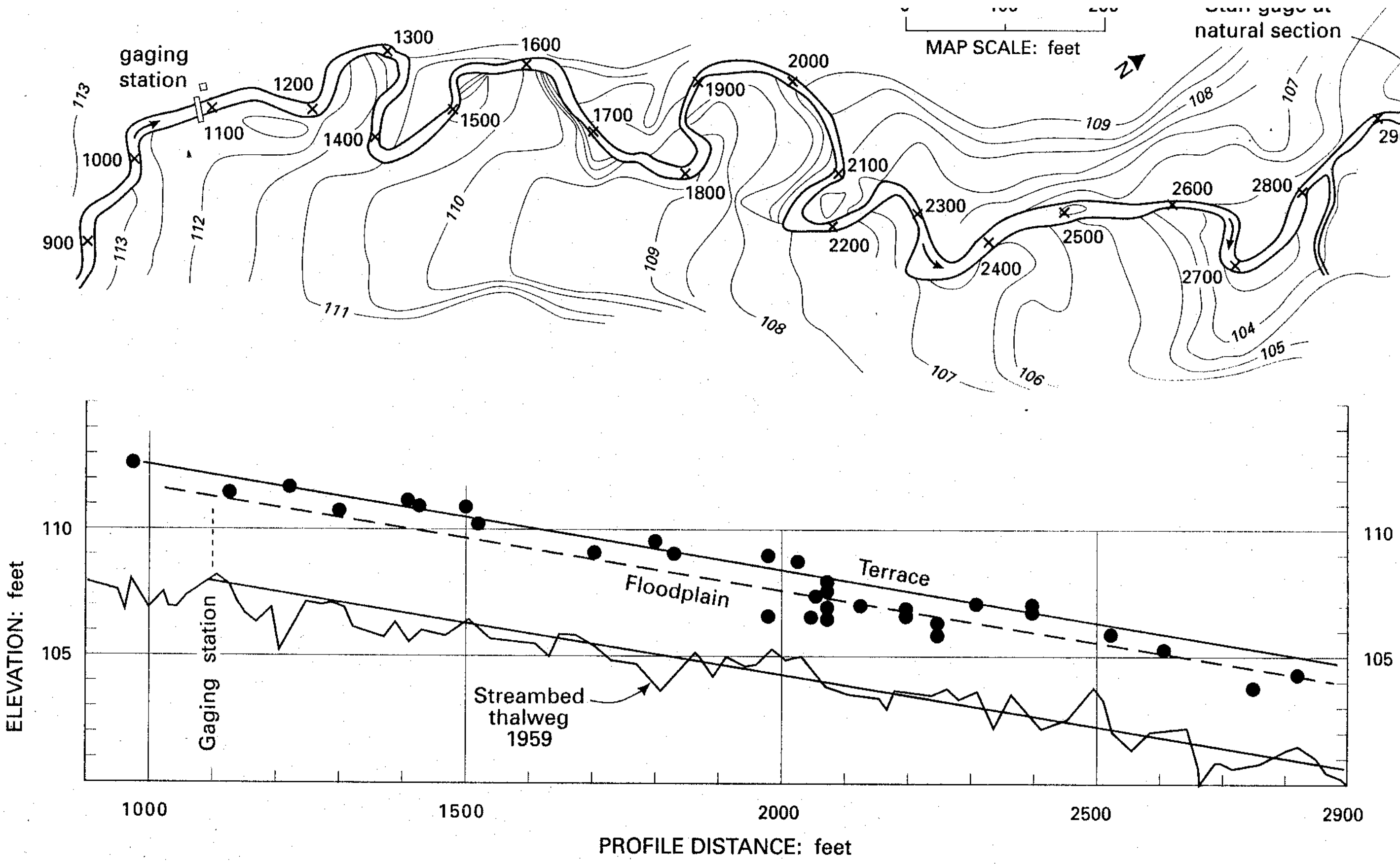

Figure 9.4 Plan and profile of the study reach of Watts Branch located 500 feet downstream of Highway 28.

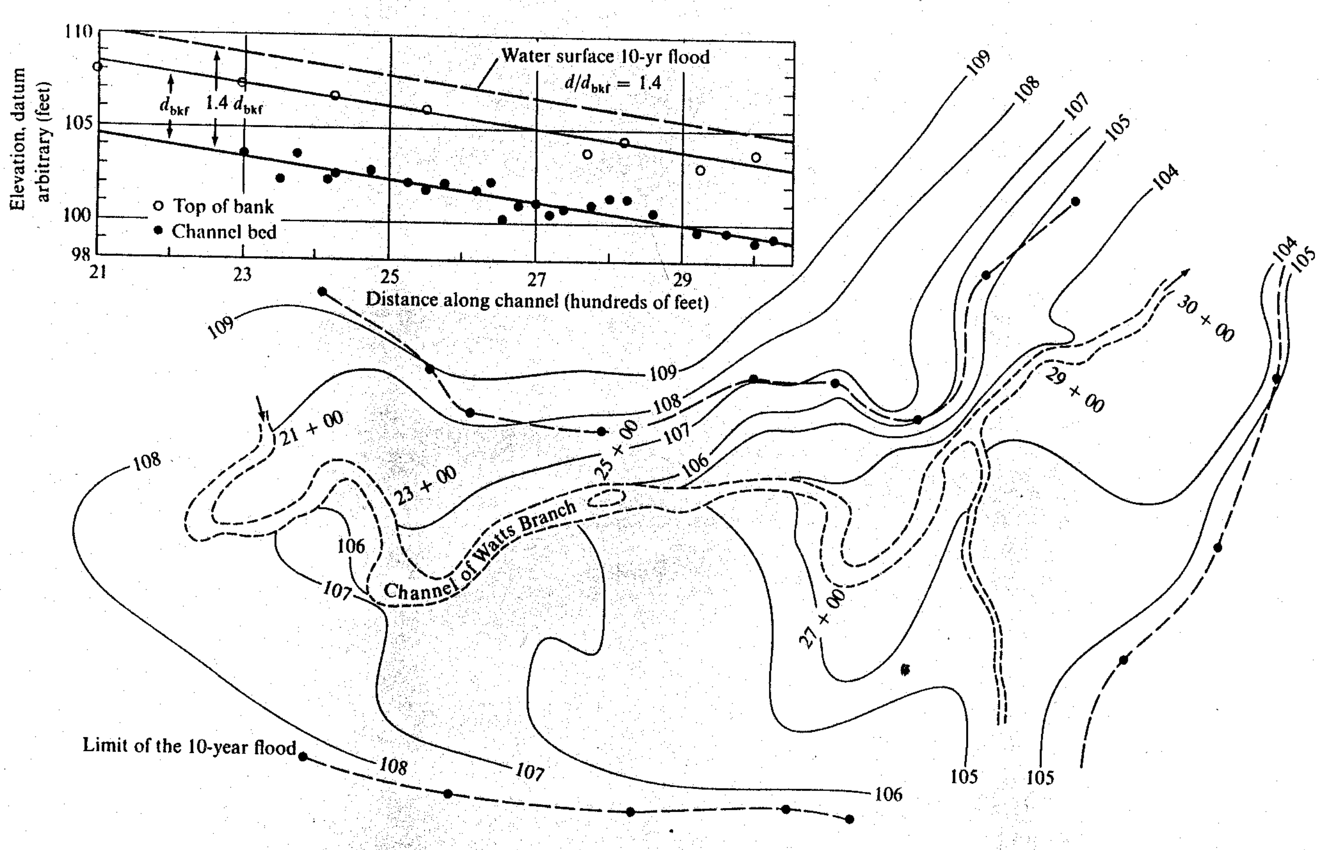

Figure 16-38 Plot of the limit of area probably flooded by a discharge of 10-year recurrence interval on a topographic map of a reach of Watts Branch near Rockville, Maryland. Elevations of water surface are read from the profile using the information from the dimensionless rating curve that the depth for a 10-year flood is 1.4 bankfull depth