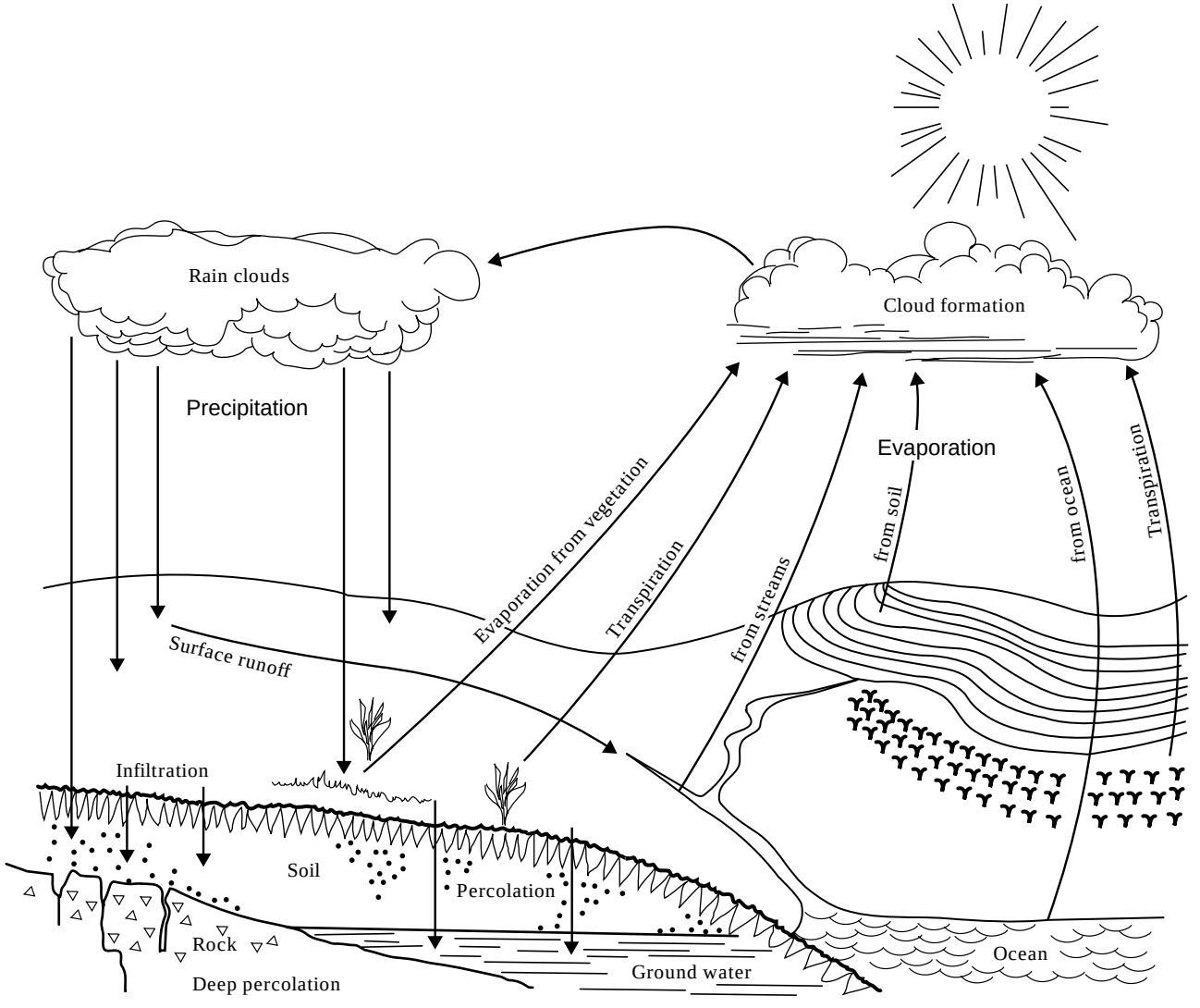
United States
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**Natural
Resources
Conservation
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Part 630 Hydrology
National Engineering Handbook

Chapter 4 Storm Rainfall Depth



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Chapter 4 Storm Rainfall Depth

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Chapter 4 Storm Rainfall Depth

630.0400 Introduction

Chapter 4 gives a brief account of the sources, variability, and preparation of storm rainfall data used for estimating storm runoff (chapter 10) and for designing floodwater-retarding structures (chapter 21). The chapter also applies to monthly and annual rainfall. Probable maximum precipitation is discussed in chapter 21, and Technical Release No. 60, Earth Dams and Reservoirs (USDA 1985). A discussion of rainfall generators, rainfall distributions, and computer models is outside the scope of this chapter.

630.0401 Sources of data

The storm rainfall data used in this handbook are the amounts measured at rain gauges and published by the National Weather Service (NWS), and statistical analyses carried out by the NWS. The choice of data is due to their availability on a national basis.

A comprehensive account and bibliography of rain gauge designs, installations, and measurement research is given by Kurtyka (1953). Gauges used in the NWS network are described by the National Oceanic and Atmospheric Administration (NOAA) (USDC 1989) and Brakensiek, et al. (1979).

(a) Published data

Daily amounts of rainfall measured at gauges in the official networks operated by the NWS are processed and published by the National Climatic Data Center (Asheville, NC) in monthly issues of “Climatological Data” for each state.

The times of daily measurement vary, as indicated in the publications. More detailed observations of storm totals and durations are available from the Hourly Precipitation Data, also published by the National Climatic Data Center for each state. Other Federal and State agencies, and universities, publish rainfall data at irregular intervals, often in a special storm report or a research paper.

The SCS Climate Data Access Facility (CDAF), obtains, evaluates, manages and disseminates the climatic data to support agency programs and activities nationwide. The data are provided through agency-wide climatic data management and analysis service through the Climatic Data Access Network (CDAN). CDAN consists of Climatic Data Liaisons (CDL) established in each state, National Technical Centers, and in National Headquarters.

Climatic data, such as precipitation, evaporation, and temperature, are available for the continental United States and the Pacific and Caribbean Islands. Annual, monthly, and daily data are available in a variety of formats.

Hourly, and 15-minute time series, along with other climatic variables, are supported off-line by CDAF. Requests for these special data types should be made to CDAF through the appropriate CDL at the state office or NTC.

Climatic data are also available from state climatologists, who coordinate the observations made by weather observers throughout the States before they are sent to the National Climatic Data Center.

(b) Unpublished data

Various Federal and State agencies sometimes make field surveys after an unusually large storm to collect "bucket-survey" data, which are measurements of rainfall caught in narrow-bore tubes, buckets, watering troughs, bottles, and similar containers. Ordinarily, these data are used to give more detail to rainfall maps based on standard-gauge data. The bucket gauge data should be carefully evaluated. Data from bucket surveys are generally not published, but are available in the offices of the gathering agency.

Narrow-bore tubes used by many farmers and ranchers have given results almost equal to those from standard gauges. Tube gauges must be properly exposed and serviced to obtain such results. Many farmers and ranchers keep a daily or storm record of catches.

Newspaper offices, banks, and municipal offices, including water-treatment plants, collect measurements at their own gauges and keep daily records.

(c) Data quality

Every observation is subject to certain errors, which may be classified as systematic errors, random errors, or mistakes.

Systematic errors may be because of defects in the instruments, in its exposure, or in the observational procedure. A gradual change in the surroundings of a station may be a source of systematic error. Systematic errors are best handled by correction before the data are used in statistical analysis. Systematic errors that are constant throughout the range of observations alter only the average value, leaving the frequency distribution unaltered.

Random errors occur from time to time because of a variety of unrelated causes. In general, they partly or wholly cancel out, so that correction is seldom needed.

Mistakes are widely discrepant readings that cannot be reconciled with readings from other locations. They are often caused by misreading the scale, misprints in writing, or data entry errors. Mistakes generally are easy to recognize and can often be corrected. If the mistake cannot be resolved, it must be rejected before observations can be treated statistically or in model execution.

Presently, no sanctioned procedure is available for eliminating errors from an archived data set. In general, known errors are corrected by the user and may not be incorporated in the official data set.

Reasons for missing data can be traced to a number of factors, including observer vacation, broken equipment, or lost records. Standard meteorologic textbooks describe how to handle missing data. CDAF is developing procedures for treating missing data, mistakes, and errors in the data. CDAF data sets can be used in model execution or treated statistically.

630.0402 Data analysis

The Special Studies Branch and the Hydrometeorological Branch of the NWS have a number of reports that summarize many years of weather observations over the country. The NWS personnel use refined statistical and error analyses to make these publications as reliable as possible.

(a) Published rainfall-data analyses

In many kinds of hydrologic work, it is unnecessary to use actual rainfall data because published analyses of data provide the required information in more usable form. The following published rainfall-data analyses were made by the NWS in cooperation with SCS:

(1) Documents covering durations to 1 day and storm return periods up to 100 years

- "Rainfall Frequency Atlas of the United States," United States Weather Bureau, Technical Paper No. 40; 115p, 1961. This reference is to be used for States east of the Rockies, except for durations of 60 minutes or less.
- "Five to 60-Minute Precipitation Frequency for the Eastern and Central United States," NOAA Technical Memorandum NWS HYDRO-35, 36p, 1977.
- "Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands," United States Weather Bureau, Technical Paper No. 42, 94p, 1961.
- "Rainfall-Frequency Atlas of the Hawaiian Islands," United States Weather Bureau, Technical Paper No. 43, 60p, 1962.
- "Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska," United States Weath-er Bureau, Technical Paper No. 47, 69p, 1963.
- National Oceanic and Atmospheric Administration Atlas 2. Precipitation Atlas of the Western United States, 1973:

  Vol. l, Montana
  Vol. II, Wyoming
  Vol. III, Colorado
  Vol. IV, New Mexico
  Vol. V, Idaho
  Vol. VI, Utah
  Vol. VII, Nevada
  Vol. VIII, Arizona
  Vol. IX, Washington
  Vol. X, Oregon
  Vol. XI, California

(2) Documents covering durations from 2 to 10 days and storm return periods to 100 years

- Two- to Ten-Day Precipitation for Return Periods of 2 to 100 years in the Contiguous United States, United States Weather Bureau, Technical Paper No. 49, 29p, 1964. Includes the 48 contiguous states. (Use SCS West National Technical Center Technical Note-Hydrology-PO-6, Revised 1973, for States covered by NOAA Atlas 2).
- Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in the Hawaiian Islands, United States Weather Bureau, Technical Paper No. 51, 34p, 1965.
- Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in Alaska, United States Weather Bureau, Technical Paper No. 52, 30p, 1965.
- Two- to Ten-Day Rainfall for Return Periods of 2 to 100 years in Puerto Rico and the Virgin Islands, United States Weather Bureau, Technical Paper no. 53, 35p, 1965. Documents from NWS and NOAA covering probable maximum precipitation data.
- Probable Maximum Precipitation in California, Interim Report, United States Weather Bureau Hydrometeorological Report No. 36, 202p, 196l.
- Probable Maximum Precipitation in the Hawaiian Islands, United States Weather Bureau Hydrometeorological Report No. 39, 98p, 1963.
- Probable Maximum Precipitation, Northwest States, United States Weather Bureau Hydrometeorological Report No. 43, 228p, 1966.
- Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages, NOAA Hydrometeorological Report No. 49, 161p, 1977.
- Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 51, 87p, 1978.
- Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian, NOAA Hydrometeorology Report No. 52, 168p, 1982.
- Probable Maximum Precipitation and Snowmelt Criteria for Southeast Alaska, NOAA Hydrometeorological Report No. 54, 115p, 1983.

- Probable Maximum Precipitation Estimates - United States Between the Continental Divide and the 103rd Meridian, NOAA Hydrometeorological Report No. 55, 245p, 1984.

These publications, except for the NOAA Atlas 2, are available from the National Technical Information Service in Springfield, Virginia. The NOAA Atlas 2 Precipitation Atlases are available from the NWS in Silver Spring, Maryland.

(b) Use of published analyses

Methods of using the rainfall information in the NWS technical papers are given in the papers themselves, and additional examples will be in chapter 21. Figures 4–4 and 4–6 (see appendix) do not apply to rainfall information from these papers. A discussion of the errors involved in use of the depth-duration-frequency maps of those papers are on pages 4 and 5 of NWS Technical Paper 40, where the following statement is made:

> Evaluation.—In general, the standard error of estimate ranges from a minimum of about 10% wherea point value can be used directly as taken from a flat region of one of the 2-year maps, to 50% where a 100-year value of short-duration rainfall must be estimated for an appreciable area in a more rugged region.

630.0403 Watershed rainfall

In watershed work, it is often necessary to know the average depth of storm rainfall over an area. The average depth can be determined in various ways, depending on the kind of data being used. If the rainfall amount is taken from one of the NWS technical papers, it is for a specific point and the point-area relationship given in the paper is used to estimate the average depth over the area. Examples in the papers illustrate the procedure. It is difficult to obtain an average depth from data of several rain gauges because the results are influenced by the number and locations of gauges and the storm variability. Methods of using such data are given in this section.

(a) Methods of estimating average depths

(1) Use of one gauge

How well the rainfall measured at a single gauge represents the average depth over an area depends on

- distance from the gauge to the center of the area,
- size of the area,
- kind of rainfall amounts being used, and
- orographics (topography) of the locality.

The effects of the first three influences are illustrated in figure 4–1 (see appendix). The fourth is described later in this section under the heading (c) Orographic influences.

The effect of distance is shown in figures 4–1a and 4–1b. In 4–1a, a single gauge is located near the center of a 0.75-square-mile watershed. Storm rainfall catches at the gauge are seen to be quite close to those of the watershed averages, which were determined using a dense network of gauges. However, in 4–1b, where the gauge is located 4 miles from the watershed boundary, the storm rainfall catches at the gauge often differ significantly (in the statistical sense) from the watershed averages. A similar effect is found when the area of application is increased, as shown in figure 4–1c, where the gauge is near the boundary of a 5.4-square-mile watershed.

The correspondence between gauge catches and area averages is close where the rainfall amounts being used are sums of catches, such as monthly or annual rainfalls, because the errors for single storms tend to offset each other. The gauge and watershed used for figure 4–1c are also used in figure 4–1d where annual rainfalls are plotted. The differences between gauge and watershed amounts are relatively smaller than those for the storm comparison of figure 4–1c.

Thecorrespondence between gauge and area amounts are also close if the storm rainfalls are used with the methods shown in chapter 18 to construct frequency lines for gauge and area. The correspondence occurring then is for amounts having the same frequency.

The examples were developed from data taken from a nonmountainous region, where orographic influences are not significant; otherwise, the results might be very different. The examples show that the use of a single gauge leads to errors in areal estimates and to the question of how much error is permissible. Accuracy of rainfall estimates is discussed in section 630.0403(b).

(2) Isohyetal method

The spacing of gauges in an areal network is seldom sufficiently uniform to permit use of the numerical average of the gauge catches as the area average. Isohyetal maps are often used, with networks of any configuration, to get area averages or for studies of rainfall distributions. An isohyet is a line connecting points of equal rainfall depth. The map is made by drawing the lines in the same manner that contour lines are drawn on topographic maps, using the gauge locations as data points.

Figure 4–2 in the appendix illustrates construction and application of the isohyetal method to a research watershed in Nebraska. The watershed average depth can be obtained as follows:

If the isohyetal pattern is fairly even across the watershed as in figure 4–2c, a point at the center of the area gives the average depth. The estimate made using point A in figure 4–2c is 1.59 inches.

If the isohyetal pattern is not even, divide the watershed into parts for which the pattern is sufficiently uniform, make an estimate for each part, and get the watershed average by weighting or averaging the amounts for the parts.

A denser network may give a more complicated isohyetal map (fig. 4–2d) where the total network on this research watershed is used to depict the storm. There is an important change in depth on parts of the watershed, but the watershed average is 1.61 inches, which is not a significant improvement in accuracy over the estimate in figure 4–2c. A particular network may therefore be excessively close for one kind of estimate at the same time that it is too open for another kind. The relative error of an area average obtained through use of a network can be estimated as shown in section 630.0403(b).

(3) Thiessen method

Another method of using a rain gauge network for estimating watershed average depths that is especially suitable for electronic computation is the Thiessen method (fig. 4–3 in appendix). In this method, the watershed area is divided into subareas using rain gauges as hubs of polygons. The subareas are used to determine ratios that are multiplied by the subarea rainfall and summed to get the watershed average depth. The ratios are the percentages of area in the basin represented by each rain gauge. Construction of the polygonic diagram is illustrated in figures 4–3a and 4–3b.

The Thiessen weights are the ratio of the gauge's polygon area divided by the area of the entire watershed, as indicated in figure 4–3c. Watershed average depths are computed as shown in table 4–1, in which the storm of figure 4–2a is used. If a gauge is added or removed from the network, a new diagram must be drawn and new weights computed. Figure 4–3d shows the Thiessen method for a denser rain gauge network.

Table 4–1 Watershed rainfall depth by the Thiessen method

Rain gauge rainfall	Measured rainfall (inches)	Thiessen weight	Weighted (inches)
A	1.40	0.407	0.570
B	1.54	0.156	0.240
C	1.94	0.437	0.848
			Sum - 1.658*

* Watershed weighted rainfall depth is 1.658 inches, which is rounded off to 1.66 inches.

The Thiessen method is not used to estimate rainfall depths of mountainous watersheds since elevation is also a strong factor influencing the areal distribution (see section 630.0403(c), Orographic influences).

(4) Other methods

Other methods for estimating areal average rainfall from a system of point rain gauge measurements include the reciprocal-distance-squared method (Wei and McGuiness 1973; Singh and Chowdhury 1986) and use of geostatistics (krieging) (McCuen and Snyder 1986; Bras and Rodriguez-Iturbe 1985).

(b) Accuracy

Accuracy of the resulting rainfall estimate depends mainly on the distance between a gauge and the point of application of the estimate, regardless of the method used. In mountainous areas, the vertical distance may be more important than the horizontal, but for flat or rolling country, only the horizontal distance matters. For a network, both distance and arrangement of gauges affect the accuracy. Unless special studies at a gauge site have been made, the measurement errors are generally ignored.

Figure 4–4 (see appendix) can be used to estimate the range of error likely to occur nine times out of ten if the catch at a single gauge is used as a depth for a location some distance away. It was developed from information given by Huff and Neill (1957) for small areas in Illinois. Equation 5 of this reference was modified to give results on a 10 percent level of significance. Horizontal distance is used, so the diagram does not apply in mountainous areas or high desert country. The following examples show how the diagram can be used.

Example 4–1—The storm rainfall depth at a gauge is 3.5 inches. What rainfall depth is likely to have occurred, with a probability of 0.9 (9 chances out of 10), at a point 5 miles away from the gauge?

1. Enter figure 4–4 with the distance of 5 miles, and at the intersection of the 3.5-inch line (by interpolation), read a "plus error" of 2.1 inches.

2. Compute a minus error as half of the plus error:

$$\frac{2.1}{2} = 1.05$$

   Round off to 1.1 inches.

3. Compute the range of rainfall likely to have occurred nine chances out of ten. The limits are 3.5 + 2.1 = 5.6 inches, and 3.5 - 1.1 = 2.4 inches. Therefore, where the gauge has a catch of 3.5 inches, there is a probability of 0.9 (9 chances out of 10) that the rainfall depth at a point 5 miles away from the gauge is between 5.6 and 2.4 inches.

In step 2 of example 4–1, the minus error is taken as half the plus error. This is an approximation, but example 4–2 and the discussion following show this approximation generally applies.

In example 4–2, the graphs of figure 4–5 (see appendix) show the variation to be expected when data at one gauge are used to estimate the rainfall depth at a distant point.

Example 4–2—Rain gauges B28R and G42R, on the Agricultural Research Service watershed in Webster County, Nebraska, are 4.3 miles apart. Given any storm rainfall of 0 to 4 inches depth at G42R, compute the range of error to be expected if the rainfall at B28R is to be estimated from that at G42R. Use figure 4–4. Compare the computed range with the plotting of actual data for the two gauges.

1. Plot a line of equal values, which is the middle line on figure 4–5a.

2. Select three values on the G42R depth scale. These values will be used with figure 4–4. For this example, the selected values are 1, 2, and 4 inches.

3. Enter figure 4–4 with the distance of 4.3 miles, and at the intersections of the 1-, 2-, and 4-inch rainfall lines read plus errors of 1.15, 1.50, and 2.15 inches, respectively. (The reading for the 1-inch rainfall line requires an extrapolation.)

4. Compute the minus errors. These are 0.58, 0.75, and 1.08 inches.

5. Plot the plus-error and minus-error lines as shown on figure 4–5a. The plotted points shown are for actual measurements at the gauges. Only three points of the gauged (less than 10 percent) data fall outside the error range, so the expected error for this pair of gauges is somewhat less than that predicted by figure 4–4.

One advantage in using figure 4–4 is that where a rainfall estimate is to be made for some distant point, the error lines can be drawn in advance to give an idea of the value of the estimate. Note that the percentage of error decreases as the rainfall amount increases. Error lines have also been drawn on figure 4–5b, c, and d, using the method of example 4–2, as a further check on figure 4–4. In each of the plottings, a different number of points falls outside the error lines, but on the average only 10 percent should be outside. This is confirmed by the computation shown in table 4–2.

Figure 4–6 in the appendix serves the same purpose for an area that figure 4–4 serves for a point. It was developed from work by McGuinness (1963) for a range of rainfall amounts and geographic locations in the Middle West. The user must exercise some judgment before applying the information in this figure in other locations.

In using figure 4–6, the number of gauges on the watershed must first be determined. The number is seldom clearly evident, as the typical examples of figure 4–7 in the appendix show.

In figure 4–7a, the gauge network ABC would be used for an isohyetal map or in computing Thiessen weights. The watershed average rainfall depth estimated from an isohyetal map based on the use of ABC would be more accurate than if based on BC. Therefore, it would not be correct to say there are only two gauges "within" the watershed when figure 4–6 is used.

In figure 4.7b, however, all six gauges of the network DEFGHI are physically within the watershed, but gauges DEFG are much too close together (by comparison with the remaining gauges) to be considered as individual gauges.

In figure 4.7c where gauges JKLMNP have varying distances between adjacent gauges, determining how many gauges are "in" the watershedis even more difficult. With the case shown in figure 4–7d, where the network QRST is completely outside the watershed (but still usable for construction of an isohyetal map) any decision on the number of gauges "in" the watershed would be arbitrary.

Therefore, figure 4–6 should be used without spending much time on deciding how many gauges are applicable. The examples that follow will illustrate what can be done even with the extreme cases of figure 4–7. Note that figure 4–6 gives an average error that is of the same magnitude plus and minus, in this respect differing from figure 4–4.

Example 4–3—Assuming that the watershed of figure 4–7a has a drainage area of 200 square miles and an average annual rainfall of 35 inches, find the average error of estimate when the watershed average depth is 4.5 inches.

Figure 4–6 is used first with a network of two, then of three, gauges and the results are compared. The 2-gauge network gives an error of about 13 percent, and a 3-gauge network gives an error of about 8 percent. In either case, the error is relatively small.

Example 4–4—The standard percentage error (see chapter 18) can be estimated, if it is needed, by taking 1.5 times the average error. For example 4–3, the computations were:

2-gauge network, standard error = 1.5 (13) = 19.5%
3-gauge network, standard error = 1.5 (8) = 12.0%

Table 4–2 Computations for percentages of points outside of error lines

Figure 4–5:	(a)	(b)	(c)	(d)	Total
Number of points	91	35	7	20	153
Number outside lines	3	10	0	3	16
Percentage outside lines	3.3	28.6	0	15.0	10.46

Example 4–5—The size of the watershed itself can have no bearing on the watershed average rainfall depth when the network is that of figure 4–7d. In such cases the area of the polygon formed by the network QRST is used in figure 4–6. If the watershed average annual rainfall is 35 inches and the network polygon area is 375 square miles, then figure 4–6 gives an estimate of about 8 percent error for a 5-inch rain. This is for the area of the polygon and, presumably, for any watershed within it. It is reasonable to expect that the smaller the watershed, the larger the error will be, but this cannot be determined on the basis of present information.

Figure 4–6 must be used with some imagination. As examples 4–3 through 4–5 show, it gives only rough approximations. And, for cases such as the networks in figures 4–7b and 4–7c, neither the number of gauges to be used nor the area of applicability is easy to define. Despite these limitations, figure 4–6 functions well in keeping the hydrologist aware of the range of error possible in calculations.

(c) Orographic influences

In hilly or mountainous country, rainfall catches are influenced by physiographic variables, both local and distant. Some of these are:

- Elevation or altitude
- Local slope
- Orientation of the slope
- Distance from the moisture source
- Topographic barriers to incoming moisture
- Degree of exposure, which is defined as "the sum of those sectors of a circle of 20-mile radius centered at the station, containing no barrier 1,000 feet or more above station elevation, expressed in degrees of arc of circle (azimuth)" (Hiatt 1953)

In the ordinary watershed study, it is seldom possible to determine the influences of all these variables. When a special study is needed for a project, the SCS hydrologist or hydraulic engineer can apply to the director, Engineering Division, National Headquarters, Washington, DC, who can make arrangements for a cooperative study by the NWS.

Figure 4–8 in the appendix shows an example of the influences of altitude and topographic barriers on rainfall. The rainfall amounts indicated by the points in figure 4–8a were recorded during the storm of February 27 to March 4, 1938, in southern California, in the vicinity of the Santa Ana, San Bernardino, and San Gabriel mountains, which lie roughly parallel to the California coast. The series of moisture-laden air masses associated with the storms swept in from the Pacific Ocean to encounter the mountain ranges at almost right angles to their path. The mountains acted as obstructions, thrusting the warm, moist air upward into colder air, and the resultant rapid condensation produced excessively heavy rainfall, particularly on the coastal side of the ranges. The desert side of the ranges (fig. 4–8b) had significantly less rainfall. Much of the moisture had already been pulled out of the air mass by the time it reached the desert side of the ranges. As the air mass warmed moving down the desert side of the mountain slopes, it no longer had a ready moisture source and thus became drier.

630.0404 References

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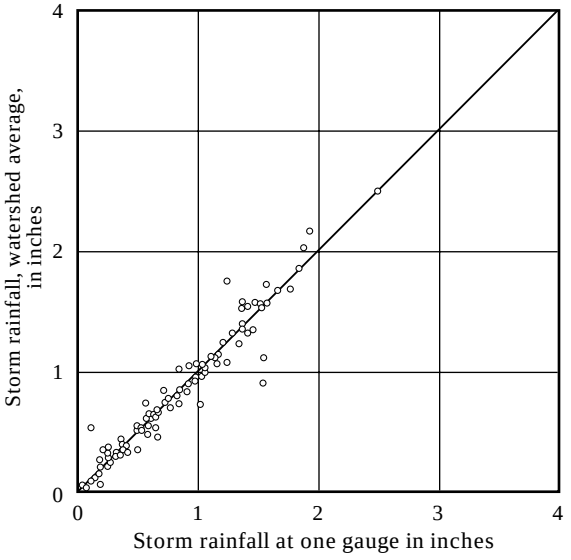
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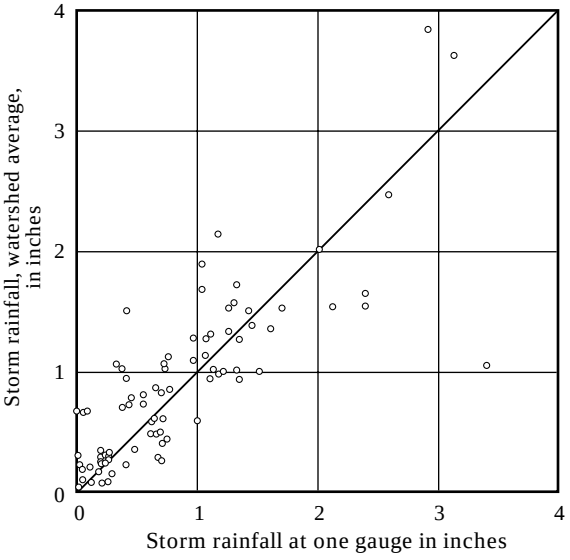
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630.0405 Appendix

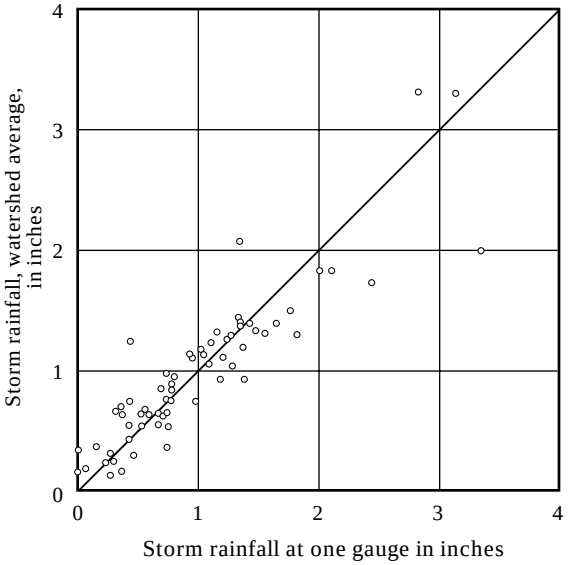
Figure 4–1 Errors caused by use of catches at one gauge as estimates of watershed average rainfall (based on data from ARS Experimental Agricultural Watersheds in Hastings, Nebraska)



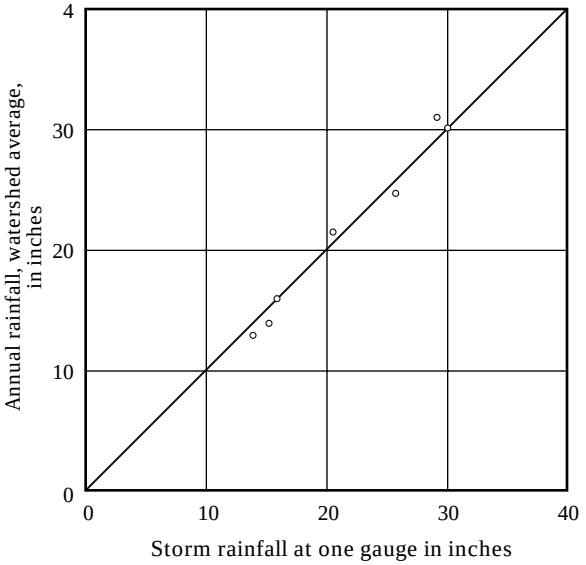
(a) Watershed area is 0.75 square miles and gauge is near the center.



(b) Watershed area is 0.75 square miles and gauge is 4 miles outside the water shed boundary.

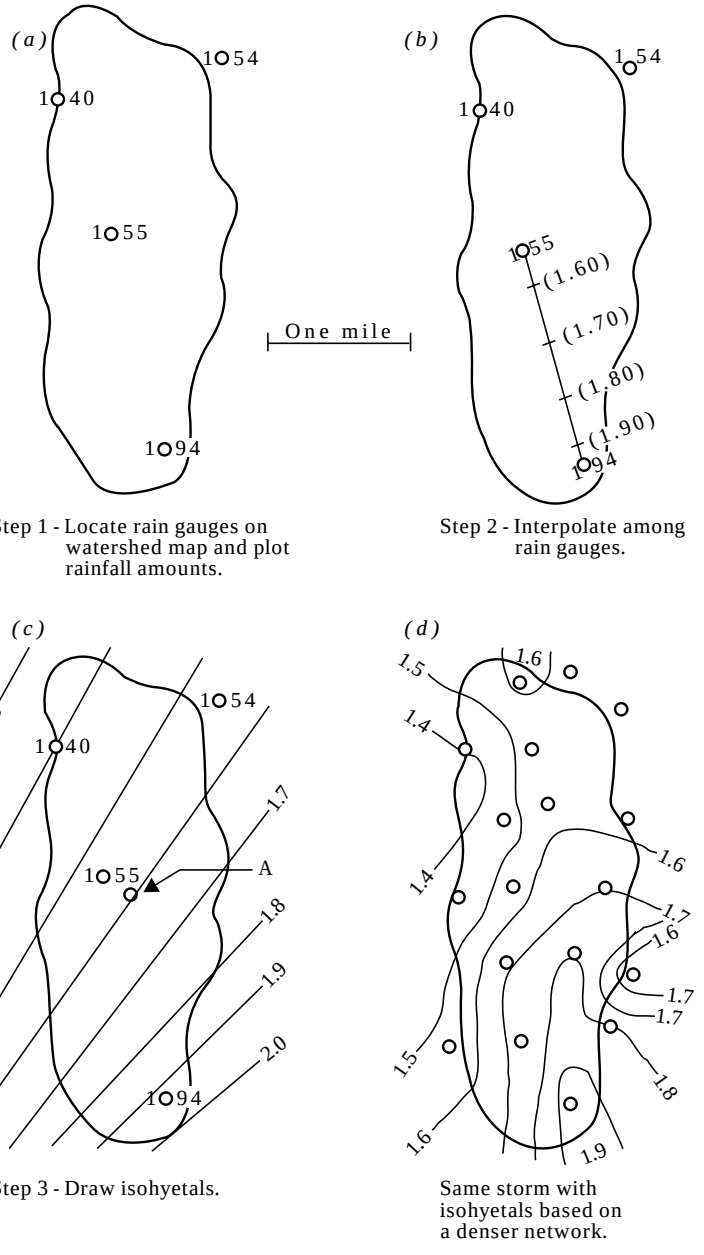


(c) Watershed area is 5.45 square miles and gauge is on the boundary.



(d) Watershed area is 5.45 square miles and gauge is on the boundary.

Figure 4–2 Steps in construction of an isohyetal map (based on data from ARS Experiemental Agricultural Watershed in Hastings, Nebraska)



Step 1 - Locate rain gauges on watershed map and plot rainfall amounts.

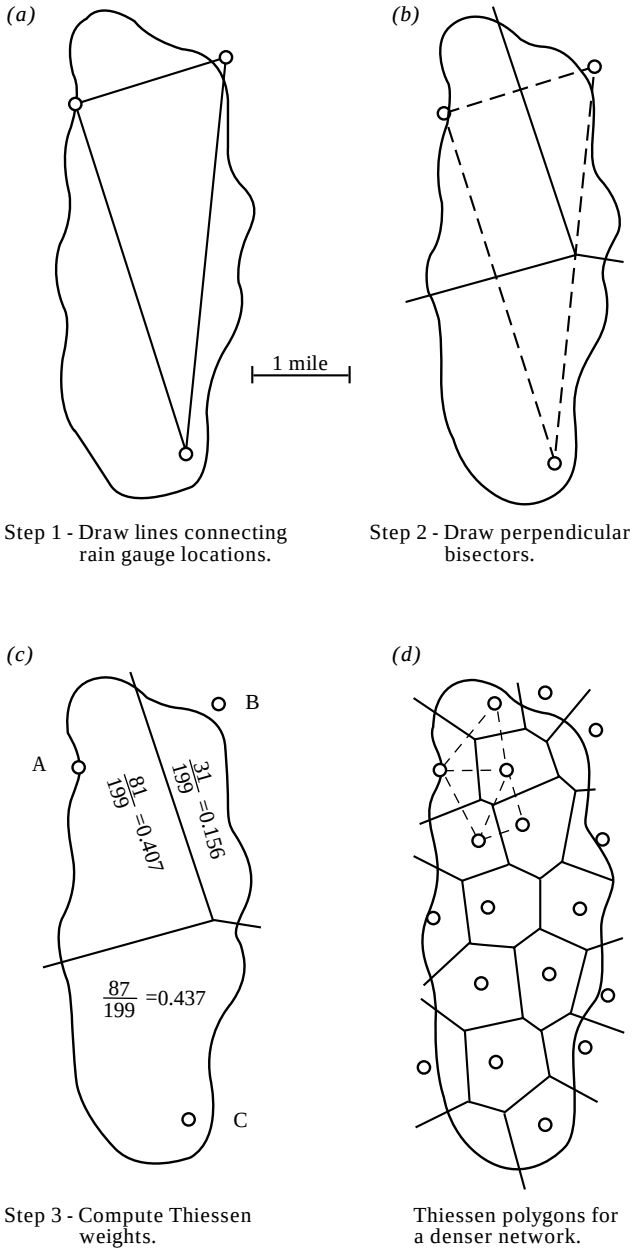
Step 2 - Interpolate among rain gauges.

Step 3 - Draw isohyetals.

Same storm with isohyetals based on a denser network.

Circles used as decimal points also denote rain gauges. Figures c and d illustrate the variations caused by the use of different networks of gauges.

Figure 4–3 Steps in the determination of Thiessen weights



Step 1 - Draw lines connecting rain gauge locations.

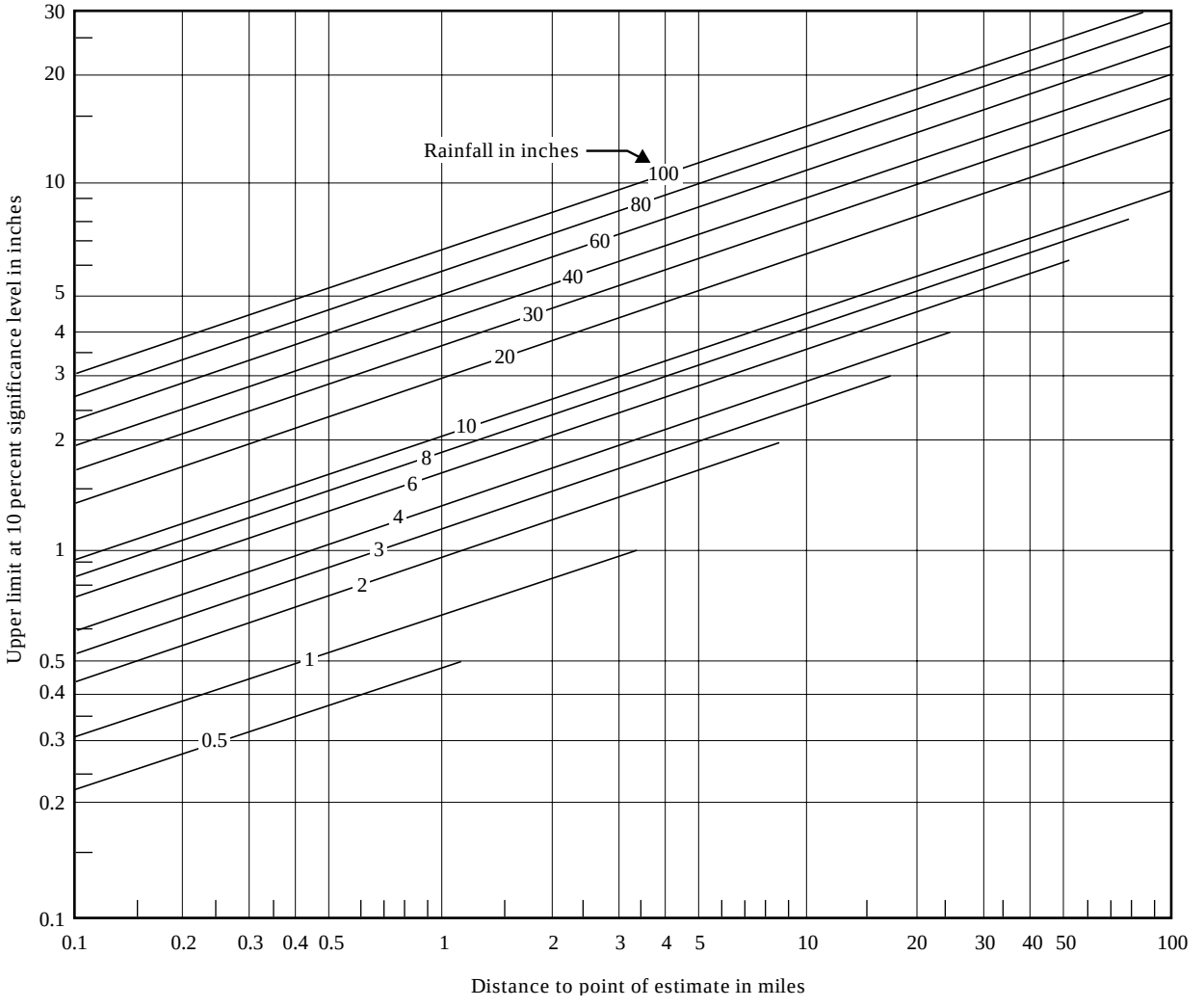
Step 2 - Draw perpendicular bisectors.

Step 3 - Compute Thiessen weights.

Thiessen polygons for a denser network.

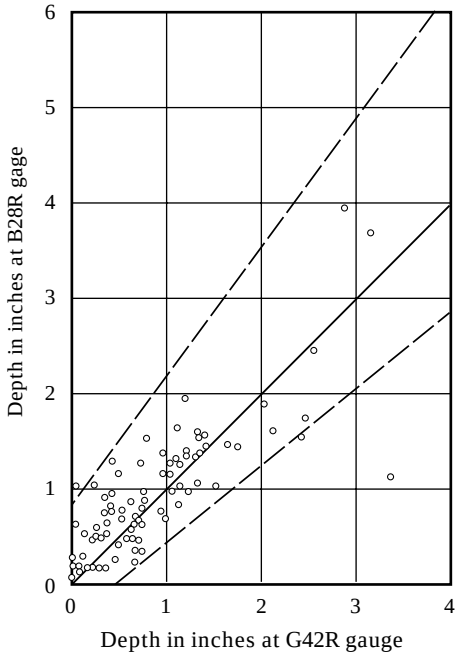
Figures c and d illustrate the variations in polygons caused by use of different networks of gauges.

Figure 4–4 Estimating the upper (positive) increment of error in transposed rainfall amounts (modified from Huff & Neill 1957)

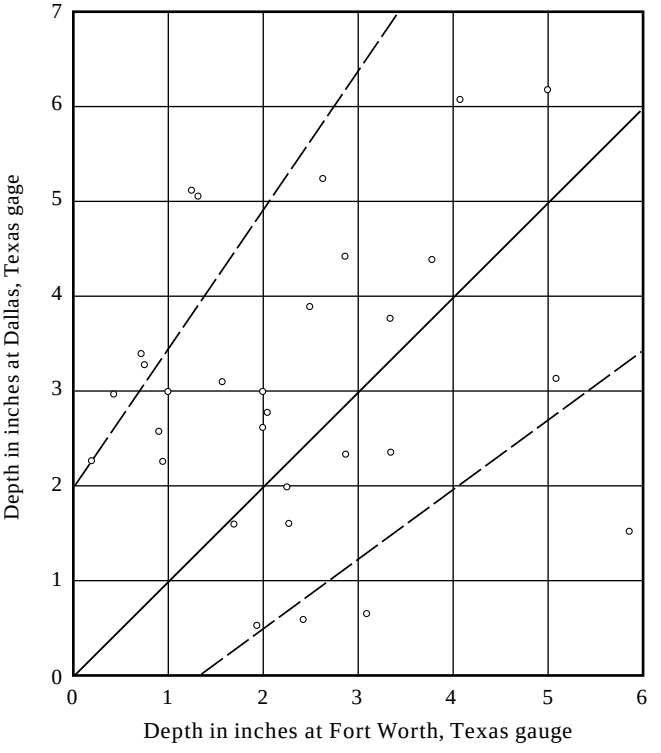


The 10 percent level of significance applies to the positive increment. The lower (negative) increment is taken as half the upper. The graph does not apply to rainfalls in mountainous area.

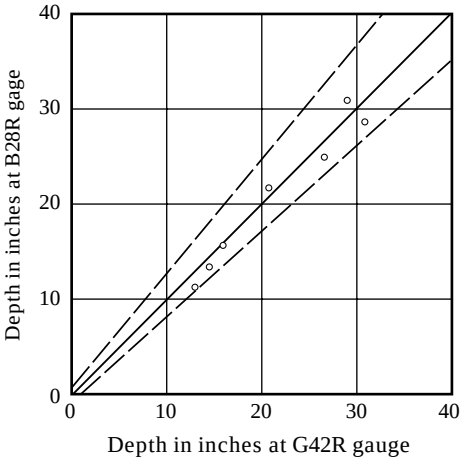
Figure 4–5 Applications of figure 4–4



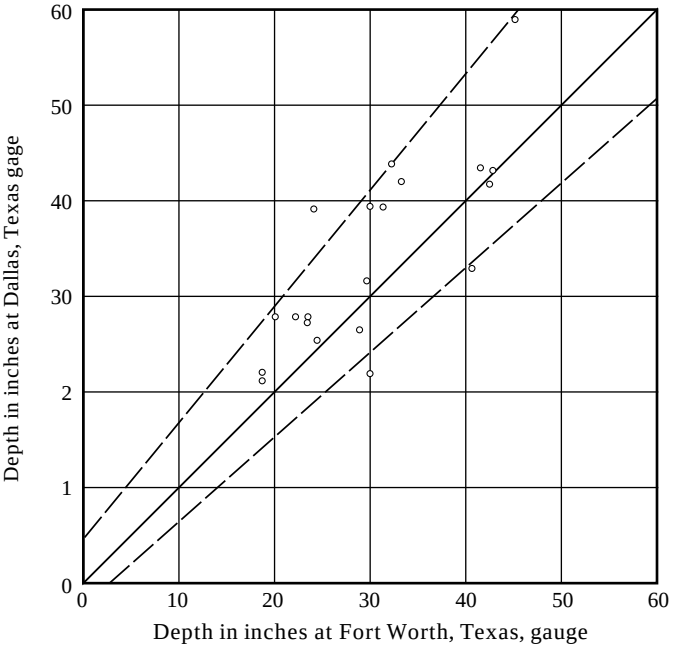
(a) Storm rainfall at gauges 4.3 miles apart



(b) Storm rainfall at gauges about 30 miles apart



(c) Annual precipitation at gauges 4.3 miles apart



(d) Annual precipitation at gauges about 30 miles apart

The dashed lines show the range in rainfall to be expected 90 percent of the time at a distant location (ordinate) when the rainfall amount at a gauge (abscissa) is transposed. The plotted points are actual measurements at the distant and gauge locations. (Figures a and c are based on data from the ARS Experimental Agricultural Watershed at Hastings, Nebraska.)

Figure 4–6 Network chart for estimating the error in watershed average rainfall amounts (modified from McGuinness 1963)

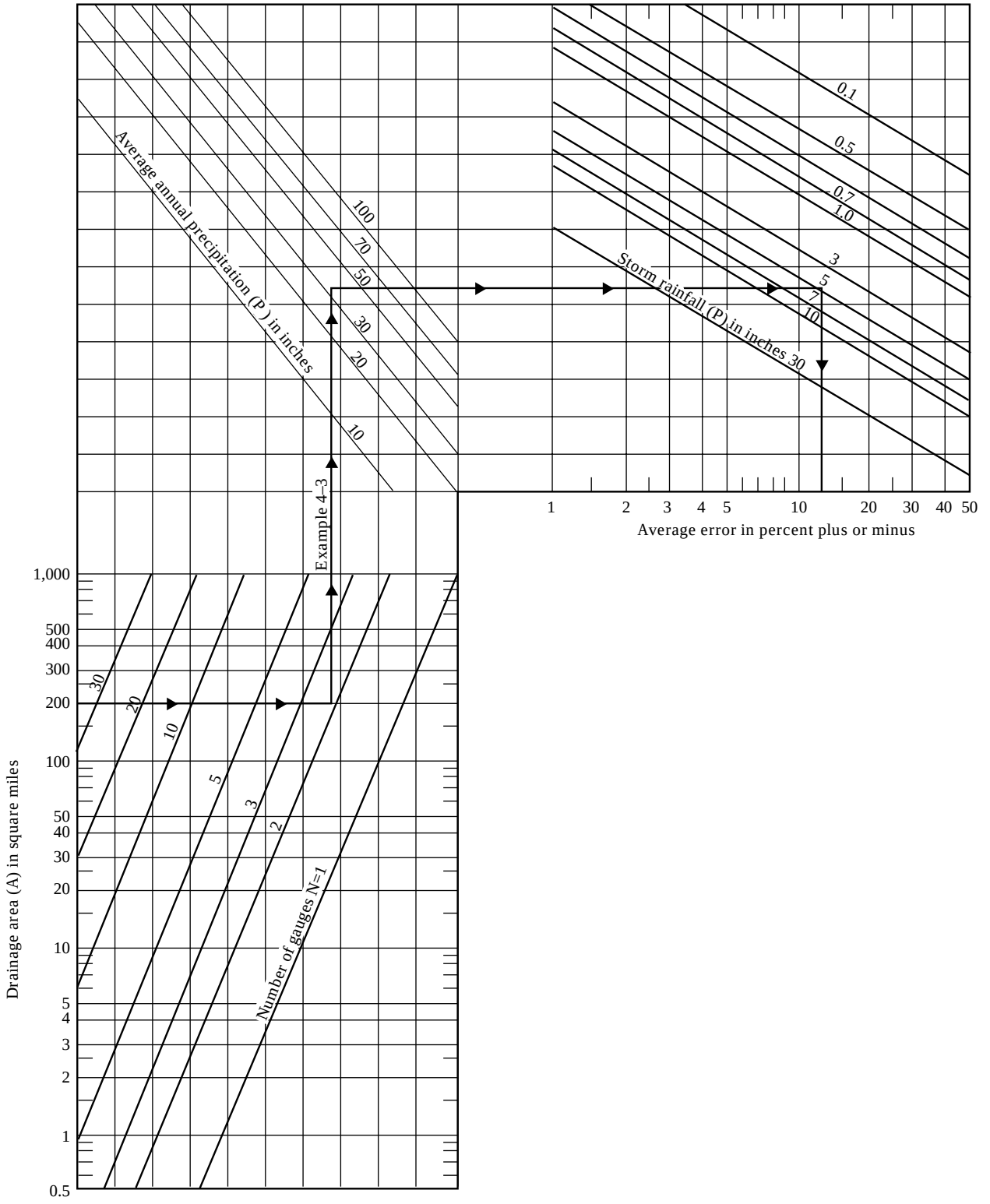


Figure 4–7 Typical rain gauge networks

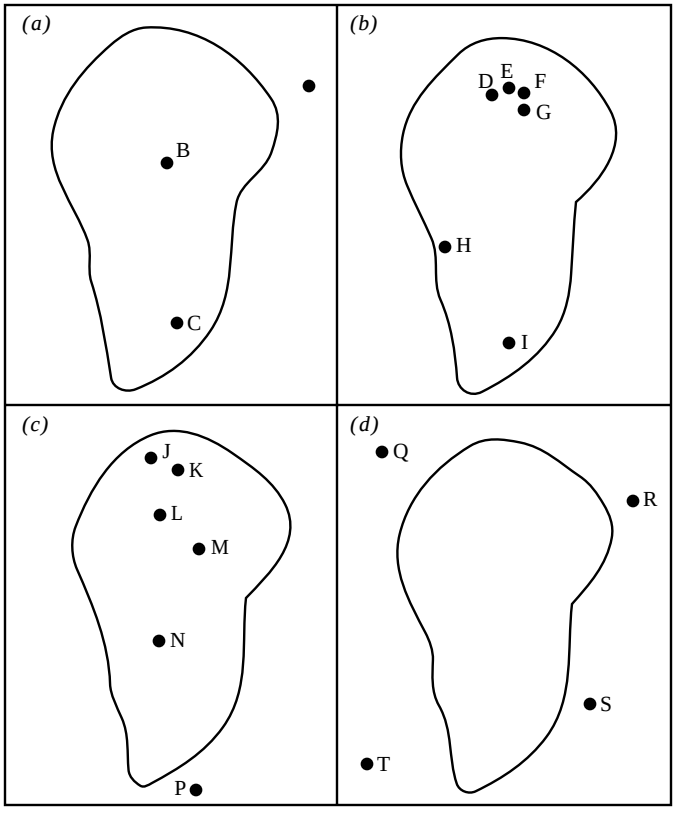
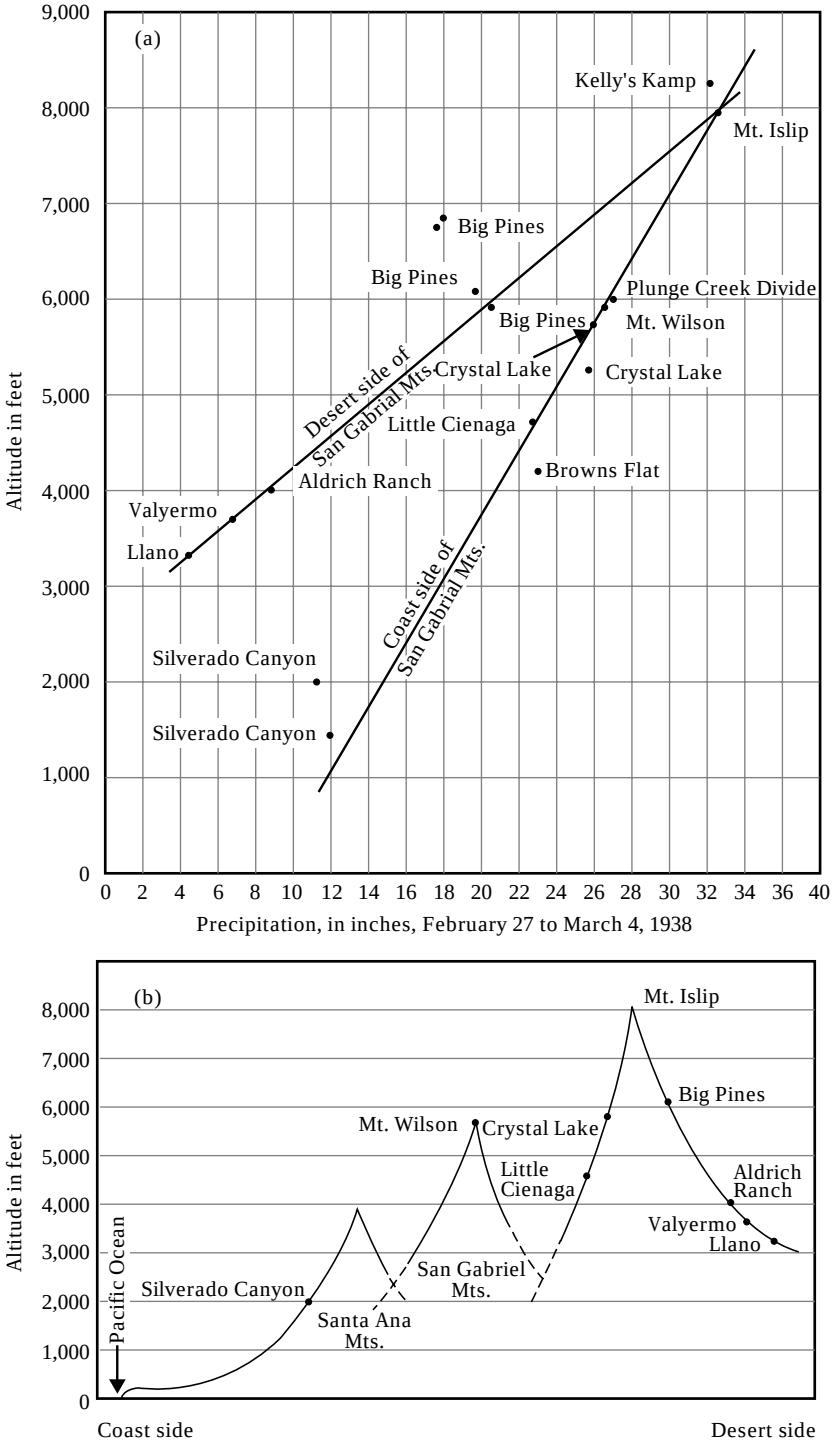


Figure 4–8 Orographic influences on rainfall (Source: USGS 1942)



Points denote rain gauge catches.