Chapter 4
Flood Risk Assessment

Chapter Overview

Any floodplain management program must be established on a sound technical and scientific basis in order to be effective, whether for flood loss reduction or to manage natural resources, or both. For management purposes, nature of the flood hazard and the degree of flood risk for a specific site often has to be determined.

This chapter reviews commonly applied hydrological computational techniques for arriving at estimates of flood flows in streams, needed to identify flood hazard areas and flood risk within those areas. The next chapter reviews commonly applied techniques in delineating areas subject to flooding from floods of varying magnitudes. The occupancy or use of flood-prone areas involves a degree of risk, the first subject of this chapter.

Hazard Identification

The American Planning Association defines a **hazard** as "an event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss." **Hazard identification** is defined as "the process of defining and describing a hazard, including its physical characteristics, magnitude and severity, probability and frequency, causative factors, and locations or areas affected." [1] Finally, **a flood hazard** is the potential for inundation that involves risk to life, health, property, and natural floodplain resources and functions. It is comprised of three elements: severity (magnitude, duration, and extent of flooding), probability of occurrence, and speed of onset of flooding.

Vulnerability

There is a relationship between exposure to a flood hazard, risk (the next topic of this chapter), and vulnerability. Vulnerability is the measure of the capacity to weather, resist, or recover from the impacts of a hazard in the long term as well as the short term. Vulnerability depends upon many factors such as land use, extent and type of construction, contents and use, the nature of populations (mobility, age, health), and warning of an impending hazardous event and willingness and ability to take responsive actions. This means that within an identified flood hazard area there may be the same exposure or risk of flooding, but a wide range of vulnerability to the hazard. This will be examined in more detail in subsequent course topics. Floodplain managers and programs need to recognize and account for ranges of vulnerability to flood hazards.

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[1] FEMA/EMI, Floodplain Management, Session 15

Risk Assessment

The occupancy or use of flood-prone areas involves a degree of risk. Risk is exposure to an undesired event. It can be expressed in probability that the event will happen, often during a calendar year.

Probability is a numerical index of risk; it is a measure of the likelihood that the undesirable event will occur. If the event is sure to occur, the probability is 1.0; if it cannot occur, the probability is 0.0.

EVENT	ANNUAL PROBABILITY
Electrocution	0.0000053
Airline accident	0.00005
Motor vehicle accident	0.00024
Some form of cancer	0.0028
"100-year flood"	0.01
"10-year flood"	0.1

Calculated risk is basic to the occupancy and use of flood-prone areas. How much risk are we willing to assume? Decisions may be based on a certain flood event or risk. The key is how much risk and to whom and how will they be affected.

Timing of Floods

Human occupancy of floodplains is a gamble not unlike the gamble of playing roulette at Las Vegas. The same rules of chance apply. The stakes are high – one wins only if the losses from floods are less than the values gained from being in the floodplain. Because floods are bound to occur, the odds, over the long run, are against winning. The biggest losses in built-up areas come from catastrophic floods such as the 1993 Midwest flood or those produced by hurricanes or major flash floods. Fortunately such events are rare, but their magnitude makes even a small chance for such a disaster a matter of concern. On the other hand, more frequent flooding occurs on bottomlands near a river or stream, where the watercourse might overtop its banks on the average every year.

These differences in the chances of experiencing floods of different sizes are expressed in the concept of a **recurrence interval** (average period of time for a flood that equals or exceeds a given magnitude), expressed as a period of years. The probability of occurrence of a given flood can also be expressed as the odds of recurrence of one or more similar or bigger floods in a certain number of years. Flood-frequency curves such as the one in Figure 4-1 express the chances of equaling or exceeding a given discharge (rate of stream flow, usually expressed in cubic feet/second, because the cross-sectional area through which flow occurs is expressed in square feet, and water velocities are measured in feet per second) in terms of the concept of flood **frequency** or **probability** (percent chance that a flood will occur in a given year). Large, catastrophic floods have a very low frequency or probability of occurrence, whereas smaller floods occur more often. The larger the number of years in a recurrence interval, the smaller the chances of experiencing that flood in a particular year. However, the odds are never zero – even very large, uncommon floods always have a very small chance of recurring every year.

Annual Probability	Recurrence interval
1.0	Annual
0.5	2-year
0.2	5-year
0.1	10-year
0.02	50-year
0.01	100-year
0.002	500-year

Newspaper and other media accounts of floods often refer to a given event as the "100-year" or some other time interval flood. But using a term such as the "100-year flood" associates it with a specified time or return period, particularly with those outside of professional circles. It is important to note that the time referred to is the expected recurrence interval of that size of flood. It does not mean that a flood such the "100-year flood" will occur only once every 100 years. Statistically speaking, over the long period of time, such as a thousand years, ten such floods are expected to occur. Several could occur during any given 100-year period, or one might not occur for several hundred years. The odds for occurrence of this flood in any given year are 1 in 100 (1% chance).

It is also important to note that once a flood occurs, its chance of recurring remains the same. Every year is a new spin of the roulette wheel, such as one with 100 slots, 99 blank and 1 with "flood." When the pointer is in the "flood" slot, then the "100-year flood" occurs that year. A community that has experienced a "100-year" flood in a given year still has a chance of being visited by a flood of equal size, or by a larger flood, in the next year – another spin of the roulette wheel. The odds remain the same. In fact, it is possible, though very uncommon, for two or more "100-year floods" to occur on a given floodplain in the same year. Such an event would be a "long shot," but it has happened.

Although the laws of chance apply to the flood experience at any given location, flood occurrences vary significantly in time and space. Differences in magnitudes between rare great floods and more common low water flows may be greater in the mountainous areas of the East and West than in the plains of the Midwest.

Sources of Information for Determining Flood Risk

- Site-specific data such as stream gaging records
- Rainfall records
- Historic information – flood marks on buildings and other structures, areas flooded (discuss with long time residents)
- Newspaper accounts, diaries
- Marking of flood levels after an event
- Botanical evidence such as scars on trees
- Physical and geomorphic techniques, e.g., look at boulders along streams, water transported debris along walls of canyons
- Regional information, i.e., look at flood occurrences along similar streams in the area

Determining Flood Probability

Several methods are used to delineate flood-prone areas, depending on the level of detail and accuracy required, the types of floodplain management measures to be used, land values, political considerations, and other factors. The most accurate and widely used method employs engineering principles and computations to calculate flood levels for given flood flow rates, which provide the basis for delineating floodplain or flood-prone areas for differing flood frequencies, magnitudes, or recurrence intervals, whatever terminology is used.

Flood flow rates (hydrology) and channel or floodplain characteristics (open channel hydraulics) are needed for engineering mathematical models. The end products are calculated flood levels for floods of various magnitudes and the transfer to maps or photographs to outline areas subject to the occurrence of those floods.

Hydrological Computational Processes

Hydrologists have a plethora of methods from which to choose for a specific task. The most commonly applied techniques used to define flood probabilities are:

- Statistical analysis of stream-flow records
- Regional methods
- Transfer methods
- Unit hydrograph technique
- Empirical equations, and
- Watershed modeling

Assessments of these techniques should include the estimates developed and their accuracy. As revealed on the following page some are more reliable and accurate than others.

Some communities or regulations require use of a specific method. Many agencies and firms have their own procedures. The objective of a hydrologic study in the context of this course is to define the probability of flooding, now and in the future.

Of interest is:

- Peak rate of water flow
- Runoff volume from the event (rainfall and/or snowmelt)
- Time distribution of flow

The interest depends upon the type of project to be carried out.

The peak rate is needed for water conveyance design (natural and constructed), and determination of areas subject to flooding. Runoff volume is needed for design of storm and floodwater storage facilities. Time distribution is needed for flood warning systems, emergency actions, and the design of measures to attenuate water flows.

We often have to deal with predicting large events (magnitude, probability) with a small sample of data. In determining probability of flooding, exact science is not involved. Often conclusions are drawn from conflicting information. An estimate can be provided, but don't be surprised if something unexpected happens, e.g., a flood probability is estimated and it is exceeded in a short period of time.

We base designs or decisions on a certain flood event (e.g., 1% annual chance flood) or risk, and then a larger event occurs. You assume a certain element of risk unless you are willing (or your client) to use a flood magnitude that, statistically, has almost no probability of occurring. The key is how much risk and to whom and how will they be affected.

Statistical Analysis of Stream-flow Records

Measured stream flow can be analyzed by statistical methods. This method produces a probabilistic statement about the future occurrence of a stream flow event of specific magnitude. Employment of this method assumes there exists a reliable representative sample of the universe or population of stream flow data (no watershed or climate changes). It also assumes the events are random and independent of each other.

An accurate estimate of the flood damage potential is a key element to an effective flood damage abatement program. To obtain both a consistent and accurate estimate requires development, acceptance, and widespread application of a uniform, consistent and accurate technique for determining flood-flow frequencies.

In a pioneering attempt to promote a consistent approach to flood-flow frequency determination, the U.S. Water Resources Council, comprised of federal water management agencies, in 1967 published "A Uniform Technique for Determining Flood Flow Frequencies." An extension and update of the 1967 bulletin was published in 1976 as "Guidelines for Determining Flood Flow Frequency." It presented the currently acceptable methods of analyzing peak flow frequency data at gaging stations with sufficient detail to promote uniform application.

The present guide, Bulletin 17B, published in 1981 and editorially corrected in 1982, revised some of the techniques in previous editions and offers a further explanation of other techniques. It is the result of a still continuing effort to develop a coherent set of procedures for accurately defining flood potentials. The two goals of accuracy and consistency have not been fully attained.

The guide incorporates acceptable technical methods with sufficient detail to promote uniform application, i.e., two independent investigators using basically the same data should arrive at generally the same results. It is limited to defining flood potentials in terms of peak discharge and exceedance probability at locations where a systematic record of peak flood flows is available.

The Pearson Type III distribution with log transformation of the flood data (log-Pearson Type III) is recommended as the basic distribution for defining the annual flood series. This recommendation is based on a study of some 300 watersheds. The method of moments (a standard statistical computation for estimating the moment of a distribution from the data of a sample) is used to determine the statistical parameters of the distribution from station data.

Necessary assumptions for a statistical analysis are that the array of flood information is a reliable and representative sample of random homogenous events.

Flood events can be analyzed using either annual or partial duration series. The annual flood series is based on the maximum flood peak for each year. A partial duration series is obtained by taking all flood peaks equal to or greater than a predefined flood base (may want to know all events that cause flood damage). If more than one flood per year must be considered a partial duration series may be appropriate. The base is selected to assure that all events of interest are evaluated, including at least one event per time period. A major problem encountered in using a partial-duration period is to define flood events to ensure that all events are independent.

Utilizing relationships developed at the stream gaging site to convert water levels to stream discharge, data series are plotted on log-normal paper. A curve is best fitted to the data, as shown in Figure 4-1. This method produces a flood discharge-probability relationship to provide stream flow data needed to calculate expected flood levels along the stream being studied.

Voluminous calculations are typically required to perform statistical analyses using log-Pearson. Computer programs, such as those developed by the U.S. Army Corps of Engineer's Hydrologic Engineering Center (website: www.hec.usace.army.mil) are available to assist with the computations.

One of the problems with utilization of the statistical analysis method is that stream-flow records do not exist for most of the nation's streams. Where records do exist, they typically provide data for only several decades. Even the longest records, with a few notable exceptions, cover less than 100 years. The user is often faced with making determinations of stream flows associated with infrequent flood events such as the 1% annual chance or 0.2% annual chance floods utilizing stream flow data having much shorter periods of record. As a rule of thumb, statistical methods should not be used to estimate recurrence intervals in years that are more than twice the number of years of available homogeneous data.

Statistical analysis of stream flow records is not likely to be applicable in urban or urbanizing areas for two reasons. First, gauging stations are usually not located in the small watersheds typically analyzed in urban surface water management. Even if the gauging station exists, the length of record is likely inadequate because stream flow monitoring in urban areas is a relatively recent development. Second, the urban watershed may have been significantly altered as a result of various aspects of urbanization during the period of stream flow records, and therefore the record would not be suitable for statistical analysis because it would not be heterogeneous.

Where records do not exist or there is an inadequate length of homogeneous stream flow data to allow determination of flood events, other methods may be employed as described below.

Regional Methods

This method involves correlation of a dependent variable (e.g., x-year recurrence interval discharge) with one or more causative or physically related, and readily determined, watershed and stream system factors for a defined geographic area. This category of hydrologic methods is specified as being regional because any given method is applicable only within the region that provided the stream flow and watershed data used to develop the method (usually the state).

The United States Geological Survey (USGS) has performed regression analyses and developed equations for floods of different frequencies for each state, and areas within a state having similar hydrologic zones. See Table 4-1. Included with the state equations are "standard errors of estimate." These represent the standard deviation of the distribution or spread of the given points along the fitted line of regression. For an explanation of these terms, refer to a statistics text. The standard error of estimate inherent in many of these equations may be unacceptably high, being averaged from widely diverse conditions across many watershed shapes, sizes, slopes, land uses, and others.

An extensive database and a major analytic effort are required to develop a regional method. In Tennessee, the USGS, in cooperation with the Tennessee Department of Transportation, updated a 1992 study in developing current flood-frequency prediction methods for unregulated, ungaged rivers and streams in the state. The methods are intended to estimate 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence-interval floods for most unregulated rural streams in Tennessee. They are not intended for use in heavily developed or storm-sewered basins with impervious areas greater than 10 percent.

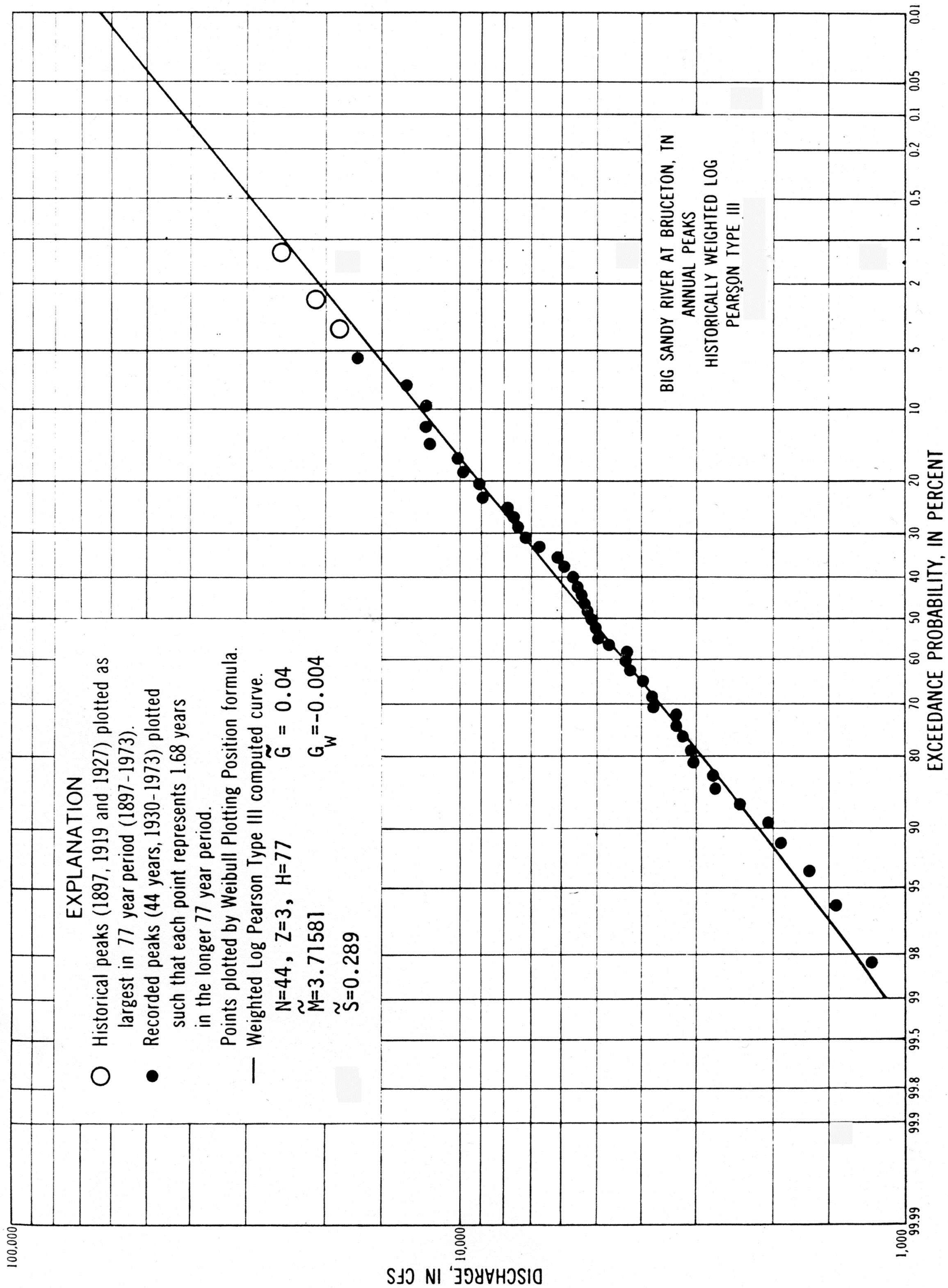


Figure 4-1. Flood discharge-probability relationship

Table 4-1. USGS State Equations, applicable within the Tennessee Valley, for estimation of peak flows at the 100-year recurrence interval.

State	Peak Flow Equation	Standard Error of Estimate
Alabama	$Q_{100}=664*A^{.722}$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs)	36%
Georgia	$Q_{100}=610*A^{.680}$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs)	31%
North Carolina	$Q_{100}=719*A^{.643}$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs)	52%
Tennessee	$Q_{100}=524A^{.709}$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs)	50%
Virginia	$Q_{100}=269*A^{.730}*S^{.21}*RF$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs) S=Main channel slope (ft/ft) RF=Regional Factor for Virginia	60%
Upper Eastern Kentucky*	$Q_{100}=798*A^{.777}*Bs^{-.373}*Ss^{-862}*1.060$ A=Contributing drainage area (mi^2) Q_{100}=100-Year Peak Flow (cfs) Bs=Basin factor (Area/channel $length^2$) Ss=Main channel sinuosity	35%
*This area is not in the Tennessee River Valley.		

A report describing the methods was published in 2000. See following page for a reproduction of the report cover. The entire study can be downloaded: www.google.com, type in the report name "Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee," in the search box.

Prepared in cooperation with the
Tennessee Department of Transportation

Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee, 2000

Water-Resources Investigations Report 03-4176

U.S. Department of the Interior
U.S. Geological Survey

Cover of USGS Water Resources Investigations Report on Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee, 2000.

Basin characteristics and flood-frequency estimates for 453 gaging stations located in Tennessee and adjacent states were merged to form the database that was used to develop the regional-regression equations described in the report. The equations were derived by using both single-variable and multivariable regional-regression analysis.

Contributing drainage area is the explanatory variable used in the single-variable equations. Contributing drainage area, main-channel slope, and a climate factor are the explanatory variables used in the multivariable equations. Prediction methods include a newer region-of-influence method, employed to improve flood frequency estimates. The region-of-influence methods calculate multivariable equations for each ungaged site and recurrence interval using basin characteristics from 60 similar sites selected from the study area.

Explanatory variables that may be used in regression equations computed by the region-of-influence method include contributing drainage area, main-channel slope, a climate factor, and a physiographic-region factor. According to the USGS report, comparison of the regional-regression method to the region-of-influence method, based on average predictive ability of the methods, indicates that the region-of-influence method is the better of the two methods tested for predicting flood frequency in Tennessee.

The state was divided into four hydrologic areas, following its general physiographic province boundaries. Figures 4-2 and 4-3 are a map of the state showing the areas.

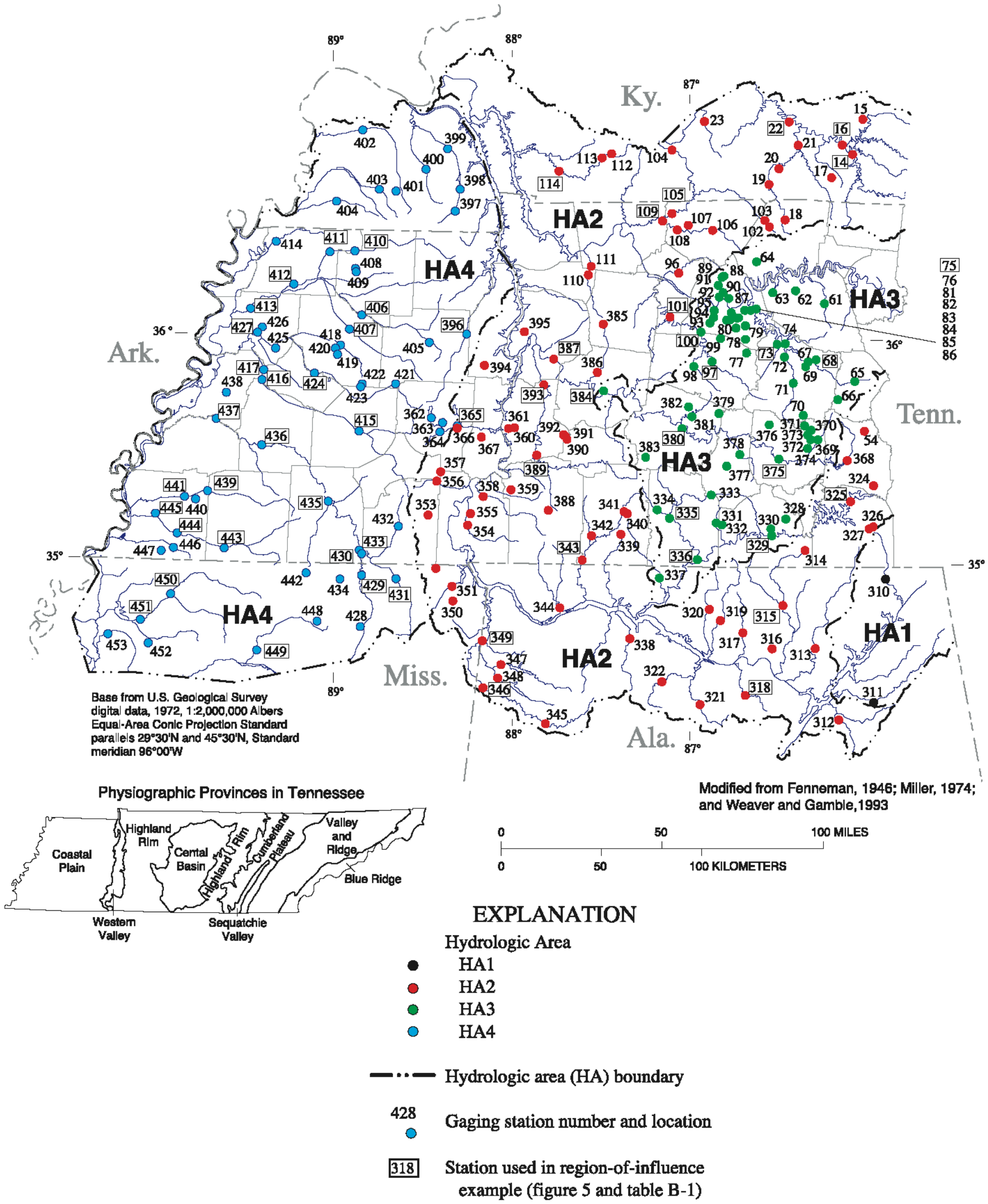


Figure 1. Gaging stations, hydrologic areas, and physiographic provinces in the study area.

4 Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee, 2000

Figure 4-2. Gaging stations, hydrologic areas, and physiographic provinces in the study area.

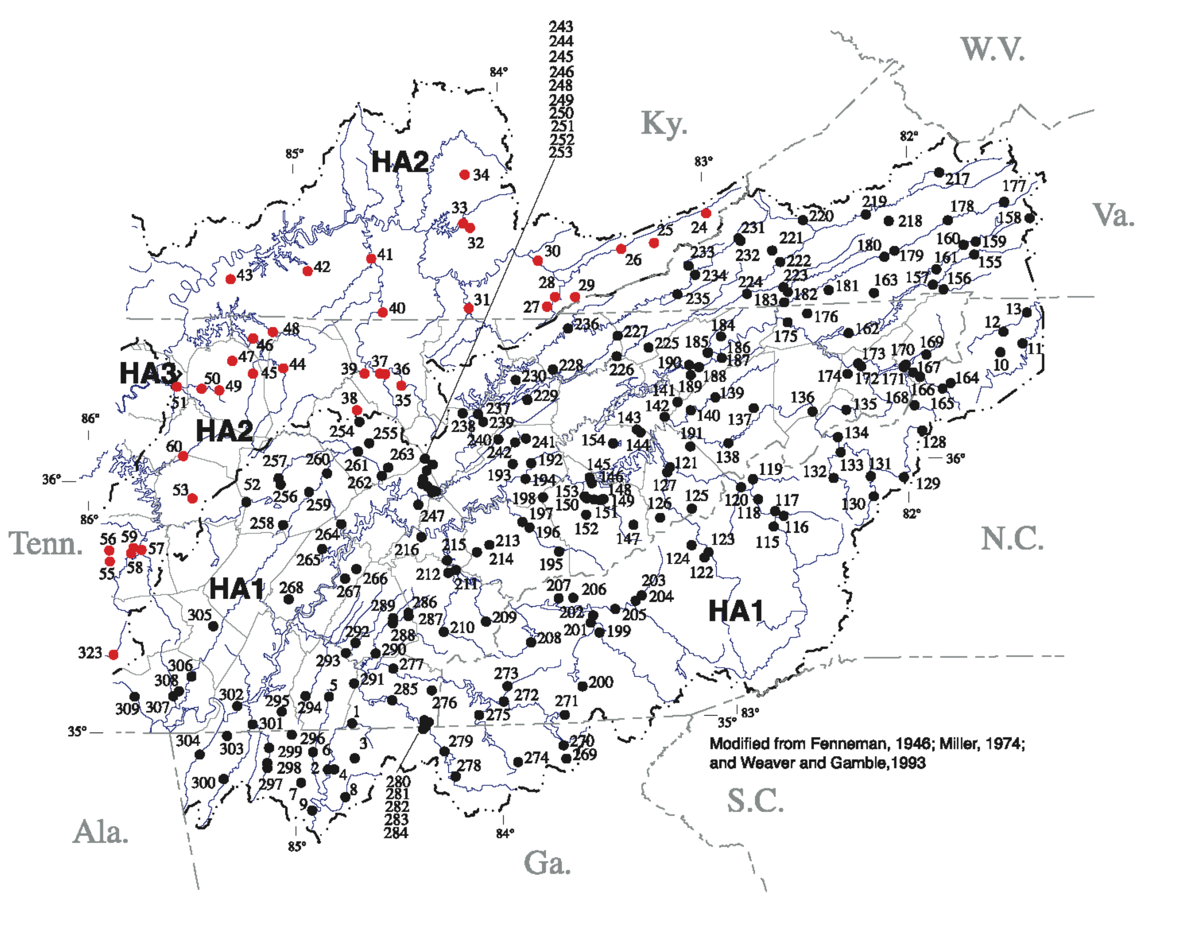


Figure 1. Gaging stations, hydrologic areas, and physiographic provinces in the study area—Continued.

Figure 4-3. Gaging stations, hydrologic areas, and physiographic provinces in the study area – continued.

Table 4-2 provides a tabulation of the single-variable regression equations to be used to compute flows (Q) for different magnitude floods within the four hydrologic areas. Table 4-3 provides a tabulation of multivariable regression equations.

Table 4-2. Single-variable regional-regression equations and accuracy statistics.

[ft³/s, cubic feet per second; *CDA*, contributing drainage area in square miles; see figure 1 for hydrologic area locations; mi², square miles]

Recurrence interval, in years	Peak-discharge equation, in ft³/s	Average prediction error, in percent	Prediction-error departure: Under-estimation, in percent	Prediction-error departure: Over-estimation, in percent
Hydrologic area 1 (CDA=0.20 to 9,000 mi²)				
2	$119CDA^{0.755}$	42.9	-33.7	+50.9
5	$197CDA^{0.740}$	42.2	-33.3	+49.9
10	$258CDA^{0.731}$	43.0	-33.8	+51.0
25	$342CDA^{0.722}$	44.9	-34.9	+53.6
50	$411CDA^{0.716}$	47.0	-36.1	+56.4
100	$484CDA^{0.710}$	49.5	-37.4	+59.7
500	$672CDA^{0.699}$	56.1	-40.7	+68.7
Hydrologic area 2 (CDA=0.47 to 2,557 mi²)				
2	$204CDA^{0.727}$	32.0	-26.8	+36.7
5	$340CDA^{0.716}$	30.2	-25.6	+34.4
10	$439CDA^{0.712}$	31.2	-26.3	+35.6
25	$573CDA^{0.709}$	33.4	-27.7	+38.4
50	$677CDA^{0.707}$	35.6	-29.2	+41.3
100	$785CDA^{0.705}$	37.9	-30.7	+44.2
500	$1,050CDA^{0.702}$	43.9	-34.3	+52.2
Hydrologic area 3 (CDA=0.17 to 30.2 mi²)				
2	$280CDA^{0.789}$	34.3	-28.4	+39.6
5	$452CDA^{0.769}$	34.1	-28.3	+39.4
10	$574CDA^{0.761}$	34.6	-28.5	+39.9
25	$733CDA^{0.753}$	35.5	-29.2	+41.1
50	$853CDA^{0.748}$	36.5	-29.8	+42.5
100	$972CDA^{0.745}$	37.7	-30.5	+43.9
500	$1,250CDA^{0.739}$	40.8	-32.5	+48.1
Hydrologic area 3 (CDA=30.21 to 2,048 mi²)				
2	$679CDA^{0.527}$	27.4	-23.6	+30.9
5	$1,040CDA^{0.523}$	28.0	-24.0	+31.6
10	$1,280CDA^{0.523}$	29.6	-25.1	+33.6
25	$1,590CDA^{0.525}$	32.5	-27.1	+37.2
50	$1,800CDA^{0.527}$	34.9	-28.8	+40.4
100	$2,020CDA^{0.529}$	37.7	-30.5	+43.9
500	$2,490CDA^{0.537}$	44.4	-34.6	+52.9
Hydrologic area 4 (CDA=0.76 to 2,308 mi²)				
2	$436CDA^{0.527}$	38.7	-31.2	+45.3
5	$618CDA^{0.545}$	37.2	-30.3	+43.4
10	$735CDA^{0.554}$	38.0	-30.7	+44.3
25	$878CDA^{0.564}$	40.1	-32.0	+47.1
50	$981CDA^{0.570}$	42.2	-33.3	+49.9
100	$1,080CDA^{0.575}$	44.7	-34.7	+53.2
500	$1,310CDA^{0.586}$	51.1	-38.2	+61.8

Table 4-3 Multivariable regional-regression equations and accuracy statistics.

[ft^3/s, cubic feet per second; *CDA*, contributing drainage area in square miles; *CS*, main-channel slope in feet per mile; *CF*, 2-year recurrence-interval climate factor; see figure 1 for hydrologic area locations; mi², square miles]

Recurrence interval, in years	Peak-discharge equation, in ft^3/s	Average prediction error, in percent	Prediction-error departure: Under-estimation, in percent	Prediction-error departure: Over-estimation, in percent
Hydrologic area 1 (CDA=0.20 to 9,000 mi²)				
2	$1.72\ CDA^{0.798}\ CS^{0.112}\ CF^{4.581}$	39.2	-31.5	+45.9
5	$3.41\ CDA^{0.783}\ CS^{0.114}\ CF^{4.330}$	38.2	-31.3	+45.6
10	$5.34\ CDA^{0.775}\ CS^{0.116}\ CF^{4.087}$	40.1	-32.0	+47.1
25	$9.00\ CDA^{0.766}\ CS^{0.117}\ CF^{3.778}$	42.7	-33.6	+50.6
50	$12.8\ CDA^{0.760}\ CS^{0.117}\ CF^{3.560}$	45.2	-35.0	+53.8
100	$17.9\ CDA^{0.754}\ CS^{0.117}\ CF^{3.354}$	47.9	-36.5	+57.6
500	$36.1\ CDA^{0.742}\ CS^{0.114}\ CF^{2.904}$	55.2	-40.3	+67.5
Hydrologic area 2 (CDA=0.47 to 2,557 mi²)				
2	$106\ CDA^{0.787}\ CS^{0.151}$	30.5	-25.8	+34.8
5	$170\ CDA^{0.779}\ CS^{0.158}$	28.5	-24.4	+32.2
10	$218\ CDA^{0.776}\ CS^{0.160}$	29.4	-25.0	+33.3
25	$285\ CDA^{0.772}\ CS^{0.160}$	31.8	-26.7	+36.4
50	$340\ CDA^{0.769}\ CS^{0.159}$	34.1	-28.3	+39.4
100	$397\ CDA^{0.766}\ CS^{0.157}$	36.7	-29.9	+42.7
500	$547\ CDA^{0.761}\ CS^{0.151}$	43.1	-33.8	+51.1
Hydrologic area 3 (CDA=0.17 to 30.2 mi²)				
2	$211\ CDA^{0.815}\ CS^{0.063}$	35.2	-28.9	+40.7
5	$329\ CDA^{0.798}\ CS^{0.071}$	34.9	-28.8	+40.4
10	$405\ CDA^{0.793}\ CS^{0.078}$	35.4	-29.1	+41.0
25	$497\ CDA^{0.789}\ CS^{0.086}$	36.4	-29.7	+42.3
50	$565\ CDA^{0.786}\ CS^{0.092}$	37.4	-30.4	+43.6
100	$632\ CDA^{0.785}\ CS^{0.096}$	38.6	-31.1	+45.2
500	$789\ CDA^{0.781}\ CS^{0.102}$	40.5	-32.5	+47.7
Hydrologic area 3 (CDA=30.21 to 2,048 mi²)				
2	$409\ CDA^{0.584}\ CS^{0.102}$	27.9	-23.9	+31.4
5	$767\ CDA^{0.558}\ CS^{0.061}$	28.6	-24.4	+32.3
10	$980\ CDA^{0.554}\ CS^{0.054}$	30.3	-25.7	+34.5
25	$1,200\ CDA^{0.557}\ CS^{0.056}$	33.4	-27.7	+38.4
50	$1,330\ CDA^{0.562}\ CS^{0.061}$	35.9	-29.4	+41.7
100	$1,430\ CDA^{0.568}\ CS^{0.068}$	38.6	-31.1	+45.2
500	$1,600\ CDA^{0.587}\ CS^{0.090}$	45.7	-35.3	+54.6
Hydrologic area 4 (CDA=0.76 to 2,308 mi²)				
No multivariable regression equations developed for this region (see table 6).				

Although a major effort is required to develop a regional method, they are among the easiest to use. The regional-regression equations, in particular the single-variable regression equations, are easy to solve manually. A computer application has been developed that automates the flood frequency calculations. This allows easy comparison of results produced by the different methods. The flood-frequency computer application for Tennessee can be downloaded from the previously referenced USGS website and link.

In using any equation, the user needs to investigate its basis, applicable watersheds, the watershed parameters, and its accuracy.

Tennessee Valley Authority (TVA) hydrologists have carried out numerous studies of smaller watershed units to develop multiple regression equations to calculate peak stream flows within parts of the Tennessee River basin. In a Masters thesis in the 1990s, a TVA hydrologist developed two sets of equations relating peak stream flows to drainage areas for the 2-, 10-, 50-, 100-, and 500-year recurrence intervals for the Blue Ridge and Valley and Ridge Physiographic Provinces (see Figure 4-4). The watersheds were less than 10 percent developed and drainage areas ranged from 0.1 to 100 square miles.

Five basin characteristics were chosen for the regression analyses:

- contributing drainage area
- forested area in percent of drainage area
- basin shape factor, calculated as the ratio of main channel length, squared, to the basin area
- representative channel slope
- mean annual rainfall

All of the variables selected, with the exception of rainfall, can be obtained from information that is measured from USGS topographic maps.

Of the five independent variables examined, only contributing drainage area proved to be significant in either region. The results of the study are tabulated in Table 4-4.

The equations developed in this TVA study appear to be more accurate than the USGS equations currently available. This is based on a comparison of the standard error of estimate, which is a measure of how well the observed data agree with the regression estimates. This can be attributable to the use of a smaller range of drainage areas in the study. By separating the Blue Ridge and Valley and Ridge areas and ignoring state boundaries, all areas within hydrologically similar regions could be included.

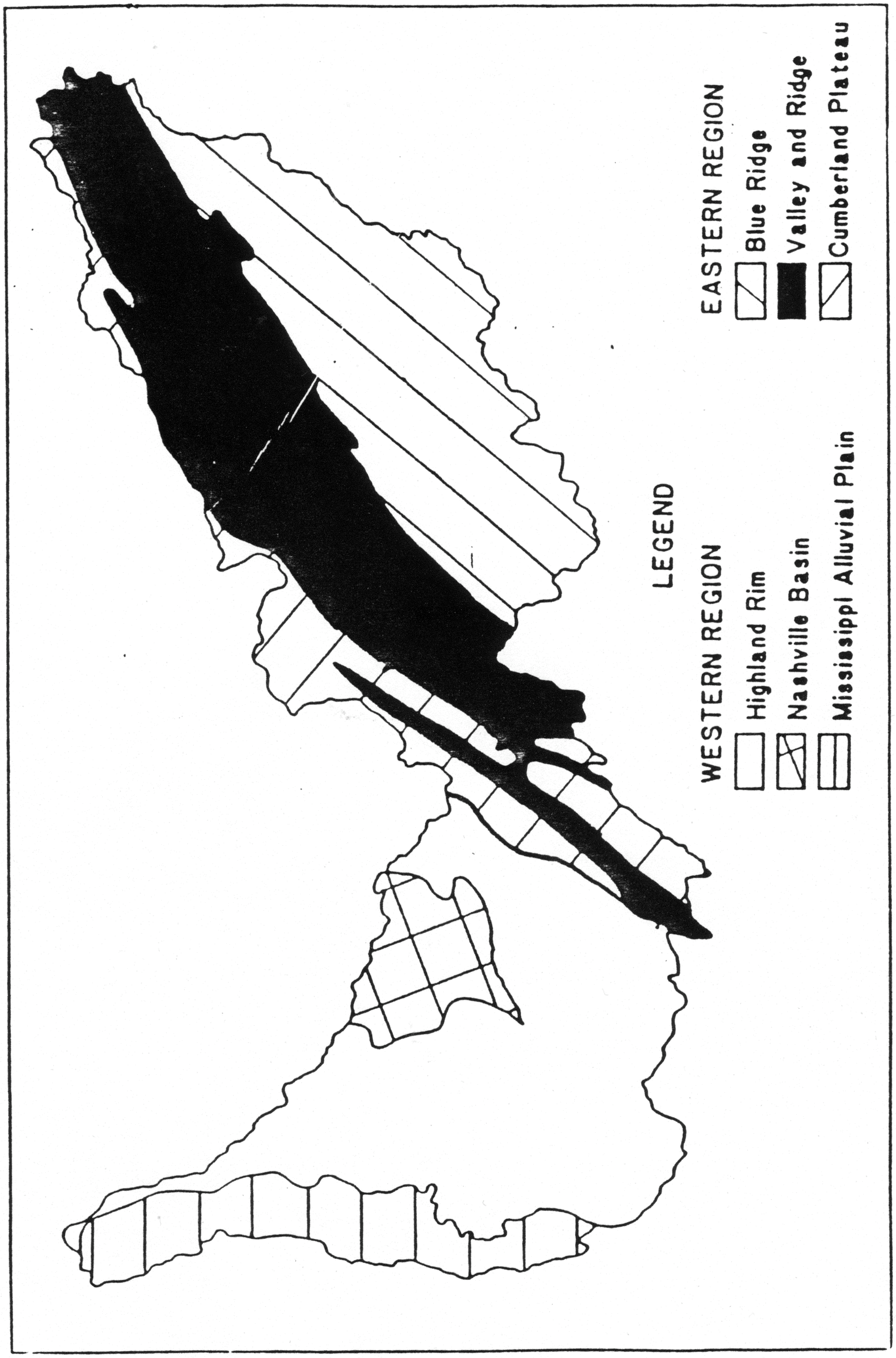


Figure 4-4. Physiographic provinces of the Tennessee River Basin.

Table 4-4. Summary of regression equations for the Blue Ridge and valley and Ridge areas.

Recurrence Interval (Years)	Magnitude of Flood (ft^3/sec)	Standard Error of Estimate (Log_{10})	Standard Error of Estimate (Percent)	Coefficient of Determination (R^2)
	Blue Ridge Area			
2	$Q_2=74*A^{.871}$	.031	7.1	.886
10	$Q_{10}=166*A^{.852}$	.039	9.0	.857
50	$Q_{50}=276*A^{.849}$	.054	12.5	.810
100	$Q_{100}=328*A^{.852}$	.066	15.3	.777
500	$Q_{500}=485*A^{.855}$	.078	18.1	.731
	Valley and Ridge Area			
2	$Q_2=116*A^{.754}$	.035	8.1	.857
10	$Q_{10}=273*A^{.711}$	.030	6.9	.862
50	$Q_{50}=478*A^{.683}$	.040	9.2	.810
100	$Q_{100}=587*A^{.672}$	.047	10.9	.778
500	$Q_{500}=889*A^{.661}$	.071	16.4	.693

Transfer Methods

In employment of the transfer method for determining peak discharge, a flood flow of specified recurrence interval for a stream of a given size and runoff characteristics is used to estimate a flood flow of the same recurrence interval for a larger or smaller portion of the watershed having similar runoff characteristics. Such transfers are made on the basis of drainage area ratios raised to an exponential power.

Underlying the transfer method is the assumption that the area to which it is being applied has runoff characteristics similar to the area for which a flow of specified recurrence interval is known. The only significant difference between the two watersheds, or two points in a given watershed, should be the size of the drainage areas.

Applying this methodology to a typical example, the 100-year recurrence interval flood flow is know for point A in a watershed and desired for point B, another location in the watershed. The desired flood flow at point B is calculated as a function of the known discharge at point A and ratio of the tributary areas raised to the exponent *n*. Points A and B could also be in different watersheds provided that the total watershed areas have similar characteristics, including being subject to similar meteorologic conditions.

Mathematically: $$\frac{Q_{100B}}{Q_{100A}} = \left(\frac{A_B}{A_A}\right)^n$$ rearranging $$Q_{100B} = Q_{100A}\left(\frac{A_B}{A_A}\right)^n$$

Unit Hydrograph Technique

A runoff hydrograph is a plot of stormwater flow at a site along a time compendium. As runoff from more and more contributing areas reach the site, the flow rate increases and peaks when runoff from the most remote location in the watershed receiving rainfall reaches the site. (The time for water runoff to travel from the most contributing remote location in the watershed to a site is referred to as the **time of concentration**.) The flow-rate peak of a hydrograph varies with the rainfall amount, while the overall shape is dependent on watershed characteristics (i.e., the time for flows from contributing areas to reach a site.)

The peak flow for storm frequencies of interest can be derived from utilization of the **unit hydrograph technique**. *A unit hydrograph for a given watershed is the direct runoff hydrograph that would result from the occurrence of a rainfall event of uniform intensity that produces 1 inch of runoff in a specified duration*. It can be used in determining peak flood flows for other events (e.g., a storm of the same duration but with a different amount of runoff can be expected to have a hydrograph with the same time base as the unit hydrograph and ordinates of flow proportional to the runoff volume).

Empirical Equations

Empirical equations utilize formulas developed without regression or unit hydrograph techniques. Among the more commonly applied methods are those relating rainfall to runoff, such as the Rational Formula and Technical Release 55 by the U.S. Natural Resources Conservation Service.

Rational Method

In engineering practice, the Rational Formula is likely the most widely used method for estimating flood peaks. The author, Mulvaney (1851), expressed grave doubts concerning its accuracy and usage. It is described in Figure 4-5.

This method employs a simple mass transfer equation. Outflow (Q) is equal to inflow (iA), where "Q" is in cubic feet per second; "A" is in acres; and "i" is in inches per hour. Because 12 x 3,600 (conversion to inches and seconds from feet and hours) is also equal to 43,560 (number of square feet in an acre), the conversion from cubic feet per second to acre-inches per hour is close enough to 1.0 for most purposes. As long as the rainfall duration is long enough for flow to arrive at the outlet from the farthest corner of a perfectly smooth surface, the equation is valid.

The problem comes in figuring what to do when not dealing with a smooth surface, but a mixed-use urban environment. There are runoff losses due to infiltration; detention areas; complex arrays of land uses such as yards, fields, buildings, and parking lots; undersized culverts; clogged ditches; and mud puddles. A single, simple factor "C," is used to account for all these potential influences on runoff.

As one would imagine, there is considerable uncertainty regarding what number to assign to "C" because of the complexity of urban watersheds, which takes it farther and farther away from reality. Many users also extend the time of concentration to the outermost corner of the site of interest with the justification that the very definition of "time of concentration" demands it.

Why does the Rational Method have such universal application? Possibly because it requires little data, is easy to apply, is cheap, and "everyone else is using it" so there can be little criticism in its use. Besides, who can prove the answer is wrong?

Some local governments limit the use of the Rational Method to 25 acres or less. For many other communities, it seems too unsophisticated. They demand that design professionals use the natural Resources Conservation Service's Technical Release 55 Method because it is more "accurate." An examination of this method is worthwhile to validate its improved "accuracy."

The SCS (TR-55) Method

The U.S. Department of Agriculture, Soil Conservation Service (now Natural Resources Conservation Service) issued a report in 1986 titled "Urban Hydrology for Small Watersheds," Technical Release 55 (TR-55). (See a following page for reproduction of the report cover.) It also utilizes a rainfall-runoff formulation, employing rather simple formulas. The SCS Method is

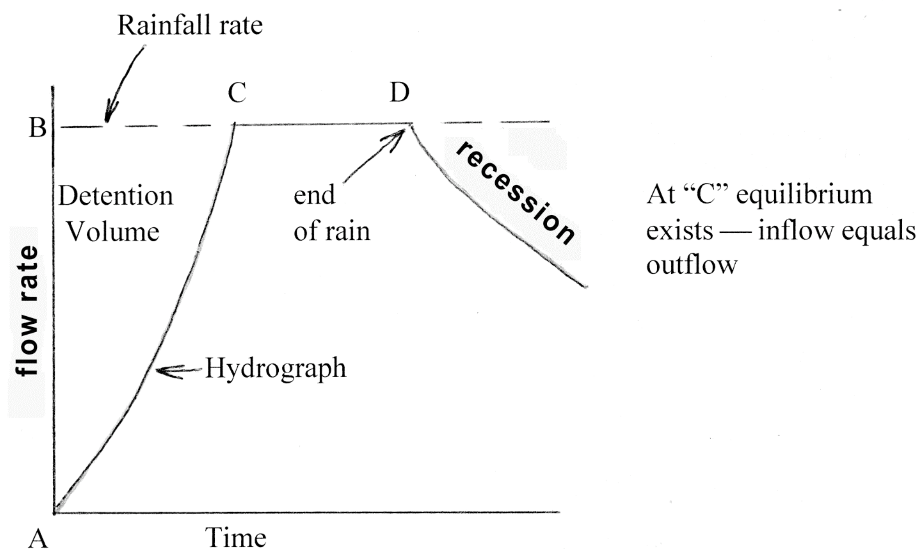
Rational Formula Q=CiA
where Q = Peak discharge for the selected frequency in cubic feet per second

C = Coefficient of runoff representing the ratio of runoff to rainfall (value ranges from 0.15 to 0.95)

i = Intensity of rainfall in inches/hour for a duration equal to the time of concentration for a selected rainfall frequency

A = Drainage area, acres

The basis of the Rational Formula is elementary hydrology.



The Formula assumes that a rainfall amount of 1 inch/hour on 1 acre of ground will produce 1 cfs of runoff. It assumes that all rainfall will run off and rain frequency equals flood frequency. This assumption is not valid. The formula is used in determining flood discharges often outside its area of applicability, i.e., for much larger watersheds than its intended use.

Figure 4-5. Rational formula.

actually a set of related methods originally designed by a group of employees from the Soil Conservation Service (SCS), now the Natural Resources Conservation Service and the Agricultural Research Service. Work began in the 1920s, and minor changes and redefinitions continue to the present as the SCS method is used for more and more things never envisioned by the developers, similar to the concerns expressed by the developer of the Rational Method.

It was initially developed to predict runoff from agricultural (i.e., undeveloped) lands. Technical Report 55 was developed during the 1970s and '80s to meet the demand for an integrated method for calculating runoff hydrographs to route those through new detention ponds that were increasingly being utilized to reduce peak flow rates. It was originally designed only to predict the *volume* of runoff from daily rainfall. Later, it was morphed to predict the direct runoff from individual rainfall events.

In order to extend the original intent of the method to allow for single storm calculations, the SCS developed a coordinated set of tools. The key tools were: (1) rainfall distributions (e.g., Type II storm), (2) losses of rainfall due to initial abstraction (such as surface storage and interception) and infiltration (i.e., Curve Numbers), (3) a rainfall unit hydrograph shape, and (4) methods to calculate the lag time for the watershed.

Regarding rainfall distributions, and to avoid the problem of developing multiple storm durations to reflect various sizes of watersheds, a large number of intensity-duration-frequency curves were analyzed, lumped, and segregated by region. Different climatic regions in the United States were termed Types I, IA, II, and III. Using the Type II storm as an example, studies have shown that when applying it over a large area, there is often a tendency to over predict the runoff.[2]

Losses of rainfall are normally in terms of initial losses (called "abstractions") and losses due to infiltration. They are reflected in SCS Curve Numbers. The Numbers reflect all physical aspects of land use, soil, and antecedent moisture within the soil–and everything else. They vary between about 40 and 95. The higher the Curve Number, the more runoff per unit of rainfall. But what classification is urban soil? For example, SCS uses the term "urban modified" to describe soils compacted by equipment or having lots of human traffic.

In using TR-55, the SCS derived a triangular unit hydrograph shape for rolling-hills type of topography. Under the unit hydrograph concept, the area under the hydrograph must be equal to 1 inch of runoff from the whole watershed. Flat and steep areas would have different hydrograph shapes than the rolling-hills hydrograph used by the SCS. Adjustments for different watershed topography are often not made by users employing this method.

Lag time is a weighted time of concentration and is related to the physical properties of a watershed, such as area, length, and slope. In hydrograph analysis it is defined as the time from the center of mass of the rainfall to the peak of the outflow. The SCS method divides up the travel time calculation into segments of like flow. Normally, this includes sheet flow, shallow flow, and stream or pipe flow segment(s). The actual calculated peak flow is sensitive to the lag time estimate. And the lag time estimate is most influenced by the grassed area sheet flow component. For urban

[2] "Voodoo Hydrology," Andrew J. Reese, Stormwater, July/August 2006, pp. 50. Website: www.stormh2o.com

areas where there is not a long stream flow segment, the grassy sheet flow component dominates the lag time calculation. This means that, using engineering judgment, the peak flow off the site of interest can be radically changed by how the grassy sheet flow component is factored, both in terms of length and dominance.

Various *legitimate* adjustments that can theoretically be made to the SCS method for any given site can result in a wide range of peak flow estimates–often of an order of magnitude change. There is frequent employment of the report methods by practicing hydrologists, despite its inherent inaccuracies, because of its relative ease of use. Employing various worksheets, tables, figures, and exhibits, the user can arrive at a flow rate for a desired flood magnitude.

The NRCS developed a computer program to facilitate use of the TR-55 method. In 1998, a work group was formed to upgrade the previous operating system. The program title is Small Watershed Hydrology (WINTR-55) Version 1.0. The program, user guide, and related documents are available on the Internet at http://www.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html.

Watershed Modeling

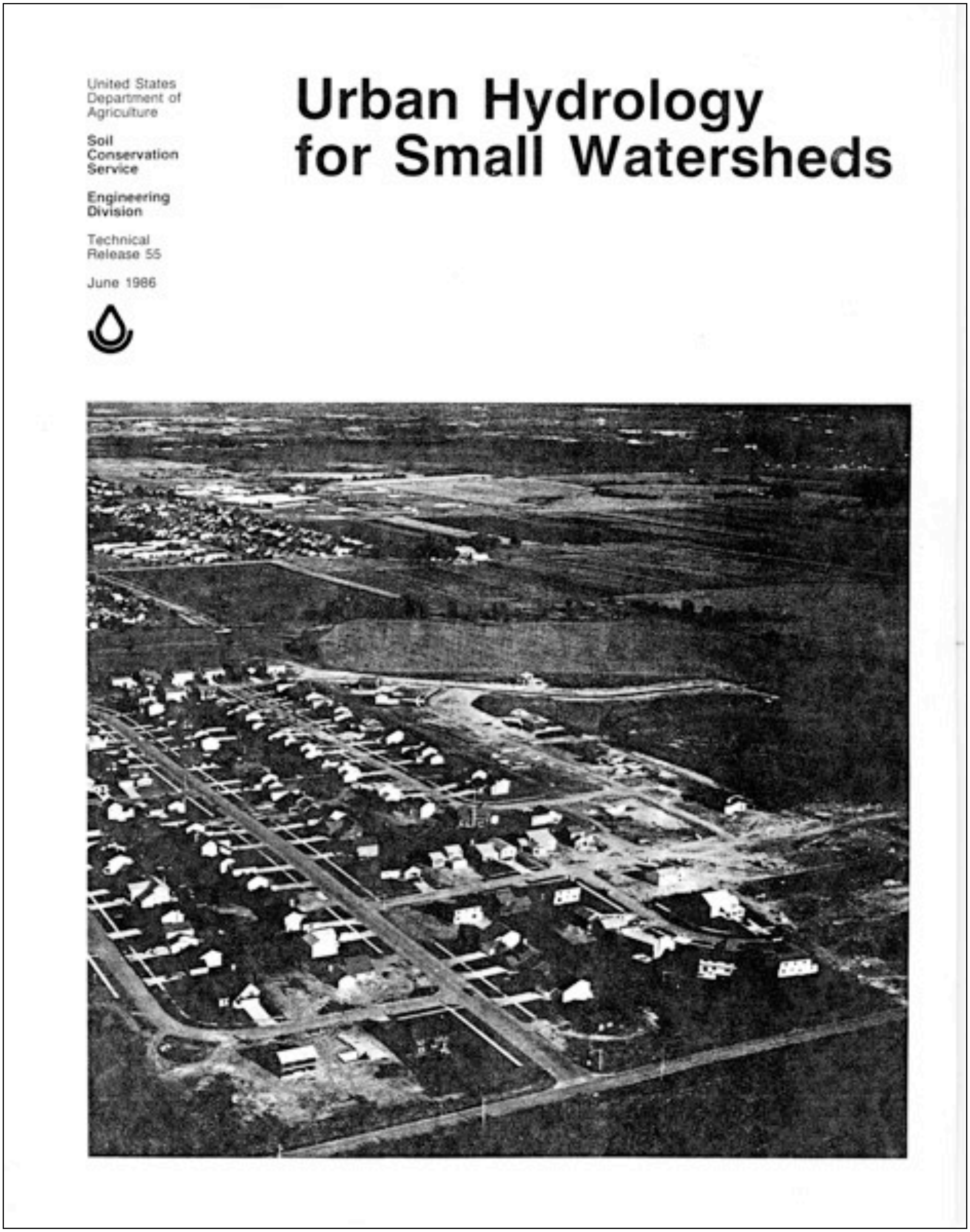
Where time and expense can be justified, watershed modeling can be carried out to arrive at peak flood flows for a stream. This is inherently the most accurate of the hydrological approaches because of the level of detail of the analyses. The modeling process is beyond the scope of this course and is mentioned here as an approach that might be investigated.

An example is a study carried out for the City of Huntsville, Alabama by TVA. Figures 4-6 to 4-8 shows the study area and a comparison of computed and observed flood flows.

Selecting a Hydrological Method

Careful practice suggests the use of more than one hydrologic method for each particular application. A detailed and complete application of a primary method, followed by, or parallel with, use of a second method helps to guard against errors in hydrologic analysis. In selecting a hydrological model to determine expected peak stream flows for a given flood frequency or recurrence interval, the user should consider the following factors:

- scale and complexity of development
- physical and climatic characteristics of the basin
- type of downstream development
- time and cost
- agency procedures
- local ordinances



United States
Department of
Agriculture

Soil
Conservation
Service

Engineering
Division

Technical
Release 55

June 1986

Urban Hydrology for Small Watersheds

Cover of USDA report on Urban Hydrology for Small Watersheds.

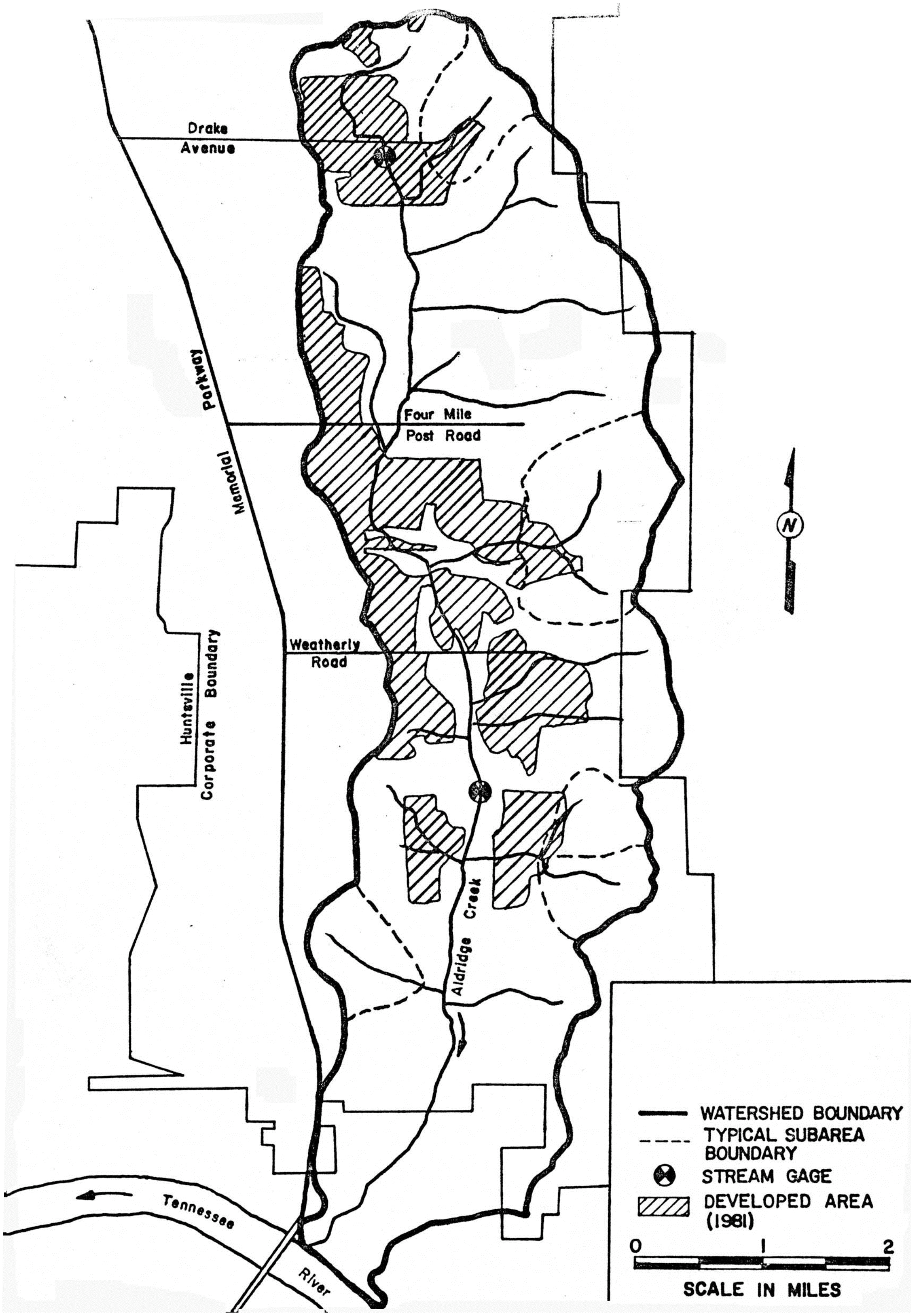


Figure 4-6. Aldridge Creek watershed map.

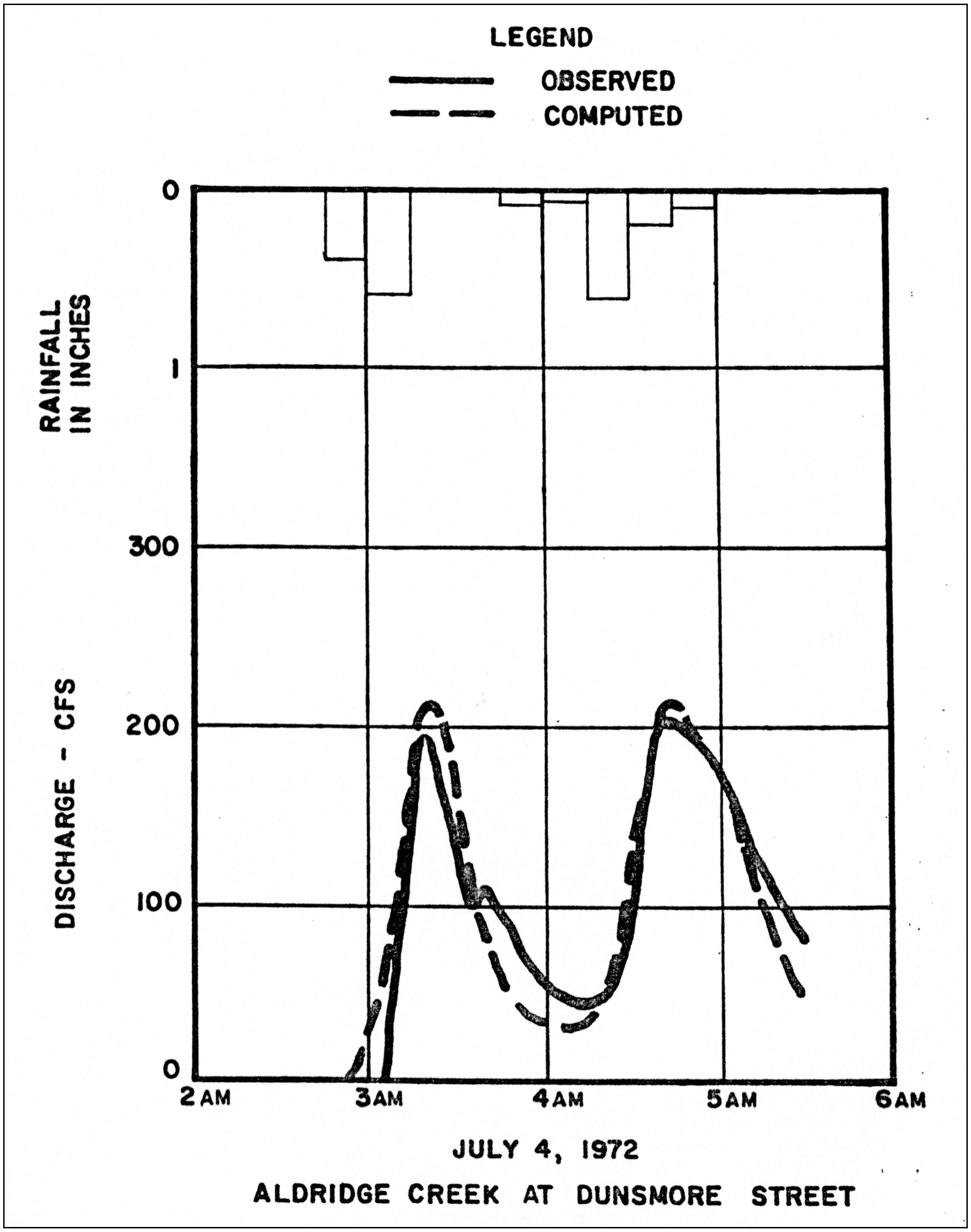


Figure 4-7. Site 1 observed and computed hydrographs.

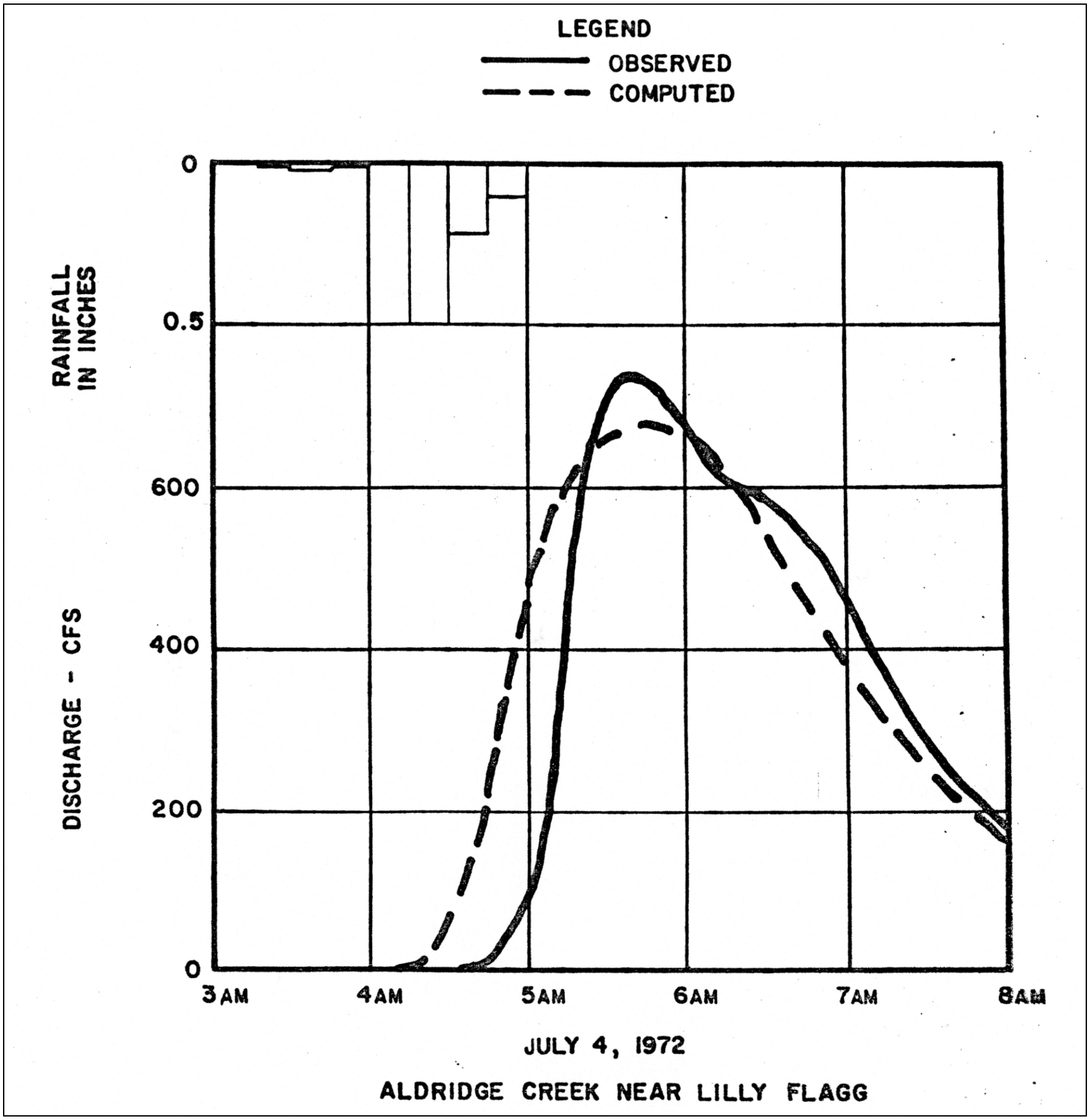


Figure 4-8. Site 2 observed and computed hydrographs.

The methods most commonly used are the Rational Formula, TR 55, and statistical regression. Where no stream flow records or other data exist, regional analyses involving statistical regression should be utilized. In some instances TR 55 might be employed. In very small areas, the Rational Formula might possibly be utilized. The few tests available suggest that procedures and assumptions in common use for estimating flood peak frequency for ungaged streams are subject to large errors and are biased toward overestimates. An interesting study would be to design a situation to allow application of all the above procedures, test each method against observed stream flows, and determine the impact of assumptions on differences in results.

How Good are Flood Estimates?

A common problem for hydrologists is estimation of peak flow frequencies at locations with little or no stream flow data, or data for only a short period of record. The different procedures in common use often provide different estimates at the same site. Further, an estimate made using a particular method often will vary among hydrologists.

How good are the flood estimates hydrologists are making? Ray K. Linsley, a noted hydrologist, poses this question in an insightful discussion of this subject.[3] The hydrologic problem is almost always the same: how to determine the flow which has a specified probability of being equaled or exceeded. By far the greatest number of these estimates will be for ungaged streams.

Under these conditions there are few clues to tell the analyst whether his/her answer is right or wrong. It is assumed that the methodology and assumptions give the right answer. An answer is sought which is within "reasonable" tolerances, but for ungaged streams or even streams with a short record, it is not known if such a goal has been achieved. Is the faith in the many methods that are in use really justified? It is unlikely that all methods can be equally reliable.

Linsley contends that many persons working in hydrology make their calculations by the method prescribed for them and literally walk away from the project. He goes on to state "Since they are estimating a relatively uncommon flood (at least a 10-year event, often a 100-year event), the probability that they will ever know how the estimate comes out is low. The probability that anyone will ever point a finger and say 'you were wrong' is equally remote. If the estimate is exceeded, it is 'obvious' that the new flood is more than the 10- or 100-year event, as the case may be. If the estimate is not exceeded, then there is no reason to think about it. It is not surprising that few hydrologists ever feel that the methods they use are inadequate." Concerning the accuracy of estimates, he notes that the most frequent response by hydrologists is that they are within 20 percent [of the "correct" number] and that such errors are acceptable.

[3] "Flood Estimates: How Good Are They?" Ray K. Linsley, Water Resources Research, Vol. 22, No.9, Pages 159S-164S, August 1986.

In the absence of a national guide, based on a test of commonly applied procedures using the criteria of accuracy, reproducibility, and practicality, there remains a question regarding what procedures are likely to be the most accurate and consistent in determining peak flow frequencies for ungaged watersheds. Accuracy and consistency are further weighed against convenience and "common practice."

Chapter Homework Assignment

The author of a text on municipal stormwater management is quoted as saying, "I love urban hydrology. They can never prove you are wrong, only inconsistent." From the text description of hydrologic computational processes for determining flood probability, there is evidently a black box nature to urban hydrology, and the often minimal level of understanding of some of the basics of methods that have been taken for granted for years by those who are involved in urban design. What is your assessment of the currently used hydrological computational processes regarding their applicability? And, in the absence of any direction from your employer, how might you proceed in arriving at peak flow estimates in the urban environment?

What is the longest present continual operating, i.e., daily flow records, stream gage in the United States? Investigate several possible sources of this information. Document the sources and probable accuracy of your answer in your written submittal.