ANNOTATED BIBLIOGRAPHY AND COMMENTS ON THE

ESTIMATION OF FLOOD PEAKS FROM SMALL WATERSHEDS

by

B. M. Reich, Department of Agriculture, Union of South Africa

currently studying for the Ph. D. degree

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ABSTRACT

Some one hundred and eighty books and articles were reviewed for information of value in the estimation of peak runoff from small watersheds in and around the size range from 200 acres to three square miles. Their contents have been abstracted with emphasis on material pertinent to design methods. They have also been classified according to sixteen subject headings. The most useful estimation methods are briefly discussed, with special reference to procedures followed by the USDA Soil Conservation Service. Research programs are proposed which could bridge the gap between existing data and the application of more refined estimation techniques in countries where hydrometeorology is less advanced than it is in the United States of America.

INTRODUCTION

Initially the object of this review was to explore the methods currently used in the estimation of design floods from small watersheds. It has grown into a review of the vast field of literature which appears pertinent. Arbitrary lower and upper limits of 200 acres and three square miles, respectively, were set on the watersheds. The lower limit was chosen to exclude plot, single field, and elemental airfield strip type - situations. The upper limit signified the exclusion of a watershed which is so large that the chance location of a storm in one portion of it, or the movement of a storm across the area, would markedly affect the relation between rainfall and peak runoff rate. These limits of size must obviously be flexible. In fact, the material reviewed also concerns smaller and larger watersheds. More detail has been retained, however, in the abstracts of material pertaining to small watersheds.

Encroachment into related subject matter fields is unavoidable. This occurred where the classification of an article in an abstracting journal or its title was misleading. For instance "runoff" is used to signify direct runoff during a storm sometimes, while other times it has the connotation of annual runoff, which does not concern us here. The contents of all such articles have been briefly listed here so that future workers may be saved the inconvenience of consulting inappropriate references.

Watersheds within the selected small size class are very sparsely represented by experimental data. This can be appreciated from studying the size-distribution of the instrumented watersheds maintained and/or analyzed by the USDA, ARS (1958). Out of a total of

335 watersheds which they study, only 31 have areas within the range 200 acres to three square miles, while 236 watersheds have areas less than 50 acres.

PROCEDURE

As many technical papers and bulletins were reviewed as possible. Abstracting and indexing journals used in the process included, amongst others: Applied Science and Technology, Engineering Index, Bibliography of Agriculture, both volumes of the Annotated Bibliography of Hydrology, Agricultural Index, Forestry Abstracts and Bibliography of North American Geology. Some of the classical work, like the article by Ramser (1927), are included since they are frequently referred to even in modern literature.

In abstracting any article, accent was laid on the phases which apply to determining flood peaks on small watersheds. Any extraneous material is simply listed briefly by name. Wherever possible the areas of the watersheds involved are denoted.

In the section entitled "Results", one or more capital letters appear to the left of each author's name. These symbolize the type of material covered in each article and should facilitiate the tracking down of specific subjects. The symbols have the following significance:-

- A regional synthesis of flood peaks
- B watersheds larger than about three square miles
- C time of concentration
- D design recommendations

F flood peaks

I inventory of available data

L watersheds smaller than 200 acres

M raw observational data

N infiltration approach

O flood volumes

P small plot results

Q qualitative discussion

R rational method

S statistical methods

T annual or monthly runoff

U unithydrograph

RESULTS

P Alles, W. S. (1958). "Some Studies on Runoff and Infiltration", Tropical Agriculturalist, 114(3):197-206, July-Sept.

One season's results of runoff and soil loss on 60' x 12' plots on 5% grade in Ceylon. Soil losses were as high as 80 kilograms and runoff 3.7 inches from one day's storm of 5.4". Intensity was 3.5 in/hr for 70 minutes.

F Allis, J. A. and Kelly, L. L. (1958). "Runoff from Small Watersheds", Soil Conservation, March, pp. 164-166.

Good runoff figures for meadow, pasture, corn and wheat; at popular level. (Average annual peak rates of runoff from four-acre cultivated watersheds at Hastings, Nebraska; inches per hour are given).

F Anderson, H. W. (1950). "Flood Frequencies and Sedimentation from Forest Watersheds (with discussions)", AGU Tr., Vol. 30, pp. 567-586, 1949, Vol. 31, 621-623, 1950.

A multi-watershed, multi-storm, multi-variable approach was used to develop a hydrologic basis for evaluating flood control in southern California. Twenty-nine watersheds ranging in size from 1.2 s.m. to 214 s.m. were studied on the south-facing slopes of the San Gabriel and San Bernardino Mts. of southern California. They possessed (1) steep topography (2) highly fractured igneous and metamorphic rocks (3) shallow coarse textured soil and (4) vegetation which varied from thin chamise and sage to mixed chaparral and conifers.

Flood peaks are related to: (1) watershed areas, (2) two storm precipitation variables, (3) temperature index of snow, (4) watershed wetness, (5) forest cover conditions. Sedimentation is also discussed.

Schiff points out some weaknesses in the analysis and variables chosen.

BFG Anderson, D. V. and Bruce, J. P. (1958). "The Storm and Floods of October 1954 in Southern Ontario", Extrait des Comptes Rendus et Rapports -- Assemblee Generale de Toronto, 1957. Tome III, pp. 331-341, Gentbrugge, 1958.

A brief review is given of the Oct. 14-16, 1954 storm which produced the greatest 6- to 48-hour rainfalls on record. The meteorological events and field survey procedure are described. Precipitation data are presented on maps and a depth-area analysis, which shows how much higher the bucket survey results were to that of official observations only. Stream flow estimates were made for the composite watersheds, which ranged in size from 49 to 342 square miles. Peak discharges varied from 42 to 263 c.s.m., and percentage runoff volumes from 38 to 71.

S Andrews, R. G. (1957). "Aids for Determining Runoff Probability", Ag. Eng., Vol. 38, No. 3, March 1957, pp. 164-167.

Very clear exposition of five statistical methods used in return frequency analysis.

Q Andrews, R. G. (1959). "Hydrology in Soil and Water Conservation", Soil Conservation, 25(2):36-39, Sept. 1959; 24(ii):239-242; (12):268-270; 25(i):15-17, June-Aug. 1959.

Non-technical articles explaining the duties, responsibilities and methods of service hydrologists.

FB ASCE, Committee on Floods. (1953). "Review of Flood Frequency Methods", ASCE Tr., Vol. 118, pp. 1220-1230, 1953.

Summarizes the available methods of predicting flood frequencies. It considers the factors affecting the accuracy of their predictions and gives the various approaches inherent limitations.

AR Azar, E. and Cardwell, D. W. (1943). "Run-off from Small Agricultural Areas of Dunmore Silt Loam and Related Soils in the Limestone Valleys and Upland Section in the Southeast", Va. Agr. Exp. Sta. Tech. Bul. 90, 20 pp., Nov. 1943.

Studies on rates of rainfall and runoff made at Blacksburg, Virginia, on a 1/5 acre plot and watersheds 5.4 acres and 19.3 acres. Very good soils map with 2 ft contours and all other pertinent data. Tables of total rain and runoff for months and individual storms. Hydrograph and hyetographs of 8 major storms. "Attempts at application of the rational formula showed wide variations in possible time of concentration of the watersheds on different dates". Determination of the runoff coefficients showed considerable inconsistency and lack of agreement with the following values, which are usually employed in designs locally:

Corn Lands,	C = 0.75
Wheat Lands,	C = 0.40
Hay Lands,	C = 0.25

"The limestone soils, when dry seem to be capable of absorbing fairly high rates of rainfall. When wet, however, they can become almost impermeable". "Since so many rains fall on relatively dry soil during a season, the total volume of runoff may be quite low when compared to other localities. More than likely, however, there will be one or more high intensity rains that will cause instantaneous rates of runoff to reach quite high values". Measurements are being conducted on the watersheds which have since been contour-cultivated and strip cropped. Prevailing slopes range from 3% to 13%.

DA Baird, R. W. and Potter, W. D. (1950). "Rates and Amounts of Runoff for the Blacklands of Texas", USDA Tech. Bul. No. 1022, July 1950.

Results applicable to the Blacklands of Texas, Arkansas and Oklahoma as shown on map. Long, hot summers and short, relatively mild winters. Av. annual rainfall 35 to 40 inches. Short storms of high intensities are common. Rainfall distributed evenly throughout 12 months. Cotton primary cash crop, grain, badly eroded land abandoned to weeds and Johnson grass. $31\frac{1}{2}^{\circ}$ N.

latitude, 450-600 ft elevation. Twenty-three watersheds ranging in size from 2.7 to 5,860 acres. Ave. slopes from 1% to 4%. Percent cultivated from 75 to 100. Deep soils of the Houston series and have typical shrinkage cracks when dry. Differences in rainfall in different parts of the Blacklands result in different peak rates of runoff. To compensate for these rainfall differences it is necessary to make appropriate adjustments in runoff values according to ratios plotted on a map. Probability studies were made of the maximum annual flood peaks for the 23 experimental watersheds as well as for six large USGS watersheds. Flood peaks were corrected to what they would have been if the rainfall at each watershed during the period of runoff record had been a good sample of a long-term rainfall record at Waco. Least squares relations were obtained for the corrected peak rate of runoff for a recurrence interval of 10 years with watershed area ranging from 1 acre to 1,000 acres. The reduced peaks for small areas is attributed to: (1) small watersheds do not have well-defined drainage channels and that a considerable proportion of the watershed is made up of flat slopes. (2) For small watersheds with T.O.C. 5 to 15 minutes the rainfall excess lost to soil cracks has an appreciable effect on the magnitude of flood peaks, up to about 150 acres. Table provided of flood peak design values for 2, 5, 10, 25 and 50 yrs. for 2 to 10,000 acres. Coeffts. used with 10 yr. value are: 2-yr. .47; 5-yr. .785; 25-yr. 1.27; 50 yr. 1.47. Over a three-year study, an almost constant reduction of 0.48 inches per hour for three watersheds less than 360 acres. Graphs of % reduction for greater return periods is given.

BU Barnes, B. S. (1959). "Consistency in unitgraphs: Bibliog." ASCE Proc. 85, HY8, No. 2128:39-61, Aug. 1959.

The successful application of the unitgraph requires both experience and judgment. This paper undertakes a reappraisal of certain common assumptions and presents a rapid and positive arithmetical method of deriving unitgraphs from compound hydrographs. The need for more study of lag relationships is demonstrated.

P Barnett, A. P. (1958). "How Intense Rainfall Affects Runoff and Soil Erosion". Ag. Eng., Vol. 39, No. 11, pp. 703-707, Nov. 1958.

An attempt to correlate erosion damage from a given storm to rainfall data so that Weather Bureau and soils data could be used to outline the geographic distribution of erosion. Thirteen items of the literature are reviewed. Results from plots at the Southern Piedmont Conservation Experiment Station, Watkinsville, Georgia for 13 years are analyzed on a single storm basis. Multiple correlation analysis were used to determine the degree of relationship between erosion and the following: T.O.C.; Duration of storm; Amount of storm rainfall; Max. rainfall intensity for 5, 15, 30 and 60 minutes; antecedent soil moisture based on API; runoff. No single rainfall characteristic or combination was found which would serve to adequately predict the expected erosion from a given storm for the conditions studied. Max. 60-min. rainfall intensity was most closely related to erosion (r = 0.769). The average annual erosion measured was 20.5 tons/acre while the estimate was 29.34.

T Bartel, M. J. (1949). "The Relation of Runoff to Precipitation in the Sierra Nevada, California". AGU Tr., Vol. 30, No. 1, pp. 89-97, Feb. 1949.

A method is presented for estimating the amount of delayed runoff due to accumulated snow on a drainage area.

BA Benson, M. A. (1959). "Channel-Slope Factor in Flood-Frequency Analysis", ASCE Proc., J. Hydr. Div., Vol. 85, No. 4, Paper 1994, 9 pp., 1959.

Peak discharge records of 170 gaging stations in New England having at least 10 years record were analyzed. The areas ranged from 1.64 to 9,661 sq. m., three being less than 10 s.m., 31 less than 50 s.m. Relations were analyzed by graphical multiple-correlation combined with rank-correlation methods. The following parameters were studied: (1) Drainage area, (2) Four slope factors, (3) Five water-supply indices, (4) Three shape factors, (5) Mean elevation, (6) % of lakes, swamps and reservoirs, (7) Stream density, (8) Temperature. The main channel slope was found next in importance to drainage-area size. The slope for that part of the main channel between 85% and 10% of the total distance above the gaging point provides the best correlation with flood magnitudes.

F Berndt, H. W. (1960). "Precipitation and Streamflow of a Colorado Front Range Watershed", Rocky Mountain Forest and Range Exp. Sta., USFS, Stat. P. No. 47, 14 pp., March 1960.

Presents information obtained during 1940-58 from the 7.2 sq. mile ponderosa pine watershed (and its subsections) of Missouri Gulch at the Manitou Experimental Forest. Total annual precipitation averaged 18.2". Stony sandy loam. Series of annual peak flows are given, the highest being 16.1 c.s.m. Twelve of these 18 were recorded in May, within three weeks after instantaneous spring peak. A typical storm hydrograph is presented together with the intensity record (almost 5"/hr.) of the 20 minute rain (centered on the lower part of the watershed) which caused it. Peak runoff came 20 minutes after storm peak and 1.2% of rainfall appeared as runoff.

Bernard, M. (1944). "Primary Role of Meteorology in Flood Flow Estimating", ASCE Tr., Vol. 109, pp. 311-351, and 30 pages of discussion by ten authorities, 1944.

Precipitation data from 350 storms were analyzed. The principal meteorologic elements are defined. The distribution of moisture in the atmosphere and the dynamic action between air masses are discussed with regard to "possible maximum storm".

BA Bertle, F.A. (1955). "Flood Frequency Studies of Some Colorado Streams", M.S. Thesis, C. U., 1955.

N Bertoni, J., Larson, W. E. and Shrader, W. D. (1958). "Determination of infiltration rates on the Marshall silt loam from runoff and rainfall records", Soil Sc. Soc. Am. Proc. 22(6):571-574, Nov./Dec. 1958.

Describes calculation of infiltration equation from three plots from hydrograph and hyetographs were available for over 20 years at Shenandoah, Iowa. There was great variation between storms and seasons of the year.

BA Bigwood, B. L. and Thomas, M. P. (1955). "A flood flow formula for Connecticut", USGS Circular 365, 16 pp., 1955.

Records of 10 to 40 years length were studied for 44 watersheds having contributing areas mostly from 4 to 400 sq. m. and a max. of 1,386 sq. m. A method is developed by which the flood for any particular recurrence period is expressed as a ratio to the mean annual flood, according to a given graph. The mean annual flood is related to the product "effective drainage area x basin slope" for either of three straight line log-log relations - one for urban residential, one for normal, and one for a channel storage condition.

S Brakensick, D. L. (1957). "Estimation of Surface Runoff Volumes from Agricultural Watersheds by Infiltration Theory", Iowa St. College J. Sci. 31:364-365, 1957.

This is an abstract of a doctoral thesis submitted in Dec. 1955.

U Brater, E. F. (1939). "The unit hydrograph principle applied to small watersheds", ASCE Proc., Vol. 65, pp. 1191-1215, 1939.

Data from watersheds in the high rainfall belt of the southern Appalachians were analyzed and showed that the unit hydrograph could be applied to small streams. Areas ranged from 4.2 to 1,876.7 acres; 8 were from Bent Creek, 10 from Coweeta and 6 from Copper Basin. The unit hydrograph method of estimating peak discharge possesses numerous advantages. The following outline is for applying the method to small watersheds: (1) complete knowledge of size, shape, topography, soil and vegetation type. (2)(a) Study the physical characteristics of these watersheds in relation to the shapes of their distribution graphs. (b) Determine range of variation of runoff coefficients. (3) Determine max. storm that has occurred in the region and transpose this rainfall upon the watershed and compute the volume of water applied to the watershed. (4) A portion of this volume will appear as surface runoff. Hydrograph may now be constructed.

U Brater, E. F. (1940). "The Unit Hydrograph Principle Applied to Small Watersheds", ASCE Tr., Vol. 105, pp. 1154-1192, 1940.

Unit hydrograph and hyetographs from 22 watersheds in the Appalachians, ranging in size from 4.2 to 1,876.7 acres, showed that: (1) Unit hydrographs are produced on small watersheds. (2) Duration of rain must be less than or equal to period of rise. (3) Period of rise is a function of watershed characteristics and is the time required for the major portion of the watershed to release its accumulated rainfall load. (4) There is a definite correlation between the shape of the distribution graphs and the watershed characterisitcs. (5) "The unit hydrograph principle provides a fundamentally sound method of predicting surface run-off".

D Bruce, J. P. (1959). "Rainfall Intensity-Duration-Frequency Maps for Canada", Meteorological Branch - Dept. of Transport - Canada, Circular 3243, Tec. 308, 9 pp. plus 18 maps and charts, 28 August 1959.

Very brief discussion of method of producing maps of the 5-, 10-, 15-, 30- and 60-minute rainfall maxima expected to recur within 5-, 10- and 25-years. British Columbia and southwestern Alberta are not covered by the maps. Gumbel plots for their stations at Vancouver and Victoria are, however, provided. Recording raingage data was from nine stations with an average record length of twenty two years. Eighty-five stations, with records ranging from 14 to 19 years, were available where six hourly rain amounts had been observed for synoptic observations. A Gumbel analysis was applied to these and six-hour maps were drawn. The six-hour rainfall was correlated to that of shorter duration, so that the short-duration maps could be drawn. Some U. S. Weather Bureau results were also employed to provide more points on the maps and for comparison.

DFR Bruce, J. P. and Bartlett, G. S. (1958). "Design of Spillways for Farm Ponds in Southern Ontario", Ontario Department of Planning and Development, 16 pp., March 1958.

Guide for use of field officers on the rational method. It includes tables of C, discharge from pipes, spillways, etc.; and graphs for determining time of concentration and rainfall intensity for Toronto.

RC California, Div. of Highways, (1955). "California Culvert Practice", reprint of a series of technical abstracts from California Highways and Public Works, 2nd edition, 119 pp., after July 1955.

Very good nomogram for T. of C. and rational method,

$$T = \left(\frac{11.9\ L^3}{H}\right)^{.385} \qquad i = 18.2\ (6.02T)^{.17\ \log_e \left(\frac{P_{60}}{18.2}\right)}$$

is presented. Remaining 100 pages concern constructional details.

R Cardwell, D. W. (1940). "Runoff from Small Agricultural Watersheds". Ag. Eng., Vol. 21, No. 12, pp. 479-482, 1940.

Discussion of two years data from seven watersheds ranging in size from $13\frac{1}{2}$ to 59 acres, in Virginia and Georgia. Tremendous variation in C shows that much other work, particularly infiltration approach needs to be studied.

O Carmichel, E. F. (1959). "A Method for Determining Detention Storage for Floodwater Retarding Structures", Paper No. 59-717, presented at Winter Meeting ASAE, 17 pp., 1959.

Map giving 25 yr. runoff volumes for southeastern states. Tables and graphs for hydrograph and reservoir routing explained in method.

AF Chen, M. C. (1960). "Effect of Watershed Characteristics on Peak Rates of Runoff in Eastern Colorado", M. S. Thesis, Colorado State University, Fort Collins, 94 pp., 1960.

A Gumbel analysis of peak flows from thirteen watersheds, ranging in size between 14 and 1125 square miles, is the basis of analyzing the ten year return flood. Multiple correlations are established graphically between this Q_{10} and (1) watershed area, (2) total channel length, (3) soil index, (4) location parameter and (5) precipitation parameter.

F Chow, V. T. (1955). "Hydrologic Studies of Urban Watersheds; Rainfall and Runoff of Boneyard Creek Champaign-Urbana, Illinois", mimeographed Civil Eng. Studies, Hydraulic Engineering Series No. 2, 66 pp., reissued Nov. 1955.

Nine and one-half sq. miles with population of 62,397. Items considered in detail are: frequency of rainfall intensity, areal distribution of storm, hydrograph analysis and consumptive use of water.

Clark, R. A. (1958). "Design Storm Values for the Area West of the 105th Meridian", paper presented at the 166th National Meeting of the American Meteorological Society, Logan, Utah, 13 pp., June 1958.

Generalized maps of the six-hour point rainfall are based on about 200 design storms. Time- and areal- distributions are presented. Moderate frequency storm values are also derived (reprint obtainable from Hydrology Branch, Division of Project Investigations, Bureau of Reclamation, Denver, Colorado).

UB Commons, G. C. (1942). "Flood Hydrographs", Civil Eng., Vol. 12, pp. 571, 572, 1942.

Presents his hydrograph which was developed primarily from Texas, but fits floods from Connecticut, New York, Pennsylvania, etc. equally well. Shows an example of 356 sq. miles which it fits well.

N Cook, H. L. (1946). "The Infiltration Approach to the Calculation of Surface Runoff", AGU Tr., Vol. 27, pp. 726-747, Oct. 1946.

A very good report on the state of knowledge and needs with clarification of definitions and concepts. He sums up with the following important points: (1) The infiltration approach, while a very useful tool, is still young. (2) Only surface runoff may be determined by the use of infiltration data. Conversely, infiltration data cannot be derived from measurements of runoff containing subsurface flow. (3) Runoff must be separately calculated for each complex and these values summed to obtain the runoff from a multi-complex area. (4) The only rational way to calculate the runoff from a single complex is by the use of infiltration curves. (5) Three kinds of infiltration curves: a) Those showing the variation of the actual infiltration rate through a rain, b) those showing the variation of infiltration capacity with time, c) standard infiltration-capacity curves. (6) The infiltration data should be accompanied by a full description of the procedure used in their derivation.

C Cooper, A. W. and Neal, J. H. (1942). "A Method of Determining the Velocity of Runoff Water", Ag. Eng., Vol. 23, pp. 385-387, Dec. 1952.

Laboratory experiments to determine velocity of overland flow.

LF Cox, M. B. (1956). "Rainfall-Runoff Relations on Wheatland", Ag. Eng., Vol. 37, No. 2, pp. 117-119, Feb. 1956.

Rate of rainfall and runoff data for 13 years from a 7.8 acre watershed of 1½% slope in deep permeable soil planted to wheat are studied, at Cherokee, Oklahoma. Average annual precipitation equals 25.3". A graph of rainfall intensity expectancy shows that the 5-min. values are about 18% greater during the spring than during the fall. Yet the seasonal peak rates of runoff are reversed. 4.6 cfs/ac. and 3.1 for the 25 year fall and spring season rates respectively.

Q Craddock, G. W. and Pearse, C. K. (1938). "Surface Run-off and Erosion on Granitic Mountain Soils of Idaho as Influenced by Range Cover, Soil Disturbance, Slope and Precipitation Intensity", USDA Circular No. 482, 24 pp. August.

Qualitative description of the range types, soils and rainfall intensities of the region and their expected effects on runoff and erosion. Portable infiltrometer experiments on 30% and 40% slopes are described and tables are given of (1) runoff as % of applied rainfall and (2) tons eroded per acre. A four page appendix describes the apparatus.

NUFB Creager, W. P., Justin, J. D. and Hinds, J. (1945). "Engineering for Dams", VI. pp. 99-205 of 245 pp.; John Wiley & Son, Inc., New York, 1945.

One thousand unusual flood peaks for U.S.A. and foreign rivers are listed. These are plotted in terms of q, the flood in cfs, vs. drainage area in square miles, A. Creager's equation

$$q = 46\ CA^{(0.894A^{-.048}-1)}$$

is shown to be the upper envelope with C = 100, the lower with C = 30 and average for C = 60. Discussion continues to include: physical characteristics, flood frequency studies, flood hydrographs and infiltration techniques.

F Crow, F. R. (1955). "Runoff Studies in the Reddish Prairie Grasslands of Oklahoma", mimeographed paper from Okla. State Univ., Librarian, of paper presented at Winter Meeting of ASAE at Chicago, Dec. 1955. Approved as Journal Manuscript No. 246, of Okla. Ag. Exp. Sta., Stillwater.

This reports data from a four-year study of three culverts gauged below three small watersheds on native grassland 15 miles north of Stillwater. The total annual and minimum runoff were studied as well as the way they were affected by ponds. The third section deals with peak rates of runoff. The two major storms, which occurred after the watershed were saturated, were as follows:

	Precipitation Amount inches	Precipitation 30-minute intensity in./hour	Runoff Rate Inches per Hour		
Acres			16.7	92	206
1st Storm	4.20	4.00	5.29	4.74	1.67
2nd Storm	2.63	2.28	3.03	2.35	1.39

Pondage corrections made a significant difference to both magnitude and timing of peak. Hyetograph and hydrographs together with other graphs are presented.

LFO Dils, R. E. (1953). "Influence of forest cutting and mountain farming on some vegetation, surface soil and surface runoff characteristics", USDA Southeastern Forest Exp. Sta. North Carolina, Station Paper No. 24, June 1953.

Volume, peak rate, unit hydrograph of floods of a 23 acre watershed are presented.

C Donovan, D. E. (1945). "Chart for drainage calculations", Eng. News Rec., Vol. 135, pp. 106-107, Aug. 23, 1945.

The rational formula is amended to $Q = rA$ where $r = i-a$, a being the intensity required to establish runoff (author admits values of a are unknown and suggests very small values be used until exptl. data is available). These two and Manning's eqn., with an averaging of velocity, thus far, to v give

$$t = 0.146 \frac{n^{0.6} d}{S^{0.3} r^{0.4} B^{0.4}}$$

A graphical solution is provided for this.

N Dortignac, E. J. and Love, L. D. (1960). "Relation of Plant Cover to Infiltration and Erosion in Ponderosa Pine Forests of Colorado", ASAE Tr., Vol. 3, No. 1, pp. 58-61, 1960.

Results of 750 tests made with the Rocky Mountain infiltrometer at the Manitou Experimental Forest are summarized. Histograms and table show the differences in infiltration rate (fc) between the alluvial and residual soils (of granitic origin) and cover types of grassland, pine-grass and pine-litter. The total soil loss during a field test or during a rainstorm is directly dependent upon and related to that portion of the applied or natural rainfall that exceeds the infiltration rate of the soil. Infiltration rates increased 1.31 and 1.01 in/hr. in grassland and in pine-grass after 14 years of protection from grazing. Infiltration and erosion indices measured with infiltrometer compared well with those from runoff plots.

ML Drake, R. R., Michael, S. A. and Baum, R. O. (1940). "Hydrologic Studies - Compilation of Rainfall and Runoff from the Watersheds and Terraced Areas of the Fort Hays Cons. Exp. Sta., Hays, Kansas, '30-'38". SCS-TP - 37, 15 pp. (mimeographed) 1940.

Description, topographic maps and photographs of the seven watersheds with areas ranging in size from 0.87 ac. to 2.95 ac. Tables of storm data with hydrographs and hyetographs. (Probably over 100 pages of data are appended).

T Dunford, E. G. (1949). "Relation of grazing to runoff and erosion on bunchgrass ranges", Rocky Mountain Forest & Range Exp. Sta. Research Note No. 7, 2 pp., 1949.

Very brief with three before grazing and after grazing histograms for both runoff and erosion during the period June to September. The former is altered from 0.16 inches for this season ungrazed to 0.52 inches with heavy grazing.

TP Dunford, E. G. (1954). "Surface Runoff and Erosion from Pine Grasslands of the Colorado Front Range", Jour. of Forestry, Vol. 52, No. 11, pp. 923-927, Dec. 1954.

Six 1/100 ac. plots in bunchgrass were used to check total runoff and erosion from heavy, moderate and no grazing. Effects of removing litter and trees from a Ponderosa pine stand was similarly studied.

LF Edminster, T. W. and Lillard, J. H. (1948). "Rates of Runoff in the Ridges and Valleys of Virginia", SCS-TP - 67, May 1948.

Deals with rates of runoff only. Seven years for 5.4 and 19.3 acres, 5 years from 14 acres and 3 years from 6.1 acres data were available at Blacksburg, Va.; Washington County; and Lee County. Slopes ranged from 3 to 13%. Presents curves of rate of runoff from 4 to 100 acres for "straight row" and contour cultivation; as well as for pasture and mixed cover; for 10 year freq. with various conversion factors for 25-year design. Map is given of Blacksburg's permanent features.

U Edson, C. G. (1951). "Parameters for Relating Unit Hydrographs to Watershed Characteristics", AGU Tr., Vol. 32, No. 4, pp. 591-6, Aug. 1951.

It is suggested that the physical characteristics of a watershed exert two simultaneous and distinct influences upon the resultant hydrograph: one, whereby the runoff is brought to the valley; the other, in getting the runoff through the month. The empirical equation $Q = BT^x e^{-yT}$ for the unit hydrograph is discussed mathematically.

R Exum, J. P. (1951). "Waterway areas for culverts and bridges", Ohio State Univ., Eng. Exp. Sta. Bul. 145, pp. 61-63, Sept. 1951.

Discussion of rational method for estimating flood flows after disposing of the Talbot's formula,

$$a = C \sqrt[4]{A^3}$$

where A is in acres. A recent survey showed that 35 state highway departments were making some use of Talbot's formula. This formula gives an area in square feet.

Federal Inter-Agency River Basin Committee, Sub-Committee on Hydrology. (1948). "Instructions for Compilation of Unit Hydrograph Data", Bul. No. 1, distributed with the minutes of the 28th meeting, April 1948.

Presents recommendations of the sub-committee on Hydrology as to the content and form of unit hydrograph compilations with the intent of systematizing the procedures and facilitating the exchange of data among government agencies.

QF Fletcher, H. C. and Rich, L. R. (1955). "Classifying Southwestern Watersheds on the Basis of Water Yields", Jour. of Forestry, pp. 196-202, March 1955.

Results from Sierra Ancha Exp. Watershed, 40 m. N. of Globe, Ariz., are discussed. Time of water yield is related to precipitation distribution of the 700 acre Parker Creek. Periods of water use by plants and loss by evaporation are illustrated by good monthly-charts. Flood potentials and sediment are factors that should be considered in the Southwest. "The logical use for summer precipitation is to supply the needs of a protective plant cover to control erosion. This should not interfere with water yield ..."

PD Foster, E. E. (1948). "Rainfall and Runoff", Macmillan, N.Y. 487 pp., 1948.

Chapter 9 deals with runoff; first total annual and then infiltration and the unit hydrograph. Horton's formula for runoff from small plots is given, viz.

$$q_s = \sigma \tanh^2 0.922\, t \left(\frac{\sigma}{nL}\right)^{\frac{1}{2}} S^{\frac{1}{4}}$$

where S = slope, σ = the supply which is the effective rainfall, L = length of elemental slope, t = time in minutes and n = a roughness factor given by Hathaway as follows:

Smooth pavements	.02
Bare packed soil, no stones	.10
Poor grass cover or rough bare surface	.20
Average grass cover	.40
Dense grass cover	.80

D Frevert, R. K., Schwab, G. O., Edminster, T. W. and Barnes, K. K. (1955). "Soil and Water Conservation Engineering", John Wiley & Son, N. Y., 479 pp., 1955.

Regarding the estimation of design runoff rates this book gives ten pages. Rational formula is discussed with a table of C values based on various land use and three soil types. A graph gives

$$Tc = 0.0078 \left(\sqrt{\frac{L^3}{H}}\right)^{0.77}$$

Cook's method is presented, Q = PRF, where F is the frequency factor 1.2 or 1.4 relating the 25- or 50-year value to the 10-year Q. A table presents W values for the factors of relief, soil infiltration, vegetal cover and surface storage ranging from extreme to low degrees. According to the value of $\sum W$ a certain one of a family of curves relate runoff R, in cfs, to drainage area. A map of the USA presents a correction factor for the precipitation variation, P. A simplified method of determining the volume runoff based on a linear rate of infiltration and Hathaway's (1945) mass rainfall curve, is presented. A basic hydrograph is presented.

I Gleason, C. H. (1958). "Watershed Management: An Annotated Bibliography of Erosion, Streamflow and Water Yield Publications by the Calif. Forest & Range Exp. Sta.", USFS, Calif. Forest & Range Exp. Sta., TP 23, 79 pp. Jan. 1958.

Includes photographs of some research installations.

R Gregory, R. L. and Arnold, C. E. (1932). "Run-off--Rational Run-off Formulas", ASCE Tr., Vol. 96, pp. 1038-1177, 1932.

Very good particularly for urban areas. Includes discussion by: Sherman, Bates, Raymond, Ryves, Tapley, Hicks, Kemmerer, Longacre, Hickox, Baker, Arledge, Jarvis, Grunsky, Powell, Bernard, Lee.

DF Greve, F. W. (1943). "Bridge and culvert flow areas", Civil Eng., Vol. 13, pp. 381-382, Aug. 1943.

Discusses current practice in determining flood peaks: (1) Comparison with similar gauged watershed. (2) If stream is at all times confined within its banks then the cross-sectional area of waterway can be multiplied by velocity (assumed to be 10 feet/sec.). (3) Q = CRD, where C = variable coefficient, R = total rainfall in inches, D = area in square miles: no good. Talbot's formula is based on data collected from areas of less than 50,000 acres in the Mississippi Valley. Myer's formula applied to a watershed of 100 acres gives a peak 2.5 times that of Tidewater equation. For 100,000 acres, the maximum runoff calculated with the Peck formula was 8.5, 15 and 53 times, respectively, that computed by the Tidewater, Talbot and Myer eqn. (4) Rational method, Q = CIA. Usually surface flow on lateral slopes will move with a velocity of from 0.5 to 1 mile/hour. C is from .5 to .75 sometimes higher, recommends using 1. (5) Current meter measurements. (6) Weir discharge. Up until a decade age many engineers used 600 C.S.M. for central section of Mississippi V. Now commonly use 2,000 to 2,500 C.S.M. for small watersheds. Suggests using short-pipe eqn. for culvert discharge.

DF Greve, F. W. (1943). "Bridge and Culvert Flow Areas", Purdue Univ. Eng. Bul., Vol. 27, No. 2, pp. 135-151, 1943.

Same material as is presented in Aug. 1943 issue of Civil Engineering. Empirical formulae are discussed. It is conceded that the hydrologists' approach of rainfall and infiltration, etc. is fundamentally sounder, but it is shown that the application of these methods in practice require the assumption of many unknowns.

D Hamilton, C. L. and Jepson, H. C. (1940). "Stock-water Developments", USDA, Farmers Bul. No. 1859, 70 pp., 1940.

Useful booklet containing many illustrations and tips on stock watering developments and farm ponds. A family of curves relates peak discharges to drainage area from 1 to 10,000 acres.

A map relates these by a coefficient to other part of the USA. Values were based on H. L. Cook's unpublished method of the SCS and are considered to have a 25 year freq. for 10 year reduce by 15%; for 50 year increase by 20%.

ML Harrold, L. L. (1944). "Hydrological Studies - Compilation of Rainfall and Runoff from Terraces C5, C6 and C7 and Watersheds C8 and W 26 of the Central Piedmont Soil and Water Cons. Sta., Stateville, N. C., 1933-38", SCS-TP - 52, 91 pp., (mimeographed), 1944.

Areas are 1.41, 1.63, 1.80, 5.12 and 6.01 acres resp. Description of physiography and land use. Tables of single storms and their runoff. Over 100 hydrographs and hyetographs. No discussion of results.

QB Harrold, L. L. (1949). "Has the Small-Area Flood been Neglected?" Civil Eng., Vol. 19, No. 10, pp. 38-39, Oct. 1949.

Floods should be separated into two distinct classes: the large area flood which is a winter menace to metropolitan centers on large rivers; and the small area flood which is a summer menace to crop land and causes the bulk of erosion and reservoir sedimentation. Histograms of frequency and magnitude of monthly occurrence of floods by sizes from 7.2 s.m. to 76,580 s.m. in Ohio.

D Harrold, L. L., Krimgold, D. B. and Westby, L. A. (1944). "Preliminary Report on Watershed Studies Near Waco and Garland, Texas: Rates and Amounts of Runoff and Related Information for the Hydrologic Design of Conservation Practices and Structures in the Blacklands of Texas", USDA, SCS-TP - 53, 22 pp., April 1944.

Two or three years results from 18 natural watersheds ranging in size from 20 to 5,900 acres were analyzed to give these tentative design criteria. Tables and graphs present 2-, 5-, 10- and 25-year values for rates of runoff from catchments ranging from 5 acres to 2,000 acres. Annual runoff, evaporation, seepage and silting conditions affecting small ponds are described. Design procedures and examples are given.

D Hathaway, G. A. (1945). "Design of Drainage Facilities", ASCE Tr., Vol. 110, pp. 697-730, 1945.

A procedure is outlined for the design of airfield drainage facilities utilizing surface pondage for temporary storage of

runoff from high intensity storms of short duration. Standard rainfall intensity-duration curves are presented. Horton's overland flow equations for paved and turfed areas are used.

DQ Hauger, R. L. (1947). "Drainage surveys in Texas Gulf Coast area", Ag. Eng., Vol. 28, pp. 18-21, Jan. 1947.

What has been done since the SCS started work in the 5,000,000 acres along the Texas Gulf Coast. Future plans are also outlined. Accepted curves of discharge per sq. mile against watershed area are given for various forms of land use, without any derivation.

PT Hays, O. E. (1955). "Factors Influencing Run-off", Ag. Eng., Vol. 36, No. 11, pp. 732-735, Nov. 1955.

Mainly concerned with total amounts of runoff. Yearly and monthly amounts are given for various cropping practices at La Crosse, Wis. One table gives the highest storm runoff for each month during the period 1942-1952 from grain. Figures are included for four other plots as also the total storm amount, the 5-, 30- and 60-minute intensities corresponding.

CR Herner, R. C., Mainfort, R. C. and Pharr, R. L. (1950). "Use of the rational formula in airport drainage", U.S. Civ. Aero. Adm. Tech. Dev. Rep. 131, Indianapolis, Ind., 54 pp., Dec. 1950.

Two years data of rates of rainfall and runoff from partially paved airport surfaces at Rome, Georgia are presented. Six other areas tested by the Army at Lockbourne, Freeman, Godman and Saint Anne brought up the number of watersheds to nine. These were located in similar geographic and soil areas. Hyetograph and hydrographs are presented. The validity of the rational formula is tested and found to be satisfactory. Recommended runoff coefficients are given for use under specified conditions (including API), and empirical methods of estimating ponding requirements are developed.

Some conclusions: (1) Runoff coefficients commonly used are generally too low. (2) Great economies can be affected by providing even a limited amount of ponding, using temporary channel or pipe storage, or allowing temporary overflow.

FU Hertzler, R. A. "Engineering aspects of the influence of forests on mountain streams", Civil Eng., 9:487-489. 1939.

Good: Objectives and methods of studying the hydrologic effect of forests at the Appalachian Forest Exp. Sta. near Ashville, N. C. are described. Photo's of 120° V-notch installation with stilling basin, San Dimas Flume, and a modified Columbus Type 1-A Deep Notch control. A graph presents the frequency distribution of peaks on small watersheds with various types of cover and is based on 1,550 individual hydrographs on 21 watersheds of 4 to 1,859 acres in the southern Appalachians. It shows, for example, that taking runoff from forested lands as unity, for 10% freq. of all the storms over $\frac{1}{2}$", abandoned farmland, overgrazed pasture and denuded lands produce peak discharges respectively 12, 24 and 47 times as great as forest land. Six month summaries of stream flow are also given. Hydrograph analysis of infiltration is discussed with an example hydrograph. Analysis of 2 to 6 unit-graphs for each of 22 drainages revealed correlations between the shape of the distribution-graph and physical characteristics of the watershed: (1) For forested areas peak % of runoff consistently decreases as A increases. (2) Width of base increases with area. (3) Effect of vegetated cover is reflected in peak % and width. Pluviographs were also studied.

DN Hicks, W. I. (1944). "A Method of Computing Urban Runoff", ASCE, Vol. 109, 1944, pp. 1217-1253.

A good discussion of the infiltration approach to generating the runoff hydrograph. Complete method of prediction developed and compared to measurements from Los Angeles and St. Louis.

CU Hickok, R. B., Keppel, R. V. and Rafferty, B. R. (1959). "Hydrograph Synthesis for Small Arid-Land Watersheds", Ag. Eng., Vol. 40, No. 10, pp. 608-611, 615, Oct. 1959.

Based on hydrograph analysis from 14 watersheds ranging in size from 11 to 790 acres at Albuquerque, Santa Fe, N. M.; Safford, Ariz.; and Colorado Springs.

$$T_L = K_1 \left[\frac{A \cdot 3}{S_a \sqrt{DD}} \right]^{0.61} \quad \text{or} \quad T_L = K_2 \left[\frac{\sqrt{L_{sa} + W_{sa}}}{S_{sa} \sqrt{DD}} \right]^{0.65}$$

T_L = lag time (time from limited block of intense rainfall to peak of hydrograph). A = watershed area in acres, S_a = ave. landslope of watershed %. DD = drainage density (total length of visible channels per unit area). $K_1 = 106$, $K_2 = 23$, L_{sa} from outlet to C. of G. of source area. W_{sa} = width of source area (the half of the area with the highest average land slope).

$$\frac{q_p}{V} = \frac{545}{T_L \text{ minutes}}$$

Table is presented of generalized dimensions of hydrograph and mass curve. Shape of dimension less hydrograph was found to be independent of rainfall pattern and of soil and cover condition.

SL Hobbs, H. W. (1946). "Runoff behaviours of small agricultural watersheds under various land-use practices", AGU Tr., Vol. 27, pp. 69-80, Feb. 1946. (Miscellaneous Publication No. 38, Contribution No. 1974 of the Maryland Agr. Exp. Sta., Dept. of Agronomy).

A graphic method is applied to the study of freq. of recurrence of runoff peaks from short-term records on agricultural watersheds, ranging in size from 3-8 acres.

FL Hobbs, H. W. (1946). "Rates of runoff in the coastal plains of N. J., Delaware and Maryland", SCS-TP - 60, 60 pp., July 1946.

Experimental watersheds were from 3 to 103 acres. Prevailing slopes from 1 to 10%. Ten-year recurrence values for rates of runoff from 2 - 40 acre areas are listed for various catchment conditions. Curves are also presented for areas up to 1,000 acres. The last two thirds of the paper describes how the results were obtained and contains some good general discussion on the factors affecting the magnitude of runoff peaks.

N Holtan, H. N. (1958). "Infiltration Estimates Based on Vegetation and the Soil Profile", reprint of paper presented at Winter Meeting of ASAE, Chicago, 24 pp., Dec. 1958.

Considers that greater accuracy can be maintained by estimating a potential volume of infiltration and subsequently providing a shape to the curve of progress towards this total. The available porosity is not always filled before the rate of infiltration becomes constant. The extent to which available porosity is exhausted appears to be a function of the type of vegetation present. Also $f - f_c = a\,F_p^n$.

LN Holtan & Kirkpatrick. (1950). "Rainfall, Infiltration and Hydraulics of Flow in Runoff Computation", by H. N. Holtan and M. H. Kirkpatrick. AGU Tr., Vol. 31, No. 5, pp. 771-779, 1950.

Infiltration approach analysis by the time-condensation method. Very good for catchments 5 acres to 50 acres. Three experimental watersheds near Chatham, Virginia ranged in size from 13 to 17 acres. Graphs give the volume of detention required to produce various rate runoff from different types of watersheds.

NML Horner, W. W. (1940). "The Analysis of Hydrologic Data for Small Watersheds", SCS-TP - 30, 103 pp., (mimeo.), 1940.

Analysis for hydrographs and hyetographs from watersheds at: Bethany, Miss., La Crosse, Wisc., Pima, Ariz., Globe, Ariz., and Edwardsville, Ill. One was 280 acres, another was five plots, another 27 acres, while the others ranged from $6\frac{1}{2}$ to 2 acres. Very full discussion of methods. These were the basic techniques followed by many later investigations.

RN Horner, W. W. (1944). "The Drainage of Airports", Ill. Univ., Eng. Exp. Sta. Circular 49, 48 pp., Nov. 1944.

Sub-surface drainage. Surface water drainage. An airport drainage system must be adequate to remove surface water from rains occurring on the average once in two years to the extent necessary to prevent pondage on or within 50 feet of runways. Inlet gratings. Uniform intensity-, advanced-, intermediate- and delayed-patterns of rainfall. "A Rational Method of Storm Sewer Design" appeared in Eng. News, Sept. 29, 1910 after a St. Louis City design eng. adapted it in 1907 from its original promulgation in 1887 by Kuichling. After 20 years of sewer gaugings Horner and Flynt (1936) revised the C estimates for urban areas. Discussion of hydrology of surface runoff by means of explicit time curves of rainfall-, and infiltration-rates, etc.

$$C = \frac{K - K'}{K} K'' \sqrt{\frac{A}{S}}$$

where K, K' and K'' are parameters of the equations of the rainfall curve, infiltration curve and hydraulic flow formula, A is the area in acres and S the controlling slope. This illustrates the futility of attempting to find a few values of C that can satisfactorily represent the relations between rainfall and runoff. Engineers have reached the conclusion that there is no simple and royal road to the determination of surface runoff, and that the calculation of fairly representative values of runoff must necessarily involve as much detailed eng. computation as, for example, the stress analysis of a bridge." Designs at: Lambert Field 1929, Washington Natl. Airport 1939, Idlewild Airport. Typical Design Table. Army Fields, Inlet spacing and field shaping.

R Horner, W. W. and Flynt, F. L. (1936). "Relation between Rainfall and Runoff from Urban Area", ASCE Tr., Vol. 101, 1936.

Analysis of rainfall/runoff data from practically all heavy storms in St. Louis, Mo., from 1914 to 1933. Besides these studies the frequency of runoff rates is considered.

N Horner, W. W. and Jens, S. W. (1942). "Surface Runoff Determination from Rainfall without using Coefficients", ASCE Tr., Vol. 107, pp. 1039-1117, 1942.

The recent improvement in hydrologic data with respect to precipitation and streamflow, and information regarding infiltration is described. A method of applying this information to the evaluation of surface runoff from precipitation data without the use of a coefficient is presented.

NB Horton, R. E. (1937). "Determination of Infiltration-Capacity for Large Drainage-Basins", reprint from AGU Tr., Pt. II, pp. 371-385, Eighteenth Annual Meeting, 1937.

Describes a method of determining the average infiltration-capacity over a drainage-basin during large storms where a runoff-record, together with adequate rainfall data are available.

BFQ Hoyt, W. G. (1940). "Current Techniques in Rainfall-Runoff Analysis", Univ. Iowa, Studies in Eng. Bul. 20, pp. 69-80, March 1940.

Discussion of what has been and what still remains to be done in hydrological research. "In many areas the flood problem will not be entirely solved until our citizens recognize that nature designed and formed river channels, valleys and overflow areas for the temporary storage and eventual passage of floodwaters."

UL Hursh, C. R. and Brater, E. E. (1941). "Separating Storm-Hydrographs from Small Drainage-Areas into Surface - and Subsurface - Flow", AGU Tr., Part III, pp. 863, 1941.

Problems and the procedure followed on a 40 acre watershed at Coweeta are considered by way of an example.

NFP Hutchinson, Sir. J., Manning, H. L. and Farbrother, H. G. (1958). "On the characterization of tropical rainstorms in relation to runoff and percolation", Roy. Met. Soc. Q.J. 84(361):250-258, July 1958.

Statistical analysis is made of six years data collected at Namulonge, Uganda, with a Farbrother rainfall rate recorder. Intensities as high as 13 in/hour were recorded. The instrument can be made in a local workshop and was described on page 170 of Vol. 33, Emp. Cotton Growers Rev., 1956. Various relationships were established. Percolation rates were studied for various cover conditions from circular plots of 2% slope and 3 sq. yd. area, to relate these to storm parameters. Results are compared with those from the Ozark Highlands in Arkansas.

F Institution of Civil Engineers. (1959). Report entitled "Design Floods", Water Power, Vol. 11, pp. 344-348, 1959.

Discusses amendments which a sub-committee on Rainfall and Run-off of the Institution's Research Committee proposed to the 1933 Interim Report on "Floods in Relation to Reservoir Practice".

FLD Izzard, C. F. (1954). "Peak discharge for highway drainage design", ASCE Tr., Vol. 119, pp. 1005-1024, 1954.

Maximum floods of record in Kansas showed no well-defined relation to the size of the drainage area because the probable frequencies extend over a wide range. Consequently the design of bridge waterways on the basis of maximum floods alone is a less satisfactory procedure than is the consideration of the probable freq. of a flood. Twenty-five year floods are graphed for areas from 1,000 to 10,000 sq. miles to obtain four regional curves. Peak rates of runoff for watersheds of less than 1,000 acres is also graphed.

FNL Jamison, V. C. and Thornton. (1958). "Water Intake Rates of Shelby-Grundy Soils from Hydrograph Analysis", paper presented to meeting of ASAE, Chicago, 11 pp., Dec. 1958.

Twelve storms analyzed from eight watersheds with areas from 2-8 acres and rolling country of 8% ave. slope, and lengths of 200 to 400 feet. Soil typifies that of N-Central Missouri, S-Central Iowa, S.E. Nebraska and N.E. Kansas. Infiltration-rate vs. time curves given for croplands and pasture for two antecedent moisture conditions. Histograms of intake rate given for terraced pasture and other land use practices.

SFB Jarvis, C. S. (1942). "Floods", in Meinzer, O.E. ed. "Hydrology:Physics of the Earth, Vol. IX", pp. 531-560, New York, Dover Publications, Inc., 1942.

Discusses causes of floods and relation with vegetation by discussing W. R. Thompson's Preteria (S. Africa) annual runoff and erosion totals. He graphed the most reliable flood flow formulae. He concluded the most suitable was the "modified Myers formula" - $Q = 100p \sqrt{M}$ cfs, where M = square miles of drainage area, and p is the numerical percentage rating on the Myers scale - for watersheds larger than nine square miles. Spot values for q are shown on a map of USA, originally presented in "Low Dams". For less than four square miles he recommends the rational method. Other aspects of flood control and hydrographs are discussed verbally. Mention is made of the infiltration approach, aerial distribution of rainfall, etc.

MFB Jarvis, C. S. and others. (1936). "Floods in the United States: Magnitude and Freq.", USGS Water Supply Paper 771, 497 pp., 1936.

Mainly concerns large watersheds. It covers the following subjects: methods of estimating flood flows, with examples; tabulated floods; study of methods applied to Tennessee R.; reliability of statistical methods; hydrologic conditions as affecting the results of the application of methods of frequency analysis; and the unit-hydrograph.

ND Jens, S. W. (1948). "Drainage of airport surfaces - some basic design considerations", ASCE Tr., Vol. 113, pp. 785-836, 1948.

A method is presented for design involving retention, infiltration and overland flow. Peak-reducing pondage is also considered.

N Johnson, H. P. and Howe, J. W. (1956). "Infiltration Frequency on Ralston Creek Watershed", AGU Tr., Vol. 37:5, pp. 593, 594. Oct. 1956.

Indices were derived for 92 selected storms from 29 years of record. The infiltration index was ϕ, defined by Linsley, Kohler and Paulhus (1949, pp. 426-427).

U Keifer, C. J. and Chu, H. H. (1957). "Synthetic storm pattern for drainage design", ASCE Proc., J. Hydr. Div., Paper 1332, Vol. 83, 22 pp., 1957.

As a part of the comprehensive study of the principles involved in the rainfall-runoff relation, Chicago's Sewer Planning Div. developed a synthetic storm pattern, for use in the hydrograph method of design. This storm pattern is developed from the rate-duration curve for a selected frequency. The most important characteristics affecting the peak runoff rate for a specific period of duration are as follows: (1) Volume of water. (2) Amount of antecedent rainfall. (3) Location of peak rainfall intensity. The synthetic rainfall encompasses the statistical average of these; and is shown to produce no greater runoff peaks than that of the rainfalls of the separate durations.

C Kerby, W. S. (1959). "Time of Concentration for Overland Flow", Civil Eng. 29:174, March 1959.

A nomograph is presented to solve G. A. Hathaway's (Trans. ASCE, Vol. 10, pp. 697-730, 1945) formula

$$t^{2.14} = \frac{2Ln}{3\sqrt{s}}$$

where n is as follows:

Type of Surface	Value of n
Smooth impervious surface	0.02
Smooth bare packed soil	0.10
Poor grass, cultivated row crops or moderately rough bare surface	0.20
Pasture or average grass	0.40
Deciduous timberland	0.60
Conifer timberland, deciduous timeberland with deep litter or grass	0.80

Kessler, E. and Atlas, D. (1959). "Model Precipitation Distributions", Aero/Space Eng. 18:36-40D, 1959.

Three cases are considered: I. semi-tropical atmosphere; II. cool atmosphere with moist adiabatic lapse rate; III. during surface snowfall. The steady-state precipitation content of the air is given as a function of updraft and height. The vertical distribution of steady-state precipitation rates is derived from these. Cloud water, which was not considered in the above calculations is discussed. Correlations established between vertical radar reflectivity profiles in the cores of summer thunder storms and ground observations by R. J. Donaldson in "Vertical Profiles of Radar Reflectivity in Thunderstorms", Proc. 7th Weat. Radar Conf.; Am. Meteor. Soc., Boston, Mass., are discussed.

FA Kinnison, H. B. and Colby, B. R. (1945). "Flood Formulas based on drainage-basin characteristics", ASCE Tr., Vol. 110, pp. 849-904, 1945.

Formulas are developed from stream-flow records of Massachusetts streams for which fairly complete data are available. Although a relationship exists between precipitation and peak discharge, a much closer relationship exists between precipitation and volume of runoff which is expressed as depth in inches over the watershed.

DC Kirpich, Z. P. (1940). "Time of Concentration of Small Agricultural Watersheds", Civil Eng., Vol. 10, No. 6, p. 362, 1940.

Agricultural watersheds considered by Ramser (J. of Ag. Res., Vol. 34, 9, 1927) from $1\frac{1}{4}$ to 112 acres are subjected to analysis. Two alternate methods are proposed. The intermediate parameters K_1 and K_2 are equal to $L/\sqrt{S_1}$ and $L/\sqrt{S_2}$ where S_1 = av. fall from farthest point to gauging station, S_2 = av. slope of watershed. The correlation is good. The two graphs are presented for use from one acre to 200 acres.

A Kohler, M. A. and Linsley, R. K. (1951). "Predicting the Runoff from Storm Rainfall", USWB, Res. Paper No. 34, 9 pp., Sept. 1951.

A graphical multiple correlation is developed for the Monocacy River at Jug Bridge, Md. From it the volume of storm runoff can be predicted according to: Antecedent Precipitation Index, Week of Year, Storm Duration and Storm Precipitation.

Krimgold, D. B. and Weber, J. L. (1949). "Pondage Corrections Involved in Measuring Surface Runoff from Small Drainage Basins", SCS-TP - 77, 16 pp., prepared 1939, revised March 1949.

Considers drainage basins less than 2,000 acres. Method is completely described. In cases of rapid rises in stage the pondage corrections may amount to as much as 50% or more of the apparent peaks, that the peaks of surface gauge heights, and that minor peaks of runoff resulting from high rainfall intensities of short duration which do not appear if pondage is neglected.

ANR Krimgold, D. B. (1947). "Rates of Runoff from Small Agricultural Drainage Basins", Ag. Eng., Vol. 28, pp. 25-28, Jan. 1947.

Clear discussion of deficiencies in the rational method. A complete outline of the infiltration approach in layman's terms. Current approach of engineers engaged in applied research is outlined as follows: (1) Application of probability analysis directly to short records of runoff. (2) Testing the short periods of records to determine how closely they represent longer periods with respect to watershed conditions, precipitation, and other factors. (3) Determine the rates of runoff for various expectancies from (1) and (2). (4) Designation of the general physiographic and soil provinces and of specific conditions within them to which the rates of runoff for each area are applicable. (5) Determine the relationship between size of drainage area and peak rates of runoff for each area of application. A typical table and graphs are shown.

AD Krimgold, D. B. and Minshall, N. E. (1945). "Hydrologic Design of Farm Ponds and Rates of Runoff for Design of Conservation Structures in the Claypan Prairies", SCS-TP - 56, 25 pp., May 1945.

Applicable to portions of Indiana, Illinois, Iowa, Missouri, Kansas and Oklahoma. Part I gives design data and worked examples on pond sizes and dependable water supply. Part II gives 25-year values for rates of runoff from catchments ranging in area from five acres to 1800 acres, for either pasture or row-crops. These were based upon the following watershed studies: (1) Six years, Edwardsville, Ill., 12.5, 27, 50 and 290 acres. (2) Five years, Muskogee, Okla., 14,5, 22, 25 and 65 acres. (3) Three years, McCredie, Missouri, 153 acres.

AB Kohnel, J. W. (1949). "A Reference Plane of Flood Volumes in the Sacramento-San Joaquin Basin, California", AGU Tr., Vol. 30:1, pp. 98-115, Feb. 1949.

One hundred forty eight recorded basins ranging in size from 7 to 9300 s.m. were used to develop two sets of graphical multiple correlations involving: (a) basin mean elevation, area in sq. miles, annual runoff in inches to give runoff from summer snow melt in inches for 5, 30, 60 or 120 days; and (b) basin mean elev., area, orientation and annual runoff to give winter rain runoff for 1, 3, 5, 20 or 40 days.

Q Larson, N. G. (1957). "Small watersheds: a selected list of references", USDA Libr. List 63, 16 pp., October 1957.

This bibliography is limited to administrative, legal and economic aspects of watershed development with particular emphasis on the Watershed Protection and Flood Prevention Act, Public Law 566.

N Leatham, Paul and Riesbol, H. S. (1950). "Infiltration and retention tests as related to spillway design floods", AGU Tr., 31:(2) 234-241, April 1950.

Analysis of infiltrometer tests in Colorado and Kansas prove that this approach may be helpful in design of floods from large watersheds.

PN Ligon, J. T. and Johnson, H. P. (1960). "Infiltration Capacities of Fayette Silt Loam from Analysis of Hydrologic Data", ASAE Tr., Vol. 3, No. 1, pp. 36, 37, 1960.

Nine years rainfall- and runoff-rate data from 16% slope, 72.6 ft x 6 ft plots in the Upper Mississippi Valley Station near La Crosse, Wis. were studied. Only summer storms which gave a definite runoff peak were considered (65 individual plot-storms). Seven curves of infiltration capacity vs. time were given for continuous corn for various API's. Results showed the range of individual plot-storm final infiltration rates in inches/hour: continuous corn, .04-.20; corn in rotation, .13-.40; grain, .21-.58; meadow, .14-.93.

Q Lillard, J. H. and Burford, J. B. (1959). "A research technique for hydrology studies on small watersheds", Assoc. South Agr. Workers Proc. 56:54, 1959.

One page description of the concerted effort to collect hydrological data from small watersheds in Virginia by: (1) Establishing 10 selected representative watersheds. (2) Use of highway culverts. (3) Close cooperation of interested agencies. (4) Special emphasis on supporting studies.

DUL Linsley, R. K. (1943). "Application of Synthetic Unit-Graphs in the Western Mountain States", AGU Tr., Vol. 24, Part 2, pp. 580-587, 1943.

Data collected from 18 basins in Central Valley of California, ranging in size from 100 to 3,700 sq. miles were compared to Snyder's unitgraph which he developed in 1938 for the Appalachians. Essential formulae are tabulated for the two regions.

T Linsley, R. K. and Ackerman, W. C. (1942). "Method of Predicting the Runoff from Rainfall", ASCE Tr., Vol. 107, pp. 825-846, 1942.

An analysis is made of hydrological and meteorological records of the Valley R. Basin in N. Carolina to develop a rational method of predicting runoff based on average rainfall and evaporation from a standard land pan.

Linsley, R. K. and Kohler, M. A. (1951). "Variations in Storm Rainfall over Small Areas", AGU Tr., Vol. 32, No. 2, pp. 245-250, 1951.

Fifty-five gage network over 220 s.m. in Ohio proves that very dense network is not necessary.

R Marston, F. A. (1924). "The Distribution of Intense Rainfall and Some Other Factors in the Design of Storm-Water Drains." With discussion, ASCE Tr., Paper 1540, Vol. LXXXVII, pp. 535-588, 1924.

Records from 12 recording rain gauges in Boston from 1918-1922 are studied, as are those from six gages in a storm at New Orleans. Rainfall intensity hyetograph and area/intensity curves are drawn. It is concluded that for the size of tributary areas usually considered in the rational formula, the assumption of uniform rate is justified.

Q McComas, J. R. (1948). "Storm-drain design shortcomings under scrutiny in Maryland", Eng. News-Rec., Vol. 141, pp. 91, 92, Nov. 11, 1948.

Baltimore city and the contiguous Baltimore County Metropolitan District were inconsistent in the design of their storm drains. The former was using the rational method while the latter were using the McMath formula. The state department of health was called in to arbitrate. Their committee reviewed the situation and made recommendations for experiments including one recording rain gage per five sq. miles.

D Miller, J. F. and Paulhus, J. L. H. (1957). "Rainfall-Runoff Relation for Small Basins", AGU Tr., Vol. 38, pp. 216-218, April 1957.

For basins where the time interval between rainfall peak and flood crest is less than about six hours - 11 years record was available for rainfall intensity and runoff from 4.1 sq. m. of the Little Falls Branch near Bethesda, Maryland. Was also used satisfactorily on basins for 2-15 sq. m. as far off as N. Carolina. However, a different relation (also shown holds for Ralston Creek, Iowa).

DFU Minshall, N. E. (1960). "Predicting Storm Runoff on Small Experimental Watersheds", ASCE Proc., Vol. 86, No. HY 8, pp. 17-38, August 1960.

Analysis is based upon quite flat watersheds of 27, 50 and 290 acres near Edwardsville, Ill. A method is presented for extending the period of runoff records based on analysis of existing short-term records of runoff and rainfall for the watershed. The method can also produce synthetic unit hydrographs for ungauged areas. It involves: (1) estimating storm runoff volumes from the rainfall pattern and antecedent rainfall, and (2) distributing this runoff through an adaption of the unit hydrograph principle.

RL Minshall, N. E. (1941). "Preliminary results of runoff studies at Fennimore, Wis., show low rates and amounts of runoff", AGU Tr., Vol. 21, pt. 3, pp. 871-874, 1941.

Two years storm data are listed for four watersheds ranging in size 22.8 to 330 acres, and in slope from 4% to 10%. The biggest C is about 0.45. Total amounts of runoff do not go much above 25% of rainfall amounts.

PU Mockus, V. (1957). "Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application", AGU Tr., 38(3), 418, June 1957.

A rational analysis of unit hydrograph relations gives the peak rate equation $q_p = \frac{KAQ}{T_p}$ where q_p = cfs, K = constant generally 484.

A = drainage area in square miles, Q = total runoff in inches,

T_p = time in hours from beginning of rise to the peak rate.

$T_p = \frac{D}{2} + L$ where D = unit storm duration, and L = basin or watershed lag = 0.6 Tc where Tc = time of concentration in hours. Relates his peak rate equation to those given by others: e.g., Rational Method; Armco Culvert; Jesse Zabriski, Texas; Snyder's Synthetic unitgraph; Mockus, 1949; Edson, 1951; Armco Rational Method. Triangular hydrograph is recommended for practical problems on ungaged streams.

CR National Resources Committee (1938). "Low Dams: A manual of design for small water storage projects", prepared by the Sub-committee on Small Water Storage Projects of the Water Resources Committee of the N.R.C., Washington, D. C., 431 pp., 1938.

Chapter 2 and Appendix A: The Rational Method is mentioned as being the only method of determining expected flood flows from watersheds of 10 sq. miles and less. Rainfall intensity is based on Yarnell's data. $C = C \max \left(\frac{T}{100}\right)^x$ where T is the return period and x is an exponent from 0.15 to 0.23 which has been mapped for the eastern half of USA. A table gives values of the powers of this fraction.

Time of concentration, t_c minutes = $\frac{J^{1/e}}{(CAK)^g \, T^{xg}}$

where the various coefficients and exponents are related by maps and graphs to catchment characteristics and storm probability.

BDF Newton, D. W. (1960). "Storms and Floods on Small Areas", J. of Geop. Res., Vol. 65, No. 7, pp. 2117-2123, July 1960.

A simple, easily applied procedure for areas up to approximately 500 square miles in the TVA enables one to estimate the maximum expected discharge. A basic family of depth-area-duration curves is found. Support for the technique is found in observed events in the region.

O Ogrosky, H. O. (1960). "Hydrologic Techniques in Watershed Planning", ASAE Tr., Vol. 3, No. 1, pp. 84-85, 1960.

Describes the uses and method of computing volume of storm runoff from NEH4 before and after land use practices have been applied.

R Ordon, C. J. (1954). "A modified rational formula for storm-water runoff", Water Sewage Works, Vol. 101, pp. 275-277, 1954.

Discussion of rational formula proposing new values of the runoff coefficient. Suggests an area factor to reduce computed flows for areas over 500 acres. Reduction, $F = 1.11 - 0.058 \log A$ where A is in acres. Thus $Q = CIAF$. e.g. $F = 0.88$ for 10,000 acres. The graph shows how C varies with I for various surface conditions.

Orr, H. K. (1959). "Precipitation and Streamflow in the Black Hills", Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, Station Paper No. 44, Aug. 1959. 25 pp.

Rainfall trends and annual and monthly rainfall runoff relations are presented.

LF Parsons, D. A. (1949). "The Hydrology of a Small Area Near Auburn, Alabama", SCS-TP - 85, 40 pp., Sept. 1949.

Description of the manner of movement of water to and from a farm pond located on a 27 acre watershed. Points relating storm rainfall to surface runoff are graphed for two-year record.

F Paulhus, J. L. H. and Miller, J. F. (1957). "Flood Frequencies Derived from Rainfall Data", ASCE Proc., J. Hydr. Div. Paper 1451, 18 pp., Dec. 1957.

The study, involving 36 basins ranging from 2.2 to 521 s.m. scattered from New Jersey to northeastern Georgia, showed that it was feasible to use rainfall data (even from outside the problem basin) to obtain flood frequencies. Similarly, rainfall-runoff relations already derived for other basins may be easily modified to apply to the problem basin. It was found that a precipitation network would yield satisfactory results provided: (1) its area roughly approximated the size of the problem basin, (2) its rainfall-intensity-frequency characteristics were similar to those of the basin, and (3) the seasonal distribution of rainfall was the same as that of the basin.

DT Potter, W. D. (1946). "Hydrologic Design of Small Farm Ponds in the Forested Interior West Gulf Coastal Plains Areas of Arkansas, Louisiana and Texas", SCS-TP - 59, 14 pp. June 1946.

Tables and simple calculations with three examples pond dimensions required to water certain numbers of livestock.

SF Potter, W. D. (1948). "Analytical Procedures for Determining the Effect of Land Use on Surface Runoff", Ag. Eng., Vol. 29, No. 2, pp. 64-71, Feb. 1948.

Very good. Considerations of research techniques to show the effect of altered land use on two 400 acre watersheds at Hastings, Nebraska. Normalcy of rainfall. Analysis of surface runoff; peak rates versus rainfall intensities is not very hopeful; direct comparison of peak rates; correlation between peak rates according to freq. distribution for two watersheds vary greatly for different frequency methods used on the same data.

FC Potter, W. D. (1949). "Effect of Rainfall on Magnitude & Frequency of Peak Rates of Runoff", AGU Tr., Vol. 30, pp. 735-751, 1949.

Two well instrumented watersheds (481 and 2,086 acres) at Hastings, Nebraska, were studied, Relation between Q and I for T.O.C. were studied. Wide scatter was accounted for by postulating three classes which signified the watershed condition at the beginning of the high intensity period. The proportion of the annual number of storms that may be expected to occur when a watershed is in a maximum or intermediate condition is primarily dependent on the amount of rainfall and number of excessive storms and varies as some function of their product. There is a wide difference between the frequency with which it produces maximum peak rates of runoff. S- and P- rainfall indices are introduced. Maps of Kansas and Nebraska give equal Q-ratio's lines.

A Potter, W. D. (1950). "Surface runoff from agricultural watersheds", Hwy. Res. Bd. Res. Rep. 11-B, pp. 21-35, 1950.

Twenty s.m. considered as upper limit of small watershed. Their characteristics are different from those of large watersheds (above 100 s.m. in area): definition of drainage pattern and increased T.O.C. He comments disparagingly upon: (1) Direct relationships between rainfall and runoff. (2) The Rational

Method. (3) The Unit Hydrograph, and (4) Infiltration Theory. He feels the use of probability studies should integrate the frequency of occurrence of various watershed conditions with the frequency of occurrence of various rainfall intensities and patterns. Classes of Probability Curves - Hazen & Forster Curves - Gumbel - Rations of $\frac{Q\ (\text{cultivated})}{Q\ (\text{mixed cover})}$ and $\frac{Q\ (\text{pasture})}{Q\ (\text{mixed cover})}$. Area of Watershed vs. Peak Rate of Runoff. Summary of Runoff Studies completed to date.

AF Potter, W. D. (1953). "Rainfall and Topographic Factors that Affect Runoff", AGU Tr., Vol. 34, pp. 67-73, 1953.

Allegheny-Cumberland Plateau. Very good, 51 catchments 100 - 350,000 ac. were used to analyze Q_{10} correlations with Q_{25} and Q_{50}. A multiple correlation is developed for area, P- and S- rainfall factors and a topographic factor.

DAB Potter, W. D. (1954). "Use of Indices in Estimating Peak Rates of Runoff", Public Roads, Vol. 28, pp. 1-8, 1954. Bureau of Public Roads, Dept. of Commerce, Washington 25, D. C.

This approach requires the measurement of the principal factors that affect runoff and the determination of their relations to the magnitude and frequency of peak rates. Analyses are made of the two physiographic areas: Allegheny-Cumberland Plateau and the Glaciated Sandstone and Shale Areas of N.Y., Penn., and Ohio. Figures and maps enable the estimation of peak rates of 10 to 50 year recurrence for watersheds ranging in size 1,000 to 400,000 acres. For the first area, q was related to A, T = a topographic index and P = a precipitation index. $Q_{50} = Q_{10} \times 1.46$, $Q_{25} = Q_{10} \times 1.26$.

For second area use was made of 47 mixed cover watersheds from 1,000 to 400,000 acres which USGS gaged for about 12 years to produce a graphical correlation of Q_{10} with: area A, topographic factor T, precipitation factor S, and storage factor K. For watersheds where K is zero, multiply the 10-year peak rate by 1.22 to obtain Q_{25}, or by 1.39 for Q_{50}. As K increases progressively smaller ratio's can be used. Estimates are within 18%.

S Potter, W. D. (1958). "Upper and lower frequency curves for peak rates of runoff", AGU Tr., Vol. 39, pp. 100-105, 1958.

Using a sample of 69 gaged watersheds with records ranging in length from 26 to 48 years, a high degree of correlation is found to exist between the upper and lower freq. curves for 10- and 50-year recurrence interval.

Q Ramey, H. P. (1959). "Storm Water Drainage in the Chicago Area", ASCE Proc., Vol. 85, HY 4, Paper 1995, 26 pp., 1959.

Discusses past and recent flooding conditions. Stresses the need to improve the main drainage if smaller tributary drainage developments are to become effective.

LCR Ramser, C. E. (1927). "Runoff from Small Agricultural Areas", J. of Ag. Research, Vol. 34, No. 9, pp. 797-823, May 1927. USDA Publication D015.

Proper C values for Q = CIA for agric. areas. Six watersheds ranging in size from $1\frac{1}{4}$ acres to 112 acres. Four and one half miles southeast of Jackson, Madison County, Tenn. A table shows areas; fall of channel; (1) at gauging site, ave., max.; dist. from furthest point to gauge; T.O.C.; % timber (0-55.5). Topographic map. Tabulated observations and observed C's for about ten storms are given for each watershed. Photo's of catchments. Only one tipping bucket rain gauge (1/3 width within edge of almost circular complex of catchments - about 2,000' dia.). Data is presented for the year 1918.
T.O.C. was considered as the somewhat variable amount of time required for the runoff to rise from low flow to peak discharge: 20.7 ac. = 5 m.; 49.2 ac. = 10 m., 112 ac. = 17 m., $1\frac{1}{4}$ ac. = $1\frac{1}{2}$ m., and 2.8 ac. = 3 m., and 15.7 ac. = 7 m.
Conclusions: (1) Biggest storm of year with 4.2 and 3.5 in./hour during the T.O.C. of the unforested and forested and unforested watershed gave respective C's of .51 to .46; this occurred after about 3/4" had fallen. (2) The highest C was 0.86 from a 112 ac. watershed of which $\frac{1}{4}$ was forested. This is double what other C's had reached. So C for large storms is far greater than C for most runoff's. These are the first measurements of this type and should be followed up.

LT Ramser, C. E. (1934). "Result of Engineering Experiments at the Soil Erosion Stations", ASAE Tr., 28:39-44, 1934.

Discussion and tables of annual soil loss and annual runoff for terraced and unterraced land in various states. Effects of terrace grades also shown.

SD Reich, B. M. (1959). "Probable Maximum Precipitations for Short Durations in the Union of South Africa". Unpublished M. S. Thesis; Iowa State University, 226 pp., 1959.

After statistical analysis of available data and the application of suitable empirical methods, design maps and graphs are presented. The rainfall intensity for 15, 30, 45, 60 minute- and 24 hour-duration can be estimated for any return period ranging from 2- to 100-years.

PQ Reid, E. H. and Love, L. D. (1951). "Range-Watershed Conditions and Recommendations for Management, Elk Ridge & Lower Elk Ridge Cattle Allotments, Roosevelt National Forest, Colorado." Mimeographed report, USDA, Forest Service, 136 pp., June 1951.

Descriptive report illustrated with photographs, tables and graphs. Thirteen pages cover erosion and runoff characteristics based upon: (1) streamflow measurements on two sample watersheds, and (2) portable type FA infiltrometer.

M Reimann, L. F. and Hamilton, E. L. (1959). "Four Hundred Sixty Storms: Data from the San Dimas Experimental Forest", USDA, Forest Service Pacific Southwest Forest and Range Exp. Sta., Berkeley, California, 101 pp., Misc. Paper No. 37, July 1959.

Entirely a tabulation of data from their major gauge as follows: (1) daily rainfall amounts (2) annual summaries of maximum storm rates.

R Roe, H. B. and Snyder, C. G. (1943). "A logical modification of the rational formula for runoff from small agricultural areas", Ag. Eng., Vol. 24, pp. 423-427, Dec. 1943.

One hundred sixteen storms and their runoff from watersheds at Jackson, Tennessee, and Coshocton, Ohio were analyzed to see how a general formula $q = CI^{x}A^{y}S^{z}$ would fit the data. The final recommendations are:

Group I	$q = 0.60\ AI^{1.14}$
Group II	$q = 0.36\ AI^{1.14}$
Group III	$q = 0.22\ AI^{1.14}$
Group IV	$q = 0.07\ AI^{1.14}$

The specified groups depend upon the intensities and lengths of the storms. Group I. Low intensities (for most part less than 0.5 in/hr). Long storms (average 114 minutes). Watershed areas 75-373 acres. Group II. Moderate to high intensities (for most part appreciably in excess of 1.5 in/hr, ave. 2.28 in/hr). Storms from medium length to short (ave. 38 min), watersheds, 21-112 acres. Group III. Moderate to low intensities (mostly appreciably less than 1 in/hr average 1.01 in/hr). Storms moderate length (average 51 min.). Areas of watersheds 75 to 373 acres. Group IV. Moderately high intensities (for most part well in excess of 1 in/hr., average 1.25). Storms short and sharp (many under 25 min.). Areas of watersheds 75 to 373 acres.

DCN Rosa, J. M. (1954). "Guides for Program Development: Flood Prevention on Small Watersheds of the Rocky Mountain Area", USDA, Forest Service, Ogden, Utah, 152 pp., Jan. 1954.

Manual telling how to design and construct small flood control works and erosion checks on small watersheds. Many tables and graph of infiltration rates, C-values, etc. are drawn together where various methods are described.

F Rothacher, J. S. (1953). "White Hollow Watershed Management: 15 Years of Progress in Character of Forest, Runoff and Stream Flow", J. of Forestry, Vol. 51, No. 10, pp. 731-738, Oct. 1953.

Fifteen years of protection and reforestation have so improved the forest cover of 1,715-acre watershed in eastern Tennessee that summer peak flows have been reduced 73 to 92%; the duration of summer storm runoff has been prolonged up to 500%. Description, photo's, tables, histograms comparing peaks before and after.

ALD Rouse, H. K. (1948). "Rates of Runoff for the Design of Conservation Structures in the High Plains of Colorado and New Mexico", SCS-TP - 66, 45 pp., April 1948.

Based on data covering six to nine years record from Colorado Springs and Vegas, Texas, whose areas ranged from 10 to 130 acres. Peak rates of runoff are tabulated for 2 - 200 acres for cultivated, mixed or grass cover; for four classes of topography and soil. Twenty-one pages of discussion of the factors influencing peak rates of runoff. Good topographic-soils maps of the area are included.

DN Schiff, L. (1949). "Surface Runoff Supply Estimates Based on Soil-Water Movements and Precipitation Patterns", SCS-TP - 86, 18 pp., 1949.

Describes a method of estimating surface supplies to runoff by superimposing potential infiltration curves over storm patterns. Histograms and hyetographs involve the Muskingum Silt Loam and Keene Silt Loam, but are applicable in general where the required soil tests have been made.

NL Schiff, L. (1951). "Surface Detention, Rate of Runoff, Land Use and Erosion Relationships on Small Watersheds", AGU Tr., Vol. 32, No. 1, pp. 57-65, Feb. 1951.

Based upon rainfall, runoff and soil loss data for major storms during nine years; areas ranging in size from 0.65 - 2.71 acres. Infiltration curves were derived. For identical rates of runoff the average depth of detention storage on a watershed on the rising limb of the hydrograph was found to be noticeably greater than that for the falling side. Laminar and turbulent states of runoff depend on % cover.

LN Schiff, L. (1951). "Hydrology of Rates and Amounts of Surface Runoff from Single- and Mixed-Cover Watersheds", SCS-TP - 104, 27 pp., March 1951.

Hydrologic laws operating on a watershed are based largely on: (1) Precipitation pattern, i.e. intensities of ground rainfall and sequence of its occurrence. (2) The infiltration rate curve for a specific land use on a particular soil at a definite soil-moisture content. (3) The depth and movement of detention storage (overland flow). The maximum excess rainfall (i.e. rainfall intensity-infiltration rate) lasting for the T.O.C. usually produces the maximum rate of surface runoff. There are cases when the intensity of rainfall is so great for a period of time less than the T.O.C. as to produce the maximum rate of runoff for a specific watershed. Methods of determination must allow for this. A comparison is made between computed and measured rates and amounts of surface runoff from single and mixed cover watersheds up to 75.6 acres. The effects of antecedent soil-moisture and different precipitation patterns and changes of land use are also computed.

P ...... precipitation, as measured, corrected for interception storage by plants if appreciable and warranted by accuracy.

i ...... intensity of precipitation, inches/hour.
f ...... infiltration rate, inches/hour.
f_c ...... infiltration capacity; i.e. rate at which infiltration would take place at any instant were the supply to equal or exceed this capacity, inches/hour.
f_p ...... potential infiltration rate; i.e., the rate at which infiltration would take place at a given soil-moisture content, at any instant, were the supply to equal or exceed this potential rate, inches/hour.
Note: f_p is only used when rates of rainfall $< f_c$.

E ...... increment of excess rainfall (i.e. rain in excess of infiltration), for time interval $T_2 - T_1$.
$\sum E$ ..... accumulated excess rainfall, inches.
Q_{sc} ...... computed accumulated surface runoff, inches.
q_{sc} ...... computed rate of surface runoff, inches.
Q_{sm} ...... measured accumulated surface runoff, inches.
q_{sm} ...... measured rate of surface runoff, inches.
D_s ...... average depth of detention storage (i.e. depth of water on watershed) at any specific time, inches.

The method is outlined which includes balancing the bookkeeping equation:

$$E = \left[\frac{q_{sc1} + q_{sc2}}{2}\right]\left[\frac{T_2 - T_1}{2}\right] + \left[D_{s2} - D_{s1}\right]$$

for an actual or hypothetical storm. A graph is presented for the relation of Rate of Surface Runoff to Detention Storage. Each curve is double since detention storage is greater for the rising side for a given rate of surface runoff. These relationships were established through hydrograph analysis. They could be used to estimate such relationships for a reasonably similar watershed from which hydrologic data were not available. Computed peak rates and volumes of storm runoff were compared with those observed for similar storms for watersheds of 0.65, 1.37 and 75.6 acres. Very close agreement was obtained.

DN Schiff, L. (1951). "Hydrology of Surface Supplies to Runoff", SCS-TP - 90, 25 pp. 1951.

Clear explanation and application of the infiltration analysis. Curves give capacity infiltration rates for various crops with various soil moisture contents.

NL Schiff, Leonard and Dreibelbis, F. R. (1949). "Infiltration, soil-moisture and land-use relationships with reference to surface runoff", AGU Tr., Vol. 30, pp. 75-88, 1949.

Work conducted at the North Appalachian Experimental Watershed located about 10 miles north of Coshocton, Ohio. Four watersheds, ranging from 0.6 to 1.7 acres on well-drained and slowly permeable soils with land slopes from 6% to 21% were considered during storms. Transmission rates or velocities of water moving through the top soil were as high as 10 inches/hour; they did not exceed 1.5 inches/hour for the sub-soil.

DNL Schiff, L. and F. R. Dreibelbis (1949). "Movement of Water within the Soil and Surface Run-off with Reference to Land Use and Soil Properties", AGU Tr., Vol. 30, No. 3, June 1949.

This paper supplements the one by the same authors on pp. 75-99 of this volume. It deals with the conditions leading to the development of storage space within the soil. Three watersheds near Coshocton, Ohio, 1.4 to 1.7 acres in area were studied. Analysis of hydrographs by infiltration theory for various storms. Relationships established furnish a means of relating the influence of soil properties and land use to the hydrologic performance of watersheds.

ND Sharp & Holtan (1942). "Extension of graphic methods of analysis of sprinkled-plot hydrographs to the analysis of hydrographs of control-plots and small homogeneous watersheds", AGU Tr., pp.578-593, 1942.

Simultaneous studies on small watersheds by means of infiltrometers and small control plots, and the watershed as a whole has led to the development of more precise methods of hydrograph analysis. Types A-, B- and C-storms are classified. Hydrographs and hyetographs are examined and Rate of Runoff versus Detention Relations are developed for each. A method is also provided for determining depression storage.

NL Sharp, A. L., Holton, H. N., Musgrave, G. W. (1949). "Infiltration in relation to runoff on small watersheds", SCS-TP - 81, 40 pp., June 1949.

Experimental watersheds: (1) 27.2 ac. and 49.9 ac. on claypan soil of Edwardsville, western Illinois; prevailing land slopes 1% and 1% + 12%; pasture, mainly alfalfa. (2) 35.4 ac., 6% slope typical of fair range condition of high plain of Colorado. At Colorado Springs, slopes have Bresser clay loam, bordering on a sandy loam. A multiple regression analysis of the results of these investigations revealed significance between infiltration and top soil depth, cover density, and soil moisture. Type F infiltrometers were used to sample the various segments of the area and their deviation with season. Isopotal areas (having similar infiltration characteristics) were delineated. On each of these semi-permanent plots were installed so that rates of runoff on an exaggerated scale were obtained for the same natural storms that produced runoff from the entire watershed. Synthetic hydrographs were prepared and agreed closely with actual outflow from entire area. Very detailed topographic and soil maps are provided. Hydrographs and hyetographs are given, as well as many infiltration rate curves. It was clearly shown by a plot that there is no consistent relationship between the total storm rainfall and runoff.

ML Slosser, J. W. (1940). "Hydrologic Studies-Compilation of Rainfall and Runoff from the Watersheds of the Red Plains Cons. Expt. Stn. Guthrie, Okla. 1931-38", SCS-TP - 32, 40 pp. illus. (mimeographed).

One watershed is 35 acres, the others vary from $2\frac{1}{2}$ to 6 acres. Slopes vary from $2\frac{1}{2}$ to $5\frac{1}{2}\%$. Topographic maps. Single storms tabulated and hydrographs and hyetographs are presented with discussion or unifying analysis.

Smith, J. L., Crabb, G. A., Jr. (1956). "Patterns of Classes of Rainfall at East Lansing, Michigan, and Their Effect Upon Surface Runoff", Article 39-7, August 1956. Reprint from the Quarterly Bulletin of the Michigan Agr. Exp. Sta., Mich. State Univ. of Agriculture and Applied Science, East Lansing, Vol. 39, No. 1, pp. 47-62, August 1956.

(Some patterns after Horner & Jens 1941).
Rainfall class: is the range of intensity within while the major portion of precipitation occurred during any given storm (essentially the same classes as those developed by Schiff 1943). The rain > 0.25 in. were considered. Precipitation pattern: is that section of storm, with relation to time, at which the highest intensities are concentrated. Conclusions: of the three factors: class pattern and total amount of storm rainfall; is of more significance in producing runoff than intensity under cultivated conditions. However, because of the complex inter-relation between these factors and those of soil moisture, vegetal cover, climate and physical conditions, none of these factors can be accepted alone as a primary runoff-producing factor.

R Snyder, C. G. (1949). "Additional arguments for modification of the Rational Formula for runoff from small agricultural watersheds", National Research Council, AGU Tr. of 1944, Part I, pp. 45-57.

The value of C is primarily dependent on the character of the storm. Note: A. F. Pillsbury in discussion points out uncertainties in the analysis and the data which cast doubt on the validity of the exponent 1.

TB Snyder, F. F. (1939). "A conception of runoff-phenomena", AGU Tr., Part IV, pp. 725-738.

Rainfall is considered to be dissipated in the following ways: Surface runoff, groundwater recharge, additional loss, cappilary water, initial loss. A 1147 s.m. watershed in the Appalachian Highlands is then studied with regard to monthly discharges, temperatures, etc.

UB Snyder, F. F. (1938). "Synthetic Unit Hydrographs", AGU Tr., Vol. 19, Part I, pp. 447-454.

Presents an empirical method of deriving synthetic unit-graphs for drainage areas of 10 to 10,000 sq. miles.

UCF Snyder, F. F. (1958). "Synthetic Flood Frequency", ASCE Proc., J. Hydr. Div., Vol. 84, No. 5, Paper 1808, 22 pp.

Based on: natural areas 4.1-1600 s.m., airfield drainage 0.1-38.4 acres, and areas with storm sewers 0.2-7.5 s.m.; this study developed a method of predicting flood discharge utilizing:- area, length, slope, friction and shape. Patterned after Rational Method utilizing T.O.C. with a unit hydrograph, but recognizes and evaluates separately the effect of storage existing in all types of channels and conduits and an average rainfall-runoff relation. Variables have been evaluated for the vicinity of Washington, D. C. Observed T.O.C. is listed for 21 cases. Four worked examples fit very closely with estimates from observed floods; from 2 to 100 year freq.

SU Snyder, W. M. (1955). "Hydrograph Analysis by Method of Least Squares", ASCE Proc., Vol. 81, Separate 793, Sept. 1955.

Hydrographs of ten storms were analyzed by a technique based on the method of least squares. Five were taken from a watershed with changing cover, while the others were taken from a smaller watershed with stable cover. The coeff. of runoff distribution for the storms on changing cover show a change in shape of the total storm hydrograph.

T Stage, A. R. (1957). "Some Runoff Characteristics of a Small Forested Watershed in Northern Idaho", Northwest Science, Vol. 31:1, pp. 14-27.

A 950 acre watershed is considered with regard to monthly, annual and long-term variations in stream flow and precipitation.

Q Storey, H. C. (1959). "Effects of Forest Runoff", J. Soil & W. Con., 14(4); pp. 152-155, July 1959.

Qualitative discussion of the effects of: interception, infiltration, soil moisture storage and movement. In discussing the effect on storm runoff results are quoted from the 2.68 s.m. White Hollow Watershed in T.V.A. This was a poor area with only 66% forest in 1936. By increasing this to 100%, discharge rates during storm periods were only 8-27% of those for prior comparable storms.

OP Tamhane, R. V., Biswas, T. D., Das, B. and Naskar, G. C. (1959). "Effect of Intensity of Rainfall on the Soil Loss and Runoff", Jour. Indian Soc. Soil Science, 7(4);231-238, December.

In 1946 four runoff plots, 3.5% slope, 5' X 50' were laid out. A regression $Y = 38.4 + 77.95X$ was obtained between Y, the amount of runoff (cu. ft./acre) per mm of rainfall, and X = intensity of rainfall (mm/min) but the positive correlation was only 0.22 thus the above relationship was abandoned. In seeking another relationship, rain in excess of 0.1 mm/min (=0.24 in/hr) was found to be erosive. The intensity of erosive rainfall had highly significant and positive correlation with the runoff and soil loss. The relationship was discovered to be curvilinear.

BU Taylor, A. B. and Schwarz, H. E. (1952). "Unit-hydrograph Lag and Peak Flow Related to Basin Characteristics", AGU Tr., Vol. 33, pp. 235-246, April.

Unit-hydrograph lag and peak-flow values have been empirically related to basin characteristics and to the duration of rainfall excess. Characteristic data for 20 drainage basins ranging from 20 to 1600 s.m. and located in the north and middle Atlantic states were used in the study. Unit-hydrograph values were obtained from 65 rainfall excess periods. The study indicates that the most significant basin characteristics were: drainage area, length of longest water course, length to center of area, and equivalent mainstream slope. Graphs of the correlation are given and a method for determining equivalent mainstream slope is presented. A nomogram for the computation of synthetic unit hydrographs is presented on the basis of the derived equations. Hereby the unit hydrographs for ungauged watersheds in similar areas may be derived.

LQ Thames, J. L. and Ursic, S. J. (1960). "Runoff as a Function of Moisture-Storage Capacity", J. of Geophysical Union, Vol. 65, No. 2, pp. 651-654, Feb. 1960.

Records from two $2\frac{1}{2}$-acre watersheds in northern Mississippi indicate that surface runoff is strongly correlated with storage opportunity in the upper six inches of soil. A procedure for calculating soil-moisture storage over a watershed is presented.

DN Tholin, A. L. and Keifer, C. J. (1959). "Hydrology of Urban Runoff: Chicago Hydrograph Method", SA 2 No. 1948; 47-106 March 1959; correction 85 SA 4 No. 2098:113 Jour. 1959 Disc. 85. HY 8 No. 2138:119-21 Ag., SA 5 No. 2181 37-56 S'59, ASCE

A detailed study of rainfall-runoff relations in urban areas is made on the basis of a "Design Storm". The "Chicago Hydrograph Method" of sewer design evaluates, in detail, the rainfall abstraction and flow detentions affecting the hydrographs of sewer supply and sewer outflow. Based upon sewer hydrographs, derived from studying several types of land use with various ground storage and depression storage, a series of easy-to-use design charts are presented. The effect of non-uniform areal distribution of rainfall is evaluated. A condensed description of the hydrograph type of analysis is:

(1) Determine typical layout of the drainage area;
(2) Determine chronological storm pattern or hyetograph of the design storm;
(3) The evaluation of the abstractions from rainfall.
(4) Determine runoff hydrographs at the lower end of elemental strips of both pervious and impervious strips.
(5) Routing of the mixed flow from the elemental strips along the channel of the street gutter to the inlet or catch basin grating.
(6) Routing of the sewer supply hydrographs from roofs and street inlets along a typical headwater sewer lateral.
(7) Routing of the lateral overflow hydrograph by a time-offset method along the sub-mains and main outlet sewers to the point of discharge of the sewer system.

(8) Production of a series of easy-to-use design charts (with help of digital computer). Two worked examples are given. Some considerably different views are expressed in the discussion of the article.

U. S. Army, Corps of Engineers (1946). "Drainage and Erosion Control: Drainage and Erosion Control Structures for Airfields", Eng. Manual, Part XIII, Ch. 3, p. 31, July 1946.

Discussion, pictures and design charts for: inlets, head walls, drop structures and check dams, chutes, stilling basins, gutters, open channels, erosion checks, and terraces.

R U. S. Army, Corps of Engineers. (1946). "Drainage and Erosion Control: Drainage Facilities for Roadways and Built-Over Area", Eng. Manual, Part XIII, Ch. 4, July 1946.

Ten year design storm and rational formula recommended. Drawings and brief discussion of: drainage ditches, culverts, storm drains, sub-surface drains, pipes, inlets, manholes, headwalls, drainage chutes and stilling basins, ditch lining, erosion checks, bridges.

D U. S. Army, Corps of Engineers. (1946). "Surface Drainage Facilities for Airfields", Engineering Manual, Part XIII, Chapter 1, p. 42, July 1946.

Design objectives; rainfall; infiltration; supply; runoff. Design procedure based on Horton's modified formula:

$$q = \sigma \tanh^2 \left[0.922\, t \left(\frac{\sigma}{nL} \right)^{0.5} S^{0.25} \right]$$

q = rate of overland flow at the lower end of an elemental strip in inches/hour per acre of drainage area.
σ = rate of supply, i.e. rainfall in excess of rate of infiltration.
t = time in minutes, from beginning of supply. S = slope of surface.
n = retardance coeff. L = length of overland or channel flow in ft.
Complete graphical solution, as well as design procedure for storm drains.

U U. S. Army, Corps of Engineers. (1948). "Hydrologic and Hydraulic Analysis: Hydrograph Analysis and Computations", Eng. Manual for Civil Works, Part CXIV, Chapter V, p 102, March 1948.

Superseding E.M. Civil Works, Part III, Chapter 5, April 1946. Analysis of a flood hydrograph is discussed in detail. Computation of hypothetical hydrographs from design storm, infiltration indices, unit hydrographs and combination. Has been superseded by "Flood-Hydrograph Analysis and Computations", U. S. Army, Corps of Engineers, Manual, EM 1110-2-1405, 31 August 1959.

Q U. S. Army, Corps of Engineers. (1957). "Airfield Pavement Design General Provisions and Criteria", Eng. Manual 1110-45-301, p. 4 , 15 August.

General provisions and criteria for airfield design. Some brief definition of terms. No engineering methods.

DU U. S. Army, Corps of Engineers. (1959). "Flood Hydrograph Analysis and Computations", Eng. Manual 1110-2-1405, 60 pp., 31 August 1959. Supersedes: (1) Eng. Man. for Civ. Works Constr., Part CXIV, Ch. 5; March '48; and (2) Hydrologic and Hydraulic Analysis, Flood-Hydrograph Analysis and Computation EM 1110-2-1405; and (3) Civ. Works Eng. Bul. No. 49-22, Unit Hydrograph Compilations, 7 Dec. 1949.

Estimation of the intensity, depth and areal distribution of precipitation causing the runoff. Computation of difference between precipitation and direct runoff. Determination of combined effect of drainage area and channel characteristics upon the unit hydrograph. Computation of hypothetical hydrographs; worked example. Apart from one Weather Bureau paper, all items in its bibliography are 1947 and earlier.

DFI LRU U. S. Army, War Department, Corps of Engineers. (1947). "Report on Drainage Verification at Military Establishments and Appendices I, II and III", Louisville Engineer District, Louisville, Kentucky, 315 pp. plus 471 pp. of appendix, June 1947.

Collection and analysis of basic rainfall and runoff data from plots on the Air Force bases Freeman Field and St. Anne Auxiliary Field, Indiana, Godman Field, Kentucky, Lockbourne Army Air Base and Wright Field, Ohio. Areas ranged from 0.67 acres to 687 acres, while cover ranged anywhere from 100%

paved to 100% turf. Good qualitative confirmation is obtained for R. E. Horton's theory and basic equations of overland flow. The mass-area, unit hydrograph, Izzard's method, and various rational methods show considerable promise.

I USDA, Agr. Res. Ser., Soil & Water Res. Br. (1955). "Inventory of Available Hydrologic Data on Agricultural Watersheds", Watershed Hydrology Section, Beltsville, U. S. Agr. Res. Ser., 18 pp., 1955.

Listing of major statistics such as: area, period of record, slope, cover, etc.

M USDA, Agr. Res. Ser., "Monthly Precipitation and Runoff for Small Agricultural Watersheds in the United States", Soil and Water Conservation Research Branch, ARS, Washington 25, D. C. Large volume in loose leaf binder, July 1958 and subsequently augmented.

Besides providing data for each year of record, this book gives complete data on each watershed and its use history.

MOF USDA, Agr. Res. Ser., "Annual Maximum Flows from Small Agricultural Watersheds in the USA", Soil and Water Con. Res. Br., ARS, Washington 25, D. C.

For each of the watersheds the annual maxima of the following quantities are listed: rate, vol. for 1-, 2-, 6-, 12-, 24-, 48-, and 192-hours.

FM USDA, Agr. Res. Ser., "Selected Runoff Events for Small Agricultural Watersheds in the USA", Soil and Water Cons. Res. Br., ARS, Washington 25, D. C.

Histograms and hyetographs of three or four storms and detailed topographic maps of selected watersheds representing major size classes at each research establishment are presented. The data is tabulated for the same events.

NDF USDA, Soil Conservation Service, "Engineering Handbook; Hydrology: Section 4", mimeograph, 127 pp.

Descriptive material, maps and graphs on: climate, precipitation, time distribution of storm rainfall, areal distribution, infiltration, storm runoff.

CUT NDF S USDA, Soil Conservation Service (1957). "Engineering Handbook; Section 4, Hydrology, Supplement A", about 200 pages, mimeograph, as corrected 18 Dec. 1957.

After discussing the responsibilities, procedures and working details in hydrologic investigations the following subjects are discussed: hydrologic soil groups, land use and treatment classes, hydrologic soil-cover complexes, estimation of direct runoff, area-inundation relations, stage-discharge relations, T.O.C. and lag, flood routing, frequency methods, transmission losses, watershed yield, and hydrographs. The following methods are presented completely with all necessary tables and graphs: (1) Summation of triangular hydrographs for cases where the following is given, (a) geographic location, (b) drainage area, (c) hydrologic soil-cover complex, and (d) time of concentration. (2) Complex watershed solution by summation. (3) Large watershed having T_c is greater than 6 hours. (4) W. J. Owen's family of semi-dimensionless hydrographs. (5) Computations of peak discharge from a storm of any distribution pattern typical of certain parts of USA.

IUD B USDI, Bureau of Reclamation. (1960). "Design of Small Dams", U. S. Govt. Printing Office, ($6.50), Washington, pp. 19-61 of 611.

Probable maximum precipitation charts for USA are presented, for area of 10 sq. m. and 6-hour duration. Curves relate intensities for other durations and catchment areas. Hydrograph analysis is discussed. Unit-hydrograph derivation for ungauged watershed is outlined completely. The basis for this method is the USDA, SCS, NEH4 infiltration approach.

FL Viessman, W., Jr. (1960). "Progress Report on the Storm Drainage Research Project: July 1, 1959 to June 30, 1960", The Johns Hopkins University, Department of Sanitary Engineering and Water Resources, Baltimore, Maryland, 66 pp., 1960.

The study includes the effect of slope on the peak discharge from small drainage areas and the relationship of maximum short interval rainfall intensity to the duration of the intense part of a storm.

FL Viessman, W., Jr. (1958). "The Inlet Method and Its Application to Storm Drainage Design Problems", The Johns Hopkins University, Department of Sanitary Engineering and Water Resources, mimeographed report, 21 pp., August 1958.

Presents and explains the use of a complete set of curves and tables of this empirical approach to the determination of storm water runoff rates from small urban areas. It employs composite triangular hydrographs whose peaks are obtained by multiplying the inlet area in acres by the maximum five minute intensity of rainfall and by a coefficient C_i. The latter can be selected from a family of curves depending upon the five minute intensity and the percentage imperviousness. An example of a complex drainage area is worked.

DFR Vorster, J. A. (1946). "The Engineering Problems in Soil Erosion Control", Union of So. Africa, Dept. of Agr., Bulletin No. 259, 83 pp., 1946.

General handbook on the mechanical aspects of soil conservation. In one chapter maps of South Africa are presented which divide the country into six areas of similar rainfall-intensity characteristics. Intensity-duration-frequency curves for each of these is given by making a qualitative comparison to American regions for which Yarnell's data was available. The effects of watershed parameters, soil vegetation and drainage channels upon runoff peaks are discussed. Rational method is presented with tables and graphs. Design applications such as the design of terraces, farm dams and gully control works are discussed.

Vorster, J. A. (1940). "The rational method of determining maximum runoff", Farming in South Africa, 15:299-303, Aug. 1940.

Outlines the method and suggests design coefficients based on American literature.

NB Whelan, D. E., Miller, L. E. and Cavallero, J. B. (1952). "A Method of Determining Surface Runoff by Routing Infiltrated Water Through the Soil Profiles", Northeastern Forest Experimental Station, USDA, Forest Service Station Paper No. 54, 15 pp.

Based on a detailed hydrologic study of the storm of 17-18 July 1942 on the 1,690 sq. m. watershed of the Alleghany River.

DN Whelan, D. E. (1959). "Hydrologic Condition of Forest Lands", paper presented at 1959 Winter Meeting, ASAE, Chicago, Paper 59-716, 17 pp.

Very good with graphs for use with NEH4 of USDA.

QF Williams, G. R. (1960). "Design Flood Procedures in the United States", Water Power, Vol. 12, No. 6, pp. 224-226, June.

Outline of American trend of thought on estimating design floods. (1) Major projects should have spillway design based upon a meteorological determination of the maximum precipitable moisture that can be expected in the region for different durations of time on an area the size of the drainage basin above the dam. Losses prior to runoff should be based on an infiltration index determined from a study of great storms and floods in the region. Apply unit-hydrograph and inflow routing. (2) Spillway design floods for project of secondary importance should be based on a consideration of the most severe storms and resulting floods that have occurred in the same and similar regions. (3) Flood frequency analysis are useful for determining frequent floods for the design of flood channel improvements or for the design of spillways for small ponds. (4) "There seems to be no question but that the rational method has no place in deriving design floods for natural areas of more than a few acres."

NU Wisler, C. O. and Brater, E. F. (1959). "Hydrology", John Wiley & Sons, Inc., New York, Chapman & Hall, Ltd., London, 408 pp. July.

Modern methods with particular reference to watersheds smaller than 10 sq. m. of flood determination are among the subjects discussed. The infiltration approach and the synthetic hydrograph are presented.

IM Word, O. C., Jr. (1941). "Hydrologic Studies, Rainfall and Runoff Data from the Watersheds of the Arkansas, Louisiana, and East Texas Sandy Lands", SCS-TP - 41, Tyler, Texas, June 1941.

Includes about 100 pages of storm data and graphs. Six watersheds ranging from 0.25 to 7.9 acres are described. No synthetic analysis is attempted.

IM Zingg, A. W. (1941). "Hydrographic Studies - Compilation of Rainfall and Runoff from the Watersheds of the Shelby Loam and Related Soils, Cons. Exp. Sta., Bethany, Missouri, 1933-40", SCS-TP - 39, 25 pp. (mimeographed) together with supplements 1 & 2 of 1942 and 1943.

Scale map of relative positions of eight watersheds whose areas ranged from two to eight acres. Description and topographic maps of watersheds. About 200 pages of storm data and graphs. No general analysis or synthesis.

LN Zingg, A. W. (1943). "The Determination of Infiltration Rates on Small Agricultural Watersheds", AGU Tr., 24:475-479.

Describes the application of the "infiltration" techniques of Horner or Sharp & Holton to analyze the hydrograph obtained from a $7\frac{1}{2}$ acre watershed in Bethany, Missouri. The storm, which occurred on 31 October 1941, was generally of low intensity and lasted for $31\frac{1}{2}$ hours. Infiltration-rate decreased from 0.12 inch/hour at the start of rainfall-excess to less than 0.01 inch/hour about 15 hours later.

SQ Zoch, R. T. (1939). "The Mathematical Synthesis of the Flood-Hydrograph", AGU Tr., Part 2 (Symposium of Floods) pp. 207-218, 1939.

Discussion type article on how equations may be selected, or derived, which can be used to represent an observed flood-hydrograph. Two radically different lines of approach are possible. (1) curve-fitting, and (2) that of the mathematical physicist.

DISCUSSION

The problem of estimating flood peaks has plagued engineers involved in urban-, airport- and highway-drainage as well as those in the small farm structure field for more than half a century. The frequent appeals made for experimentation went largely unheeded, although the profession appreciated how insecure the basis of flood estimates were. It is largely the work of the U. S. Department of Agriculture around about 1940 which led to sound procedures, which have been progressively improved to meet more exacting requirements of their nationwide flood control program. Today techniques for determining the design hydrograph exist, which are comparable to the stress-analysis of a bridge, or any other sound engineering procedure. Nevertheless, a large number of peak-flow estimates are still being made by rule-of-thumb and empirical formulae. Exum (1951) reported that thirty five state highway departments were making some use of Talbot's formula, which gives the waterway area of a culvert as a power of watershed area times a variable constant.

The four methods which can be justifiably used today are briefly discussed below. They are followed by a broad outline of the methods used by Soil Conservation Service engineers of the United States Department of Agriculture.

Infiltration Approach

This is the most refined method available for determining the rate of runoff from small watersheds. It is based upon the sequence of natural events which cause runoff. The calculation requires an estimate of infiltration capacity for the soil type. This may be obtained either by on-site testing with portable infiltrometer or from regional soil surveys. The precipitation pattern, i.e., the intensities of ground-level rainfall and its sequence of occurrence, must be decided upon from a regional study of meteorological events. The relationship between the rate of surface runoff and surface detention; as is presented graphically for various land use practices from previous studies of hydrographs, is needed in the calculation. Schiff (1951 b) presents this method as the balancing of a bookkeeping equation:

$$E = \left[\frac{q_1 + q_2}{2}\right]\left[\frac{T_2 - T_1}{60}\right] + \left[D_2 - D_1\right]$$

where: E = increments of excess rainfall (i.e. rain in excess of infiltration)

q = rate of surface runoff

D = average depth of detention storage (i.e. depth of water on watershed).

The subscripts 1 and 2 refer to conditions at the time, T, at the beginning and end of elemental periods.

Trial and error calculations involved in building up the outflow hydrograph become formidable. Complex watersheds, which comprise blocks of different soil and vegetation types, must be split into homogeneous elements whose hydrographs must be routed to the outflow point and there combined. This much professional labor is seldom warranted for designs on small watersheds. It is perfectly feasible, however, to use the infiltration method to check the validity of simpler estimating techniques in a limited region by applying it to typical watersheds.

Moreover, one must not allow the complexity or realistic basis of the method to blind one to its limitations. The selection of appropriate storm distribution, antecedent moisture condition of the soil, and infiltration capacity are factors requiring judicious estimation; since they are chance variables which combine in nature in an unknown way to produce the crucial peak flows. Ligon and Johnson (1960) have shown how widely infiltration capacities actually vary among naturally occurring storms. It is worth noting that the developments of the "Chicago hydrograph method" by Tholin and Keifer (1959), applied the same principles of rainfall abstractions and flow detentions to urban drainage. Although the calculations they employed in preparing "easy to use" design charts required electronic computation, this method involves many basic numerical assumptions.

Unit Hydrograph

The unit hydrograph principle has been shown to apply satisfactorily to small watersheds. In the absence of observed hydrographs from similar watersheds within the same climatic region as the proposed structure, a synthetic hydrograph may be used. Sufficient studies have been made to enable one to construct a flood hydrograph based on excessive rainfall, hydrologic and topographic characteristics of the basin, in many parts of the USA. The present methods used by the Soil Conservation Service (1957) are based upon this. In fact, it was the Soil Conservation Service's simplifying assumption of a triangular hydrograph which facilitated the extension of the unit hydrograph method. Mockus (1957) expresses one of these simplified results in his equation for peak rate in cubic foot per second.

where: K = constant generally 484,

A = drainage area in square miles,

Q = total storm runoff in inches,

$q = \frac{KAQ}{T_p}$

T_p = time in hours from beginning to rise of peak,

$T_p = D/2 + L$ where D = unit storm duration, and

L = basin lag = 0.6 times the time of concentration.

Regional Synthesis of Frequency Analysis

The need for a simple method of estimating peak rates of runoff with 10- or 25-year return frequencies has led to the correlation approach. Since rapid application rather than great accuracy are the desiderata, this approach neglects the hydrologic components of individual flood events, and presents a multiple graphical correlation of factors which may be easily read off maps. Satisfactory correlations can be assured by restricting the region in which the method may be applied, or by introducing a zonal parameter. The basis of this method is an adequate network of flow recorders, so that statistical fluctuations may be accounted for. Potter (1950, 1953, 1954) has treated this subject extensively.

The Rational Method

Despite the fact that Kuichling originally promulgated this method in 1887 it has outlived many more complicated formulae. In fact it is the simplicity of $Q = CIA$ which not only accounts for its popularity but also justifies its use in the absence of more elegant techniques. As from about 1940 this method received much criticism from researchers. The connotation "rational" was criticized. The basic simplifying assumption of uniform rainfall intensity in time and space was criticized. "C" was shown not to be constant but rather to vary from one storm to another. It has been suggested that peak rates of runoff are frequently caused by intense rain of duration far shorter than the time of concentration. Various modifications have been suggested, such as raising A to a greater power than unity, or making C depend on rainfall intensity as well as on land use. The other weakness in the method, that of determining the time of concentration, has received much attention. Many nomograms have been produced on the basis of either hydraulic theory or watershed observations.

Detailed airfield studies made by Herner, Mainfort and Pharr (1950) resulted in an optimistic view of the Rational Method, but recommended larger C values than are commonly used. Where refined techniques are inapplicable this method still can serve as a basis upon which engineers may build and apply their experience. It utilizes rainfall data which are fairly generally available. It provides a simple unifying method which can be applied to a larger number of designs, each of which do not warrant protracted study.

Current S.C.S. Methods

The USDA's Soil Conservation Service (1957) have produced half a dozen routine methods for deriving spillway design hydrographs. Maps, tables and graphs have been presented which require only the following watershed data for their application: geographic location, drainage area, hydrologic soil-cover complex, and time of concentration.

The geographic location enables a direct estimate to be made of the probable maximum 6-hour point rainfall. This estimate is modified according to the size of the drainage area, by using one of three curves applicable to the various major climatic regions of the USA. The sequential accumulation of this rainfall is then tabulated for short durations by using the appropriate storm distribution curve, selected from the four which apply in different parts of the country. The hydrologic soil-cover complex number must be determined from a table giving 128 combinations of land use or cover, treatment, hydrologic condition and relative infiltration rates of the soil. Hydrologic soil-cover complex numbers obtained from this table correspond to average antecedant moisture conditions. In a region where heavy rainfall or light rainfall and low temperatures are likely to occur during the five days prior to the design storm, a higher hydrologic soil cover complex number should be used. For optimum flood dampening conditions of a soil, which will probably be dry but not to the wilting point and is plowed or cultivated satisfactorily, a lower number should be used. A table provides for the conversion of a hydrologic soil cover complex number for the intermediate condition to that for either of the other conditions. The appropriate hydrologic soil cover complex number signifies a particular curve in a family which relates rainfall in inches to direct runoff in inches. These relationships intrinsically consider various initial abstractions and infiltration curves. The runoff curve, described in the second last sentence, is used to estimate the series of accumulated direct runoffs. The next step in the tabular solution of a design problem is to obtain the increments of direct runoff for the previously selected uniform time intervals, as differences between successive runoff accumulations.

The preceding steps result in a series of Q values, which can be thought of as the total storm runoffs from each of a staggered set of elemental hydrographs. Peak values for each of these can be obtained from the equation mentioned on page 57, i.e. $q = \frac{484AQ}{T}$.
Knowing the time to peak (see page 57), and using the generalization that recession lasts $^5/_3$ times longer than this, it is a simple matter to plot the elemental hydrographs in sequence. Arithmetic addition of all these elemental hydrographs generates the composite hydrograph for use in spillway design.

Procedural alterations for dealing with situations presented by complex or large watersheds, and for the computation of peak discharges for a storm of any duration are described. Any differences involving soils, or cover, or topography possessed by a watershed may be ignored, provided that: (1) they are about uniformly distributed over the watershed, or (2) they are at the hydraulically remotest parts of the watershed. The composite hydrograph derived from as few as two incremental triangular hydrographs provides relatively accurate results. It depicts the watershed and storm influences which may be overlooked with a single triangular hydrograph.

A large portion of the USDA's, SCS (1957) handbook is devoted to dimensionless hydrographs, which are presented in graphical and tabular form. Little good would come from describing these techniques here, as they can not be applied to other countries which lack sufficient flood records from small watersheds.

RECOMMENDATIONS

Tremendous progress has been made, particularly during the last decade, in techniques for the estimation of flood flows from small ungauged watersheds. Most of the work has been done in the United States. However, since the contributing factors have been satisfactorily isolated, these methods could be transposed to remote lands with a minimum of local observational research. If suitable analysis is applied to existing meteorological data and if infiltration and short term runoff observations are made promptly, then the advances in this branch of technology can benefit the development of young countries within three or four years. More refined results can come from other long-term research, which can now be planned efficiently upon the basis of American discoveries.

Some research proposals are, therefore, outlined which would enable the newer countries to take advantage of the newest design procedures. The benefit would not be restricted to work in watersheds from 200 acres to three square miles, but would affect designs on catchment areas of a hundred square miles and more. The cost of executing the research would be negligible in comparison with the savings of public and private capital on hydraulic structures which currently are either overdesigned or which fail prematurely due to the inadequacy of present knowledge.

Rainfall-Intensity-Frequency Determinations

As always the starting point for a runoff-peak estimate is a reasonable estimate of the rainfall-intensity. The production of rainfall-intensity-frequency maps should constitute one of the first hydrologic investigations of an emerging country. If recording rain gauge data is available, it should be subjected to a Gumbel or similar extreme value analysis. In the absence of country-wide recorder data this analysis may be supported by or replaced by empirical correlations with commonly observed climatological data. Such empirical means of estimating short duration rainfall intensity based on United States observation were found satisfactory and used extensively by Reich (1959) to predict rainfall intensities for fifteen- to sixty-minute durations in the Union of South Africa. Bruce (1959) has also made ingenious use of limited data to produce design charts for Canada. It may be well to point out that estimates of the six-hour rainfall maxima should be strived for, as this will facilitate the application of the USDA, SCS (1957) runoff methods.

Time-Distribution of Storm Rainfall

It is also important that the characteristic time-distribution of severe rainstorms should be described for the climatic zones throughout the continents. The chronological record of rainfall needs only be analyzed for the few very intense storms, so that no large amount of work is involved. The end-product of this storm analysis would be a curve, for each climatic zone, depicting the ratio between the six-hour amount of rainfall to that precipitated at any earlier time in the storm. A dimensionless presentation should be possible, so that international differences in units will present no problem.

Antecedent Precipitation Index

There is an additonal way in which existing meteorological data can contribute to the improved runoff techniques. Regional studies could present the moisture conditions likely to prevail over the watershed when design storms are most likely to occur. Perhaps the Anticedent Precipitation Index for five days prior to synoptic conditions favorable to "cloud-bursts" could be studied from past records.

Infiltration

A soil physics team should obtain runoff hydrographs from the major combinations of soil- and plant-cover-type as soon as possible. Such information would serve as a preliminary guide in estimating the "hydrologic soil-cover complex number" required in the application of the SCS flood-peak determinations. Well organized teams should be able to prepare tentative estimates for each country within two years, after which they could proceed with further refinements. Techniques have been fully described by Sharp, Holtan and Musgrave (1949), Sharp and Holtan (1942) and many others. Portable infiltrometers could simply be built according to one of the tested American designs. Standardization on this or simpler equipment is desirable so that results from various countries may be compared directly.

Rainfall/Runoff Observations

Autographic recording gauges should be installed immediately to obtain hydrographs and hyetographs from a few small watersheds in each interested country. Three or four years' data of this type would show tentatively how the SCS method could simply be adapted to each country's conditions. A minimum of three small watersheds should be instrumented in each of the country's major hydrographic regions. Additional information may sometimes be obtained from existing stream gauges. Frequently an inexpensive alteration will be necessary to enable the old recorders to reproduce fluctuations with time more precisely. The addition of cheap crest-stage recorders to existing low-flow stations will frequently be beneficial.

Areal Distribution

The areal distribution of storm rainfall can be neglected in the calculation of runoff peaks from areas of less than ten square miles. When considering larger watersheds appreciable reductions may need to be made to the point-estimates of rainfall. This becomes more important when short duration storms are concerned. A tentative estimate of the appropriate reduction may be made from American curves. There are meteorological reasons to believe, however, that this storm characteristic differs between various climatic zones. Since refined runoff estimates for larger watersheds involve this relationship, suitably located long-term studies should be commenced as soon as possible. To meet this requirement each climatic or rainfall region should be provided with one or two intensive rainfall-rate networks. Each of these should contain, if possible, twenty five or more gauges within a fifty square mile or larger area. Results from these studies would be greatly enhanced if field engineers were to conduct bucket surveys to obtain storm totals as soon as exceptional rainfalls are reported in their locality.

Probable Maximum Storms

The above areal studies of storm rainfall will be of great value to meteorologists later entrusted with the task of computing probable maximum storms for special important structures. Such major water-control structures are not designed on a frequency analysis but rather upon the total amount of moisture which could blow in over the watershed on any occasion. The appropriate computations have been described in hydro-meteorological literature and involve the following: (1) taking the results of depth-area-duration analysis of major storm precipitations which have or could occur locally, (2) using the moisture charge and rate of inflow for assumed atmospheric conditions, and (3) enveloping the adjusted values for all storms to obtain the depth-area-duration curves of probable maximum precipitation. Such estimates like those of Clark (1958) have been generalized into maps for all of continental USA. It is not considered that universal coverage of this type is required by many of the emerging countries, but individual projects will arise where this information is necessary. Since data on numerous past storms are required to make even isolated determinations, time should not be lost in recording details of major storms as they occur. This is a further justification for commencing the areal distribution studies proposed in the preceding section.

The investigations mentioned above should, of course, be supported by long-term hydrologic research on small watersheds. This, however, is a subject of many facets and can not be discussed here. The foregoing is merely a review of the most urgent studies which should be made if wasteful expenditure on many small structures is to be avoided, and if disasters are to be eliminated, by sound runoff design.

SUMMARY

After abstracting many papers, the four main methods applicable to the evaluation of flood peaks from small watersheds are presented. The USDA's Soil Conservation Service design method for these and larger watersheds is presented briefly. In conclusion certain simple studies are outlined which should be undertaken if other countries are to make use of the advanced design techniques developed in the United States.

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