RAINFALL AND RUNOFF STUDY OF SMALL DRAINAGE AREAS

Final Report

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Prior to 1951 extensive studies were made for the purpose of developing runoff formulae. Typical variables were rainfall intensity, slope, and ground cover. In principle the method of study was that of measuring the rainfall and comparing it to the runoff measured at stage recorders. Fitting curves to the data completed the process and provided formulae for estimating runoff quantities. The most widely used was the so-called Rational formula. The formula gives satisfactory results for watersheds of a few thousand acres to several hundred square miles.

For the largest watersheds, where correlated rainfall and runoff data are likely to be available, the rational method has come to be replaced by the unit-graph method. The unit-graph method is used to supplement the scanty data on which guidelines for application of the rational method had to be based.

Highways designed during the 20's - 40's used drainage structures designed to carry the flow indicated by such formulae. Highway design of drainage structures ranges from small pipes for basins of a few acres to suspension bridges over major rivers with watersheds of millions of acres. As experience was amassed with estimating quantities and observing performance of completed work, it became apparent that the degree of success varied with the size of the watershed; that is, the quantities were sufficiently accurate for large watersheds but of limited value for the small watershed. The present project was undertaken in an effort to develop guidelines especially applicable to very small Connecticut watersheds based on an adequate amount of actual data.

During 1950, several meetings were held by representatives of the Civil Engineering Department of the University and the Connecticut Highway Department.

A long term program intended to collect information from which small watershed design methods could be devised was undertaken. Five watershed areas in Mansfield were selected as typical of the Connecticut area. The areas covered ranged from 6 acres to 375 acres.

Using the rational formula and Connecticut rainfall statistics, Parshall flumes were designed for the exit of the highway culvert which defined the downstream limit of each watershed.

These flumes were constructed in 1951-52 by private contractors. Calibration of the flumes by weir plates was carried out by University of Connecticut personnel. Each flume was equipped with a Leopold-Stevens seven-day stage recorder. The floats were placed in corrugated pipe wells alongside the flumes and connected by pipe to the bottom of the channel. The last site selected along the North Eagleville Road utilized a V-notch weir in place of the Parshall. The runoff was thus recorded continuously by pen on a chart as stage or level in the flume.

Measurement of rainfall was judged to be simpler and was accomplished by one 8 inch standard rainfall receiver per location. The positions were typically 50 to 100 feet upstream from the flume. As air disturbance was thought to cause some of the discrepancies in rain or snow retained, various shields were used around the receivers. Once a week, when the stage recorder charts were changed, the total precipitation since the last servicing was manually measured and recorded. A continuously recording rain gauge existed on the campus and would be used to supplement the weekly total.

Recognizing the randomness of rainfall distribution, it was anticipated that data would be collected for 25 years in order to accumulate sufficient information for analysis. Periodically, the data was transcribed from the stage recorder charts and rainfall data to give tabulation of rainfall versus runoff quantities. At ten years, a concentrated review of the data gave no distinct correlation and the conclusion was reached that the data were insufficient and further quantities of information were needed before trends would be apparent. Each watershed originally had certain characteristics and with time developed peculiarities. A description of each will make the difference and varying change more apparent.

The first installation at a six acre watershed was located between Route 89 and the Natchaug River, one-half mile north of the Willimantic line. The general elevation of the site was 200 feet above sea level. The watershed was limited by two sharply defined parallel ridges 800 feet apart. Vertical distance from the top of the ridges to the flow line was 40 feet. The Parshall flume had a width of 12 inches in this installation and throughout several years of record, only an occasional small stage appeared on the recorder. The stage level was typically too small to be read from the calibration. The upper portions of the ridges were covered with oak and pine. The lower portion of the slopes and the rounded valley floor were in meadow grass, uncut during the period of observation.

In 1960, the two ridges were leveled and the valley between filled. At that time, the material in and under the ridges was found to be granular. The ridges may have been remnants of glacial eskers truncated by the river and located on an old sand valley train. A large area extending a mile upstream along the river and reaching as much as one-half mile to either side is clean sand and gravel 50 - 100 feet deep. The extremely good internal drainage of this soil explains the complete lack of runoff.

The second (70 acres) and third (20 acres) areas lie east of Conn. Route 32, approximately 1,000 feet north of Browns Road. The old location of Route 32, now known as Fern Road, crosses the eastern portion of these watersheds.

The more southerly watershed included a 10 acre pond. The elevation at the perimeter of the watersheds reached 530 feet compared to 290 feet at the culverts, and thus at the flumes west of Route 32. The cover was open woods used as pasture.

In 1958, a local sand and gravel company bought the overburden material from that portion of the watersheds immediately above the flumes and started hauling to their plant in Eagleville. The topography changed constantly over a three year period. Obviously, the material removed was granular, best described as sand with many cobbles and traces of silt and clay. The area was graded to its current shape in 1966, although localized removal has continued. The excavation removed the divide between the watersheds and lowered the land surface so as to provide a large retention basin which the runoff must collect before any flow passes down the former brooks. Between storms the pond level falls due to seepage through the open granular material. This flow does not return to the brook above the stage counters. Consequently, a large storm may cause no significant flow. Yet a small storm close on the heels of a large one can cause runoff. Attempts to analyze the data from these two locations have been fruitless. Other agencies have investigated the effect of infiltration rates on runoff and up-to-date textbooks now emphasize its importance. (See Water Resources Engineering, Linsley & Franzini, McGraw-Hill).

The fourth watershed (300 acres) was located between the University and Conn. Route 44A and straddles Conn. Route 195. The measuring flume was located on the north side of Route 44A, approximately one mile east of Route 195. The rainfall collector was 100 feet south of Route 44A in the extreme northeast (downstream) end of the watershed. The recording rain gauge, at that time located at the Agriculture School, was nearer to the upper end of this drainage area than was the receiver. The central portion of the area occupied relatively flat high ground at elevation 650 feet and included several areas of swamp. The upper portion from elevation 720 feet to 650 feet was bare,open fields in grain or crops. The land falls sharply to the northeast to east to elevation 540 feet at the measuring station and on to 250 feet at the Fenton River. The receiver at elevation 550 feet did not correlate with the Agriculture School recorder on the south side of the ridge. The lack of coordination between the receiver, the Agriculture School rainfall recorder and the flume runoff stage recorder can best be explained as the result of significant variation in storm intensity over this relatively small drainage area. Depending on the direction of the storm movement, the relative rate of rainfall at various points within the watershed constantly changed. As a consequence, two rainfall measurements were not adequate to define the storm intensity.

This was the largest drainage area and was provided with a 3 foot Parshall flume. Normal flow has proven low, probably due to the flatness of much of the area, and a sizeable storm is required before the recording chart can be read accurately. For larger storms, the flume readings become more accurate, but the uncertainty due to probable variations in rainfall becomes significant. Minor changes due to change in surface cover are not reflected at the recorder due to low sensitivity of the 3 foot weir. Debris, winter sand, etc., in the weir had as much effect on stage as did the increase in runoff due to minor storms.

After installation of the above-mentioned four measuring flumes, a fifth area was added. This drainage area was basically the northwest quadrant of the University campus containing 325 acres. As local variations in rainfall intensity were not anticipated, no rainfall receiver was used. That is, it was assumed that the recording meter at the Agriculture School would be sufficient. During the period of observations, this area of the campus was in a constant state of alteration. It has proven impossible to document the quantity of roofs, pavement, curbs, gutters, pipes, fresh excavations, etc., for each peak of the runoff recorder. By 1970, only one-third of the area, consisting of 1:6 grassed and wooded slopes remained undeveloped.

Very large flows have occurred at the V notch weir. The stream channel is not adequate for a major storm. In recent years, due to increased rate of runoff from improvements, the culvert has been topped and the road washed out on several occasions. The time of concentration has understandably decreased with the most severe flooding occurring in 10 to 15 minutes. As the rainfall recorder and the stage recorder have not recorded the greatest intensity at the same times, it must be assumed that the critical storms have had very narrow or limited areas of concentration. Consequently, no records are available from which to confidently predict rainfall-runoff relationships.

Recent studies at other institutions substantiate the conclusion that a single rainfall station for a 300 acre watershed will not give adequate information for establishing rainfall intensity throughout the area.

Additional rain gauge stations could be added to the Route 44A watershed for more accurate measurements. However, there appears to be no practical means of improving the sensitivity of the 3 foot measuring flume. As Route I-84 will entirely eliminate what remains of the Route 89 station and drastic regrading has provided extensive upstream storage at the Route 32 areas, readings have been discontinued.

In recent years, spurred by Federal interest in water resources, research hydrologists have studied the general problems intensively. Multiple correlations have been used to test formulas and variables against the data from thousands of watersheds. The conclusion has been that there is no reliable method for small watersheds and that for them the rational method is as good as any. Parameters derived from a small number of stations, however, have now been proven to have little value.

Although it appears impossible to make the hoped for reliable quantitative numerical predictions from the data collected, certain general conclusions can be drawn:

a. With the exception of the extreme stages of the 1955 storms, the runoff records imply that the rational formula used for sizing the measuring flumes was conservative.

b. Permeability of the underlying soil is a major factor in determining runoff quantities. At the installation on Route 195 and those on Route 32, the low runoff rate can be explained by the high permeability of the underlying valley train or terrace material. At the Route 195 location, the entire area was granular. The Route 32 locations started on the upland, but the runoff stream crossed a substantial distance of valley train or terrace material before reaching the measuring flume.

c. With increased development of the campus, the time of concentration decreased and short intense storms became more significant. The highest flows were observed after storms of a 20 - 30 minute magnitude. Longer storms do not maintain the intensity of the short storm.

d. Rainfall intensity varies sharply in short distances. Rainfall weekly totals from the receivers at the various locations within Mansfield show significant differences.

e. Due to the physical changes which have occurred in the different areas, it is pointless to continue data collection to the end of the originally projected 25 year period.

Data Collection

Instrumentation at each site consisted of a continuous stage recorder for flow level in the measuring flume and a manual rainfall gauge. Each week when the stage recorder chart was changed, the quantity of water in the rainfall gauge receiver was noted. Raw data thus consisted of stage recorder charts and weekly rainfall totals.

All flumes were calibrated and stage data reduced to tabulations of weekly maximum stage and corresponding flow. Recorder charts and weekly rainfall data are available from November 1952 to 1970 and tabulations similar to that attached were prepared through 1964.

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Route 32 - 4 ft Flume (Area 107.95 Ac.)

Date	Maximum Gage Height in Feet	Rate of Flow (c.f.s.)
8 - 28 - 55	0.15	0.80
9 - 5 - 55	0.21	1.36
9 - 20 - 55	0.28	2.15
9 - 24 - 55	0.42	4.07
10 - 7 - 55	0.30	2.39
10 - 15 - 55	1.30	24.21
10 - 16 - 55	1.40	27.21
11 - 1 - 55	0.46	4.70
11 - 5 - 55	0.80	11.25
11 - 12 - 55	0.28	2.15
11 - 15 - 55	0.32	2.65
11 - 29 - 55	0.37	3.33
12 - 2 - 55	0.15	0.80
12 - 6 - 55	0.26	1.91
12 - 8 - 55	0.32	2.65
3 - 9 - 56	0.50	5.36
3 - 14 - 56	0.52	5.70
3 - 17 - 56	1.40	27.21
4 - 5 - 56	0.40	3.77
4 - 17 - 56	0.39	3.62
4 - 30 - 56	0.37	3.33