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Engineering Aspects of the Influence of Forests on Mountain Streams

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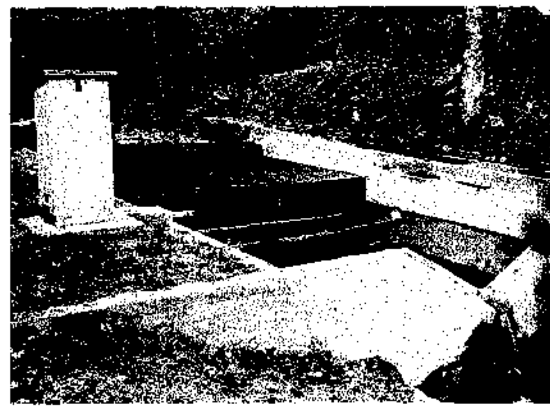

FIG. 1. A 120-DEG V-NOTCH WEIR INSTALLATION WITH SILTING BASIN, PONDING BASIN, AND BY-PASS

IN progress at the Appalachian Forest Experiment Station, near Asheville, N.C., is a comprehensive investigation of the influence of forests on mountain streams. The objectives and methods of these studies, and some of the results to date, are outlined in the accompanying article. Of particular interest are the descriptions of the special stream-gaging devices, the data on the degree of stream control afforded by forest cover, and the conclusions in regard to infiltration capacity of forest soils. Mr. Hertzler's paper was on the Hydraulics Division program at the 1939 Spring Meeting.

IN the broader sense, the purpose of the investigations now in progress at the Appalachian Forest Experiment Station is to determine the effects of forests on water and land resources as they relate to social and economic problems. Of the many phases of research falling under this head, investigations to determine the effects of forests and forestry practices on erosion control and runoff present the most interesting engineering aspects. The purpose of this phase of the investigation is to establish principles and practices of forest land-use, consistent with recognized sound methods, which will increase the quantity and quality of usable water, decrease flood flows, and control erosion.

To arrive at a practical scientific solution of these problems involves a clearer understanding of the basic laws underlying the entire hydrologic cycle than can be obtained from existing data. This is especially true of the phenomena of runoff, ground water, microclimate, and erosion processes.

Numerous experimental drainage areas have been established within several forests and in neighboring agricultural areas for the purpose of obtaining sufficient data to supply this requisite information and also to determine the relation between these phenomena and vegetative cover conditions. In the selection of the areas due consideration was given not only to vegetation but to physiography, geology, soils, and climate as well, so that the results would be as closely as possible representative of the region. Many engineering problems were encountered in the design of the experiment as a whole and in selecting the location, type, and size of stream gage to be used for individual drainages.

SPECIAL GAGING DEVICES DEVELOPED

For small streams in forested areas there was a need for a gaging device with a greater capacity than a 90-deg V-notch weir, but with accuracy at low flows and with provisions for measuring deposited material from undisturbed forest land. To meet these requirements the 120-deg V-notch weir installation shown in Fig. 1 was developed. (A detailed description of this device was given by the writer in CIVIL ENGINEERING for November 1938.) Other types of sharp-crested weirs are also used where the quantity of silt does not impose prohibitive maintenance costs.

Within the experimental area at Copperhill, Tenn., essential requirements of a gaging device are (1) that it must pass large quantities of silt, and (2) that it must measure the rapid storm runoff from completely denuded drainages. For these areas the San Dimas flume, as developed by the California Forest and Range Experiment Station, was used. (For description of this flume see "Measurement of Debris-Laden Stream Flow with Critical-Depth Flumes," by H. G. Wilm, J. S. Cotton, and H. C. Storey, TRANSACTIONS Am. Soc. C.E., Vol. 103, p. 1237.) Fig. 2 shows a typical installation with an entrance radius equal to twice the width of the flume and the floor on a 3-per cent slope. The head is measured in a stilling well into which water passes through a vertical slot placed downstream from the critical depth. This type of installation has proved very satisfactory.

For general purposes a modified Columbus type 1-A deep notch control has been recently developed (Fig. 3) and is now being rated in the National Bureau of Standards Hydraulics Laboratory. Provided the ratings are satisfactory, it will be used for many of the future installations. Its advantages are a non-silting ogee control, accuracy for a wide range of discharge, and a predetermined rating table.

A definite need for well studies was realized early in the investigations, so numerous ground-water wells, as illustrated in Fig. 4, have been constructed. Whenever possible, they are equipped with recording gages. Well data have thrown much light on the ground-water discharge to streams and also on methods of separating ground-water flow from storm flow for analyzing the hydrograph.

After the data from the installations are collected, assembled, and checked in the field, they are sent to the office for compilation and study. Precipitation, runoff, and the associated data are analyzed by six-month periods, corresponding to the growing and dormant seasons, to show the general characteristics of each of the 39 streams now under investigation. At the present stage of data analysis, certain trends are already indicated, and in some investigations definite results have been obtained. A few examples of these derivations, which involve engineering principles in the analysis and have definite engineering application, will be presented in the following paragraphs.

TYPICAL ANALYSES AND APPLICATIONS

Land-Use–Runoff Relations. From 1,550 observations of storm hydrographs on areas of different types of land-use, a frequency distribution curve of peak discharge has been prepared (Fig. 5). Data were obtained from drainage areas of the Coweeta and Bent Creek Experimental Forests and from the Copper Basin, Tenn., and include storms of 0.5 to 6.0 in. of total precipitation, varying in intensity from 0.01 to 4.26 in. per hour. The curves of Fig. 5 show separately the data from denuded lands, overgrazed pasture, abandoned farmland, and forested drainages. Taking runoff from forested lands as unity they indicate, for example, that for 10-per cent frequency of all the storms over $^1/_2$ in., abandoned farmland, overgrazed pasture, and denuded lands

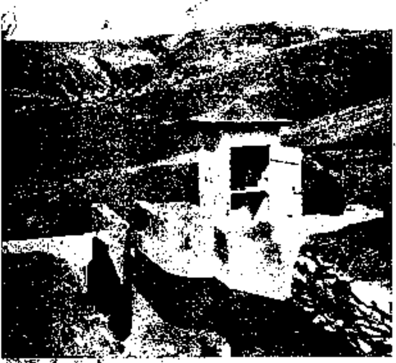

FIG. 2. A 2-FT SAN DIMAS FLUME IN THE COPPER BASIN EXPERIMENTAL AREA, TENNESSEE

FIG. 3. A MODIFIED COLUMBUS TYPE 1-A DEEP NOTCH CONTROL TO MEASURE FLOW FROM SMALL DRAINAGES

produce peak discharges respectively 12, 24, and 47 times as great as forest land. Curves of this type aid in predicting flood flows, are useful in designing hydraulic structures, and are applicable for other engineering purposes within areas of similar geology.

Six-month summaries of stream discharges form another basis for comparing stream behavior. The example shown in Table I is for the dormant season from November 1, 1936, to April 30, 1937, for streams of uniform forest cover on the Coweeta area in Macon County, North Carolina. The table contains discharges in cubic feet per second per square mile, broken down for each stream into total runoff, seepage, or ground-water flow, and storm flow. Similar tables for the entire period of record indicate that seepage flow as a percentage of precipitation increases with the area. Expressed as a percentage of runoff, seepage flow varies from 86.6 to 91.3, while storm flow varies from 8.7 to 13.4. The high seepage flow along with the corresponding low percentage of storm flow is an indication of the extent of control afforded by the vegetative cover. Records for overgrazed pasture and denuded and abandoned agricultural lands show a higher percentage of surface runoff and a lower percentage of ground-water or seepage flow than do these forested areas.

TABLE I. DISCHARGE OF STREAMS IN COWEETA EXPERIMENTAL FOREST

Six-Month Summary—November 1, 1936, to April 30, 1937

			RUNOFF					SEEPAGE FLOW			STORM FLOW		
AREA SQUARE MILES	STREAM No.	PRECIPITATION INCHES	Maximum*	Minimum*	Mean*	Inches	% of the Precipitation	Mean* (Base-flow)	% Run-off	% of the Precipitation	Area Inches	% Run-off	% of the Precipitation
0.007	5	44.37	37.14	1.190	3.807	25.621	57.7	3.392	89.1	51.4	2.793	10.9	6.3
0.016	4	42.85	31.343	1.709	5.701	38.375	90.0	5.174	90.8	81.7	3.530	9.2	8.3
0.034	6	43.81	27.01	0.658	3.171	21.343	48.7	2.822	89.0	43.3	2.348	11.0	5.4
0.036	3	42.01	21.643	1.008	2.540	17.101	40.7	2.200	86.6	35.2	2.292	13.4	5.5
0.048	2	40.32	18.217	0.557	3.189	21.466	53.2	2.885	90.5	48.2	2.039	9.5	5.0
0.061	1	40.19	13.289	0.593	2.664	17.928	44.6	2.390	89.7	40.0	1.846	10.3	4.6
0.227	7	40.28	16.100	1.016	3.646	24.544	60.9	3.329	91.3	55.6	2.135	8.7	5.3
0.332	10	42.13	20.712	1.273	4.362	29.363	69.7	3.901	89.4	62.3	3.112	10.6	7.4
2.794	9	49.20	41.990	1.575	5.267	35.456	72.1	4.596	87.3	62.9	4.503	12.7	9.2
2.932	8	44.45	29.865	1.383	5.837	32.426	72.9	4.212	87.4	63.7	4.086	12.6	9.2

* Cubic feet per second per square mile.

Until more of the hydraulic, hydrologic, and meteorologic variables can be segregated, land-use-runoff relationships can best be studied on plots and small drainages where many of these variables can be completely eliminated. To apply results from plots to small drainages and from small drainages to large ones is a problem that has not been completely solved. However, recent data have thrown much light on the problem to the extent that results from plots and small drainages can be used to predict flood flows more intelligently. This is a valuable contribution when viewed in the light of extensive flood control programs now in progress.

Infiltration Capacity. Although in recent years engineers have done much to illumine the concept of infiltration capacity, even to the point where it can be quantitatively determined with considerable accuracy for large drainages, it still remains a perplexing problem.

While analysis of runoff and precipitation data at the Appalachian Station has not as yet produced conclusive results, it has led to a clearer understanding of this phenomenon. The undisturbed, deep soils of forested areas have a very high infiltration capacity; in fact, it is questionable whether this capacity is ever exceeded by rainfall intensity.

HYDROGRAPH ANALYSIS OF INFILTRATION

An example of a hydrograph analysis to determine infiltration is presented in Fig. 6. The curve marked "observed runoff" is the storm hydrograph obtained from a continuous water-level recorder chart. The curve marked "mass precipitation" is a reproduction of the storm rainfall record from a float-type precipitation gage, subsequently corrected by subtracting 10 per cent because studies conducted by the Station show that this amount is intercepted by the vegetation covering this drainage.

Ground-water is separated from observed runoff by the following method:

1. A normal depletion curve of ground-water discharge is obtained for this stream by tracing all existing records in such a manner as to eliminate stream rises.

2. The normal depletion curve is fitted to the recession side of the hydrograph (labeled "observed runoff" in Fig. 6) and extended backwards to some point beyond the time of observed peak runoff.

3. The accretion side of the ground-water flow curve is obtained from recorded ground-water elevations in a well, correlated with known discharge rates. The points of known discharge rate are (1) on the observed runoff curve at the beginning of the stream rise (0.051 cu ft per sec at 6:40 p.m., Fig. 6) and (2) on the extended ground-water depletion curve at the time of the peak on the ground-water stage hydrograph. The determination of this second point is based on the assumption that the peak ground-water discharge occurs at the time of the maximum ground-water elevation. In the example illustrated by Fig. 6, this time, taken from a recorded ground-water stage hydrograph (not reproduced here) was 3:45 a.m. With these two points of known ground-water discharge, the recorded ground-water stage hydrograph can be converted into the discharge hydrograph labeled "ground-water flow" in Fig. 6. (In the example shown, the ground-water rise, which was very slight, occurred at the time the observed runoff returned to normal. For winter storms, with more moisture in

FIG 4 GROUND-WATER WELLS FOR DETERMINING ELEVATIONS OF THE WATER TABLE

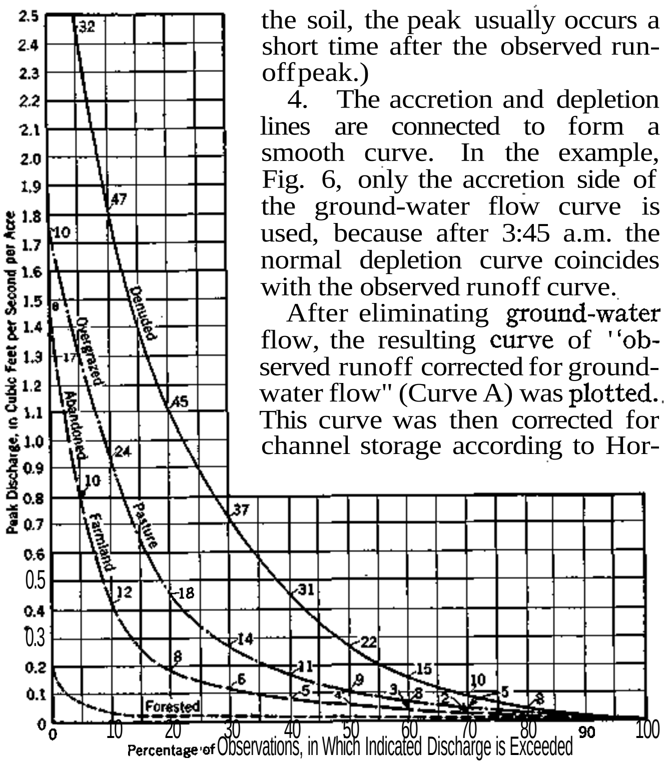

FIG. 5. FREQUENCY DISTRIBUTION OF PEAK DISCHARGES ON SMALL WATERSHEDS WITH VARIOUS TYPES OF COVER
Based on 1,550 Individual Storm Hydrographs on 21 Watersheds of 4 to 1,859 Acres in the Southern Appalachians

the soil, the peak usually occurs a short time after the observed runoff peak.)

4. The accretion and depletion lines are connected to form a smooth curve. In the example, Fig. 6, only the accretion side of the ground-water flow curve is used, because after 3:45 a.m. the normal depletion curve coincides with the observed runoff curve.

After eliminating ground-water flow, the resulting curve of "observed runoff corrected for ground-water flow" (Curve A) was plotted. This curve was then corrected for channel storage according to Horton's method[1] resulting in the curve "observed runoff corrected for ground-water flow and channel storage" (Curve B). Curve B, in turn, provides the data for plotting the "mass surface runoff" curve. Finally, surface detention and mass infiltration determined by Horton's method,[2] also surface detention and mass losses determined by Sherman's method,[3] were plotted. The difference, both in infiltration and in surface detention as computed by the two methods, can be seen by examining the curves. Apparently neither method is completely satisfactory for an infiltration analysis under the observed conditions.

This interpretation of infiltration capacity is substantiated by field observations and also by plotting precipitation intensity against infiltration capacity obtained by Sherman's and Horton's methods, in which cases the resulting graph is nearly a 45-deg line.

CORRELATIONS BETWEEN DISTRIBUTION GRAPHS AND BASIN CHARACTERISTICS

Unit-Graph Analysis of Runoff. The unit-graph principle has been investigated as a possible method of analyzing runoff from small drainage basins. The investigation of from 2 to 6 unit-graphs for each of 22 drainages revealed certain correlations between the shape of the distribution graph and physical characteristics of the drainage basin. These correlations are as follows:

1. For comparable forested areas peak percentages of runoff consistently decrease as the drainage area increases.
2. The width of the bases of the distribution graphs increases with the area.
3. The effects of vegetative cover are reflected in the peak percentage and widths of the distribution graph.

In connection with this study, pluviographs also revealed marked trends such as:

1. Runoff coefficients to be applied to the pluviograph increase with accumulated rainfall.
2. Rainfall intensity variations have a greater effect on small, lightly vegetated areas.
3. The effect of previous rainfall on the surface-runoff coefficient is greatly reduced after a break of several hours in surface runoff.

While this analysis has not yet been completed, it shows that the unit-graph principle affords a sound method of investigating land-use-runoff relations on small drainage basins.

The Appalachian Forest Experiment Station, under the directorship of Dr. R. E. McArdle, is one of twelve forest experiment stations maintained by the Forest Service of the U. S. Department of Agriculture. Dr. C. R. Hursh is in charge of the forest influence studies for this station.

REFERENCES

[1] Horton, R. E.
1936. "Natural Stream-Channel Storage," *Transactions, American Geophysical Union*, 17th annual meeting, pp. 406-415.
1937. "Natural Stream-Channel Storage," *Transactions, American Geophysical Union*, 18th annual meeting, pp. 440-456.
1935. *Surface Runoff Phenomena*, pub. 101, Horton Hydrologic Laboratory, Part 1.

[2] 1937. "Determination of Infiltration Capacity for Large Drainage Basins," *Transactions, American Geophysical Union*, 18th annual meeting, pp. 371-385.

[3] Sherman, L. K.
1938. "Determination of Infiltration Rates from Surface Runoff," *Transactions, American Geophysical Union*, 19th annual meeting, pp. 430-435.

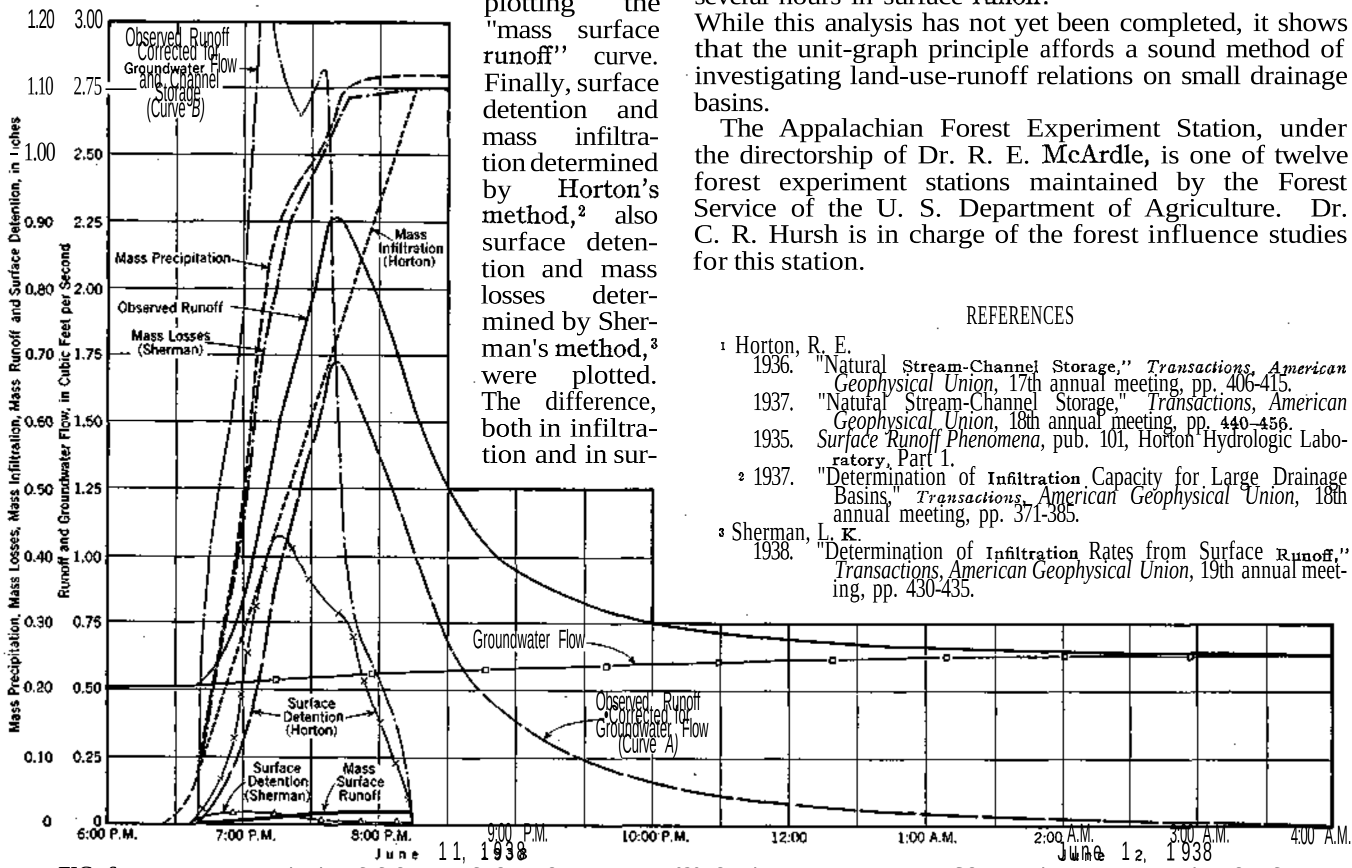

FIG. 6. HYDROGRAPH ANALYSIS OF THE STORM OF JUNE 11, 1938, ON A DRAINAGE IN THE COWEETA EXPERIMENTAL FOREST