

RESEARCH PROJECT PARTIAL TECHNICAL COMPLETION REPORT
OWRR PROJECT NO. A-006 OKLAHOMA

The Mechanism of Direct Surface
Runoff From Rainfall

Submitted to

The Oklahoma Water Resources Research Institute
Oklahoma State University
Stillwater, Oklahoma

by

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ABSTRACT

Studies on a synthetic grass material used to simulate a natural vegetation for overland flow conditions show that two regimes of flow occur, one occurring when the flow depth is less than the height of the grass (assumed as laminar flow) and another occurring when the flow depth is greater than the height of the grass (turbulent flow). Because the synthetic grass occupied a considerable portion of the flow depth the physical bottom was assumed as not being representative of the effective bottom. Thus, for turbulent flow an effective bottom was found as the intercept when water surface elevation was plotted versus discharge to the 0.6 power. The Manning coefficient for the turbulent flow range increased slightly with discharge and its value (average of about 0.032), indicated that the synthetic grass had a high retardance to the flow of water. Assuming laminar flow for the shallow depths, the Darcy-Weisbach f was calculated assuming $f = 64/R_e$, where R_e varied from about 60 to about 700.

KEYWORDS: *Overland flow/Manning coefficient/Darcy-Weisbach
f/*synthetic grass/uniform flow/effective bottom

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OWRR PROJECT NO. A-006 OKLAHOMA

Project Title: The Mechanism of Direct Surface Runoff From
Rainfall

Agreement No: 14-01-0001-806

Principal Investigators:

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This portion of the completion report
relates to that research conducted for the
period July, 1967-July, 1968.

Objectives

The ultimate goal of research of this nature is to route rainfall through the sheet flow phase of runoff, through terrace channels, grassed waterways, detention structures, and spillways to the principal outlet of a small watershed using prediction equations based on, and developed from, known laws of fluid behavior. The specific objectives of this research project are:

1. To develop prediction equations for water surface profiles of overland flow from rainfall by finite increment computer solutions of the partial differential equations of momentum and continuity for spatially varied unsteady sheet flow.

2. To measure actual water surface profiles for unsteady spatially varied sheet flow of water over various natural and synthetic surfaces, and make comparisons with predicted profiles.
3. To develop procedures of routing various rainfall rates through the sheet flow phase and into channel flow phase of surface runoff from rainfall using rational equations.

Extent of Achievement of Objectives

The material presented in this partial completion report relates to that research conducted during the period July, 1967 through July, 1968. The emphasis during this period was to evaluate the roughness characteristics of a synthetic material used as a surface cover to simulate natural vegetation. The material used should approximate hydraulically a thick mat-type, closely-cut grass. The results of this research do not achieve any of the objectives to finality, but they are necessary for the eventual achievement of the project objectives.

Procedure

The synthetic grass material (trade name of PERMA-GRASS) used to simulate a natural vegetation is a polyethylene plastic and has over 7,000 individual blades of grass per square foot. The height of the blades are fairly uniform and average about 1.00 inch in height. The blades are rather stiff and do not bend over appreciably when subjected to the flow of water through them.

The research was conducted using an indoor flume about 1.5 feet wide by 44 ft. long. The flume was constructed by laying a large steel H-beam on its side. The slope of the flume is variable (0-4%) and the flume is equipped with spray nozzles to simulate natural rainfall. Rainfall rates of approximately 2, 4, 6 and 12 inches per hour can be simulated. A base flow can be introduced at the upstream end of the flume for uniform flow tests and for spatially varied flow tests with an initial flow.

The flows introduced at the upstream end can be measured with a 3/4 inch nutating disk water meter that was calibrated with a bucket, stop watch, and scales. A calibrated 0.6 H.S. flume is positioned at the flume exit to obtain the outflow hydrographs. At low flows a bucket, stop watch, and scales are used for steady state flow determinations.

The water surface elevations are measured at four stations along the flume. These stations are equipped with point gages that can be read to the nearest 0.001 foot and with differential pressure transducers (Sanborn 268B) and dual-channel recorders (Sanborn Model 321) which permit reading to the nearest 0.0005 foot. The point gages are used for steady state conditions and the transducers and recorders will obtain traces for transient conditions.

Results

Uniform flow tests at a one percent slope were conducted and the data analyzed. These tests were run to determine the roughness characteristics and to establish the relationship

between roughness and discharge, or depth, for the synthetic grass material.

The uniform flow tests appeared to define two regimes of flow. This was due probably to the surface material used. The flow was of one type when the flow depth was less than the height of the synthetic grass and one was of another type when the flow depth was greater than the height of the synthetic grass. Using the Reynolds number criterion, the Reynolds number (Re) values indicate that, in general, the flow is laminar when the flow depth is less than the top of the synthetic grass. Critical depth calculations revealed that the flow was subcritical for all of the tests conducted.

Because the synthetic grass surface occupied a considerable portion of the flow depth, the actual physical bottom is probably not representative of the effective or hydraulic bottom. Therefore, it was necessary to give special attention to the location of an effective channel bottom. In the turbulent flow range an effective or hydraulic bottom can be found by considering the Manning equation for an infinitely wide channel. For this condition, the hydraulic radius is approximately equal to the depth of flow. Thus the Manning equation

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \quad (1)$$

can be expressed as

$$q = F(D^{5/3}) \quad (2)$$

or rearranging

$$D = G(q^{3/5}) \quad (3)$$

where

Q = flow rate in cfs

q = flow rate per unit width, cfs per ft.

n = the Manning roughness coefficient

R = hydraulic radius in ft.

S = energy slope in ft. per ft.

D = flow depth in ft.; and

F & G = denotes a functional relationship

By plotting $Q^{3/5}$ on the abscissa and water surface elevation on the ordinate on rectangular coordinate paper, the relationship for equation (3) can be found. This relationship is linear of the form, Elevation = A + B($Q^{3/5}$), where A is the intercept on the ordinate and B is the slope of the line. The effective channel bottom elevation is then equal to the intercept on the ordinate and can be found mathematically by least squares or graphically by projecting the line to the ordinate. A typical plotting of $Q^{3/5}$ and Elevation is presented in Figure 1. The effective bottom elevation is identified as are the elevations of the physical bottom and the top of synthetic grass.

For the flows when the depth was less than the top of the synthetic grass, a method was not determined to find an effective bottom elevation. Therefore, the physical bottom elevation was used for depth determination on the assumption that it adequately represented the effective bottom elevation for the low flow range.

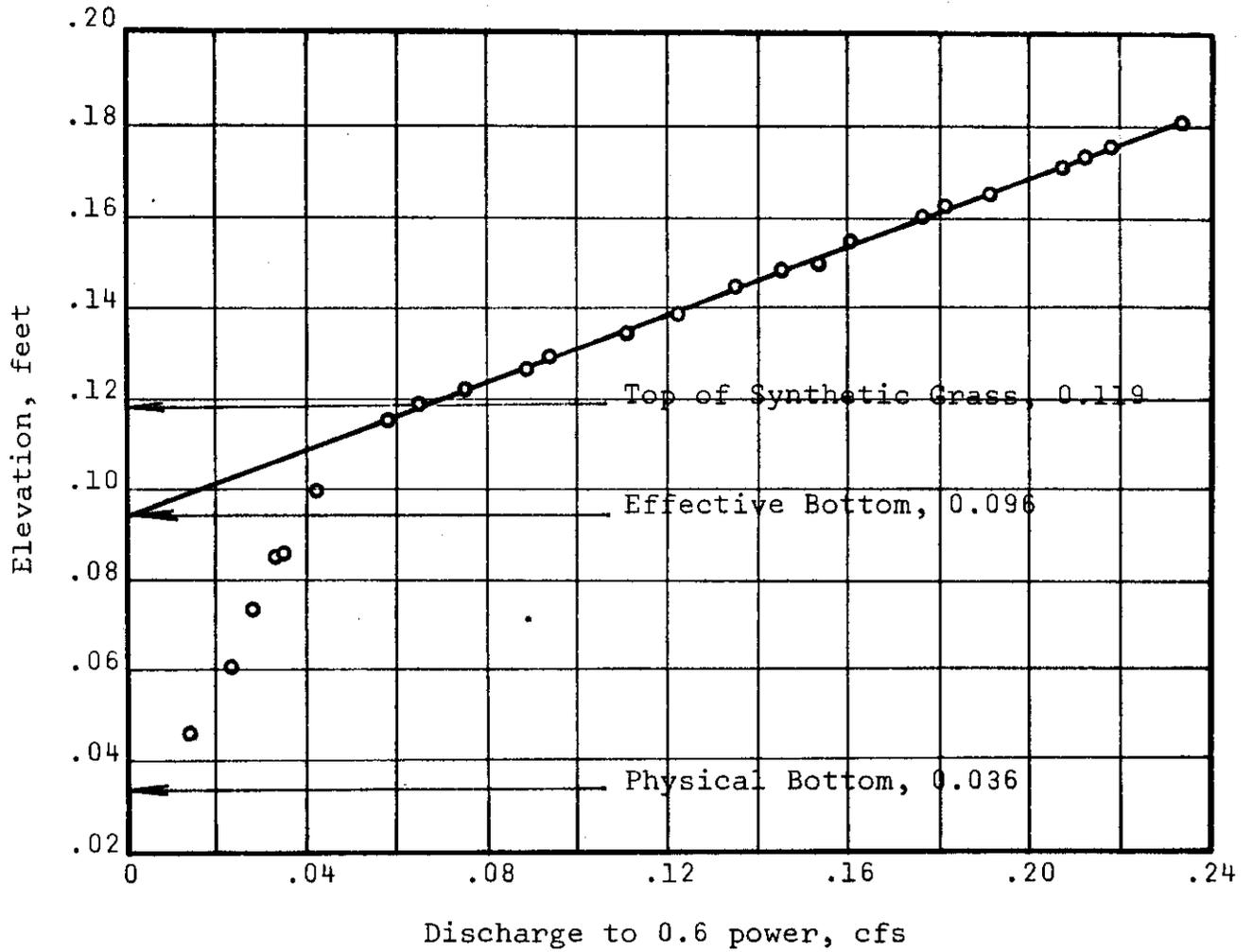


Figure 1. Water Surface Elevations

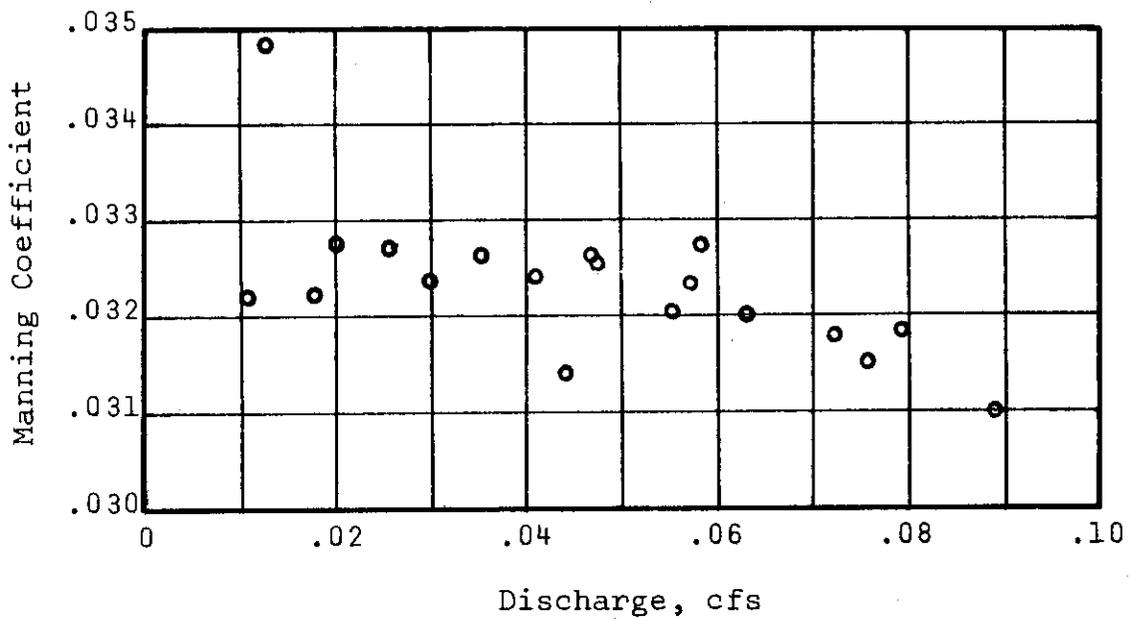


Figure 2. Manning Coefficient

The Manning roughness coefficients for the turbulent flows were calculated using equation (1). These values are presented in Figure 2 plotted versus discharge.

For the flows with depths less than the height of the synthetic grass the Darcy-Weisbach friction factor f was used instead of the Manning n as the roughness parameter. The friction factor f was calculated by two methods. In the first method, the flow were assumed as turbulent and f was calculated using the equation:

$$f = \frac{8gSD^2R}{Q^2/b^2} \quad (4)$$

where b is the channel width in ft., g is the acceleration due to gravity in ft. per sec. per sec., and with the other symbols as already defined. These data, plotted versus Re are presented in Figure 3. In the second method, the flows were assumed as laminar. For this assumption the relationship, $f = 64/Re$ was used to calculate the friction factor. These data, plotted versus Re , are presented in Figure 4.

The Manning roughness coefficient decreases slightly with an increase in discharge which is consistent with results of other researchers. The roughness, or retardance, of the synthetic grass is high as indicated by the high values of the Manning roughness coefficient, Figure 2.

The Darcy-Weisbach f calculated assuming turbulent flow increases with Re to a Re value of about 250 and then it decreases with a further increase in Re , Figure 3. This result cannot be explained with certainty, but it may be due to the

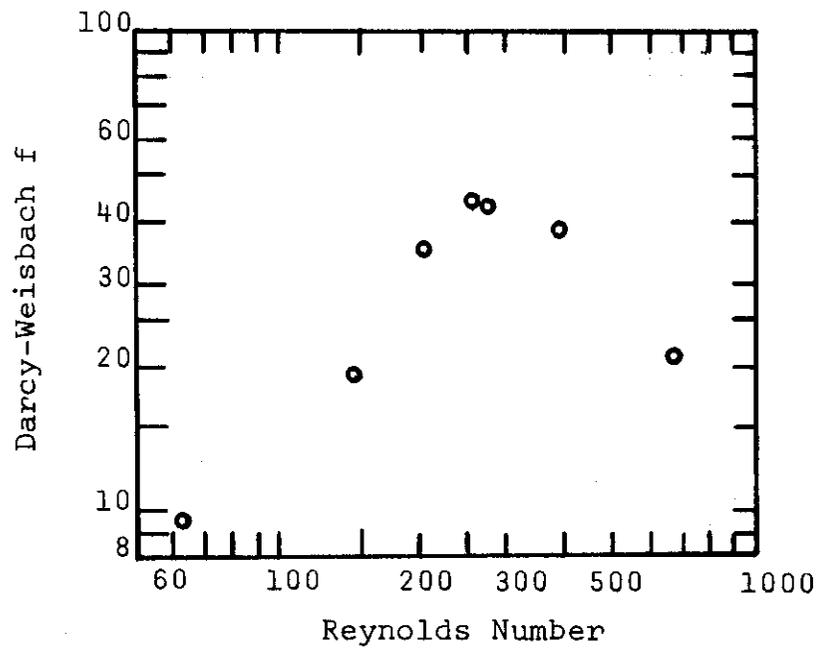


Figure 3. Friction Factor Assuming Turbulent Flow

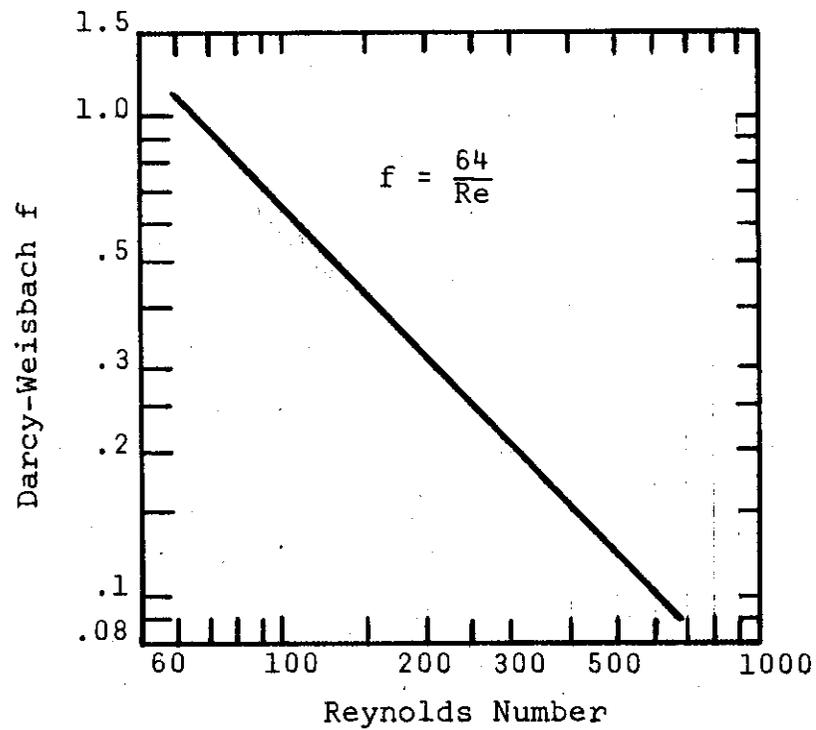


Figure 4. Friction Factor Assuming Laminar Flow

inability to accurately define an effective channel bottom for the low flows (recall that the physical bottom was assumed as adequate to define the effective bottom for the low flows). Another possibility is that the flows could be in a transition zone between laminar and turbulent flow, in which case f would not be a simple function of Re . Also, surface tension effects may influence the flows at the shallower depths.

Assuming laminar flow, f varies linearly with the reciprocal of Re , that is, $f = K/Re$, where K is a constant. Chow (1, Figure 1.4), presented data for rough channels and suggested that K varies from about 33 to 60 for rough channels. For laminar flow in pipes, $f = 64/Re$ is shown to be theoretically correct and the energy loss is assumed independent of the wall roughness. This relation was used to calculate f for the low flows in the current tests. Comparing these results with data presented by Chow (1, Figure 1.4) the f values for the synthetic grass surface are considerably larger than those presented by Chow for rough channels.

Reference Cited

1. Chow, V. T., Open Channel Hydraulics, McGraw-Hill, New York City (1959).