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EVALUATION OF THE SCS CURVE NUMBER TECHNIQUE ON A SMALL AGRICULTURAL WATERSHED

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ABSTRACT

The SCS runoff equation coupled to the triangular unit hydrograph was evaluated on a small agricultural watershed using three years of rainfall and runoff data by comparing the predicted and measured values of runoff volume and peak flow rate. The model grossly under-predicted runoff volumes, under-predicted some peak flow rates and over-predicted many of the others. Much better predictions of runoff volume were obtained by both adjusting the curve number to reflect AMC III and setting the initial abstraction equal to zero for all events. However, this resulted in gross over-predictions of peak flow rate. For better performance of the model, modifications of the criteria for antecedent moisture conditions and the parameters of the triangular unit hydrograph must be investigated.

1.0 INTRODUCTION

Engineers involved in the design of hydraulic structures such as culverts, bridges, water conveyance channels and others as recommended for conveyance, control or conservation of runoff are required to determine runoff volumes, peak flow rates and sometimes even the time distribution of runoff i.e. the runoff hydrograph.

Rainfall data are normally available for many parts of the country but there is quite often a lack of the corresponding runoff data. Engineers are therefore faced with the problem of estimating runoff volumes and peak flow rates from ungauged areas (not gauged for runoff) utilizing only rainfall and watershed data.

At present it is possible that much capital is wasted on hydraulic structures due to overdesign or due to underdesign which results in frequent failures. The SCS Curve Number Technique [1] is frequently used as a tool by engineers to confront this problem.

Although this model was developed using rainfall and runoff data from plots and small rural watersheds in the U.S.A. [2] and is therefore basically empirical, it has gained widespread acceptance throughout the world. This is perhaps due to the fact that it is simple to use, is generally not even calibrated and is purported to reliably estimate the effects of land treatment and land use changes upon runoff resulting from storm rainfall.

Nevertheless, it is necessary that studies be carried out to assess the applicability of the model for use under local conditions. Through these studies better estimates of the model parameters can be determined and therefore model accuracy and reliability can be improved. Moreover, engineers can be made aware of the limitations of the model. This paper reports the results of one such study.

2.0 THEORETICAL BACKGROUND OF THE MODEL

2.1 The SCS Runoff Equation

The SCS Curve Number Technique was originated by the United States Department of Agriculture Soil Conservation Service. The procedure involved in its use can be found in their National Engineering Handbook, Section 4, Hydrology [1]. The following has been included for the convenience of the reader to avoid confusion in changing from the Imperial to the SI system of units.

The development of the SCS runoff equation is based on the assumption that the ratio of runoff to the rainfall available for runoff is equal to the ratio of water retained during runoff to the potential amount that could be retained during an extremely long rainfall event. This is expressed mathematically as:

$$Q/(P - I_a) = (P - I_a - Q)/S \qquad (1)$$

where,

Q = runoff volume (mm)
P = cumulative rainfall (mm)
I_a = initial abstraction including interception, surface storage and infiltration prior to runoff (mm)
S = potential maximum retention (mm)

Rearranging equation (1) gives:

$$Q = (P - I_a)^2/(P - I_a + S) \qquad \text{for } P > I_a \qquad (2a)$$

$$Q = 0 \qquad \text{for } P \leq I_a \qquad (2b)$$

Field data indicated that initial abstraction was generally 20% of a maximum retention for individual storms. The data were derived by SCS scientists from records of natural rainfall and runoff from watersheds less than 4

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hectares in area. The magnitude of I_a was estimated by taking the accumulated rainfall from the beginning of the rainfall event to the time when runoff started. I_a is thus expressed as:

$$I_a = 0.2S \qquad (3)$$

Substituting for I_a from equation 3 in equation 2a and 2b yields the following:

$$Q = (P - 0.2S)^2/(P + 0.8S) \quad \text{for } P > 0.2S \quad (4a)$$

$$Q = 0 \quad \text{for } P \leq 0.2S \quad (4b)$$

The SCS developed an index, which is called the runoff "Curve Number" (CN), to represent the combined hydrologic effect of soil type, land use, agricultural land treatment class, hydrologic surface cover condition and antecedent moisture condition. Soil antecedent moisture condition (AMC) is determined by the rainfall amount 5 days prior to the event in question. AMC I applies if the 5-day antecedent rainfall is less than 36 mm, while AMC II applies if the 5-day antecedent rainfall varies from 36 to 53 mm and AMC III applies for a 5-day antecedent rainfall greater than 53mm. Tables are provided for determining curve numbers for various watershed conditions. Hawkins [3] and Bondelid et al [4] emphasized the importance of accurately estimating the curve number for better estimation of runoff volume.

The parameter S is related to CN by the following equation:

$$S = 25400/CN - 254 \qquad (5)$$

2.2 The SCS Triangular Unit Hydrograph

The SCS triangular unit hydrograph is used in conjunction with the SCS runoff equation to transform runoff volume into a runoff hydrograph. The following are the parameters of this hydrograph and are shown in Figure 1:

T_p = time to peak (h)
T_r = recession time (h)
q_p = peak flow rate (m^3/s)
T_L = lag time (h)
T_b = base of hydrograph (h)
T_c = time of concentration (h)

The SCS provides a relationship to enable the calculation of the lag time using watershed data:

$$T_L = \{ 0.0063\, L^{0.8} (111/CN - 1)^{0.7}\}/Y^{0.5} \qquad (6)$$

where,

T_L = lag time (h)
L = length of flow path from most extreme point of watershed to outlet (m)
CN = curve number
Y = average watershed slope (%)

From the triangular unit hydrograph the time to peak is given by the following equation:

$$T_p = (D/2) + T_L \qquad (7)$$

where,

T_p = Time to peak (h)
D = duration of rainfall excess or time step (h)
T_L = lag time (h)

The unit hydrograph peak flow rate for depth of runoff Q (mm) can be calculated by equating the area under the hydrograph to the volume of runoff i.e.:

$$2.67 * T_p * 3600 \text{ (seconds/hour)} * (q_p/2) = A * 10{,}000 \text{ } (m^2/ha) * Q * 0.001 \text{ (m/mm)}$$

which gives,

$$q_p = 0.00208\, Q * (A/T_p) \qquad (8)$$

where,

q_p = peak flow rate (m^3/s)
A = watershed area (ha)
T_p = time to peak (h)
Q = depth of runoff (mm)

The factor 2.67 refers to the base of the Synthetic Unit Hydrograph being 2.67 * the rising limb (T_p). In a different topography a different factor will apply.

The depth of runoff associated with the unit hydrograph was taken to be 1 mm and the corresponding peak flow rate using equation 8 then becomes:

$$q_p = 0.00208\, A/T_p \qquad (9)$$

The model converts incremental rainfall excess determined using the runoff equation into a series of triangular hydrographs by means of the triangular unit hydrograph. These triangular hydrographs are summed up to produce the total watershed hydrograph. The time step or increment, D, is given by:

$$D = 0.133\, T_c \qquad (10)$$

where,

T_c = time of concentration (h)

3.0 MATERIALS AND METHODS

3.1 Study Area

The watershed is located in Talparo, Central Trinidad. The soil type is Talparo clay with a virtually impermeable layer at a depth of 1 metre. The watershed area is 3.1 hectares with 70% citrus and the remaining 30% with shrubs and grasses. The length of the longest flow path is 280m and the average slope was found to be approximately 6%. The land use did not change over the period of data collection.

3.2 Data Collection

The collection of data began in May 1987 and ended in December 1989. Data for three rainy seasons were thus obtained. Two siphoning type recording rain gauges were installed. One was located at the centre of the watershed and the other at the highest point. The raingauge at the highest point was subsequently relocated at the lowest point of the watershed at the beginning of the second rainy season which made it more easily accessible. There was no significant variation between recordings of the two raingauges. A Parshall flume with a stage recorder located at the outlet of the watershed continuously measured and recorded the water level through the flume thereby providing the stage hydrographs.

3.3 Data Analysis

A computer program incorporating an appropriate flume discharge formula was used in an IBM PC connected to a digitizing tablet to convert each stage hydrograph to a flow hydrograph and at the same time calculate the corresponding runoff volume and peak flow rate. Another program was also used to convert the rainfall hyetographs recorded on strip charts into a numerical form and store them for use as input data files into the model.

All events with measured runoff were considered for use in the analysis. However, some runoff events could not be used because the corresponding rainfall amount could not be determined due to the stoppage of the raingauge clocks. Seventy eight rainfall-runoff events were eventually selected for use in the analysis; 1987 (25), 1988 (39) and 1989 (14). All the rainfall events were used in the estimation of runoff volume but only those giving rise to single-peak hydrographs (29) were used to estimate peak flow rates.

A weighted runoff watershed curve number was computed for AMC II and found to be 78. The 5-day antecedent rainfall for each event was also computed and the corresponding AMC determined. The curve numbers for AMC I and AMC III were found to be 61 and 90 respectively.

The model was programmed in BASIC and was run with the rainfall hyetographs as input data files to predict runoff volumes and peak flow rates. Predicted and measured values of both sets of outputs were compared.

4.0 RESULTS

The model was first run without any modifications i.e. with AMC varied (depending on the 5-day antecedent rainfall) and $I_a = 0.2S$. Runoff volumes were greatly under-predicted (Fig. 2). Peak flows were under-predicted for some events and over-predicted for many of the others (Fig. 3). It should be noted that many of the under-predicted peak flow rates were for those events whose predicted runoff volumes were zero.

The model was then run with various modifications so that there might be better agreement between predicted runoff volumes and measured volumes. With AMC III assumed for all events and $I_a = 0.2S$ a small improvement in runoff volume predictions was noticed (Fig. 4). With AMC varied and $I_a = 0.1S$ no improvement in runoff volume predictions could be discerned (Fig. 5). With AMC III and $I_a = 0.1S$ runoff volumes were better predicted (Fig. 6). With AMC varied and $I_a = 0$ runoff volumes were generally under-predicted (Fig. 7). With AMC III and $I_a = 0$ the best predictions of runoff volumes were obtained (Fig. 8).

For AMC III and $I_a = 0$ the predicted peak flow rates were compared with the measured values. It was found that peak flow rates were grossly over-predicted (Fig. 9).

5.0 SUMMARY AND CONCLUSIONS

A field study was conducted on a small agricultural watershed to assess the applicability of the SCS Curve Number Technique. Rainfall, runoff and watershed data were measured on the watershed located in Talparo, Central Trinidad. Soil type was Talparo clay and the average watershed slope was 6%. Vegetative cover consisted of 70 % citrus and 30% shrubs and grasses. Seventy eight rainfall events were used in the determination of runoff volumes and twenty nine of these rainfall events were used in the determination of peak flow rates.

The model greatly under-predicted runoff volumes, under-predicted some peak flows and over-predicted others. Good predictions of runoff volumes were obtained by adjusting CN to reflect AMC III for all events and by putting I_a equal to zero. However, this resulted in gross over-predictions of peak flow rates.

It is evident that for the model to incorporate the effect of antecedent moisture condition on surface runoff estimation the SCS criteria must be modified. In addition, the triangular unit hydrograph also needs modification to enable better predictions of peak flow rates. It is therefore suggested that more studies of this kind be carried out so that suitable parameters representing local conditions can be determined and made available to users of the model.

ACKNOWLEDGEMENTS

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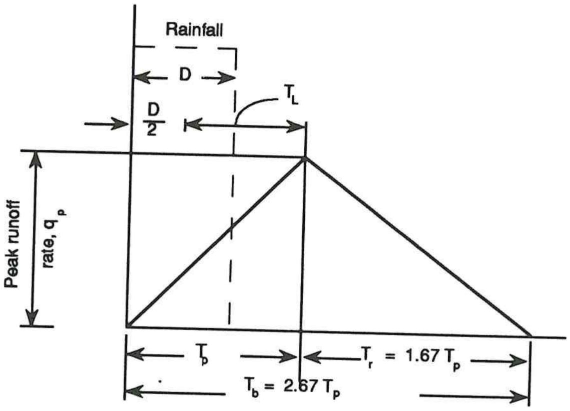

Figure 1. The SCS Triangular Unit Hydrograph

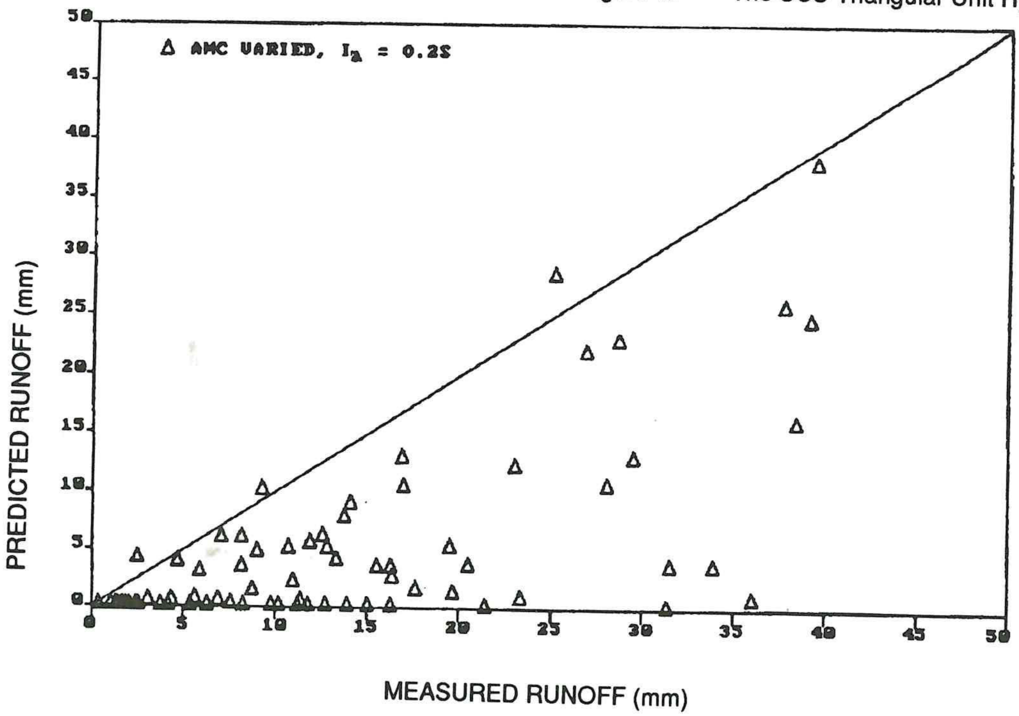

Figure 2. Measured Vs Predicted Runoff Volumes with AMC Varied and $I_a = 0.2S$

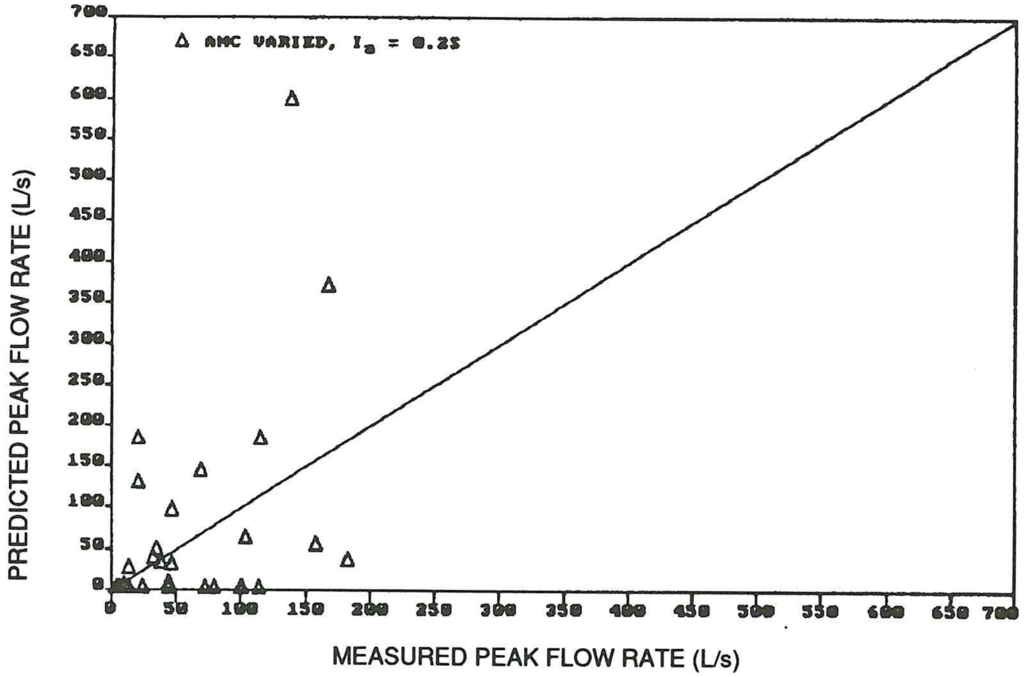

Figure 3. Measured Vs Predicted Peak Flow Rates with AMC Varied and $I_a = 0.2S$

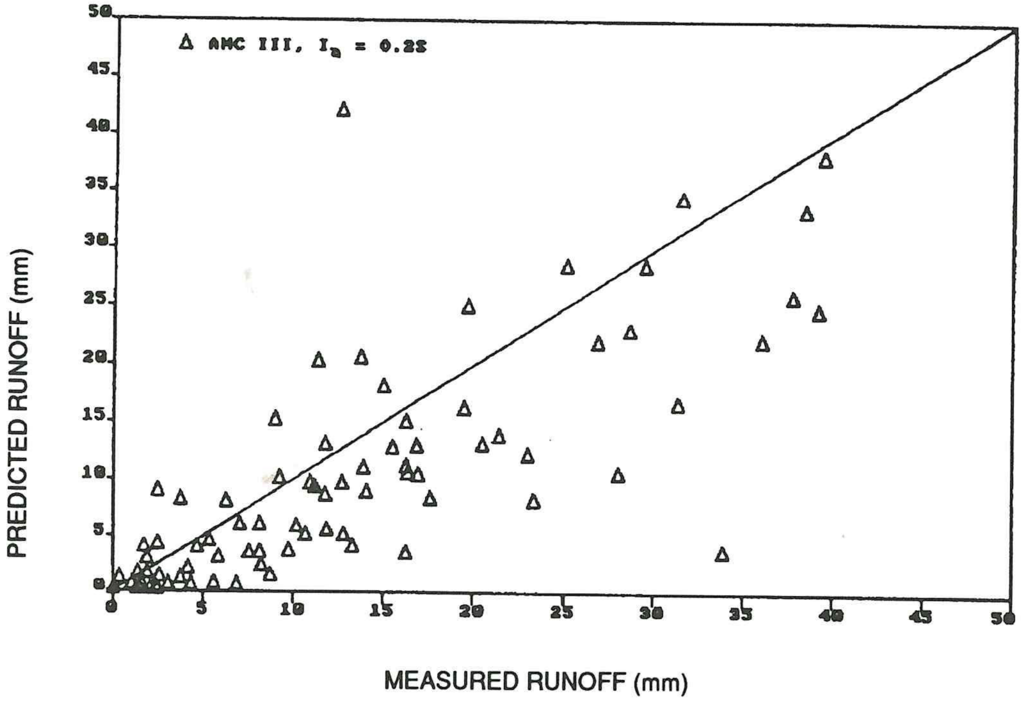

Figure 4. Measured Vs Predicted Runoff Volumes with AMC III and $I_a = 0.2S$

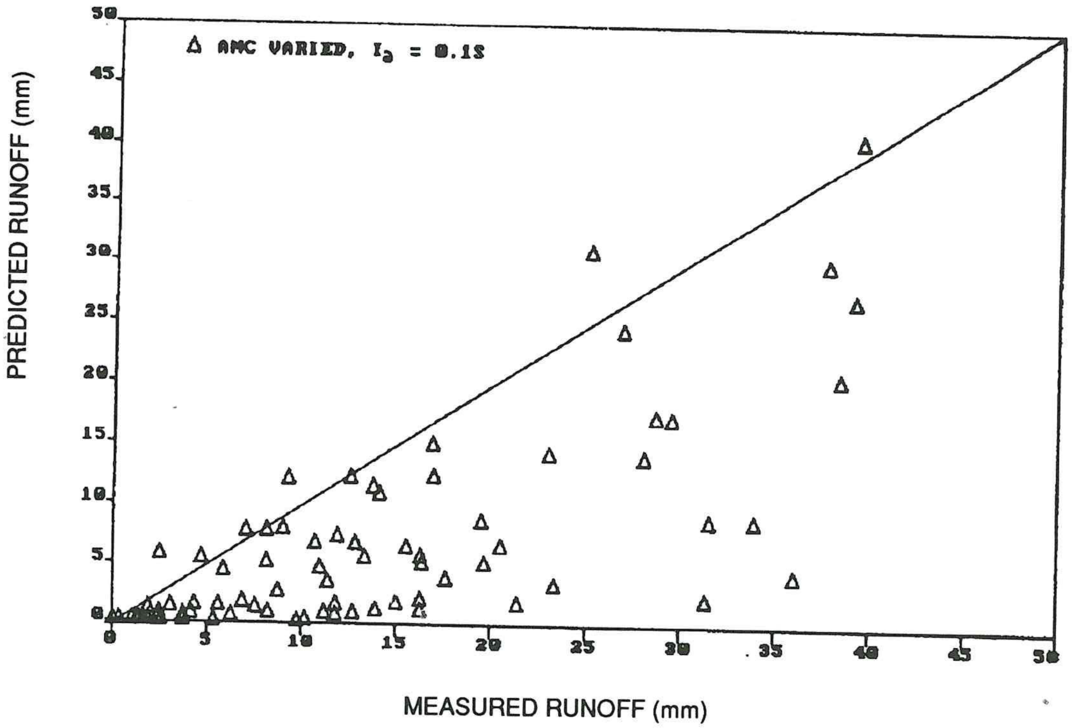

Figure 5. Measured Vs Predicted Runoff Volumes with AMC Varied and $I_a = 0.1S$

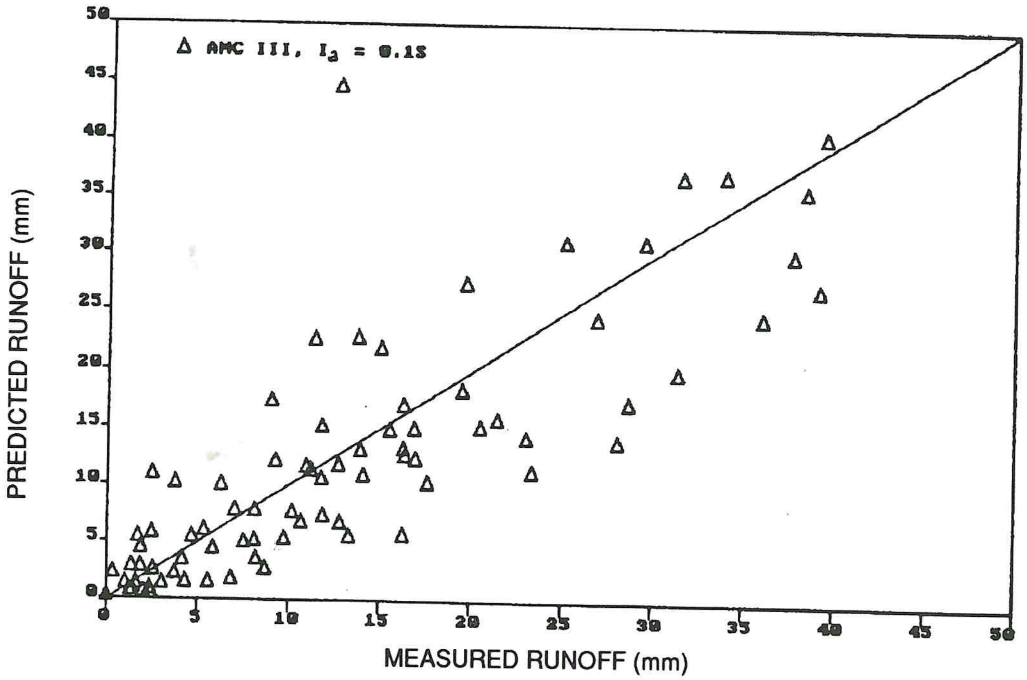

Figure 6. Measured Vs Predicted Runoff Volumes with AMC III and $I_a = 0.1S$

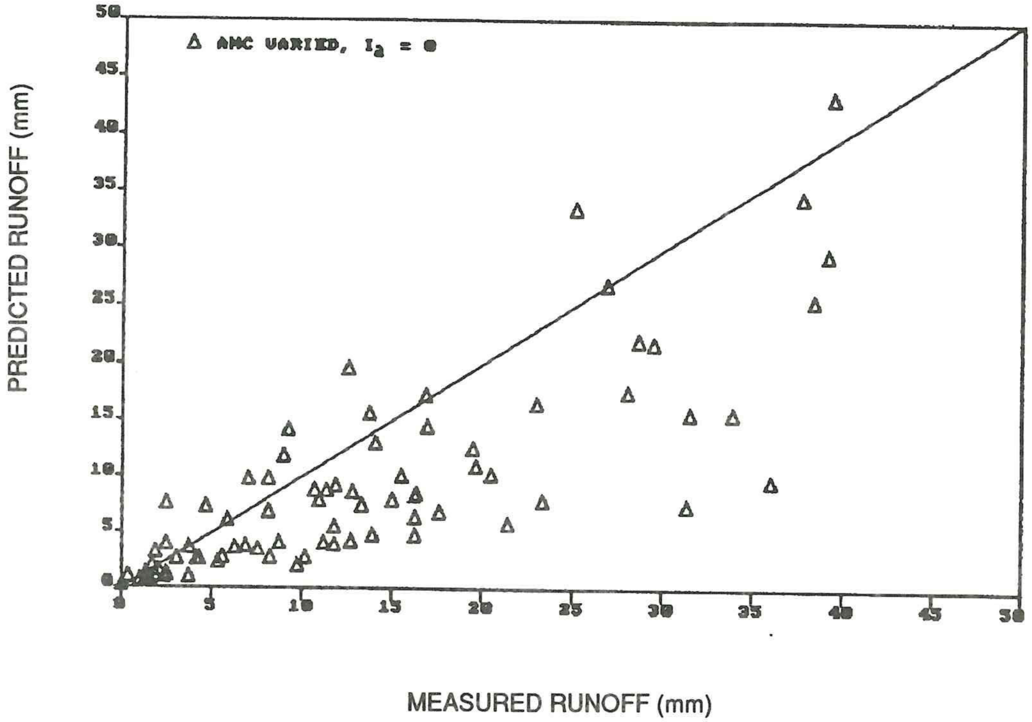

Figure 7. Measured Vs Predicted Runoff Volumes with AMC Varied and $I_a = 0$

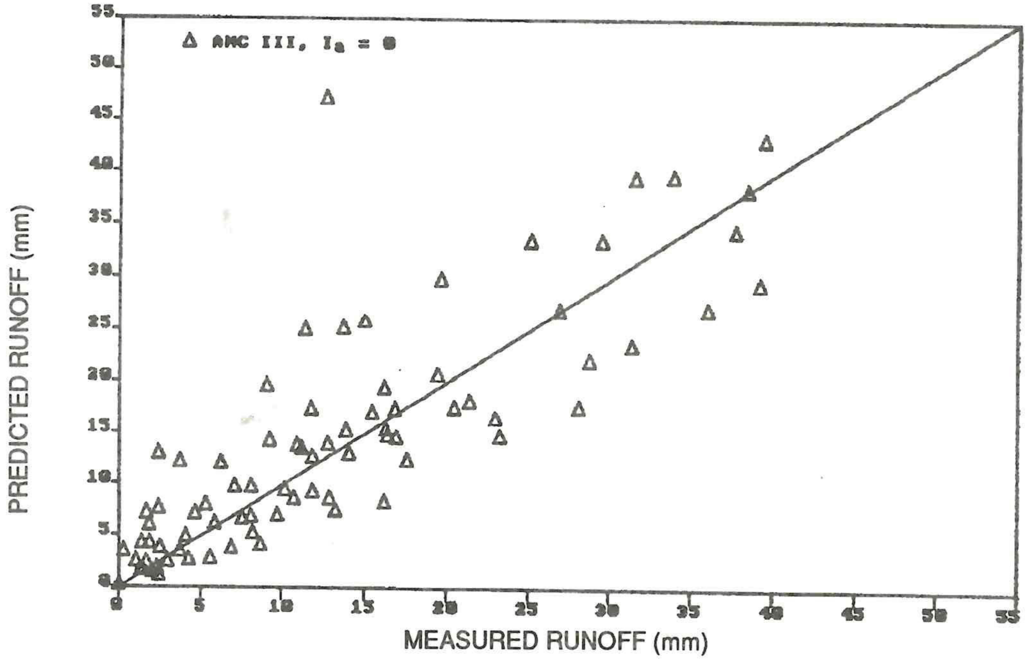

Figure 8. Measured Vs Predicted Runoff Volumes with AMC III and $I_a = 0$

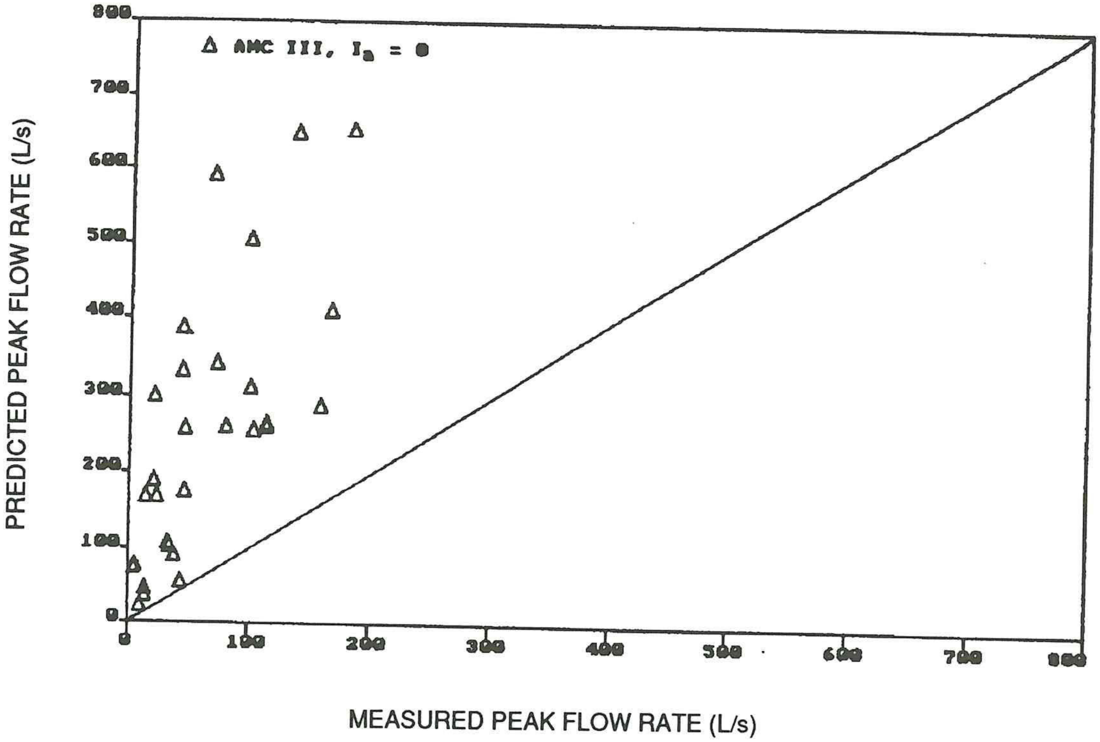

Figure 9. Measured Vs Predicted Peak Flow Rates with AMC III and $I_a = 0$