A METHODOLOGY FOR DETERMINING FLASH FLOOD FORECASTING SYSTEMS FOR A COMMUNITY

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A METHODOLOGY FOR DETERMINING FLASH FLOOD

FORECASTING SYSTEMS FOR A COMMUNITY

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CHAPTER I

INTRODUCTION

Many floods occur in the United States each year, some caused from river flooding which may have a 15-hour to 10-day time-to-peak, while others will be caused by flash flooding which may have a very short peaking time. Flood forecasting requirements for a community, city, state or river basin have been determined in the past by (1) government reaction from a flood, (2) requests from flood prone areas and (3) cooperative programs with governmental agencies. The majority of flood forecast points now in existence in the United States are for the river floods, but the disasterous flash floods of the past six years have brought to issue that forecasting procedures should be available for all floodable communities. The populous movement to rural living and the increase of camping has made people more cognizant of the flood plain areas where they are now or maybe inhabiting. These areas were always potential flood areas but heretofore were uninhabited. The occurrence in the past few years of heavy rains brings to issue the ever present threat that the Probable Maximum Storm does not exist and that it can occur in any locality. The functional Flash Flood Hydrologist must investigate these newly developing flood plains along with other little known basins to update the current Flood Forecasting Program, and to develop areas of forecasting responsibility.

A flash flood is considered to be a flood that occurs with very little warning and that constitutes an unusual event. In general, flash floods are defined as damaging floods that occur within four to six hours of the time that the causative rainfall occurs. Aside from artifically induced hazards such as dam failures, flash floods are generally the result of relatively intense rainstorms. Precise estimation of the critical rainfall intensity that is capable of producing flash flooding on any specified watershed is difficult, as many watershed and seasonal factors influence the hydrologic response, however, those areas susceptible to rainfall intensities of severe magnitude may be considered to be areas with potential hazards due to flash flooding.

If rainfall intensities of severe magnitude can be considered to be the causative mechanism of flash flooding, then almost all areas of the United States can be considered to be areas of possible flash flooding, as most areas of the United States have experienced rainfall intensities of severe magnitude. Even so, flash floods are most common in the arid and semi-arid regions of the west and southwest. This is due, in part, to the meteorological and physiographic conditions that frequently can lead to the development of large convective thunderstorm cells that are capable of producing large amounts of rainfall in short periods of time.

Formulation of practicable forecasting procedures requires the development and operation of the Flash Flood Forecast Program. The Flash Flood Forecast Program must provide communities in the United States with information concerning the flash-flood potential of streams in the communities and surrounding areas. In addition, when approaching storms or other conditions deem it necessary, flash-flood warnings are issued to appropriate community authorities and media so that actions to reduce property damage and loss of life may be initiated. Three basic methods of providing flash-flood warnings have been used or proposed by State and governmental agencies. The first approach employs conventional flood forecast techniques at the community level. Under the guidance of the local hydrologic service of a responsible government agency, the community establishes a network of rainfall and river observation stations. As conditions warrant, information concerning rainfall rates, stream stages, and observed storm movement is collected by a warning representative. Flash-flood warnings are issued by the warning representative as necessary. If radar is available in the area, warnings may be based on radar tracking and rainfall measurement, as well as observational reports from the observer network.

The second approach involves use of a recently developed flash-flood alarm mechanism. As rising stages in headwater streams or tributaries reach a predetermined height, an alarm located at a continuously occupied public authority is activated by telephone or radio signal. The trigger of the alarm system is an automatic stage measuring device located some distance upstream of the community. The positioning of the triggering device, both geographically and vertically, must be determined from consideration of expected warning times and required evacuation times.

The third approach is dependent upon the skill and alertness of the rainfall forecaster. Warnings of possible flash floods are issued on the basis of rainfall reports received by the meteorologist during the progress of the storms and the meteorologist's estimate of the continuing intensity of the storm. Telemetered rain gages can provide information on storm intensities, and radar surveillance can provide information concerning time of onset, duration, areal extent, and intensity.

The Arkansas and Red River Basins in New Mexico, Oklahoma and Texas in that portion west of the 100° longitude has been an area of little concern to flood forecasting. The general objective of this study is to find a method of determining the flash flood forecasting requirements of a community and then to apply this approach to the subject areas in New Mexico, Oklahoma and Texas. The objective will also be to determine the data input requirement for a forecasting system including equipment.

The specific objective of this research is to find an hydrologic model to predict the flash flood potential of a community based on the hydrological, geological and geographical variables for the Probable Maximum Storm.

This study will analyze the flooding potential of the following communities:

New Mexico		Oklahoma	Texas
Cimarron	Valmora	Beaver	Amarillo
Clayton	Watrous	Guymon	Canadian
Folsom		Logan	Canyon
Raton			Channing
Springer			Palo Duro
Tucumcàri			Tascosa
Ute Park			

This study involves actual on-site experimental field trips into the proposed test communities. These experimental sessions have been made to determine and establish hydrologic parameters.

During this study a way of forecasting any flash flood location has been developed and is presented in the final operational form of tables. These forecast tables are designed to forecast flash floods from varied initial base flows and the table package should allow immediate evaluation of a flash flood threat.

This study also develops a relationship between the community and the possible number of deaths that could occur from any storm. The death relationship is shown in a Flood Potential Scale of one through ten (Table I).

The flash flood potential of a community is shown as a table with ratings of one to 10. The table is called the Flash Flood Potential Scale. This type of presentation of the flood threat is a new approach in the hydrologic field. The Flash Flood Potential Scale is similar to the Richter scale for earthquakes, except that the Flash Flood Potential Scale is shown in unit values of one through 10, rather than the power of 10.

Number one of the Flash Flood Potential Scale is equal to no significant flooding. Number 10 is equal to a catastrophic flood. Numbers one through five of the scale rate the increasing flood potential with no loss of life. Numbers six through 10 of the scale predict the increasing chance of loss of life (Table I).

TABLE I

FLASH FLOOD POTENTIAL SCALE

1	=	No Significant Flooding.
2	=	Some Street and Low Land Flooding.
3	=	Street and Some Residential Flooding.
4	=	Major Street and Residential Flooding.
5	=	Stream Flooding and Property Loss, Very Light.
6	=	Stream Flooding with Chance of Loss of Life and Property Loss, Light.
7	=	Stream Flooding with Probable Loss of Life (0 to 50) and Property Loss, Moderate.
8	=	Stream Flooding with Loss of Life (50 to 150) and Property Loss, Major.
9	=	Stream Flooding with Loss of Life (150 to 400) and Property Loss, Major.
10	=	Catastrophic Flood.

Synopsis of Following Chapters

Chapter II contains a review of literature on hydrologic equations, Systems, Models and Multiple Regression Analysis.

Chapter III is concerned with the development of the Flash Flood Model, which includes the application of the MIT Catchment Model, HEC-2 program and Statistical Analysis.

Chapter IV is concerned with the Application of the Flash Flood Model. This Chapler presents the results of the Model in its application to the twenty-five original source basins and the four test basins.

Chapter V discusses the results of Chapter IV.

Chapter VI and VII are the Summary, Conclusions, and Suggestions for future study.

CHAPTER II

LITERATURE REVIEW

Hydrologic Equations, Systems and Model

Leo R. Beard (1) worked on a generalized evaluation of Flash-Flood Potential. The first criterion developed in this study is the flash-flood magnitude index. This index is defined as the ratio of the magnitudes of rare flood events to common flood events, and is indicative of the relative severity of rare flood events. Because of the relatively small variation in the observed skew coefficients for use in annual maximum stream flow frequency analysis, the standard deviation of the logarithms of annual maximum streamflows was considered to be an adequate estimation of the flash flood magnitude index. The second criterion developed was the flash-flood warning time index. This index is an inverse measure of the average warning time available during relatively rare flood events, and is, therefore, a direct measure of the intensity of expected flash-flood magnitudes. The warning time index of a location was defined as the average of the ratio of peak flow to 3-day flow, computed for the top 10% of the observed annual peak flows of the location. It was found that a larger value of flash-flood warning time index indicates less average warning time and higher intensity of flooding than does a smaller value.

Jerald F. McCain and Robert D. Jarrett (2) developed frequency studies for Colorado. Their study contains information of the 5, 10, 50, 100, 500 year floods at sites on natural-flow streams in Colorado. The report used the Log Pearson Type III method for fitting a frequency curve to gaging-station data and multiple-regression techniques for regionalization or transferring the results to ungaged basins. The three basic methods used were:

1. Flood Information at Gaged Sites.
2. Flood Information Near Gaged Sites on the Same Stream.
3. Flood Information at Ungaged Sites.

Flood Information at Gaged Sites (2)

$$Q_{T(W)} = \frac{Q_{T(S)}^{XN} + Q_{T(R)}^{XE}}{N + E} \tag{2.1}$$

where

$Q_{T(W)}$ = the weighted discharge for recurrence interval T,

$Q_{T(S)}$ = the station value of the flood for recurrence interval T,

$Q_{T(R)}$ = the regression value of the flood for recurrence interval T,

N = the number of years of station data used to compute $Q_{T(S)}$, and

E = the equivalent years of record for $Q_{T(R)}$.

Flood Information Near Gaged Sites on the Same Stream (2)

$$Q_{T(V)} = \frac{A_U}{A_G} Q_{T(G)} \qquad (2.2)$$

where

$Q_{T(V)}$ = peak discharge at ungaged site for recurrence interval T,

QT(G) = weighted average discharge at gaged site for recurrence interval T,

A_U = drainage area at ungaged site

A_G = drainage area at gaged site, and

X = exponent for each flood region

Flood Information at Ungaged Sites (2)

$$Y_t = ax_1^{b_1} X_2^{b_2} \qquad (2.3)$$

where

Y_t = a flood characteristic, either peak discharge or peak flood depth, for recurrence interval t;

X_1, X_2 = basin and climatic parameters

a = regression constants; and

b_1, b_2 = regression coefficients

The research was developed from a flood frequency analysis of gaging-station data and a multiple-regression analysis of flood characteristics and basin and climatic parameter of 258 gaged basins in Colorado and adjacent states. Annual peak discharges through September 1973 were fitted to the Log Pearson Type III distribution. Subjective appraisal of high and low outliners was made based on the reasonableness of the computed flood-frequency curves. High outliners cause frequency curves to estimate extremely large flood discharges, especially for large positive skewness. Low outliners caused large negative skewness but increased the standard deviation of the frequency distribution. Standard multiple regression techniques were used to develop equations by relating flood characteristics at gaged sites to basin and climatic parameters.

The resulting equations developed by McCain and Jarrett for Colorado and New Mexico for the Arkansas and Canadian River basins were:

$$Q_5 = 75A^{0.552} S_B^{0.460} \tag{2.4}$$

$$Q_{10} = 144A^{0.528} S_B^{0.336} \tag{2.5}$$

$$Q_{50} = 891A^{0.482} S_B^{0.154} \tag{2.6}$$

$$Q_{100} = 1770A^{0.463} S_B^{0.086} \tag{2.7}$$

$$Q_{500} = 5770A^{0.432} \tag{2.8}$$

$$Q_{PMS} = 30,560A^{0.375} \tag{2.9}$$

$$D_5 = 22. S_s^{-0.334} \tag{2.10}$$

$$D_{10} = 35.5 S_s^{-0.462} \tag{2.11}$$

$$D_{50} = 52.1\ S_s^{-0.500} \tag{2.12}$$

$$D_{100} = 59.3\ S_s^{-0.517} \tag{2.13}$$

$$D_{500} = 77.3\ S_s^{-0.533} \tag{2.14}$$

$$D_{PMS} = 156.2\ S_s^{-0.703} \tag{2.15}$$

where

Q_n = Peak discharge in cfs;

A = Drainage area in square miles;

n = Flood frequency;

PMS = Probable maximum storm;

D = Depth in feet.

V. B. Sauer (3) developed flood-frequency studies for rural and urban areas in Oklahoma and portions of adjacent states. The general form of the equation is:

$$Q_{X(U)} = \frac{7R_X Q_2 (R_L - 1)}{6} + \frac{Q_X(7-R_L)}{6} \tag{2.?6}$$

where

$Q_{X(U)}$ = Urban peak discharge for recurrence interval, X;

R_L = Adjustment factor to account for the effect of urban development;

Q_X = natural peak discharge for recurrence interval, X;

R_X = rainfall-intensity ratio for recurrence interval X.

The resulting equation developed by Sauer for Oklahoma and portions of adjacent states were:

$$Q_5 = 0.498A^{0.66} S^{0.40} P^{1.58} \quad (2.17)$$

$$Q_{10} = 1.081A^{0.67} S^{0.42} P^{1.44} \quad (2.18)$$

$$Q_{50} = 5.40A^{0.69} S^{0.47} P^{1.12} \quad (2.19)$$

$$Q_{100} = 9.14A^{0.70} S^{0.48} P^{1.01} \quad (2.20)$$

$$Q_{500} = 19.4A^{1.05} S^{0.58} P^{0.84} \quad (2.21)$$

$$Q_{PMS} = 55.5A^{2.10} S^{0.82} P^{0.54} \quad (2.22)$$

where

Q_n = Peak discharge in Cfs;

n = Flood frequency;

PMS = Probable maximum storm.

The standard error of prediction for these equations is on the order of $\pm$ 40 percent.

Wilbert O. Thomas, Jr. (4) developed techniques for estimating flood depths for Oklahoma streams. The purpose of the report was to present techniques for estimating flood depths for both natural and urban streams in Oklahoma.

The study by W. O. Thomas, Jr. (4) shows that for less than bankfull discharges a basin-wide relation exists between stream depth and discharge when discharge is of equal frequency of occurrence at all sites. It was proposed a general equation of the form:

$$D = CQ^f \quad (2.23)$$

where

D = average cross-section depth

C&F = constants for a given frequency.

Thomas (4) found this type of relation applicable for greater than bankfull discharges in New Jersey, and for simplicity modified the equation to:

$$h = C(Q_{2.33})^f \qquad (2.24)$$

where

h = height of the water surface above the average channel bottom

$Q_{2.33}$ = mean annual flood discharge

C&f = constants for a given frequency

In this study by Thomas flood depths were determined at 132 gaging stations throughout the State and these were related to basin, climatic, and channel geometry characteristics by multiple regression techniques. The analysis indicated that contributing drainage area, A, and the 2-year 24-hour rainfall are the two most useful variables for estimating flood depths in Oklahoma and portions of adjacent states.

The regression equation used was in the following form,

$$D_X = aA^bI^c \qquad (2.25)$$

where

D_X = peak flood depth in feet,

A = contributing drainage area in square miles,

I = the 2-year 24-hour rainfall in inches,

a = regression constant,

b,c = regression coefficients.

The following equations were defined and indicated by regression analysis:

$$D_5 = 0.53\ A^{0.24}\ I^{1.60} \tag{2.26}$$

$$D_{10} = 0.85\ A^{0.22}\ I^{1.40} \tag{2.27}$$

$$D_{50} = 1.58\ A^{0.20}\ I^{1.14} \tag{2.28}$$

$$D_{100} = 1.95\ A^{0.19}\ I^{1.06} \tag{2.29}$$

$$D_{500} = 2.85\ A^{0.17}\ I^{0.91} \tag{2.30}$$

$$D_{PMS} = 6.25\ A^{0.16}\ I^{0.75} \tag{2.31}$$

where

D = Depth, in feet;

n = Flood frequency;

PMS = Probable maximum storm.

P. R. Jordan and T. J. Irza (5) developed a technique of determining magnitude and frequency of floods in Kansas. In their report floods were found to be related most significantly to the contributing drainage and the 2-year 24-hour rainfall. The scope of the study was limited to peak flows and does not consider the shape or volume of the flood hydrograph. Equations developed by this study are applicable to unregulated drainage basins in Kansas, ranging in area from 0.4 to 10,000 square miles.

The method of frequency analysis used to determine the N-year flood peak at gaging stations was the fitting of a "Log Pearson Type III" distribution. This distribution uses three parameters--the mean, standard deviation, and skewness coefficient--calculated from the logarithms of the original data. Adjustments to the Log Pearson Type III frequency were made, where warranted, by one or both of the following conditions:

1. Historical data--Information identifying the highest flood during a period longer than the period of gaging station operation.

2. Low outliners--One or two exceptionally low-peak flows that have a large effect on the skewness coefficient, and thus effect the computed flood magnitudes for large recurrence intervals.

The final regression equations developed by Jordan and Irza are listed below:

where

Q = Peak discharge, in cfs;

n = Flood frequency;

PMS = Probable maximum storm.

$$Q_5 = 3.98\ A_C^{0.548}\ P_2^{4.752} \quad (2.32)$$

$$Q_{10} = 9.92\ A_C^{0.525}\ P_2^{3.591} \quad (2.33)$$

$$Q_{50} = 47.6\ A_C^{0.523}\ P_2^{2.821} \quad (2.34)$$

$$Q_{100} = 83.8\ A_C^{0.524}\ P_2^{2.529} \quad (2.35)$$

$$Q_{500} = 202.\ A_C^{0.524}\ P_2^{1.98} \quad (2.36)$$

$$Q_{PMS} = 1101.\ A_C^{0.523}\ P_2^{0.56} \quad (2.37)$$

David M. Hershfield (6) in 1961 developed the Rainfall Frequency Atlas of the United States, referred to as Technical Paper 40. Until about 1953, economic and engineering design requiring rainfall frequency data was based largely on Yarnell's Paper (7) which contains a series of generalized maps for several combinations of durations and return periods. Yarnell's maps are based on data from about 200 first order Weather Service stations.

The data for Technical Paper 40 was divided into three categories. First, there was the recording-gage data from long-record first-order Weather Service stations; second the recording-gage data of the hydrologic network which are hourly reports, and finally, the very large amount of non-recording gage data with observations made once a day.

The factors considered in the construction of the isopluvial maps were availability of data, reliability of the return period estimates and the range of duration. There was much data available for construction of the 2-year 24-hour maps (Figure 1) and these are deemed most significant. The probable maximum precipitation (PMP) relationship uses a combination of physical model and several estimated meteorological parameters. The main purpose of the PMP method is to provide complete safety design criteria in cases where structure failure would be disastrous. The PMP relationship is based on a 10-square mile value of Hydrometeorological Report No. 33 (8) (Figure 2).

2-YEAR 24-HOUR RAINFALL (INCHES)

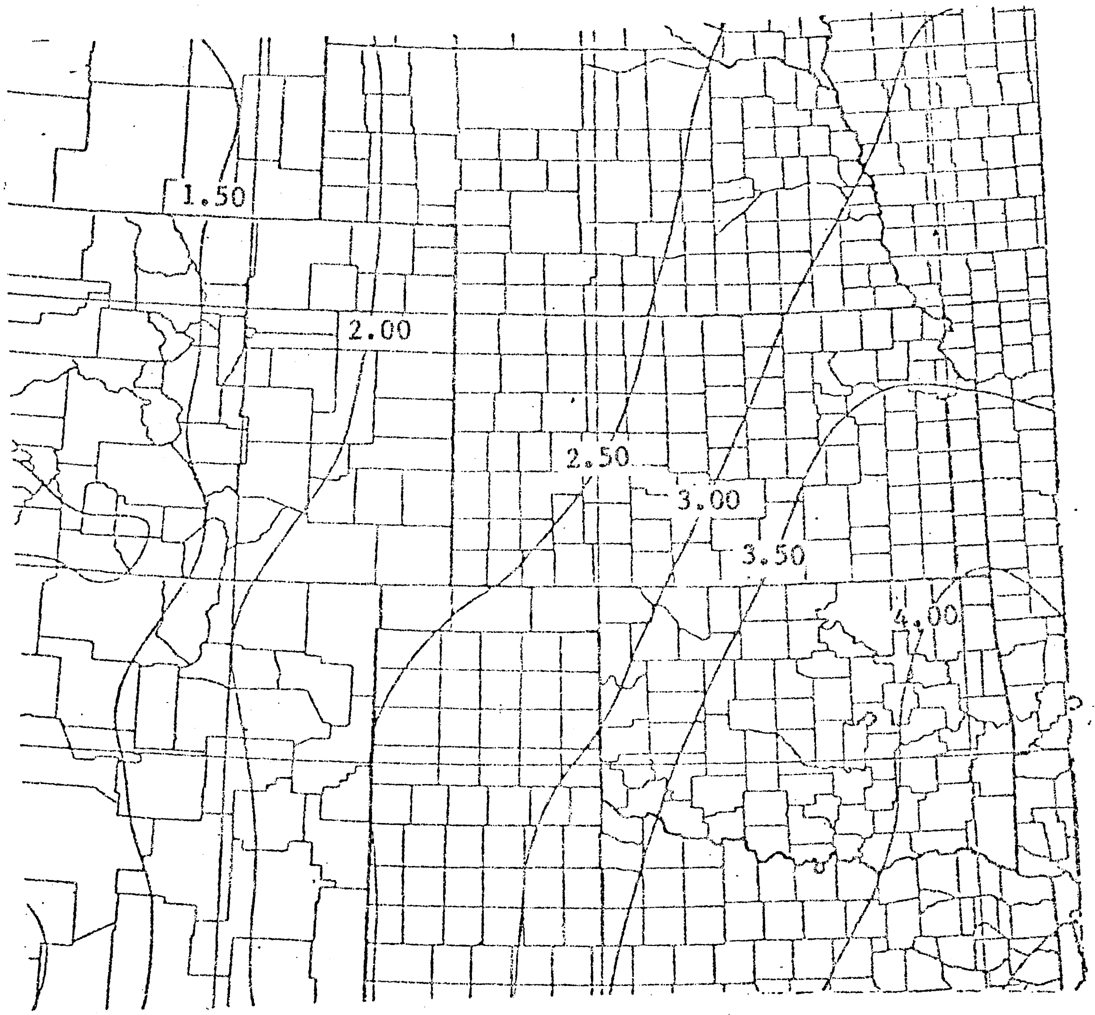

Figure 1. 2-Year 24-Hour Map, Rainfall Frequency Atlas of the United States, Technical Paper 40 (6)

PROBABLE MAXIMUM 6-HOUR PRECIPITATION

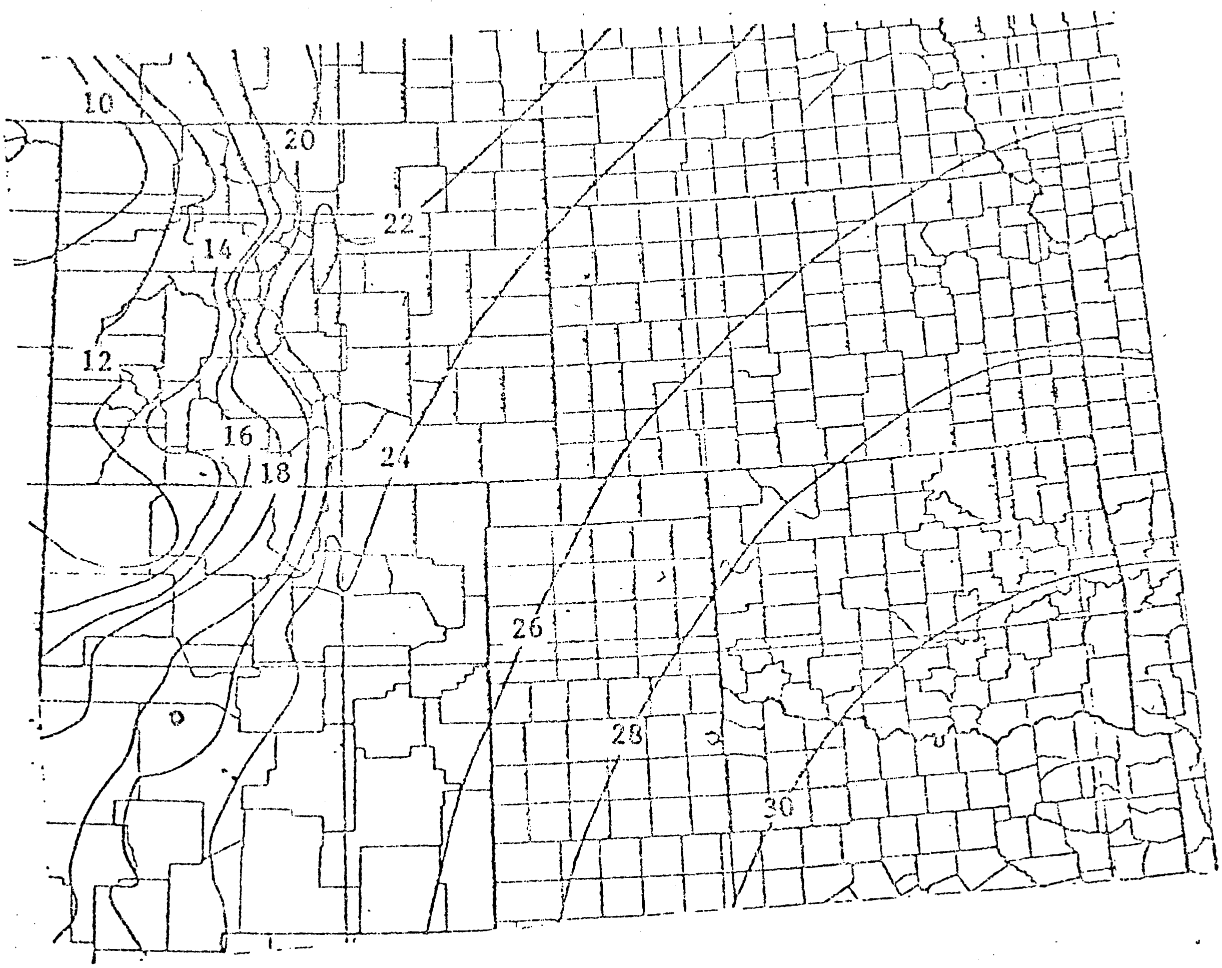

Figure 2. Probable Maximum Precipitation, Rainfall Frequency Atlas of the United States, Technical Paper 40 (6)

Digital Computer Models

Weather Service River Forecast System

The National Weather Service River Forecast System is called NWS HYDRO 14 (9). The program was developed by the National Weather Service (NWS) and the basic portion of the system is that it was developed around the hydrologic cycle. The Model has a primary requirement input from a gaged location and, therefore, could not be easily allocated to an ungaged area.

Sacramento Model

The Sacramento Model was developed from the Stanford Model (10) and the NWS Hydro 14 Model. The Sacramento Model attempts to simulate streamflow by simulating all of the significant components of the hydrologic cycle in a more simplified manner. Burnash has tried to associate each variable in the Model with a recognizable counterpart in the physical world. This Model is one more developed to fit the larger, historic basins rather than the ungaged small basin where most flash flooding occurs.

MIT Catchment Model

The MIT Catchment Model (11) represents movement of water over the catchment surface and through the network (Figure 3). model recognizes that surface geometry is extremely irregular and impossible to represent in complete detail in either a physical or a

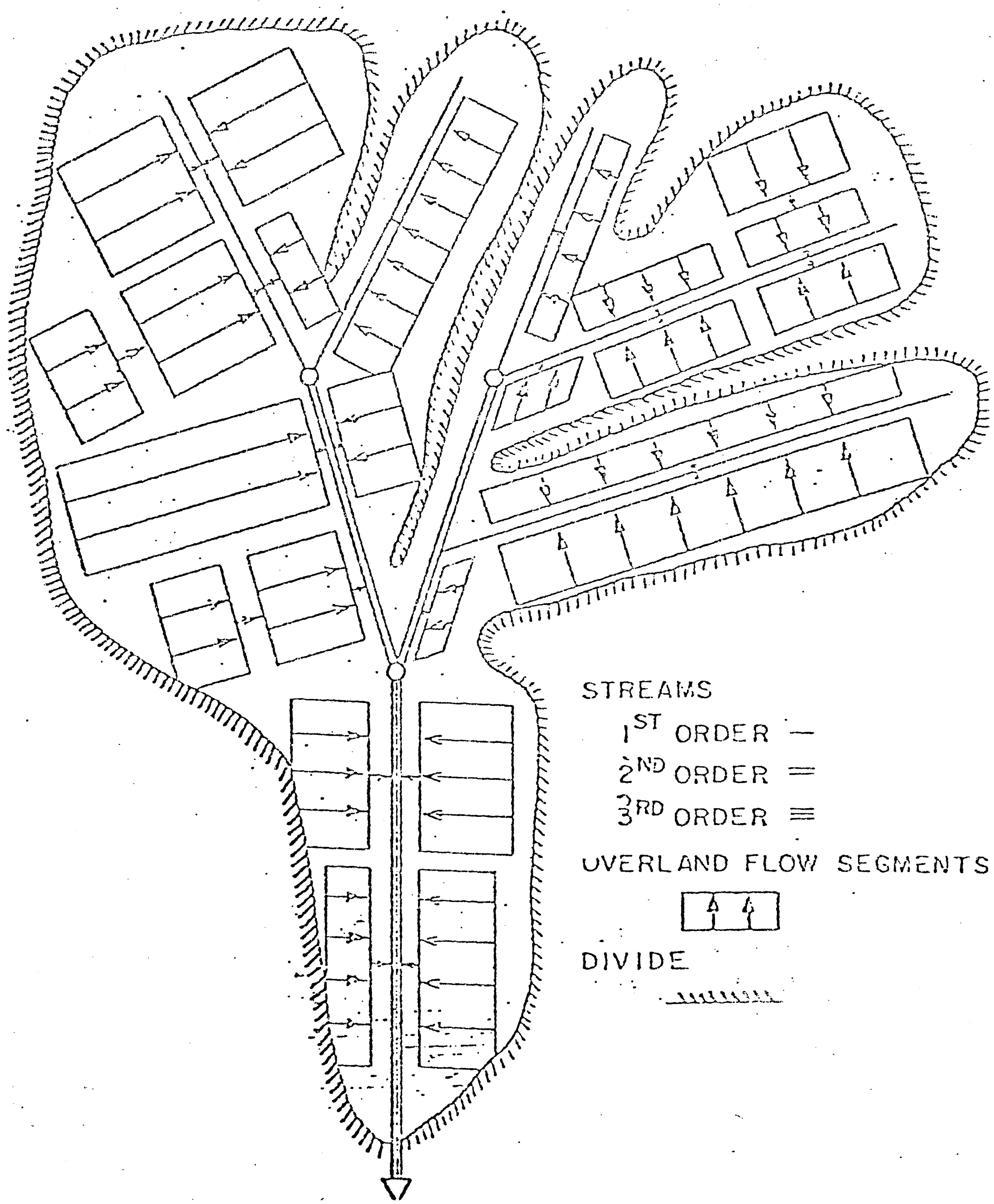

Figure 3. Equivalent Block Diagram of the Natural Catchment, MIT Catchment Model

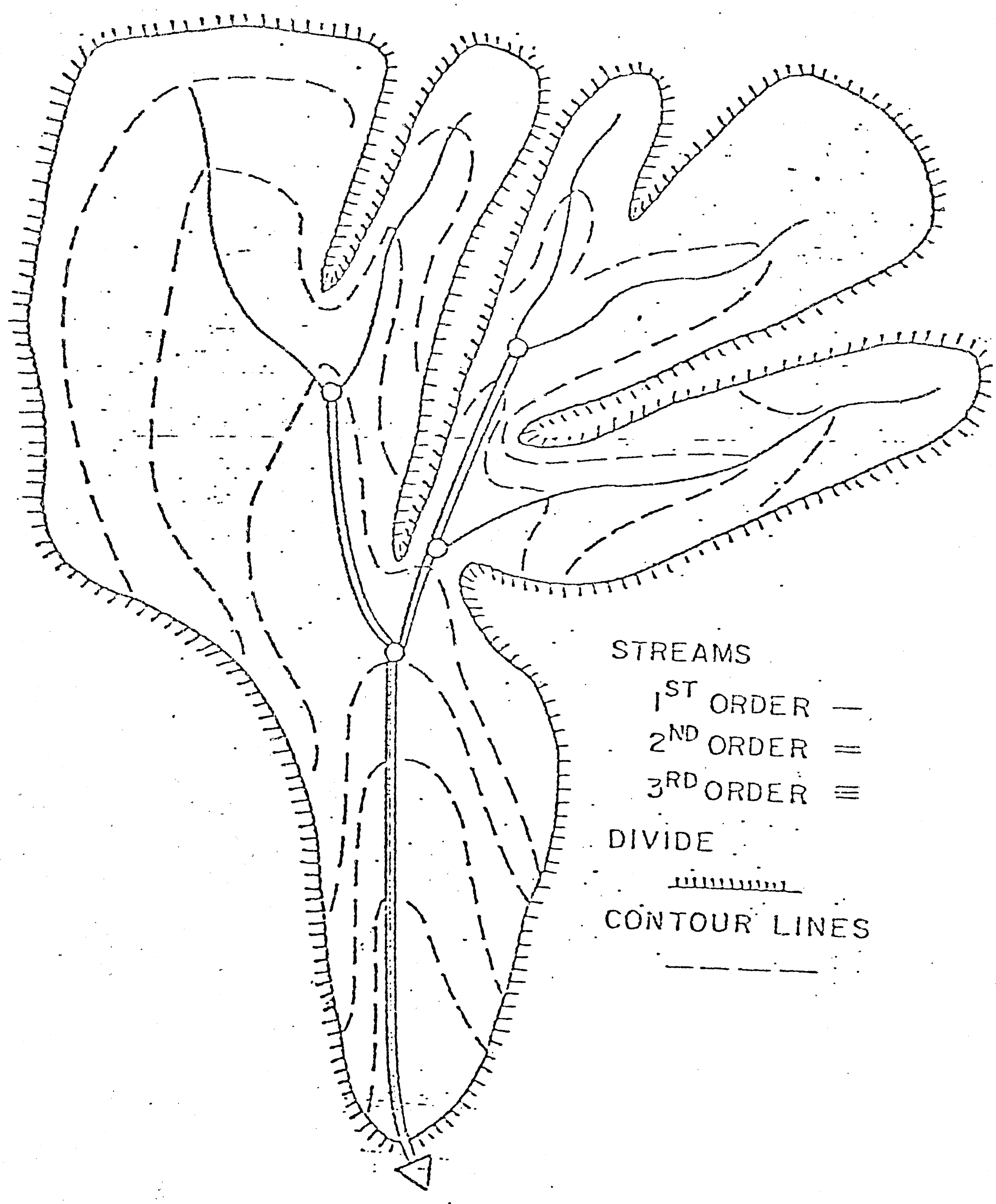

Figure 4. Typical Natural Catchment
MIT Catchment Model

mathematical model. A reductionist effect was used to replace the natural complexities with a number of simple elements such as overland flow planes, stream segments, pipe lengths, etc. A suitable combination of an appropriate number of these simple elements is assumed sufficient to model the behavior of an entire catchment.

Illustrated in Figure 4 is an example catchment. A possible combination of overland flow segments and stream flow segments would appear as a detailed model of this catchment. Consider the drawing of a simple catchment stream element as pictured in Figure 5. Rain falls on the overland flow surfaces of this simple catchment. If the surface is pervious, then the rain will soak (infiltrate) into the ground and there will be no runoff. If the intensity of the rainfall exceeds the infiltration rate, then there will be rain excess, and runoff toward the stream channel will occur. The water runs off in the form of sheet flow or overland flow, and the motion of this water is described mathematically by means of the kinematic wave approximation. It is noteworthy to realize that the kinematic wave theory was originally intended to be used to describe flow in channels, but with respect to overland flow, the water is considered to flow in very wide channels one unit of length (i.e., 1 foot) in width ($y/b \ll 1$ y = depth, b = width).

Some of the basic considerations governing the development phase of the MIT catchment model were:

1. That the model would be based on sound physical reasoning.
2. That the parameters were to be directly related to the physical characteristics of the catchment and insofar as possible to be directly measurable from map or field data.

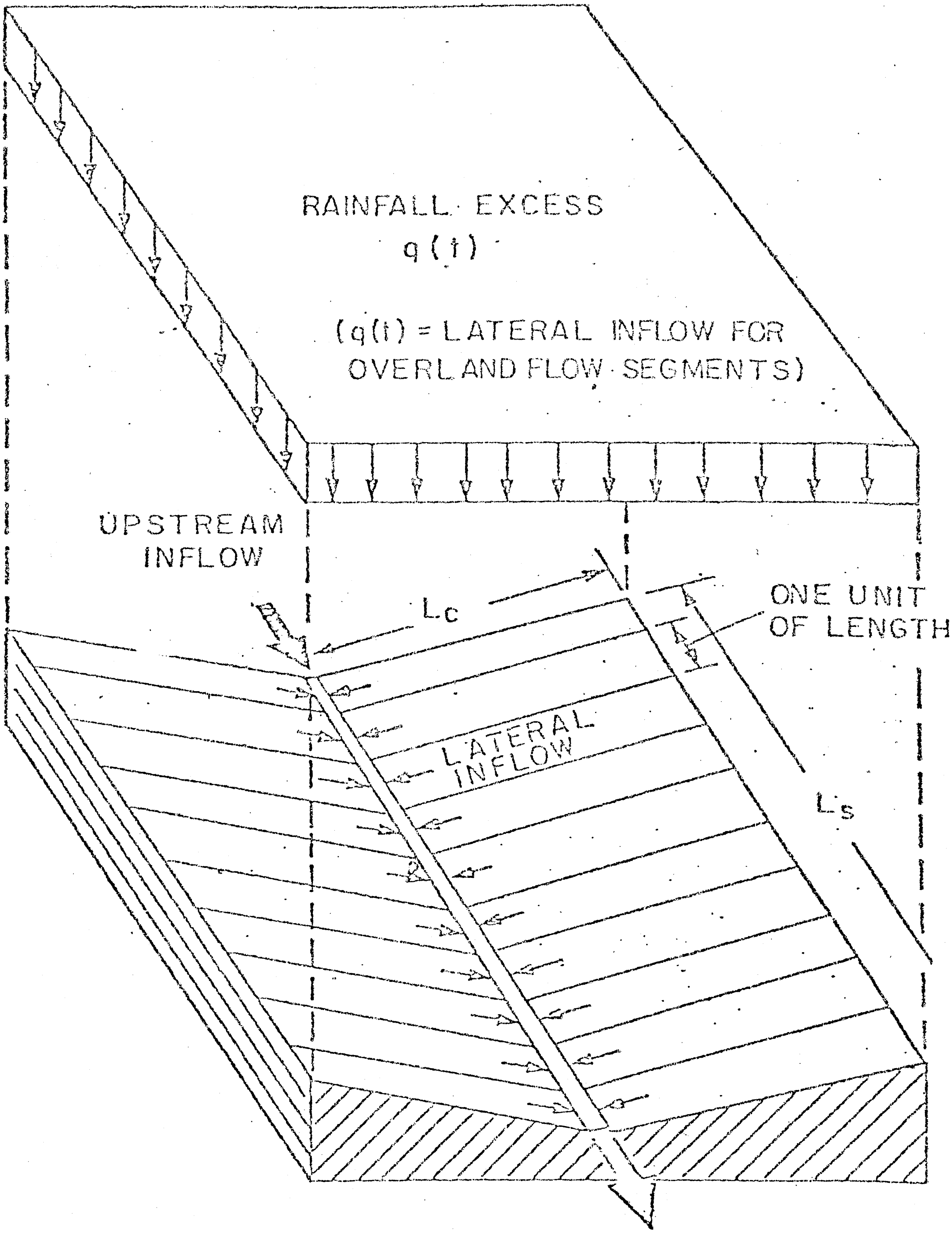

Figure 5. Simple Conceptual Catchment

3. That the model would be subject to experimental verification.
4. That the model would be based on sound hydrologic parameters.
5. The model would be as simple as possible.
6. That the time period could be from a few minutes to several hours.
7. That historic rainfall or runoff data would be eliminated or minimized.
8. That the model would handle any size catchment.
9. That flow distributed over the surface of the catchment would be modeled as planes of overland flow.
10. That the flow from the overland planes would be collected by streamflow segments as lateral inflow and then passed downstream to other stream segments.

The MIT Catchment Model defines the following parameters:

Overland Flow. In the direct runoff of a vegetated catchment, the water trickles over, through, and under a highly irregular surface. The flow regime varies between laminar and turbulent, and the flow among the stems and debris of dense vegetation may at times resemble flow through porous media. It is clear, that a vigorous mathematical description of this phenomenon would require solution of the continuity and momentum equations at an exceedingly small scale, both areally and temporally. Although computer techniques for solving these equations on single elements of homogeneous surface are well established, the amount of field data needed to implement and verify the extension of these methods to the detailed variations of natural surfaces, the computer size, and the computational expense necessary for the solution of the resulting vast systems of equations are inconsistent with the insensitivity of catchment response to this microscale of variability.

The important characteristic of overland flow is that the water is distributed over a wide area at a very small average depth until it reaches a well-defined stream channel.

Streamflow. For modelling of the stream segments many routing techniques are available, ranging from solutions of the full non-linear continuity and momentum equations through progressively simplified or linearized forms of these equations to simple para-metric storage models. It would be desirable to use a form of these equations which is compatible with the overland flow model require-ments and which would represent those nonlinearities important to the dynamic behavior of the catchment.

Lighthill and Whitham (12) in their comprehensive considera-tions of the fluid mechanics of flood movement in rivers, have separated the effects into dynamic and kinematic waves, both of which are initially present. They show that for Froude numbers less than 2, the dynamic component decays exponentially and the kinematic wave ultimately predominates. Woolhiser and Liggett (13) indicate that the rate of damping of the dynamic component will be large enough to justify neglecting the dynamic effects provided that

$$k = \frac{S_0 L}{yF^2} > 10 \tag{2.38}$$

where

S_o = Slope of the stream;

L = Length;

Y = Depth of flow;

F = Froude number.

Use of the kinematic form of the unsteady flow equations allows particularly simple numerical solutions (since all disturbances propogate only in the downstream direction), while retaining some of the non-linear effects of the full dynamic form. The successful application by Wooding (14) of this approach to natural catchments ranging from 0.84 square miles to 3383 square miles has led to the adoption of the kinematic approach as the basic routing element.

The Kinematic Wave Equation. The kinematic wave equation for an overland flow segment is

$$\frac{\partial y}{\partial t} + \frac{\partial q}{\partial x} = (i - f) / 43200 \tag{2.39}$$

$$q = a_c y^{m_c} \tag{2.40}$$

where

y = the depth of flow (ft);

q = the rate of flow (cfs/ft);

t = time (sec);

x = distance along the segment (ft);

i = the rainfall intensity (in/hr);

f = the infiltration rate (in/hr).

In equation (2.39) both i and f may vary with x and t. The difference $i - f$ may be treated as an effective rainfall rate (which by convention in hydrology is never negative), or the water remaining on the surface when f exceeds i may be permitted to continue to percolate into the soil. The fact that f may vary with x causes the model to simulate runoff only from those locations where i exceeds f.

The corresponding equation for the stream segments is

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (2.41)$$

$$Q = a_s A^{m_s} \qquad (2.42)$$

where

A = Cross-sectional area of flow (ft^2);

Q = Discharge rate (cfs);

q = Lateral inflow rate of overland flow (cfs/ft).

The above kinematic wave equations contain the parameters a_c, m_c, a_s and m_s which may be estimated from the Manning formula

$$q = \frac{1.49}{n_c} y_c^{5/3} S_c^{1/2} \tag{2.43}$$

as

$$a_c = \frac{1.49}{n_c} S_c^{1/2} \tag{2.44}$$

$$m_c = 5/3 \tag{2.45}$$

in the case of overland flow or from the Manning formula

$$Q = \frac{1.182}{n_s} \left(\frac{\sqrt{z}}{1+\sqrt{1+z^2}} \right)^{2/3} A^{4/3} S_s^{1/2} \tag{2.46}$$

as

$$a_s = \frac{1.182}{n_s} \left(\frac{\sqrt{z}}{1+\sqrt{1+z^2}} \right)^{2/3} S_s^{1/2} \tag{2.47}$$

$$m_s = 4/3 \tag{2.48}$$

in the case of flow in a triangular channel.

The MIT catchment model solves the kinematic wave equations by numerical techniques. The details of these techniques have been carefully developed over a period of many years to the point where reliable procedures have been programmed to automatically assure the most economical solution of these equations. These numerical procedures discretize time in steps of Δt and distance in steps of Δx. Over any one time step, i and f are assumed to remain constant. Variables i and f also are assumed to remain constant over x. Variations with x of f can be represented in stepwise changes by a cascade of overland flow segments. Along any stream segment, the variable q changes continuously with time but is assumed constant over the length of the stream segment.

Time of Concentration. One of the most important considerations to reduce a catchment to a network of segments is the time it would take each segment to reach equilibrium when excited by a steady-state inflow. This time is called the time of concentration and may be derived from the kinematic wave equation. The time of concentration for an overland flow segment is

$$t_c = \left(\frac{L_c}{a_c (i_e/43200)} \right)^{1/m_c} \qquad (2.49)$$

where i_e is the rate of rainfall excess (in/hr). The time of concentration for a streamflow segment is

$$t_s = \left[\frac{L_s}{a_s\, q} \right]^{1/m_s} \qquad (2.50)$$

where q is the equilibrium rate of lateral inflow to the stream from all adjacent overland flow segments and there is assumed to be no upstream inflow to the stream segment. The time of concentration for a simple model having identical overland flow segments on each side of a stream segment would be

$$t_{\ell} = t_c + t_s$$

$$= \left[\frac{L_c}{a_c(i_e/43200)}\right]^{1/m_c} + \left[\frac{L_s}{a_s(2i_eL_c/43200)}\right]^{1/m_s} \qquad (2.52)$$

Although the time of concentration is important to reduce the catchment to a minimum number of segments, it should be noted that natural rainfall events do not occur at constant intensity, and the time of concentration cannot be observed in the field.

<u>Infiltration</u>. Although infiltration research has been conducted for many years, there still is no generally recognized adequate quantitative model of natural infiltration. Considering the complex combination of soil characteristics, soil moisture conditions and other factors occurring in nature, this is not too surprising. Nevertheless, infiltration is important because it can influence not only the volume and intensity of direct runoff rates but the timing of the runoff hydrograph as well. The MIT catchment model has the capability of utilizing two different methods for determining infiltration, the Soil Conservation Service method (15) and Horton's method (16). Horton's method is a mathematical equation for defining the rate curve of infiltration capacity:

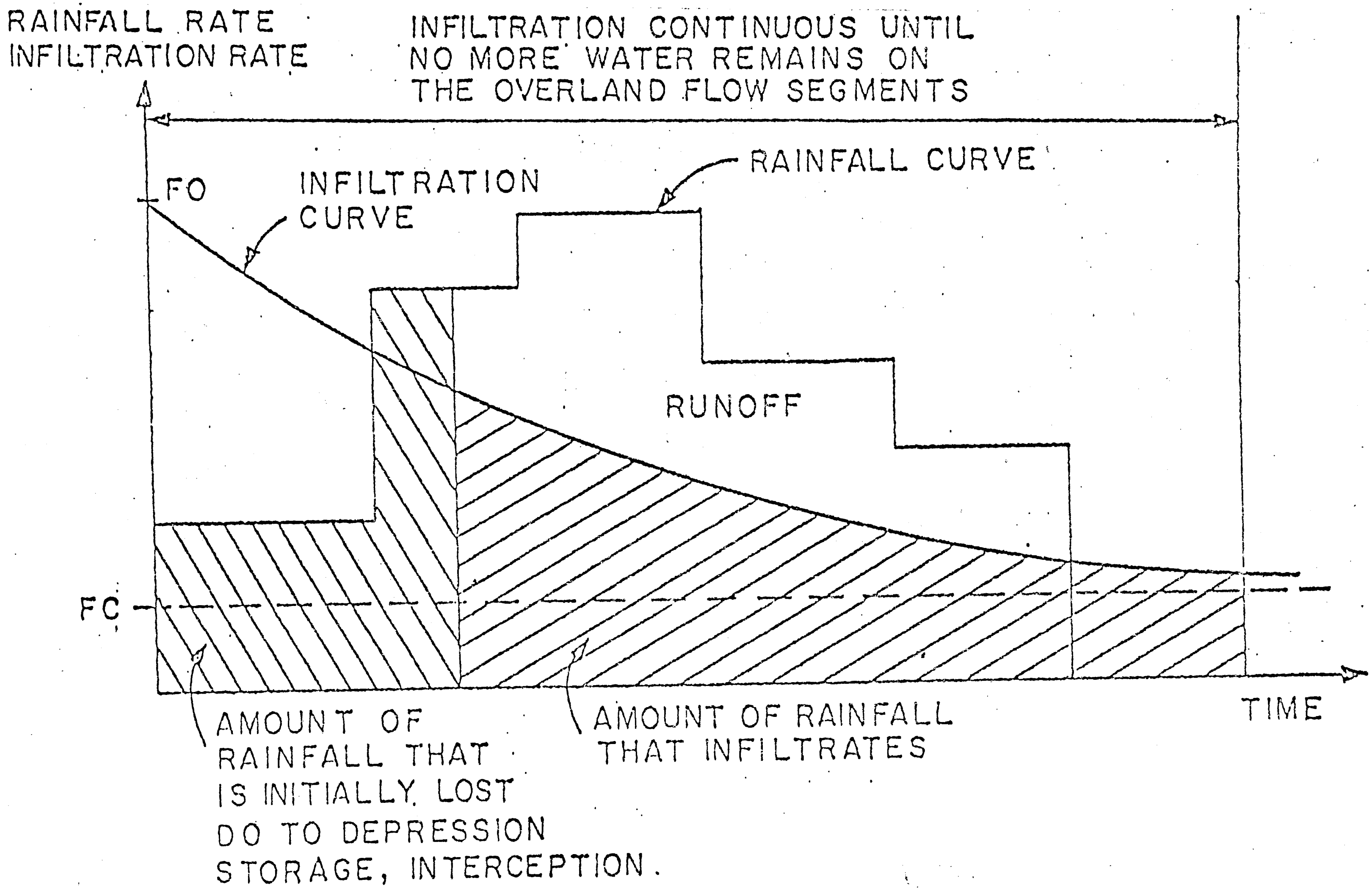

Figure 6. Infiltration Capacity Curve

$$f = f_c + (f_o - f_c)e^{-kt} \quad (2.53)$$

where

f_o = initial rate of infiltration capacity (in/hr)

e = base of natural logarithms

k = constant depending primarily upon soils and vegetation min^{-1}

t = time from start of rainfall

f_c = steady state infiltration capacity (in/hr)

See Figure 6.

The values of f_o, f_c and k are given by the model user as data input and are placed on data card number 4. All previous areas are presumed to have the same infiltration properties. However, an overland flow segment does not have to be completely pervious. The percentage of imperviousness for each overland flow segment is specified in the data input and the model user can have a 100% impervious segment, a 100% pervious segment or any combination thereof.

In computing excess precipitation for any overland flow segment, the following equation is used:

$$EP = (RAIN)(IMP)+(EXCESS)(1-IMP) \quad (2.54)$$

EP = excess precipitation

RAIN = amount of rain falling in segment

IMP = percentage of overland flow segment which is impervious

(1-IMP) = percentage of overland flow segment which is impervious

EXCESS = present rate of precipitation excess for pervious parts of the segment

The second method for determining infiltration is through the use of the Soil Conservation Service Method. The method is explained fully in the SCS National Engineering Handbook, Section 4, "Hydrology", United States Department of Agriculture, 1972 (15) but it will be briefly explained here, since it is the method used in this example.

The SCS has divided all the soils in the United States (including Puerto Rico) into four major hydrologic soil groups. Group A (low run-off potential) are soils having high infiltration rates even when thoroughly wetted and consist chiefly of deep, well - to excessively - drained sands or gravels. These soils have a high rate of water transmission. Group B are soils having moderate infiltration rates even when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission. Group C are soils having slow infiltration rates when thoroughly wetted and consists chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission. Group D (high runoff potential) are soils having slow infiltration rates when thoroughly wetted and consists chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

These four major groups are then broken down further by land use and treatment, by hydrologic soil-cover and by antecedent moisture conditions. The land use and treatment class incorporates items such as crop rotation, contouring, terracing, pasture, range, farm woodlots, commercial forests, straight-row farming, roads and urban areas. The second class, that of hydrologic soil-cover, is self-explanatory. The third class is the antecedent moisture conditions. This class is divided into three areas. A soil can be AMC-I, a condition of watershed soils where the soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes place. AMC-II is the average cause for annual floods, that is, an average of the conditions which have preceded the occurrence of the maximum annual flood on numerous watersheds. AMC-III is the condition of the soil when heavy rainfall or light rainfall and low temperatures have occurred during the five days previous to the given storm and the soil is nearly saturated. In this example AMC-II was considered in all cases.

Thus, the major soil type, land use, and ground cover were determined for each overland flow segment of the catchment. Assuming that we use AMC-II, the SCS National Engineering Handbook was consulted and from this manual, a certain curve was found. The curve number is an arbitrary number used with the SCS method.

Multiple Regression Analysis (17)(18)

If there are m variables to correlate, including one dependent and m-1 externally independent, the general equation for multiple linear regression is

$$Y = B_0 + B_1X_1 + \ldots\ldots + B_iX_i \ldots\ldots + B_mX_m \qquad (2.55)$$

where B_0 is the intercept and B_i is the multiple regression coefficient of the dependent variable Y on the independent variable X_i with all other variables kept constant, m = number of variables.

The principal results for the multiple regression model (equation (2.55) can be shown in matrix form.

To express the multiple linear regression model

$$Y_i = B_0 + B_1X_{11} + B_2X_{i2} \ldots\ldots + B_mX_{im} + \varepsilon_i \qquad (2.56)$$

In the general form, the multiple regression model (4.3) is then

$$\underset{n\times 1}{Y} = \underset{n\times(m+1)\,(m+1)\times 1}{XB} + \underset{n\times 1}{\varepsilon} \qquad (2.57)$$

where

Y is a vector of observations

B is a vector of parameters

X is a matrix of constants

ε is a vector of independent normal random variables with expectation $E(\varepsilon) = 0$ and

Variance-covariance matrix $\sigma^2(\varepsilon) = \sigma^2 I$.

The least squares normal equations for the general multiple linear regression (4.4) are:

$$\underset{(m+1)x(m+1)}{(X'X)'} = \underset{(m+1)x1}{B} + \underset{(m+1)n}{X'} \underset{nx1}{Y} \qquad (2.58)$$

and the least squares estimators are

$$\underset{(m+1)x1}{b} = \underset{(m+1)\ (m+1)}{('X')^{-1}} \underset{m+1x1}{X'Y} \qquad (2.59)$$

Let the vector of the fitted values $\hat{Y}_1$ be denoted by $\hat{Y}$ and the vector of the residual terms, $e_1 = \hat{Y}_1$.

The fitted values are represented by

$$\hat{Y} = Xb \qquad (2.60)$$

and the residual vector by

$$e = Y - \hat{Y} \qquad (2.61)$$

The sums of squares for the analysis of variances are:

Sums of squares total = SSTOT = $Y'Y - n\bar{Y}^2$ (2.62)

Sums of squares regression = SSR = $b'X'Y' - n\bar{Y}^2$ (2.63)

Sums of squares error = SSE = $e'e = Y'Y - b'X'Y'$ (2.64)

The sum of squares total, as usual, has n-1 degrees of freedom associated with it. The sum of squares error has n-(m+1) degrees of freedom associated with it since m+1 parameters need to be estimated in the regression function for model (4.4). Finally, the sum of squares regression has m+1-1 = m degrees of freedom associated with it, representing the number of X variables X_1 ....., X_m for which a coefficient has been estimated.

Table II shows these analyses of variance results, as well as the mean squares MSR and MSE:

$$\text{(MEAN SQUARE REGRESSION)} = \text{MSR} = \frac{\text{sum of square regression}}{m} \tag{2.65}$$

$$\text{(MEAN SQUARE ERROR)} = \text{MSE} = \frac{\text{sum of square error}}{n-m+1} \tag{2.66}$$

The expectation of MSE is σ^2, as for simple regression. Street and Torrie (18) stated that the expectation of MSR is σ^2 plus a quantity which is positive if any of the B_k (k = 1, ..., m) coefficients is not zero. For instance, when m+1-1 = m = 2, then

$$E(\text{MSR}) = \sigma^2 + B_1{}^2\ \Sigma(X_{i1} + \bar{X}_1)^2 + B_2{}^2\ \Sigma(X_{i2} - \bar{X}_2)^2 +$$

$$2B_1B_2\ \Sigma(X_{i1} - \bar{X}_1)(X_{i2} - \bar{X}_2)\ \ /2 \tag{2.67}$$

Thus, if both B_1 and B_2 equal zero, $E(\text{MSR}) = \sigma^2$. Otherwise, $E(\text{MSR}) > \sigma^2$.

TABLE II

ANOVA TABLE FOR GENERAL LINEAR REGRESSION MODEL

Source of Variation	Sum of Square	DF	
REGRESSION	$SSR = b'X'Y' - n\bar{Y}^2$	m	$MSR = \frac{SSR}{m}$
ERROR	$SSE = Y'Y - b'X'Y'$	n-m-1	$MSE = \frac{SSE}{n-m+1}$
TOTAL	$SSTO = Y'Y - nY^2$		

The coefficient of multiple determination, denoted by R^2, is defined as follows:

$$R^2 = \frac{SSR}{SSTO} = 1 - \frac{SSE}{SSTO} \quad . \tag{2.68}$$

It measures the proportionate reduction of total sum of squares variation in Y associated with the use of the set of X variables $X_1, \ldots\ldots, X_m$. The coefficient of multiple determination R^2 reduces to the coefficient of simple determination r^2 (simple regression) when m = 1; that is, when one independent variable is in the model (equation (2.68). Thus, for R^2 we have

$$0 \leq R^2 \leq 1. \tag{2.69}$$

R^2 assumes the value of 0 when all $b_k = 0$ $(k = 1, \ldots\ldots, m)$. R^2 takes on the value 1 when all observations fall directly on the fitted response surface; that is, when $Y_i = \hat{Y}_j$ for all i.

The coefficient of multiple correlation R is the positive square root of R^2:

$$R = \sqrt{R^2}. \tag{2.70}$$

CHAPTER III

DEVELOPMENT OF THE FLASH FLOOD MODEL

Flash Flood Model

To be able to walk across a drainage basin and from visual observation predict the flows and stage for a varied condition of runoff has been the dream of many hydrologists. The Flash Flood Model is an attempt to enable an hydrologist to be able to predict the maximum disaster and major floods that may occur to a community or to a basin by knowing a few basic basin parameters (Figure 7).

Today the urban and rural residents of our country are warned not to live in a flood plain. Many State and Federal agencies have stressed the point that the only real protection is to locate one's home or business above the 100 year flood plain. These governing bodies do not attempt to explain the possibility that a flood five times worse than the 100 year flood could occur. The development of this Flash Flood Model is an attempt to educate the citizenry and governing bodies that it is possible that a catastrophic flood could occur in their respective communities.

The specific purpose of the Flash Flood Model is to provide to the hydrologist/engineer a tool to aid him to better analyze a basin. Consider that the Probable Maximum Storm only occurs twice a year in the United States, therefore, where it does occur, the departure from normal hydrologic conditions is usually so great that any understanding of what could happen is beyond comprehension.

The Flash Flood Model first establishes within its files the average rainfall/runoff values. The index to moisture conditions within a basin is the universal application of the antecedent precipitation index P_a. The equation is:

$$P_a = b_1 P_1 + b_2 P_2 + B_3 P_3 + \ldots + b_t P_t \qquad (3.1)$$

where

P_a = Antecedent Precipitation Index (API)

b_t = A constant

P_t = Amount of precipitation which occurred t days prior to the storm.

In a day to day accounting of the index, there is advantage in assuming that b_t decreases with t according to a logarithmic recession, rather than as a reciprocal.

Therefore

$$Pat = Paok^t \qquad (3.2)$$

where

$b_t = k^t$

a = Coefficient

k = Exponent

o = Initial value of API.

then by letting t equal unit,

$$P_{a1} = kP_{ao} \qquad (3.3)$$

Therefore, the index for any day is equal to a constant k times the index of the day before. The value of k is a function of the geographic area. Experience has shown that the k value in the plains area of the United States is 0.90.

The Flash Flood Model is one main computer model with two sub-routines. The sub-routines are the MIT Catchment sub-routine and the HEC-II sub-routine (Figure 7). The Flash Flood Model has within its program four basic data arrays, namely, DATA TSA, DATA TSB, DATA TSC and DATA TSD (Figure 13). These data sets relate to soil moisture conditions in areas of four different runoff capabilities. DATA TSA is for 0.25 inches of runoff to flood an average stream in a particular area, DATA TSB is for 0.50 inches, DATA TSC is for 0.75 inches and DATA TSD is for 1.00 inch.

The four data sets were compiled from the rainfall/runoff curve relationship in Figure 13. These tables were keyed on the stream capacities of an area and the amount of rainfall required to cause stream flooding.

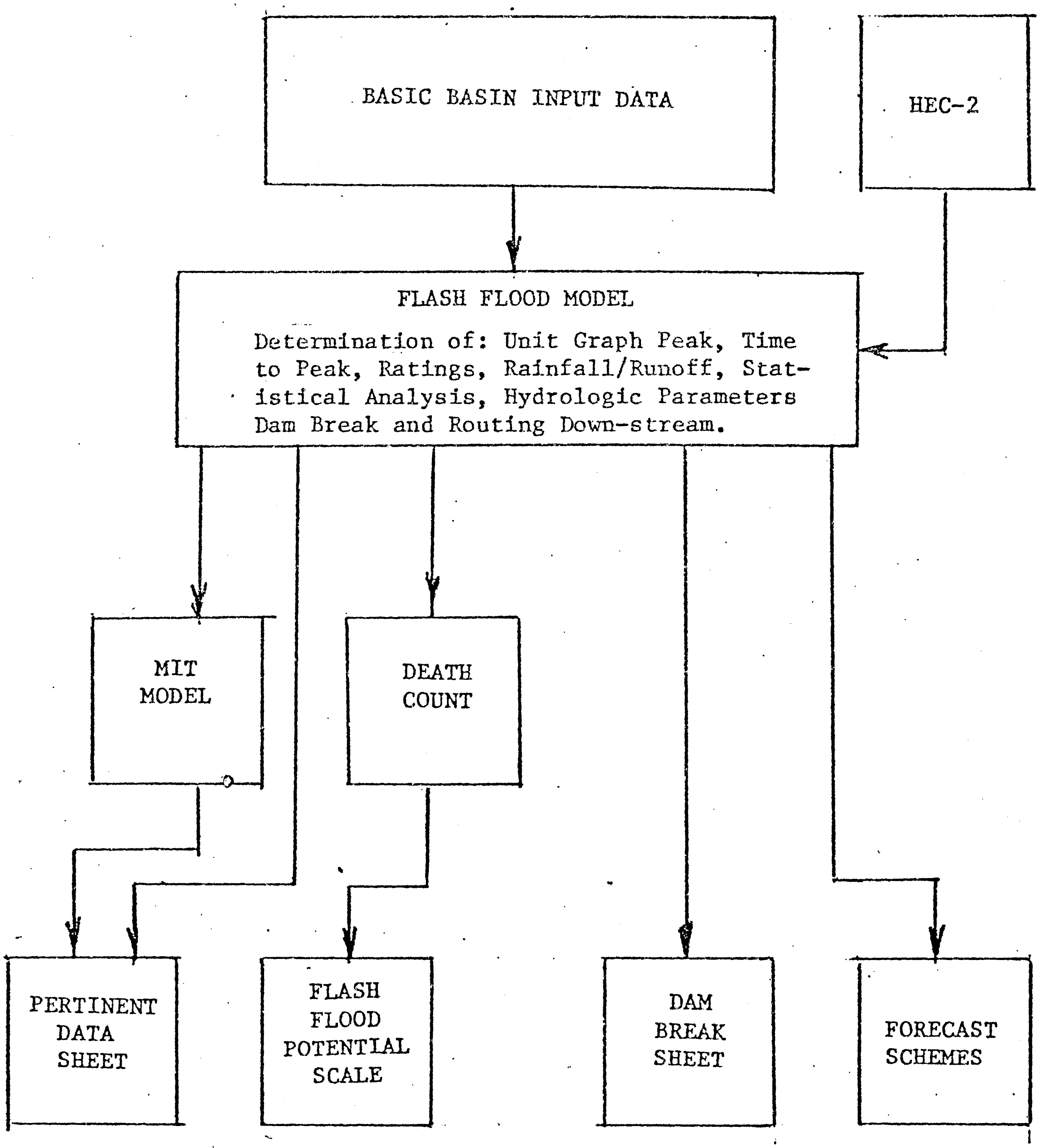

Figure 7. Flow Chart of the Flash Flood Model

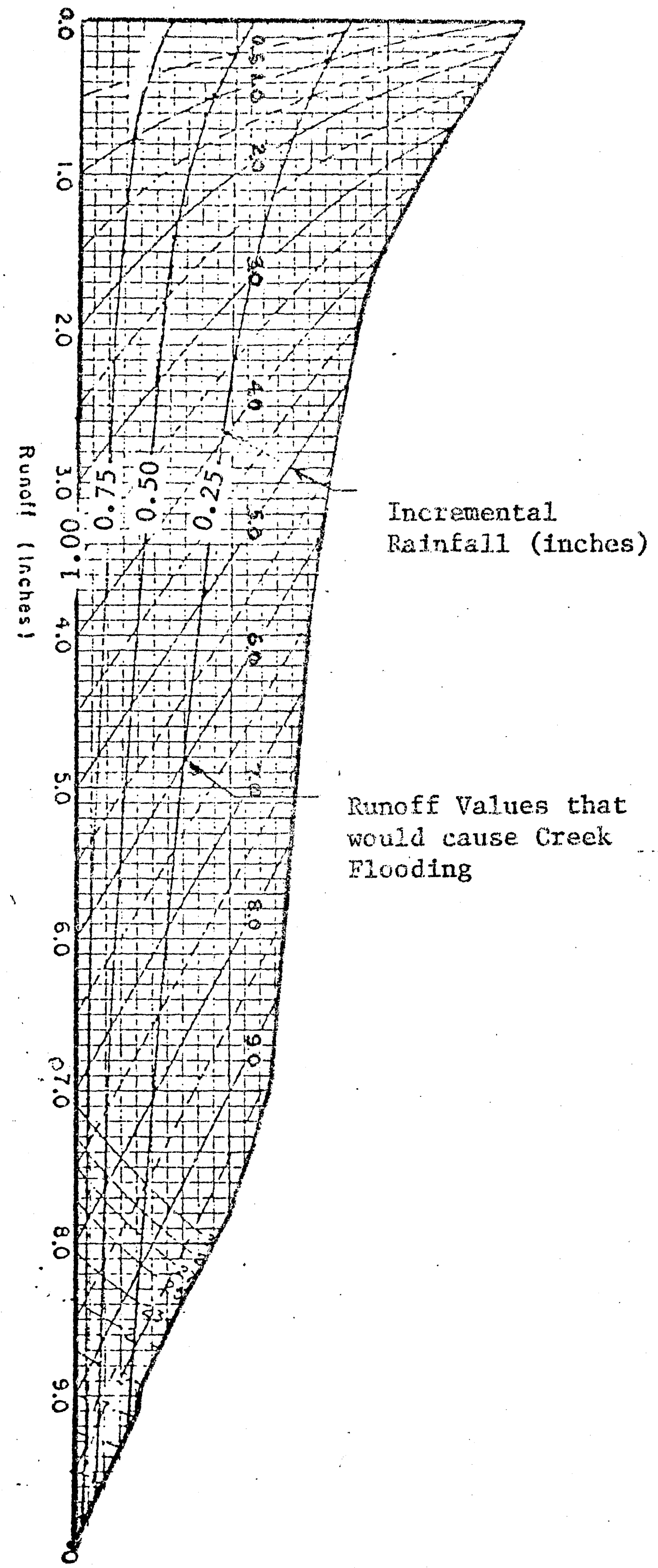

Figure 8. Rainfall/Runoff Relationship.

The next major component of the model is the data requirement as shown in Figures 9 and 10.

The model will next interrogate the statistical equations to determine the positioning of the subject basin within the population of statistical data. The model will use the statistical equation developed from the "Best" 6 variables found by the maximum R-square improvement procedure. (A description of the statistical model is located further on in this chapter). In the "Best" procedure, the variables are RFPMS (rainfall/probable maximum storm), DENFLP (population density of flood plain), DRAINA (drainage area), RAINFAL (rainfall), SLOPCN (slope of channel), SLOPBAS (slope of basin).

The main equation used in this subroutine is:

$$\begin{aligned} DEATHS = & -71.641 + 2.53RFPMS + 0.016DENFLP \\ & - 0.101DRAINA - 2.328RAINFL \\ & + 2.414SLOPCH + 0.728SLOPBA \end{aligned} \qquad (3.4)$$

Next in line of computation is the development of a stage discharge relationship called a rating. This rating employs the use of empirical formulas (2)(4)(5). The option will exist to develop the rating by the noted empirical formula or by other analytical means through use of the Corps of Engineers Hydrologic Engineer Center's Backwater Program called "HEC-II" (19).

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FORTRAN CODING FORM

Form X28-7327-2
Printed in U.S.A.

Program: FLOOD POTENTIAL SCALE - TULSA RIVER CENTER	Punching Instructions: Graphic / Punch	Card Form #	Page 1 of 2
Programmer	Date		Identification 73–80

C FOR COMMENT LOCATION

FORTRAN STATEMENT

- STATION, BASIN & LOCATION
- REACH
- DATE
- STATE
- IF COLORADO OR NEW MEXICO USE blank ALL REST, TEXAS, OKLAHOMA, KANSAS ARKANSAS & MISSOURI USE 1
- RATIO OF RAINFALL TO PMP STORM
- POPULATION OF FLOOD PLAIN
- POPULATION OF TOTAL COMMUNITY
- DRAINAGE AREA
- RAINFALL
- SLOPE OF CHANNEL IN FEET/MILE
- SLOPE OF BASIN IN FEET/MILE
- SLOPE OF SIDES IN FEET/MILE
- 2 YEAR, 24 HOUR STORM IN INCHES
- TIME TO PEAK IN HOURS OR BLANK CARD IF VALUE IS UNKNOWN.
- UNIT GRAPH PEAK FLOW OR BLANK CARD IF VALUE IS UNKNOWN.
- MAXIMUM HEIGHT OF BASIN IN MLS
- ZERO OF GAGE (LOCATION)
- DURATION OF STORM
- RIVER MILES OF REACH IN MILES.
- ANNUAL RAINFALL(AVERAGE) IN INCHES

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

Figure 9. Data Requirements for Flash Flood Model

IBM

FORTRAN CODING FORM

Form X28-7327-6
Printed in U.S.A.

FLOOD POTENTIAL SCALE - TULSA RIVER CENTER	Punching Instructions		Page 2 of 2
Program	Graphic	Card Form #	Identification (73–80)
Programmer / Date	Punch		

C FOR COMMENT LOCATION

FORTRAN STATEMENT

```
FLOOD STAGE IN FEET OR BLANK CARD IF VALUE IS UNKNOWN.
          FLOW OF PMP STORM OR BLANK CARD IF VALUE IS UNKNOWN.
DAM BREAK SELECTION - USE 1. IF YOU WANT DAM BREAK, USE BLANK CARD IF YOU DO NOT WANT DAM BREAK.
                                                        NAME OF DAM OR LAKE
SURFACE AREA IN ACRES.
DEPTH OF RESERVOIR IN FEET.
RESERVOIR LENGTH IN MILES.
ESTIMATED BREACH WIDTH IN FEET.
ESTIMATED BREACH DEPTH IN FEET.
          RESERVOIR CAPACITY IN ACRE-FEET OR USE BLANK CARD IF VALUE IS UNKNOWN.
                                                        NAME OF TOWN DOWNSTREAM
DISTANCE TO CITY DOWNSTREAM FROM DAM IN MILES.
DO YOU WANT TO DO MORE DAMS? IF YES USE BLANK CARD, IF NO USE 1.  **NOTE** YOU MUST USE A (1.) even if no dams were cal.
STATE FORECAST ZONE NUMBER
RUNOFF VALUE FOR THAT AREA OF THE STATE. (EITHER 0.25, 0.50, 0.75, or 1.00)
DATUM OF TABLE  FOR FEET USE BLANK CARD,  FOR MSL USE 1.
```

SKIP IF NO DAM(S) (brackets the lines from NAME OF DAM OR LAKE to NAME OF TOWN DOWNSTREAM)

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

Figure 10. Data Requirements for Flash Flood Model Sheet 2.

The majority of these empirical equations will be in the form:

$$Q_n = (\text{Constant})(\text{Drainage Area})^{(M)}(\text{Slope of Basin})^{(L)} \quad (3.5)$$

where

Q = Flow in CFS

n = Flood frequency

M = Exponent for drainage area

L = Exponent for slope of basin

or

$$\text{Stage}_n = (\text{Constant})(\text{Drainage Area})^{(M)}(2\text{ hour storm}) + \text{Constant} \quad (3.6)$$

where

Stage = Gage height in feet

n = Flood frequency

M = Exponent for drainage area

The model will next position the community within the Flash Flood Potential Scale. The program will determine the potential death number and then locate its number position in the scale between one to ten.

The model will next calculate hydrologic parameters from basic information supplied as noted in Table V. It is in this parameter calculation step of the model that the time to peak, unit graph peak, channel slope, overbank slope, 100 year flow, 100 year gage height, probable maximum storm flow depth, number of rainfall gages required and number of river stations required are determined.

The time of concentration is determined by the equation: (20)

$$T_c = \frac{((11.9)(RM)^{3.0})}{\Delta h^{0.35}} \tag{3.7}$$

where

T_c = Time of concentration;

RM = Distance of stream, in miles;

Δh = Difference in height of basin.

The time to peak is determined by the equation: (20)

$$T_p = ((Dur/2.0)+(0.6)(T_c))(.7) \tag{3.8}$$

where

T_p = Time to peak;

Dur = Rainfall duration in yours;

T_c = Time of concentration.

The unit graph peak is determined by the equation: (21)

$$UG = ((DA)(640))((2/(T_p+T_r)) \tag{3.9}$$

where

UG = Unit graph peak, in cfs;

DA = Drainage Area, in miles;

T_p = Time to peak;

T_r = Time of recession.

The model will next write all output on the disk, waiting for a later command to print results.

The model next investigates the input data for dam break information. If dam data is available, then flow from a total wash out break and a breach break will be determined in terms of flow and downstream stage.

Peak outflow from a complete reservoir washout is calculated by: (22)

$$Q_{Res} = (8/27)(B)(32.2)^{0.5}(DEPTR)^{1.5} \tag{3.10}$$

where

Q_{Res} = Discharge in cfs;

$B = \dfrac{(2)(\text{Reservoir Capacity})}{(\text{Depth of Reservoir})(\text{Length of Reservoir})}$

DEPTR = Depth of Reservoir

The MIT Catchment Model (23)

The basic equations of the MIT Catchment Model were described in Chapter II. The MIT Catchment Model is used as a subroutine to the Flash Flood Model. It is used to calculate the time to peak and peak flow from a predetermined study storm, or operationally for unusual storm events.

The data sheet for compiling the data input for the MIT Catchment Model is shown in Figures 11 and 12.

The computer cards for the Flash Flood Model is listed in Figure 13.

Figure 11. Data Requirements for MIT Model

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FORTRAN CODING FORM

Form X28-7327-4 Printed in U.S.A.

Program	MIT MODEL - DETERMINISTIC URBAN RUNOFF MODEL	Punching Instructions		Page 1 of 2
Programmer	Date	Graphic	Card Form #	Identification 73 - 80
		Punch		

C FOR COMMENT

STATEMENT NUMBER | CONT. | FORTRAN STATEMENT

PART 1 (TITLE, ONE CARD -- 20A4)

PART 2 (CONTROL INFORMATION -- I5, 2F5.0, 4I5, 3A4)

No of segmts	Time Interval	Output Interval	No. Rain Gages	Iopt	No. Storms		
	5.	5.		0	1	SCS	INFL

PART 3 (BASIN INFORMATION -- 8A4, 2F1, I6, F8.0, 4F5.0, 5F3.0)

Iden. of Segmt.	(Up to 3 upstream segments)	(Up to 4 sets of laterals)	Type of Segment	if flow considered	No. Intvl	Length of seg	Slope ft/ft	Manning n		Impervious (1. paved) (0. pervi)

MAX = 9

OVERLAND FLOW
(Drainage area/(avg. overland width x seg lenght))
SWALE FLOW
(Use width of channel one foot above bottom)
Thiessen coef
1.0
.8
SCS CURVE NO.
7980

PART 4 (INFILTRATION PARAMETERS 4F5.0) **** ONLY TO BE USED WITH HORTON METHOD

Initial loss	Initial Infil Rt	Steady infil R	Expnt rate decay
.	.	.	1.

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

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FORTRAN CODING FORM

Form X28-7327-4
Printed in U.S.A.

MIT MODEL - DETERMINISTIC URBAN RUNOFF MODEL		Punching Instructions		Page 2 of 2
Program		Graphic	Card Form #	Identification 73 — 80
Programmer	Date	Punch		

C FOR COMMENT — LOCATION

FORTRAN STATEMENT

Statement Number (1–5)	Cont. (6)	7 – 72
PART 5		NO. OF RAINFALL DATA CARDS --
No. of data cd		Time to Terminate
Time since start storm		Rainfall Intensity, inches/hr — Sta. 1 · Sta. 2 · Sta. 3 · Sta. 4 · Sta. 5

* A standard card form, IBM electro 888157, is available for punching source statements from this form.

Figure 12. Data Requirements for MIT Model (Sheet 2)

Computer Program

Flash Flood Model

```
C       PROGRAM TABL
        REAL MLCITY
        DIMENSION DNAME(13),CNAME(13)
        DIMENSION TSA(209), TSB(209), TSC(209), TSD(209), TSE(88)
        DIMENSION ZB(231), TS(924),ZEELV(2310),ZA(2310)
        DIMENSION RRFF(11), FFFF(21),DATE(2),STATE(3)
        COMMON STAGE(7),EV(5),Q(7),QX(10),DATUM
        COMMON BASIN(13),REACH(13)
        COMMON RF(11),FF(21),EELV(21,11)
        DATA TSA/
       1 .07,  .28,  .52,  .81, 1.21, 1.66, 2.64, 3.71, 4.80, 6.98, 8.90,
       1 .03,  .21,  .43,  .69, 1.06, 1.48, 2.42, 3.45, 4.55, 6.75, 8.66,
       1 .00,  .15,  .34,  .57,  .92, 1.30, 2.21, 3.22, 4.30, 6.52, 8.41,
       1 .00,  .12,  .28,  .49,  .81, 1.17, 2.05, 3.05, 4.11, 6.35, 8.23,
       1 .00,  .05,  .19,  .37,  .63,  .92, 1.71, 2.67, 3.72, 5.96, 7.81,
       1 .00,  .01,  .13,  .29,  .52,  .80, 1.48, 2.40, 3.43, 5.68, 7.50,
       1 .00,  .00,  .07,  .22,  .40,  .67, 1.39, 2.29, 3.30, 5.49, 7.31,
       1 .00,  .00,  .00,  .11,  .33,  .58, 1.30, 2.25, 3.28, 5.40, 7.27,
       1 .00,  .00,  .00,  .10,  .28,  .49, 1.08, 1.82, 2.70, 4.95, 6.70,
       1 .00,  .00,  .00,  .01,  .18,  .38,  .88, 1.58, 2.42, 4.56, 6.28,
       1 .00,  .00,  .00,  .00,  .10,  .29,  .76, 1.42, 2.23, 4.31, 5.96,
       1 .00,  .00,  .00,  .00,  .04,  .21,  .35, 1.25, 2.03, 4.02, 5.67,
       1 .00,  .00,  .00,  .00,  .00,  .15,  .56, 1.10, 1.84, 3.78, 5.35,
       1 .00,  .00,  .00,  .00,  .00,  .08,  .47, 1.06, 1.78, 3.77, 5.40,
       1 .00,  .00,  .00,  .00,  .00,  .03,  .38,  .94, 1.63, 3.58, 5.19,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .29,  .82, 1.49, 3.39, 4.98,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .21,  .69, 1.47, 3.34, 5.05,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .11,  .55, 1.15, 2.76, 4.22,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .07,  .46, 1.03, 2.65, 4.11/
        DATA TSB/
       1 .00,  .00,  .00,  .00,  .00,  .00,  .02,  .38,  .92, 2.42, 3.83,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .00,  .28,  .80, 2.31, 3.73,
       1 .21,  .52,  .89, 1.31, 1.82, 2.33, 3.38, 4.44, 5.49, 7.58, 9.55,
       1 .17,  .43,  .74, 1.12, 1.62, 2.13, 3.18, 4.25, 5.31, 7.43, 9.39,
       1 .10,  .32,  .59,  .89, 1.32, 1.78, 2.81, 3.89, 4.98, 7.13, 9.06,
       1 .06,  .26,  .49,  .77, 1.17, 1.61, 2.57, 3.64, 4.73, 6.92, 8.84,
       1 .02,  .18,  .39,  .65, 1.01, 1.41, 2.34, 3.37, 4.46, 6.67, 8.57,
       1 .00,  .13,  .30,  .52,  .85, 1.23, 2.12, 3.12, 4.19, 6.42, 8.31,
       1 .00,  .08,  .23,  .42,  .69, 1.01, 1.85, 2.83, 3.89, 6.13, 7.99,
       1 .00,  .04,  .17,  .34,  .59,  .88, 1.63, 2.58, 3.62, 5.87, 7.71,
       1 .00,  .00,  .10,  .25,  .48,  .75, 1.41, 2.28, 3.31, 5.56, 7.37,
       1 .00,  .00,  .08,  .22,  .44,  .70, 1.35, 2.18, 3.21, 5.46, 7.26,
       1 .00,  .00,  .01,  .13,  .31,  .54, 1.15, 1.90, 2.82, 5.07, 6.83,
       1 .00,  .00,  .00,  .07,  .25,  .45, 1.01, 1.74, 2.61, 4.82, 6.55,
       1 .00,  .00,  .00,  .00,  .17,  .36,  .85, 1.54, 2.38, 4.51, 6.21,
       1 .00,  .00,  .00,  .00,  .10,  .28,  .74, 1.36, 2.17, 4.22, 5.89,
       1 .00,  .00,  .00,  .00,  .05,  .21,  .63, 1.20, 1.96, 3.96, 5.56,
       1 .00,  .00,  .00,  .00,  .00,  .15,  .53, 1.07, 1.76, 3.71, 5.22,
       1 .00,  .00,  .00,  .00,  .00,  .06,  .41, 1.02, 1.83, 3.79, 5.46/
        DATA TSC/
       1 .00,  .00,  .00,  .00,  .00,  .00,  .33,  .87, 1.73, 3.72, 5.51,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .26,  .76, 1.51, 3.39, 5.03,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .21,  .69, 1.47, 3.34, 5.05,
       1 .00,  .00,  .00,  .00,  .00,  .00,  .16,  .60, 1.22, 3.02, 4.57,
```

Figure 13. Flash Flood Model

```
     1  .34,  .77, 1.22, 1.70, 2.21, 2.73, 3.76, 4.79, 5.82, 7.86, 9.85,
     1  .25,  .60, 1.00, 1.44, 1.96, 2.47, 3.52, 4.57, 5.61, 7.69, 9.66,
     1  .22,  .54,  .92, 1.34, 1.85, 2.37, 3.42, 4.47, 5.53, 7.61, 9.59,
     1  .16,  .42,  .71, 1.08, 1.58, 2.09, 3.14, 4.21, 5.27, 7.40, 9.35,
     1  .12,  .34,  .61,  .92, 1.36, 1.83, 2.88, 3.95, 5.03, 7.18, 9.12,
     1  .03,  .24,  .49,  .78, 1.16, 1.63, 2.67, 3.73, 4.80, 6.94, 8.88,
     1  .00,  .15,  .38,  .66,  .97, 1.43, 2.45, 3.51, 4.57, 6.70, 8.64,
     1  .00,  .15,  .34,  .57,  .92, 1.30, 2.21, 3.22, 4.30, 6.52, 8.41,
     1  .00,  .07,  .23,  .43,  .72, 1.08, 1.94, 2.92, 3.98, 6.19, 8.07,
     1  .00,  .01,  .15,  .35,  .59,  .93, 1.77, 2.73, 3.77, 5.96, 7.83,
     1  .00,  .00,  .10,  .25,  .48,  .75, 1.41, 2.28, 3.31, 5.56, 7.37,
     1  .00,  .00,  .07,  .22,  .40,  .67, 1.39, 2.29, 3.30, 5.49, 7.31,
     1  .00,  .00,  .00,  .11,  .30,  .54, 1.26, 2.15, 3.14, 5.28, 7.12,
     1  .00,  .00,  .00,  .05,  .22,  .44, 1.09, 1.96, 2.94, 5.05, 6.89,
     1  .00,  .00,  .00,  .00,  .14,  .35,  .93, 1.78, 2.73, 4.83, 6.65/
      DATA TSD/
     1  .00,  .00,  .00,  .00,  .07,  .26,  .77, 1.59, 2.53, 4.61, 6.42,
     1  .00,  .00,  .00,  .00,  .00,  .16,  .66, 1.43, 2.43, 4.48, 6.33,
     1  .00,  .00,  .00,  .00,  .00,  .09,  .54, 1.23, 2.13, 4.16, 5.96,
     1  .00,  .00,  .00,  .00,  .00,  .08,  .47, 1.06, 1.78, 3.77, 5.40,
     1  .00,  .00,  .00,  .00,  .00,  .03,  .41,  .97, 1.67, 3.54, 5.12,
     1  .00,  .00,  .00,  .00,  .00,  .00,  .33,  .84, 1.51, 3.28, 4.82,
     1  .50, 1.00, 1.50, 2.00, 2.50, 3.00, 4.00, 5.00, 6.00, 8.00,10.00,
     1  .38,  .83, 1.30, 1.79, 2.31, 2.82, 3.85, 4.87, 5.89, 7.91, 9.91,
     1  .30,  .69, 1.12, 1.58, 2.10, 2.61, 3.65, 4.69, 5.73, 7.78, 9.77,
     1  .22,  .54,  .92, 1.34, 1.85, 2.37, 3.42, 4.47, 5.53, 7.61, 9.59,
     1  .19,  .46,  .81, 1.21, 1.71, 2.23, 3.28, 4.34, 5.54, 7.50, 9.47,
     1  .15,  .41,  .70, 1.04, 1.54, 2.05, 3.10, 4.16, 5.23, 7.36, 9.31,
     1  .13,  .36,  .64,  .95, 1.40, 1.90, 2.96, 4.03, 5.10, 7.25, 9.19,
     1  .04,  .22,  .45,  .71, 1.09, 1.51, 2.47, 3.51, 4.60, 6.80, 8.71,
     1  .01,  .16,  .36,  .61,  .96, 1.35, 2.27, 3.29, 4.37, 6.59, 8.48,
     1  .00,  .14,  .31,  .54,  .88, 1.26, 2.15, 3.16, 4.23, 6.46, 8.35,
     1  .00,  .08,  .23,  .42,  .69, 1.01, 1.85, 2.83, 3.89, 6.13, 7.99,
     1  .00,  .04,  .18,  .35,  .61,  .90, 1.66, 2.61, 3.66, 5.91, 7.75,
     1  .00,  .00,  .13,  .29,  .51,  .79, 1.54, 2.47, 3.50, 5.71, 7.55/
      DATA TSE/
     1  .00,  .00,  .00,  .16,  .32,  .61, 1.40, 2.40, 3.43, 5.52, 7.42,
     1  .00,  .00,  .00,  .15,  .21,  .57, 1.19, 2.18, 3.21, 5.28, 7.18,
     1  .00,  .00,  .00,  .10,  .19,  .50, 1.10, 1.84, 2.73, 4.98, 6.73,
     1  .00,  .00,  .00,  .00,  .11,  .43,  .87, 1.75, 2.76, 4.81, 6.70,
     1  .00,  .00,  .00,  .00,  .05,  .35,  .83, 1.51, 2.35, 4.46, 6.16,
     1  .00,  .00,  .00,  .00,  .03,  .21,  .66, 1.30, 2.09, 4.11, 5.77,
     1  .00,  .00,  .00,  .00,  .00,  .14,  .57, 1.14, 1.90, 3.83, 5.45,
     1  .00,  .00,  .00,  .00,  .00,  .06,  .41, 1.02, 1.83, 3.79, 5.46/
      DATA RRFF/
     1  .5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 8.0, 10.0/
      DATA FFFF/
     1 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4,
     13.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0/
      DO 4311 I = 1,11
 4311 RF(I) = RRFF(I)
      DO 4312 I = 1,21
 4312 FF(I) = FFFF(I)
      DO 5600 I = 1,209
 5600 TS(I) = TSA(I)
      DO 5601 I = 210,418
 5601 TS(I) = TSB(I-209)
```

Figure 13. (continued) Flash Flood Model

```
      DO 5602 I = 419,627
5602  TS(I) = TSC(I-418)
      DO 5603 I = 628,836
5603  TS(I) = TSD(I-627)
      DO 5604 I = 837,924
5604  TS(I) = TSE(I-836)
5559  READ(5,104,END=5560)BASIN
 104  FORMAT(13A4)
5561  READ(5,54)REACH
  54  FORMAT(13A4)
      READ(5,103)DATE
 103  FORMAT(2A4)
      READ(5,1300)STATE
1300  FORMAT(3A4)
      READ(5,4001)STATEN
4001  FORMAT(F2.0)
      READ(5,4002)RFPMS
4002  FORMAT(F5.1)
      READ(5,4003)DENFLP
4003  FORMAT(F6.1)
      READ(5,4161)DENTOT
4161  FORMAT(F10.0)
      READ(5,4004)DRAINA
4004  FORMAT(F8.1)
      READ(5,4005)RAINFA
4005  FORMAT(F6.2)
      READ(5,4006)SLOPCH
4006  FORMAT(F6.1)
      READ(5,4007)SLOPBA
4007  FORMAT(F6.1)
      READ(5,4008)SLOPSI
4008  FORMAT(F6.1)
      READ(5,4012)TY
4012  FORMAT(F6.2)
      READ(5,4014)TPP
4014  FORMAT(F6.2)
      READ(5,4015)UNITT
4015  FORMAT(F8.2)
      READ(5,4016)HIGH
4016  FORMAT(F7.1)
      READ(5,4017)ZERO
4017  FORMAT(F7.1)
      READ(5,4018)DUR
4018  FORMAT(F4.1)
      READ(5,4019)RM
4019  FORMAT(F6.2)
      READ(5,4000)ANPC
4000  FORMAT(F6.2)
      READ(5,6996)FSI
6996  FORMAT(F5.2)
      READ(5,6984)QQPMS
6984  FORMAT(F10.0)
      DEATHS =((-71.6413)+(2.5355*RFPMS)+(.0163*DENFLP)+(-0.1005*DRAINA)
     1+(-2.3284*RAINFA)+(-2.41*SLOPCH)+(0.7283*SLOPBA))
      IF(SLOPSI-16.)8730,8731,8731
8730  DEATHS = DENFLP**.4
      SCALE = 6.
```

Figure 13. (continued) Flash Flood Model

```
      GO TO 4044
8731  CONTINUE
      MINRAF =0.15*PMS
      IF(STATEN-1.)4010,4011,4010
4011  Q(1)=0.0
      Q(2)=75.*DRAINA**.552*SLOPBA**.460
      Q(3)=144.*DRAINA**.528*SLOPBA**.336
      Q(4)=891.*DRAINA**.482*SLOPBA**.154
      Q(5)=1770.*DRAINA**0.463*SLOPBA**.086
      Q(6)=5770.*DRAINA**0.432
      Q(7)=10020.*DRAINA**0.375
      IF(QQPMS-1.)6989,6988,6988
6988  Q(7) = QQPMS
6989  CONTINUE
      STAGE(1)=ZERO
      STAGE(2)=(22.*SLOPCH**(-.334))+ZERO
      STAGE(3)=(35.55*SLOPCH**(-.462))+ZERO+1.5
      STAGE(4)=(52.1*SLOPCH**(-.50))+ZERO+3.
      STAGE(5)=(59.3*SLOPCH**(-.533))+ZERO+4.5
      STAGE(6) = (77.3*SLOPCH**(-.553))+ZERO+6.
      STAGE(7)=(136.2*SLOPCH**(-.703))+ZERO
      GO TO 4013
4010  Q(1)=0.0
      Q(2)=0.50*DRAINA**0.66*SLOPCH**0.40*ANPC**1.58
      Q(3)=1.08*DRAINA**0.67*SLOPCH**0.42*ANPC**1.44
      Q(4)=5.40*DRAINA**0.69*SLOPCH**0.47*ANPC**1.12
      Q(5)=9.14*DRAINA**0.70*SLOPCH**0.48*ANPC**1.01
      Q(6)=24.4*DRAINA**0.72*SLOPCH**0.48*ANPC
      Q(7)=80.2*DRAINA**0.75*SLOPCH**0.75*ANPC
      IF(QQPMS-1.0)6987,6986,6986
6986  Q(7) = QQPMS
6987  CONTINUE
      STAGE(1)=ZERO
      STAGE(2)=(0.53*DRAINA**0.24*TY**1.60)+ZERO
      STAGE(3)=(0.83*DRAINA**0.22*TY**1.40)+ZERO+1.5
      STAGE(4)=(1.58*DRAINA**0.20*TY**1.14)+ZERO+2.5
      STAGE(5)=(1.95*DRAINA**0.19*TY**1.06)+ZERO+3.
      STAGE(6)=(2.85*DRAINA**0.17*TY**0.91)+ZERO+4.
      STAGE(7)=(6.25*DRAINA**0.16*TY**0.75)+ZERO
4013  CONTINUE
      DIFF=HIGH-ZERO
      IF(TPP-0.25)4020,4021,4021
4020  TC=((11.9*RM**3.)/DIFF)**0.35
      TP=((DUR/2.)+(0.6*TC))*.7
      XK=0.43+0.0003*DRAINA*640.
      TR=1.38*XK
      UNIT = DRAINA*640.*1.0*(2./(TP+TR))
      GO TO 4022
4021  TP=TPP
      UNIT = UNITT
4022  CONTINUE
      IF(DENFLP-1.)7710,7711,7711
7710  DEATHS = 0.
      GO TO 4023
7711  CONTINUE
      IF(DEATHS-2.0)4023,4034,4034
4023  IF((STAGE(2)-STAGE(1))-2.)4025,4026,4026
```

Figure 13. (continued) Flash Flood Model

```
4026  IF((STAGE(2)-STAGE(1))-4.)4027,4028,4028
4028  IF((STAGE(2)-STAGE(1))-6.)4029,4030,4030
4030  IF((STAGE(2)-STAGE(1))-8.)4031,4032,4032
4032  IF((STAGE(2)-STAGE(1))-10.)4033,4034,4034
4034  IF(DEATHS-2.)4035,4036,4036
4036  IF(DEATHS-50.)4037,4038,4038
4038  IF(DEATHS-150.)4039,4040,4040
4040  IF(DEATHS-400.)4041,4042,4042
4042  IF(DEATHS-10000.)4043,4044,4044
4025  SCALE=1.
      GO TO 4044
4027  SCALE=2.
      GO TO 4044
4029  SCALE=3.
      GO TO 4044
4031  SCALE=4.
      GO TO 4044
4033  SCALE=5.
      GO TO 4044
4035  SCALE= 6.
      GO TO 4044
4037  SCALE=7.
      GO TO 4044
4039  SCALE=8.
      GO TO 4044
4041  SCALE=9.
      GO TO 4044
4043  SCALE = 10.
4044  CONTINUE
      IF(SLOPSI-5.0)7712,7713,7713
7712  DEATHS = (DRAINA*SLOPSI)**.5
      SCALE = 6.
7713  CONTINUE
      IF(DEATHS-1.)7715,7716,7716
7715  DEATHS = 0.0
7716  CONTINUE
      RAGANO = DRAINA**.5
      RVGANO = RM/6.
      IF(RVGANO-1.0)4046,4047,4047
4046  RVGANO = 1.
4047  IF(TP-2.)4048,4049,4049
4048  FFA = 1.
      GO TO 4050
4049  FFA = 0.
4050  CONTINUE
      WRITE(6,4051) DATE
4051  FORMAT(1H1,/////,66X,2A4)
      WRITE(6,4052)BASIN
4052  FORMAT(//,19X,13A4)
      WRITE(6,4053)REACH
4053  FORMAT(/,19X,13A4)
      NSCALE = SCALE
      WRITE(6,4054)NSCALE
4054  FORMAT(///,15X,'FLOOD POTENTIAL IS ESTIMATED AT ',I2,' OF A SCALE
     1OF 1 TO 10')
      WRITE(6,4055)
4055  FORMAT(//,15X,'FLOOD POTENTIAL SCALE IS LISTED BELOW;')
```

Figure 13. (continued) Flash Flood Model

```
      WRITE(6,4056)
4056  FORMAT(/,18X,'1 = NO SIGNIFICANT FLOODING.')
      WRITE(6,4057)
4057  FORMAT(/,18X,'2 = SOME STREET AND LOW LAND FLOODING.')
      WRITE(6,4058)
4058  FORMAT(/,18X,'3 = STREET AND SOME RESIDENTIAL FLOODING.')
      WRITE(6,4059)
4059  FORMAT(/,18X,'4 = MAJOR STREET AND RESIDENTIAL FLOODING.')
      WRITE(6,4060)
4060  FORMAT(/,18X,'5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.')
      WRITE(6,4061)
4061  FORMAT(/,18X,'6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND
     1')
      WRITE(6,4101)
4101  FORMAT(22X,'PROPERTY LOSS, LIGHT.')
      WRITE(6,4062)
4062  FORMAT(/,18X,'7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO
     1')
      WRITE(6,4102)
4102  FORMAT(22X,'50) AND PROPERTY LOSS, MODERATE.')
      WRITE(6,4063)
4063  FORMAT(/,18X,'8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AN
     1D')
      WRITE(6,4103)
4103  FORMAT(22X,'PROPERTY LOSS, MAJOR.')
      WRITE(6,4064)
4064  FORMAT(/,18X,'9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400)')
      WRITE(6,4104)
4104  FORMAT(22X,'AND PROPERTY LOSS, MAJOR.')
      WRITE(6,4065)
4065  FORMAT(/,18X,'10 = CATASTROPHIC FLOOD.')
      NDEAD = DEATHS
      WRITE(6,4105)NDEAD
4105  FORMAT(///,18X,'POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE '
     1,I5)
      WRITE(6,4066)
4066  FORMAT(///,35X,'RIVER FORECAST CENTER')
      WRITE(6,4067)
4067  FORMAT(/,38X,'TULSA OKLAHOMA')
      WRITE(6,4068)DATE
4068  FORMAT(1H1,////////,66X,2A4)
      WRITE(6,4069)BASIN
4069  FORMAT(//,19X,13A4)
      WRITE(6,4070)REACH
4070  FORMAT(/,19X,11A4)
      WRITE(6,4071)
4071  FORMAT(///,18X,'PERTINENT DATA')
      WRITE(6,4072)DRAINA
4072  FORMAT(/,18X,'DRAINAGE AREA = ',F6.2,' SQUARE MILES')
      WRITE(6,4073)SLOPCH
4073  FORMAT(/,18X,'CHANNEL SLOPE = ',F6.1,' FEET/MILE')
      WRITE(6,4074)SLOPSI
4074  FORMAT(/,18X,'OVERLAND SLOPE = ',F7.1,' FEET/MILE')
      WRITE(6,4075)HIGH
4075  FORMAT(/,18X,'MAXIMUM HEIGHT OF BASIN = ',F7.1,' FT MEAN SEA LEVEL
     1')
      WRITE(6,4076)ZERO
```

Figure 13. (continued) Flash Flood Model

```
4076  FORMAT(/,18X,'ZERO OF LOCATION = ',F7.1,' FEET MEAN SEA LEVEL')
      IF(FSI-1.0)6999,6998,6998
6998  FS = FSI
      GO TO 6997
6999  FS = STAGE(2)-ZERO
6997  CONTINUE
      WRITE(6,4077)FS
4077  FORMAT(/,18X,'FLOOD STAGE = ',F7.1,' FEET')
      NNQ = Q(2)/10.
      WRITE(6,4112)NNQ
4112  FORMAT(/,18X,'FLOOD STAGE FLOW = ',I4,'0. CFS')
      XG = STAGE(5)-ZERO
      NNXG = XG
      WRITE(6,4078)NNXG
4078  FORMAT(/,18X,'FLOW DEPTH FROM 100 YEAR FLOOD = ',I6,'. FEET')
      IGG = Q(5)/100.
      WRITE(6,4113)IGG
4113  FORMAT(/,18X,'100 YEAR FLOOD FLOW = ',I5,'00. CFS')
      PMS = (RFPMS*RAINFA)/100.
      WRITE(6,5110)PMS
5110  FORMAT(/,18X,'PROBABLE MAXIMUN PRECIPITATION STORM = ',F5.2, 'INCH
     1ES')
      PMSS = STAGE(7)-ZERO
      WRITE(6,4114)PMSS
4114  FORMAT(/,18X,'DEPTH FROM PROBABLE MAXIMUN PRECIPITATION STORM = ',
     1F4.0,' FEET')
      WRITE(6,4140)TP
4140  FORMAT(/,18X,'TIME TO PEAK = ',F4.1,' HOURS')
      NUNIT = UNIT/100.
      WRITE(6,4141)NUNIT
4141  FORMAT(/,18X,'UNIT GRAPH PEAK = ',I4,'00. CFS')
      NQQQ = Q(7)/1000.
      WRITE(6,4115)NQQQ
4115  FORMAT(/,18X,'PROBABLE MAXIMUM PRECIPITATION STORM FLOOD FLOW = ',
     1I3,'000. CFS')
      NGAG = RAGANO
      WRITE(6,4130)NGAG
4130  FORMAT(//,18X,'NUNBER OF RAINFALL GAGES REQUIRED = ',I3)
      NRVRG = RVGANO
      WRITE(6,4131)NRVRG
4131  FORMAT(/,18X,'NUMBER OF RIVER STATIONS REQUIRED = ',I2)
      READ(5,101)DAM
101   FORMAT(F2.0)
C     DAM BREAK PROGRAM
      IF(DAM-1.)4121,106,106
C  SRDAA = SURFACE ACRES
4121  READ(5,49)DNAME
49    FORMAT(13A4)
      READ(5,17)SRDAA
17    FORMAT(F7.2)
C  DEPTH = MAX DEPTH OF RESERVOIR AT DAM
      READ(5,18)DEPTM
18    FORMAT(F7.2)
C  CAP = RESERVOIR CAPACITY
      CAP = SRDAA*0.4*DEPTM
      READ(5,19)RESLN
C  RESLN = RESERVOIR LENGTH
```

Figure 13. (continued) Flash Flood Model

```
19     FORMAT(F5.2)
       B = 2.*CAP/DEPTM*RESLN
C  QRES = PEAK OUTFLOW OF RESERVOIR
       QRES = (8./27.)*B*32.2**.5*DEPTM**1.5
       TK = CAP/QRES*60.
C  TK = TIME IN MINUTES
       READ(5,60)TW
60     FORMAT(F7.1)
       READ(5,61)DEPTH
61     FORMAT(F7.1)
       CP = (TW/(2.*DEPTH))**2.
       QPQ = CP*4.*(DEPTH**2.5)
       CAPB = SRDAA*0.4*DEPTH
       READ(5,70)CAPBB
70     FORMAT(F12.1)
       IF(CAPBB-1.)71,72,72
72     CAPB = CAPBB
71     CONTINUE
       TKK = CAPB/QPQ*60.
       READ(5,20)CNAME
  20   FORMAT(13A4)
       READ(5,21)MLCITY
  21   FORMAT(F6.2)
       DSSTAG = (DEPTH*0.65)/(MLCITY**0.35)
       TIM =((1.486*2.8)*((SLOPCH/5280.)**0.5))/.016
       TIME = TIM*0.6812
       TRAVL = TIME/(MLCITY)
C      DAM BREAK PRINT OUT
       WRITE(6,3074)DATE
3074   FORMAT(1H1,/////,66X,2A4)
       WRITE(6,3075)BASIN
3075   FORMAT(//,19X,13A4)
       WRITE(6,3076)REACH
3076   FORMAT(/,19X,13A4)
       WRITE(6,3077)
3077   FORMAT(///,14X,'DAM BREAK DATA FOR THE BASIN')
       WRITE(6,3078)DNAME
3078   FORMAT(/,14X,'NAME OF DAM IS ',13A4)
       WRITE(6,4079)CNAME
4079   FORMAT(/,14X,'NAME OF CITY DOWNSTREAM FROM DAM IS ',20A4)
       WRITE(6,4080)SRDAA
4080   FORMAT(/,14X,'SURFACE ACRES = ',F10.0)
       WRITE(6,4081)DEPTM
4081   FORMAT(/,14X,'DEPTH OF THE WATER AT THE DAM = ',F6.2,' FEET')
       WRITE(6,4082)CAP
4082   FORMAT(/,14X,'RESERVOIR CAPACITY = ',F11.1,' ACRE-FEET')
       WRITE(6,4083) RESLN
4083   FORMAT(/,14X,'RESERVOIR LENGTH = ',F5.1,' MILES')
       NQUES = QRES/1000.
       WRITE(6,4084)NQUES
4084   FORMAT(/,14X,'PEAK CFS FLOW OF TOTAL DAM BREAK = ',I6,'000. CFS')
       WRITE(6,4085)TK
4085   FORMAT(/,14X,'RESERVOIR TIME TO PEAK AT SPILLWAY = ',F5.2,' MINUTE
      1S')
       WRITE(6,4086)
4086   FORMAT(//,14X,'WEIR BREACH -- MOST PROBABLE WAY OF DAM FAILURE')
       WRITE(6,4087)TW
```

Figure 13.(continued) Flash Flood Model

```
4087  FORMAT(/,14X,'WIDTH OF BREACH = ',F7.1,' FEET')
      WRITE(6,4088)DEPTH
4088  FORMAT(/,14X,'DEPTH OF BREACH = ',F7.1,' FEET')
      NQPQ = QPQ/1000.
      WRITE(6,4089)NQPQ
4089  FORMAT(/,14X,'PEAK FLOW AT BREACH = ',I4,'000. CFS')
      WRITE(6,4090)TKK
4090  FORMAT(/,14X,'PEAK TIME IN MINUTES AT BREACH = ',F4.0,' MINUTES')
      WRITE(6,4091)
4091  FORMAT(//,14X,'DOWN STREAM EFFECT FROM BREACH')
      WRITE(6,4092)DSSTAG
4092  FORMAT(/,14X,'STAGE AT CITY DOWN STREAM WILL BE NEAR ',F6.2,' FEET
     1')
      WRITE(6,4093)TRAVL
4093  FORMAT(/,14X,'PEAK TRAVEL TIME TO CITY WILL BE = 'F4.1,' HOURS')
 106  CONTINUE
      READ(5,4120)MORDAM
4120  FORMAT(F2.0)
      IF(MORDAM - 1.)4121,4122,4122
4122  CONTINUE
      READ(5,1301)ZONE
1301  FORMAT(I2)
      FSS = FS
      EV(1) = .5+ZERO
      EV(2) = (FSS*.25)+ZERO
      EV(3) = (FSS*.5)+ZERO
      EV(4) = (FSS*.75)+ZERO
      EV(5) = FSS + ZERO
      CALL RATING
      QX(6) = QX(5)*2.
      QX(7) = QX(5)*3.
      QX(8) = QX(5)*4.
      QX(9) = QX(5)*5.
      QX(10) = QX(5)*6.
      READ(5,31)TZ
31    FORMAT(F4.2)
      READ(5,59)DATUM
59    FORMAT(F4.0)
      IF(TZ-.25)34,33,34
33    K = 1
      DO 35 I = 1,231
      ZB(I)=TS(K)*UNIT*TZ
35    K = K+ 1
      GO TO 301
34    IF(TZ-.50) 40,39,40
39    K = 232
      DO 41 I = 1,231
      ZB(I)=TS(K)*UNIT*TZ
41    K = K + 1
      GO TO 301
40    IF(TZ - .75)44,43,44
43    K = 463
      DO 45 I = 1,231
      ZB(I)=TS(K)*UNIT*TZ
45    K = K + 1
      GO TO 301
44    K = 694
```

Figure 13. (continued) Flash Flood Model

```
      DO 46 I = 1,231
      ZB(I)=TS(K)*UNIT*TZ
46    K = K + 1
301   CONTINUE
      J = 1
      DO 3501 K = 1,10
      DO 3501 I = 1,231
      ZA(J) = ZB(I)+QX(K)
      J = J + 1
3501  CONTINUE
      DO 803 I=1,2310
      DO 8033 K = 2,20
      IF(Q(K)-ZA(I))8033,345,306
306   ZZHIG = Q(K)
      ZZLOW = Q(K-1)
      ZZELE = STAGE(K-1)
      ZZZEL = STAGE(K)
      ZZXZ = ZZZEL - ZZELE
      ZQQX = (ZA(I)-ZZLOW)/(ZZHIG-ZZLOW)
      ZZXXZ = ZZXZ*ZQQX
      ZSSS = ZZELE + ZZXXZ
      GO TO 307
345   ZSSS = (STAGE(K))
      GO TO 307
8033  CONTINUE
307   ZEELV(I) = (ZSSS - ZERO)
803   CONTINUE
      IF (DATUM-1.0)50,51,51
51    DO 52 I = 1,2310
52    ZEELV(I) = ZEELV(I) + ZERO
      FSS = FS
50    K = 1
      DO 6677 I = 1,21
      DO 6677 J = 1,11
      EELV(I,J) = ZEELV(K)
6677  K=K+1
      BASEQ = QX(1)
      CALL STAGG (BASEQ,ZERO,BASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP
      K = 232
      DO 5312 I = 1,21
      DO 5312 J = 1,11
      EELV(I,J) = ZEELV(K)
5312  K = K+1
      BASEQ = QX(2)
      CALL STAGG (BASEQ,ZERO,BASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP
      K = 463
      DO 5313 I =1,21
      DO 5313 J = 1,11
      EELV(I,J) = ZEELV(K)
5313  K = K+1
      BASEQ = QX(3)
      CALL STAGG (BASEQ,ZERO,BASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP
      K = 694
      DO 5314 I = 1,21
```

Figure 13.(continued) Flash Flood Model

```
      DO 5314 J = 1,11
      EELV(I,J) = ZEELV(K)
5314  K = K+1
      BASEQ = QX(4)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 925
      DO 5315 I = 1,21
      DO 5315 J = 1,11
      EELV(I,J) = ZEELV(K)
5315  K = K+1
      BASEQ = QX(5)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 1156
      DO 5316 I = 1,21
      DO 5316 J = 1,11
      EELV(I,J) = ZEELV(K)
5316  K = K+1
      BASEQ = QX(6)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 1387
      DO 5317 I = 1,21
      DO 5317 J = 1,11
      EELV(I,J) = ZEELV(K)
5317  K = K+1
      BASEQ = QX(7)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 1618
      DO 5318 I = 1,21
      DO 5318 J = 1,11
      EELV(I,J) = ZEELV(K)
5318  K = K +1
      BASEQ = QX(8)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 1849
      DO 5319 I = 1,21
      DO 5319 J = 1,11
      EELV(I,J) = ZEELV(K)
5319  K = K+1
      BASEQ = QX(9)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      K = 2080
      DO 5320 I = 1,21
      DO 5320 J = 1,11
      EELV(I,J) = ZEELV(K)
5320  K = K +1
      BASEQ = QX(10)
      CALL STAGG (BASEQ,ZERO,RASEF)
      CALL TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,TP,RF)
      GO TO 5559
5560  CONTINUE
      STOP
```

Figure 13. (continued) Flash Flood Model

```
      END
      SUBROUTINE RATING
      COMMON STAGE( 7),EV(5),Q( 7),QX(10),DATUM
      DO 144 I = 1,5
      DO 14 K =2,7
      IF (STAGE(K)-EV(I))14,12,13
13    HIGH = Q(K)
      XLOW = Q(K-1)
      DIFF = HIGH-XLOW
      HHI = STAGE(K)
      HHL = STAGE(K-1)
      HHH = HHI-HHL
      HA = (EV(I)-HHL)/HHH
      AFLOW = HA*DIFF
      QX(I) = AFLOW + XLOW
      GO TO 144
12    QX(I) = Q(K)
      GO TO 144
14    CONTINUE
144   CONTINUE
      RETURN
      END
      SUBROUTINE STAGG (BASEQ,ZERO,BASEF)
      COMMON STAGE( 7),EV(5),Q( 7),QX(10),DATUM
      DO 8033 K = 2,7
      IF(Q(K)-BASEQ)8033,345,306
306   ZZHIG = Q(K)
      ZZLOW = Q(K-1)
      ZZELE = STAGE(K-1)
      ZZZEL = STAGE(K)
      ZZXZ = ZZZEL - ZZELE
      ZQQX = (BASEQ-ZZLOW)/(ZZHIG-ZZLOW)
      ZZXXZ = ZZXZ*ZQQX
      ZSSS = ZZELE + ZZXXZ
      GO TO 307
345   ZSSS = (STAGE(K))
      GO TO 307
8033  CONTINUE
307   BASEF = (ZSSS-ZERO)
      IF(DATUM-1.0)55,56,56
56    BASEF = BASEF + ZERO
55    CONTINUE
      RETURN
      END
      SUBROUTINE TABLE (DATE,STATE,ZONE,      BASEQ,BASEF,FSS,ZERO,
     1TP)
      DIMENSION DATE(2),STATE(3)
      COMMON STAGE( 7),EV(5),Q( 7),QX(10),DATUM
      COMMON BASIN(13),REACH(13)
      COMMON RF(11),FF(21),EELV(21,11)
      WRITE(6,1033)DATE
1033  FORMAT(1H1,/////,66X,2A4)
      IF(TP-13.)56,57,57
56    WRITE(6,4700)
4700  FORMAT(1H ,24X,'FLASH FLOOD FORECASTING TABLE')
      GO TO 58
57    WRITE(6,4701)
```

Figure 13. (continued) Flash Flood Model

```
4701  FORMAT(1H ,27X,'FLOOD FORECASTING TABLE')
58    CONTINUE
      WRITE(6,1302)STATE
1302  FORMAT(//,55X,'STATE OF  ',3A4)
      WRITE(6,1303)ZONE
1303  FORMAT(/,55X,'FORECAST ZONE  ',I2)
      WRITE(6,1044)BASIN
1044  FORMAT(//,12X,13A4)
      WRITE(6,53)REACH
53    FORMAT(/,12X,13A4)
      WRITE(6,2001)
2001  FORMAT(1H ,26X,'CREST GAGE HEIGHT IN FEET')
5303  FORMAT(///,25X,'CURRENT FLOW = ',F7.0,' CFS')
5304  FORMAT(/,25X,'INITIAL STAGE = ',F7.1,' FT')
      WRITE(6,5304)BASEF
      WRITE(6,107)
107   FORMAT(1H ,)
      WRITE(6,113)FSS
113   FORMAT(1H ,46X,'FLOOD STAGE =      ',F5.1,' FT.')
      WRITE(6,108) ZERO
108   FORMAT(1H ,46X,'GAGE ZERO = ',F7.2,' FT.-MSL')
      WRITE(6,5024)TP
5024  FORMAT(1H ,46X,'TIME TO PEAK =  ',F4.1,' HOURS')
      WRITE(6,59)
59    FORMAT(1H ,'FLASH FLOOD')
      WRITE(6,109)
109   FORMAT(1H ,'GUIDANCE',19X,'INCHES OF RAINFALL IN 3 HOURS')
      WRITE(6,106) RF
106   FORMAT(1H ,'VALUES*',11F6.1)
      WRITE(6,63)
63    FORMAT(1H ,10X,'-------------------------------------------------
     1-------------')
      WRITE(6,305)(FF(I),(EELV(I,J),J=1,11),I=1,21)
305   FORMAT(1X,F4.1,'  I',11F6.1)
      WRITE(6,6969)
6969  FORMAT(1H ,'* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE')
1112  FORMAT(1H0,)
      WRITE(6,1112)
      WRITE(6,110)
110   FORMAT(1H0,28X,'RIVER FORECAST CENTER')
      WRITE(6,112)
112   FORMAT(1H ,31X,'TULSA OKLAHOMA')
      RETURN
```

Figure 13. (continued) Flash Flood Model

Multiple Regression Analysis

In this study, a multiple regression technique is used as a way to find the number of deaths.

Annual peak flow of the drainage area will be expressed as a function of drainage basin characteristics and climatic conditions by using multiple regression analysis as an equation of the form

$$Y = F(X_1, X_2, X_3, \ldots\ldots X_n)$$

where

Y = dependent variable death

F = the function, for example, linear function or logarithmic function

$X_1, X_2, X_3, \ldots\ldots X_n$ = drainage basin population characteristics and climatic conditions

The weighted least squares will be used to adjust the best fit of the equation when the residuals have different variances.

CHAPTER IV

APPLICATION OF THE FLASH FLOOD MODEL

Flood History of Source Data and Hydrologic Information of Study Area

Major Historic Death Storms

Folsom. The great disaster that struck Folsom, New Mexico (24), August 27, 1908, was the most destructive flood ever witnessed by people of northeast New Mexico. It was caused by a cloudburst west of town on the headwaters of the Dry Cimmarron. Just after a beautiful rain in the evening, the sun set upon a happy and prosperous little town of 800 inhabitants. The next morning it rose in a clear sky upon a scene of destruction, death, desolation and horror.

A lady who lived 8 miles up the river telephoned the Central telephone office that the most terrific flood that had ever been known here was advancing upon the town. The telephone operator, Mrs. Rooke, faithfully warned all that she could warn of the impending danger. Her office was a small building which turned over as the flood struck it, extinguishing the light and carrying this brave and faithful lady to her death.

The water soon began to spread over the town in high rolling waves. The railroad bridge west of town held it in check for awhile, then it broke and let loose a mighty volume of water that swept everything along with it. The stream was now nearly half a mile wide and was at least five feet deep in the streets and rushing along with a mad torrential velocity that picked up houses and floated them off like chips. Eighteen people lost their lives in this great northeastern New Mexico disaster.

Rapid City. The Rapid City Flood (25) that occurred on June 9, 1972, was one of the most destructive to occur in the midwest for many years. Rapid City, South Dakoka, with a population of 44,000, is located about 3,000 feet above sea level.

Rapid City takes its name from, and is divided by, Rapid Creek, a typical, boisterous mountain stream draining melted snow and rain waters from the rugged rocky crests and spruce-covered slopes of the central portion of the Black Hills. The creek has its headwaters near 7,140-foot Crooks Tower, just south of Cheyenne Crossing and 34 miles west of Rapid City. As its name suggests, its waters race 4,000 feet downhill to the city, controlled only by a dam at Pactola about midway between the city and the stream's origin. The rushing waters are only momentarily delayed as they pass through Canyon Lake at the western edge of the city. Then they accelerate as they race through the narrow gap, cut over the ages by the stream and framed by Dinosaur Hill on the right bank and "M" Hill on the left bank. The waters of the stream then flow along the main business district of the city on their way to join the Cheyenne River, 30 miles to the southeast on the prairie.

The flooding was not restricted to Rapid Creek but was equally serious to the north on Box Elder Creek, and to the south on Spring and Battle Creeks, which also flow into the Cheyenne River. Fortunately, the latter two creeks do not travel through large population centers.

Fifteen inches of rain fell at Nemo on Box Elder Creek and 14.5 inches in about 5 hours near Sheridan Lake, located on the divide between Spring Creek and Rapid Creek, southwest of Rapid City. This set the stage for the great flood on Rapid Creek and the utter destruction of two-thirds of the City of Keystone on Battle Creek. (Figure 14).

The heavy sustained rainfall for a period of 3 to 6 hours was centered just to the west and northwest of Rapid City as shown in Figure 7. This precipitation averaged about four times the 6-hour amounts that are to be expected once every 100 years in the area. The resulting runoff produced record floods along Box Elder, Rapid, Spring, and Battle Creeks. Preliminary calculations by the U. S. Geological Survey indicate that Rapid Creek had a peak flow of about 31,200 cubic feet per second, 3 miles above Canyon Lake Dam at 10:45 p.m., and 50,600 cubic feet per second, more than 10 times the flow of any previous flood of record, in downtown Rapid City at 12:15 a.m. High-water marks have been used to establish a high stage of 15.5 feet at the Rapid City gage, which reads 9.0 feet when the creek is bank full.

It appears that the relatively small volume of water normally stored behind the Canyon Lake (about 192-acre-feet) would have contributed little to the downstream flooding. The flood waters above Canyon Lake Dam carried debris which clogged the spillway so that

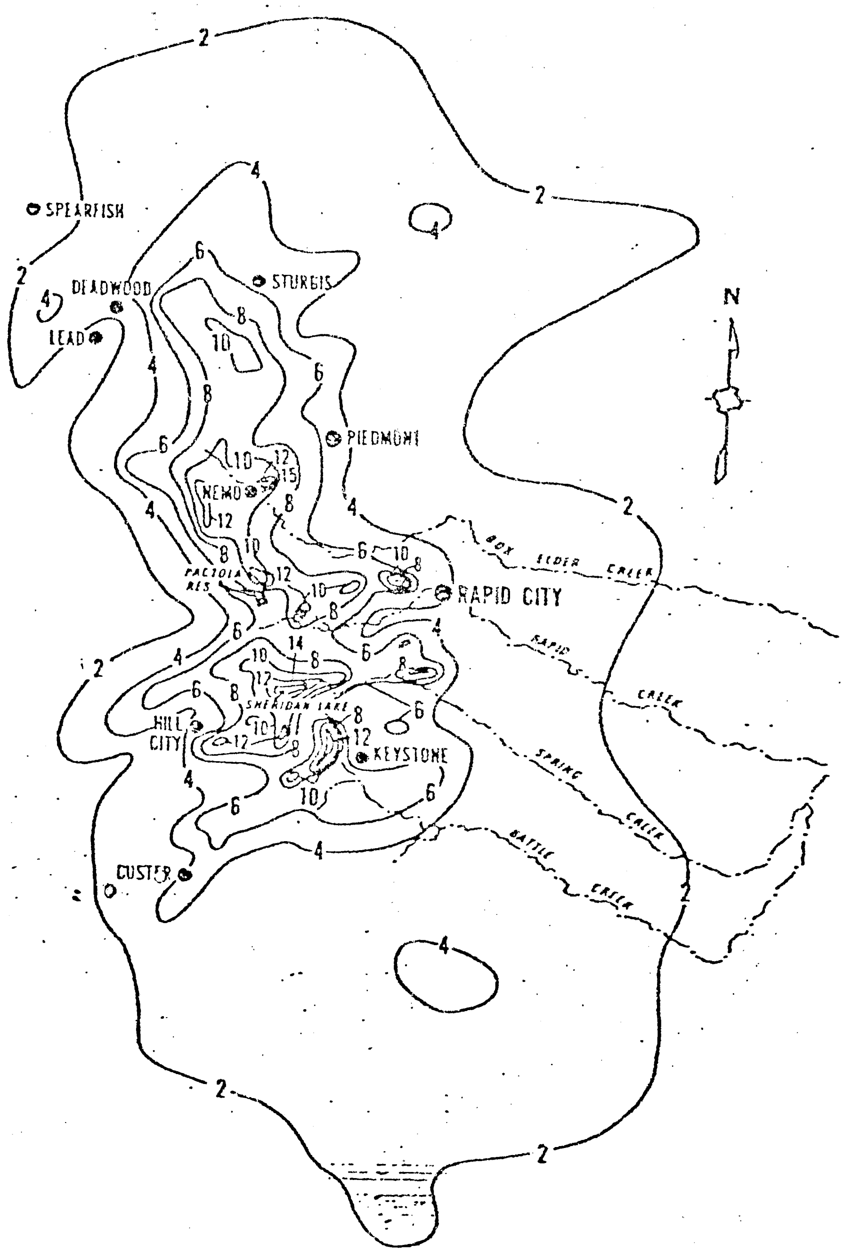

Figure 14. Total Rainfall During Evening of June 9 into Morning of June 10, 1972 Rapid City, South Dakota (25)

the reservoir pool temporarily became 11 to 12 feet deeper than normal. The total storage at this time was about 1,000 acre feet which is five times the normal capacity. Dam failure at 10:45 p.m. released this water causing a giant wave that devastated the urban area in its path and drowned more than 150 people during the next two hours.

Big Thompson. The Big Thompson Flood (26)(27)(28)(29C was one of the most costly flash floods in terms of both lives and property damage ever to occur in Colorado and the western United States. Only the disastrous Rapid City Flood is of comparable magnitude. Although destruction was the greatest in the Big Thompson Canyon, serious flooding occurred on the Cache la Poudre River and on several streams draining the adjacent foothills, including Soldier Canyon and Rist Canyon areas.

The storm cost 139 lives, with five persons still missing in mid-October, and an estimated $28.8 million in damage. In the Big Thompson Canyon alone, 316 homes were totally destroyed and 73 received major damage; 56 mobile homes were lost and 52 businesses destroyed. Yet conditions could have been far more severe. Flood peaks on the mainstream and on North Fork were not synchronous. The North Fork peaked at 2140 MDT at approximately 8,700 cubic feet per second (c.f.s.) some 40 minutes after the mainstream had peaked at Drake at the confluence. Furthermore, Dry Gulch, a small watershed of approximately four square miles near the head of the Big Thompson, received extremely heavy precipitation. Its flow eroded 6,000 cubic yards of material from the base of Olympus Dam which holds back Lake

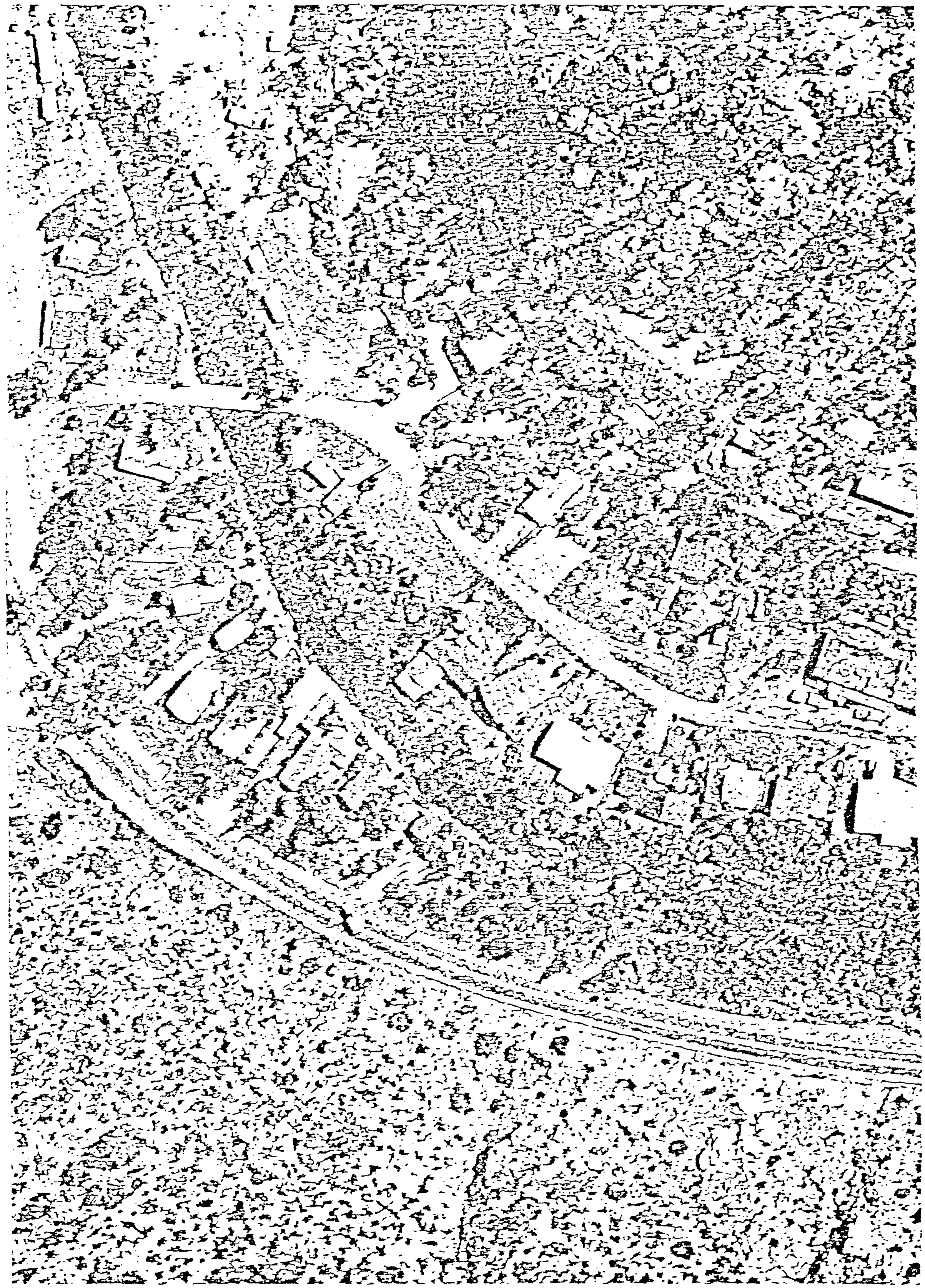

Figure 15. Before Big Thompson Flood, Natural Disaster Survey Report 76-1, National Oceanic and Atmospheric Administration (15)

Figure 16. After Big Thompson Flood, Natural Disaster Survey Report 76-1, National Oceanic and Atmospheric Administration (15)

Estes. Had the dam failed, damage would have been increased by orders of magnitude (Figures 15 and 16).

Approximate timing of flood peaks has been determined, in part, from eyewitness accounts. The Big Thompson peaked about 8:00 p.m. at Glen Comfort, 9:00 p.m. at Drake, 9:30 p.m. at the Loveland power plant (about halfway between Cedar Cove and Midway), and 11:00 p.m. at the mouth of the canyon. The flood at Dry Gulch, near the head of the canyon, was in response to a late burst of rainfall, for its peak discharge was recorded at 10:30 p.m. The flood on the North Fork was due to heavy rainfall near Glen Haven. Its peak discharge near Drake came at 9:40 p.m. See Figure 17 for Big Thompson rainfall map.

Velocities associated with these high flows were also extreme. Velocities of 25 feet per second clearly were not uncommon. Stream banks and much of the U. S. Highway 34 were undercut and removed, trees and numerous structures including the Loveland power plant were swept away. The largest clast that can be documented to have moved has a maximum intercept of 22 feet. The largest structure to be removed was the nine-foot diameter pipe which spanned the mouth of the canyon.

Tremendous quantities of material were transported by the flood. It has been estimated by one worker that 40 percent of the flow volume consisted of debris. Most of the coarse debris was deposited in the canyon, while most of the flotsam was carried completely out of the canyon.

Flash floods are merciless destroyers. The incredible destructive power and speed with which large volumes of water rush down

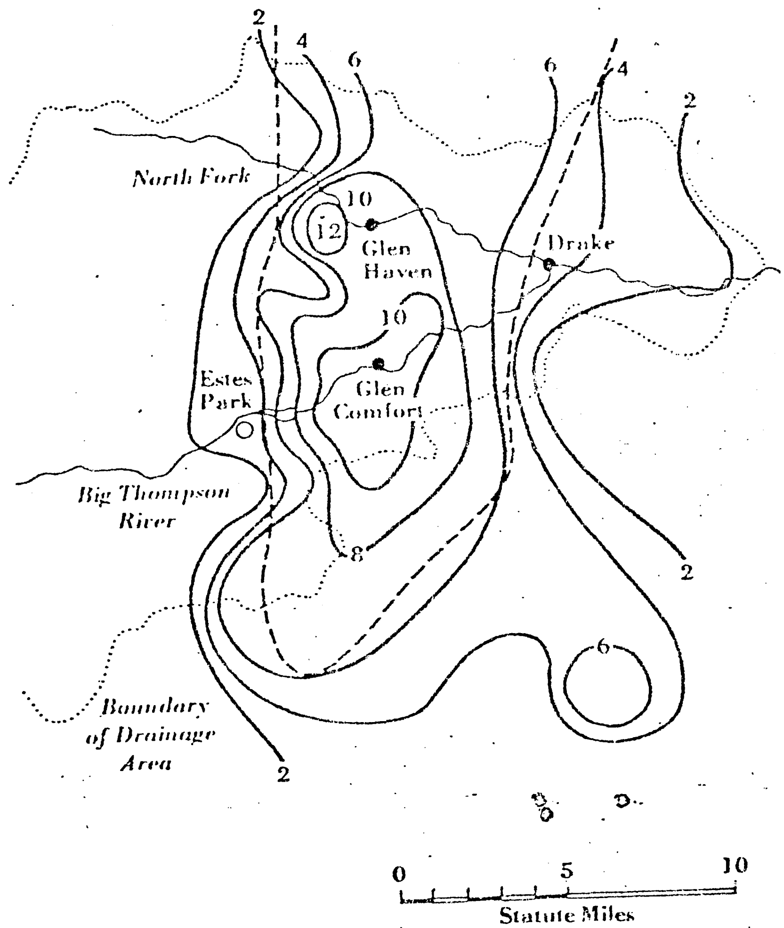

Figure 17. Total Rainfall During Evening of July 31, 1976, Big Thompson Canyon, Colorado

mountain slopes and across canyon floors make them killers. The Big Thompson flash flood which struck on the evening of July 31, 1976, was no exception.

Hays Flood. Hays, Kansas flood (18) in 1951 was a disastrous flash flood that occurred on Big Creek tributary of the Smoky Hill River on the 22nd of May. The flood waters caused six deaths and very heavy property losses in parts of Hays, Kansas, where flood depths were reported as great as 15 to 20 feet. The disaster was the worst in the history of Hays with blocks of the city and campus of Fort Hays State College inundated. This flooding followed very intense rains which fell over a limited area centered about 4 miles west and upstream from Hays near Yocemento. A later bucket survey reveals that the 12-inch 48-hour isohyet encompassed about three square miles and the 8-inch isohyet about 25 square miles. The bulk of the rain appears to have fallen in a 3 or 4-hour period beginning around 8:00 p.m. on the 21st, although rain continued until about 7:00 a.m. on the 22nd, and from 1 to 2 inches fell in the same area the night of the 20-21st. Big Creek went over its banks at Hays at about 12:30 a.m. on the 22nd, rose very rapidly and apparently crested at about 2:00 a.m. Heavy damages resulted from the flash flood with preliminary estimates placed at near 2 million dollars.

Basic Storm Data

The Folsom, Rapid City, Big Thompson and Hays Flood were listed as the type typical in the west with which people of the area are familiar. To create a base for study of a possible relationship between community rainfall and death, 21 additional floods were selected from a 37 year period, 1949 through 1976. The first condition for selection was loss of life. Next a variable geographic selection was maintained so that nearly all segments of the United States were represented. It was noted that many floods resulted in the death of from 2 to 4 people, but to vary the population of the data, only one or two floods were used when the death count was nearly the same.

Table III is a listing of the floods that were selected for the statistical analysis. All floods are of the flash flood type rather than river flood. These communities were selected at random.

TABLE III

LIST OF FLOODS FOR ORIGINAL DATA BASE - DEATH STORMS

Station Name and Location	Stream	Date	Data Number
Folsom, New Mexico	Dry Cimarron	8-27-1908	1
Hays, Kansas	Big Creek	5-21-1951	2
Merrill, Iowa	Floyd River	6-8-1953	3
Heber Springs, Arkansas	Little Red River	8-13-1957	4
Hamburg, Iowa	E. Nishnabotna Rvr.	7-1-1958	5
Charleston, W. Virginia	Local Creek	7-30-1961	6
Sapulpa, Oklahoma	Euchee Creek	6-7-1962	7
Sanderson, Texas	Sanderson Canyon	6-11-1965	8
Greeley, Colorado	South Platte Basin	6-16-1965	9
Colorado Springs, Colorado	Cheyenne Creek	7-24-1965	10
Dallas, Texas	Sabine Basin	4-20-1966	11
Wheeling, W. Virginia	Local Creek	7-4-1969	12
Maury, Virginia	James River	7-4-1969	13
Nelson Count, Virginia	Huffman's Hollow	7-4-1969	14
Payson, Arizona	Mogdlon Run	9-20-1970	15
New Braunfels, Texas	Guadalupe River	5-11-1972	16
Rapid City, S. Dakota	Rapid Creek	6-9-1972	17
Logan County, W. Virginia	Buffalo Creek	2-26-1972	18
Las Vegas, Nevada	El Dorado Canyon	9-14-1974	19
San Antonio, Texas	Balcones Escarpment	11-23-1974	20
San Antonio, Texas	Balcones Escarpment	3-26-1973	21

TABLE III (Cont'd)

LIST OF FLOODS FOR ORIGINAL DATA BASE - DEATH STORMS

Station Name and Location	Stream	Date	Data Number
Cairo, Illinois	Local Creek	3-26-1973	22
Las Vegas, Nevada	Virgin River	7-10-1975	23
Nicholas County, Kentucky	Bobtown Creek	8-10-1975	24
Big Thompson Canyon, Colorado	Big Thompson Cr.	8-1-1976	25

To test the Flash Flood Model conclusions from the original 25 data base floods, data from four additional floods was compiled to be analyzed. (See Table IV).

TABLE IV

LIST OF FLOODS FOR TEST DATA BASE - DEATH STORMS

Station Name and Location	Stream	Date	Data Number
Colorado Springs, Colorado	Monument Creek	May 30-31, 1935	1
Enid, Oklahoma	Boggy Creek	October 12, 1973	2
Pueblo, Colorado	Fountain Creek	June 3-4, 1921	3
Tulsa, Oklahoma	Mingo Creek	June 1, 1976	4

Statistical Model

Flood data was obtained from 25 historic flood sites throughout the United States. The collected data begins in 1949 and extends through a portion of 1976. In the search for data the main concern was to collect flood death information. The largest flood recorded during the period was the one on Rapid Creek in South Dakota and the smallest was a flash flood in Arizona where two persons died. The sampling was selected so as not to over emphasize any particular death count or regional location. The data collected was based more on the flash flood type of occurrence rather than the long time-to-peak river flood (30-43).

The parameter which proved to be most significant for this study was found to be the RFPMS (Rainfall/Probable Maximum Storm) which is the proportion of Rainfall to Probable Maximum Storm. This most significant test was determined by using the statistical package called "Stepwise Regression" from the Statistic System Package Program (44). See Table IV for listing of input data for Statistical Model and Table V for definition of terms.

A procedure named STEPWISE (44) was used for statistical analysis. The STEPWISE procedure applied four techniques to find which variables of a collection of independent variables should most likely be included in a regression model.

Only one Statistical Analysis System (SAS) variable may be specified as the dependent variable. The last variable in the

VARIABLES statement is taken to be the dependent variable, and the other variables in the VARIABLES statement are taken to be independent variables.

The four techniques of STEPWISE used here are the following:

Forward Selection

This technique finds first the single-variable model which produces the largest R^2 statistic. R^2 is the square of the multiple correlation coefficient; it is expressed as the ratio of the regression sum of squares to the (corrected) total sum of squares. For each of the other independent variables, STEPWISE calculates an F-statistic reflecting that variable's contribution to the model were it to be included. If the F-statement for one or more variables has a significance probability greater than the specified "significance level for entry," then the variable with the largest F-statistic is included in the model. F-statistics are again calculated for the variables still remaining outside the model, and the evaluation process is repeated. Variables are thus added one by one to the model until no variable produces a significant F-statistic.

Backward Elimination

In this technique, calculations are first performed for a model including all the independent variables. Then variables are deleted one by one until all the variables remaining in the model produce "partial" F-statistics significant at the specified "significance level for staying in" (at each step, the variable showing the smallest contribution to the model is the one deleted).

Maximum R^2 Improvement

This technique was developed by calculating regressions on all possible subsets of the independent variables. This technique does not settle on a single model. Instead, it looks for the "best" one-variable model, the "best" two-variable model, and so forth. It finds first the one-variable model producing the highest R^2 statistic. Then another variable, the one which would yield the greatest increase in R^2, is added. Once this two-variable model is obtained, each of the variables in the model is compared to each variable not in the model. For each comparison, the procedure determines if removing the variable in the model and replacing it with the presently excluded variable would increase R^2. After all the possible comparisons have been made, the switch which produces the largest increase in R^2 is made. Comparisons are made again, and the process continues until the procedure finds that no switch could increase R^2. The two-variable model thus settled on is considered the "best" two-variable model the technique can find. The technique then adds a third variable to the model, according to the criteria used in adding the second variable. The comparing-and-switching process is repeated, the "best" three-variable model is discovered, and so forth. This technique differs from the STEPWISE technique in that here all switches are evaluated before any switch is made. In the STEPWISE technique, removal of the "worst" variable may be accomplished without consideration of what adding the "best" remaining variable would accomplish.

Minimum R^2 Improvement

This technique closely resembles the one just described. Here, though, when a switch is to be made, the switch which produces the smallest increase in R^2 is the one actually performed. For a given number of variables in the model, the maximum R^2 improvement technique and the minimum R^2 improvement technique will usually produce the same "best" model. More models of a given size will be considered when the latter technique is applied.

The parameter which proved to be most significant for this study was found to be the RFPMS (Rainfall/Probable Maximum Storm) which is the proportion of Rainfall to Probable Maximum Storm.

Definition of terms used in the STEPWISE regression is shown in Table V. Originally, the study included five additional terms but these terms were found less significant than the eight chosen, because the five terms deleted were either directly related to or reflected in the eight variables chosen or the significance was minor.

The data input for the statistical model is shown in Table VI. This table lists the input data from the 25 original basins.

TABLE V

DEFINITION OF TERMS FOR ANALYSIS OF VARIANCE TABLE

Variable	Definition
DEATHS	= Number of persons killed (dependent variables)
DRAINA	= Drainage area in square miles
RAINFA	= Amount of rainfall, in inches
RFPMS	= Rainfall/probable maximum rainfall
DENTOT	= Population/size, total
DENFLP	= Population/size, flood plain
SLOPCH	= Slope channel feet/mile
SLOPBA	= Slope basin feet/mile
SLOPSI	= Overland slope feet/mile

In this stepwise regression procedure, several regressions are computed; the first one includes all eight basin and climatic characteristics: rainfall/probable maximum storm, population density of flood plain, drainage area, rainfall, total population density of community, slope of the channel, slope of the basin, and slope of the over land. A "backward elimination" computer program will make the first computation, eliminate the least significant variable, and recompute the regression, then continue the elimination process.

In the "Forward Selection, Stepwise" it was found that three

TABLE VI

DATA INPUT FOR STATISTICAL MODEL

	DEATHS	DRAINA	RAINFAL	PROMAXS	RFPMS	DENFLPL	SLOPCHN	DENTOTA	SLOPBAS	SLOPSID
1	18	90	8.0	22.0	56.0	3000	33.00	2000	101.00	300.00
2	6	25	12.0	25.8	46.5	2400	7.00	3600	20.00	41.00
3	14	22	13.0	25.1	51.8	2000	8.00	1210	25.00	40.10
4	3	60	8.0	30.1	26.5	2666	7.00	5025	21.00	37.00
5	19	70	12.0	25.6	46.9	2800	8.20	2971	26.20	45.20
6	22	30	5.0	28.0	17.9	2857	14.00	5881	25.00	42.00
7	2	7	8.0	28.9	27.7	500	50.00	100	110.00	260.00
8	22	32	12.0	30.2	39.7	1400	10.00	3067	25.00	60.00
9	11	26	8.0	20.2	39.6	1700	76.00	1206	210.00	430.00
10	3	12	7.0	22.8	30.7	1500	110.00	500	370.00	625.00
11	27	37	7.6	31.8	24.5	1875	1.30	1041	8.00	13.00
12	37	40	23.0	27.2	84.5	750	38.00	2272	86.00	170.00
13	126	90	27.0	27.2	99.3	1111	40.00	18	89.01	35.02
14	54	10	25.0	27.2	91.9	1167	48.00	227	96.00	190.00
15	23	28	5.8	10.0	58.0	2666	55.00	1500	140.00	380.00
16	18	356	16.0	31.5	50.8	3100	1.00	4545	3.00	10.00
17	236	100	15.0	19.8	75.8	2777	28.00	4870	120.00	320.00
18	118	40	6.0	27.2	22.0	6700	24.00	4286	117.60	340.00
19	9	23	3.5	17.4	20.1	2643	36.00	2222	140.00	410.00
20	13	310	10.0	31.5	31.7	3100	1.00	4545	3.00	11.00
21	4	260	13.0	31.5	41.0	2675	1.20	2500	3.30	12.00
22	10	140	10.0	28.1	35.6	3000	0.30	4447	2.50	7.00
23	2	20	5.1	17.4	29.3	1700	34.00	1666	140.00	480.00
24	2	45	4.5	26.1	17.2	750	0.46	666	1.40	6.00
25	144	70	12.0	22.1	54.3	3083	25.40	1666	65.00	85.00

variables were deemed significant at the 0.500 significance level. The three variables were RFPMS (rainfall/probable maximum storm), DENFLP (population density of the flood plain) and drainage area. The output from the analysis is shown in Table VII.

Regression equation based on the three variables would be

Deaths = -83.252 + (1.667) RFPMS + (0.283) DENFLP + (-0.115) DRAINA (4.1)

(Table VII)

In the "Backward Selection, Stepwise" it was found that two variables were deemed significant at the 0.100 significance level. The two variables were RFPMS (rainfall/probable maximum storm) and DEMFLP (population density of the flood plain). The output from the analysis is shown in Table VIII.

Regression equation based on the two "backward" variables would be:

Deaths = -82.882 + (1.601) RFPMS + (0.021) DENFLP (4.2)

In the statistical analysis "Maximum R-Square Improvement" it was found that variable RFPMS (rainfall/probable maximum storm) is the best one variable found by the maximum R-square improvement procedure.

Regression equation based on the "Best" one variable would be:

Deaths = 18.393 + (1.276) RFPMS (4.3)

The output from the "Maximum R^2 Improvement" analysis is shown in Table IX.

TABLE VII

LINEAR MODEL EQUATIONS - DEATHS RELATED TO EIGHT VARIABLES - FORWARD SELECTION

No. of Variables	Equation	Variables	Observed Significant Level
3	Deaths = -83.252 + 1.067 RFPMS + 0.024 DENFLP - 0.115 DRAINA	RFPMS DENFLP DRAINA	.0006 .0059 .2655

TABLE VIII

LINEAR MODEL EQUATIONS = DEATHS RELATED TO EIGHT VARIABLES - BACKWARD SELECTION

No. of Variables	Equation	Variables	Observed Significant Level
2	DEATHS = -82.882 + 1.601 RFPMS + 0.021 DENFLP	RFPMS DENFLP	.0010 .0094

TABLE IX

LINEAR MODEL EQUATIONS - DEATHS RELATED

TO EIGHT VARIABLES - MAXIMUM R^2 IMPROVEMENT

No. of Best Variables	Equations	Variables	Observed Significant Level
2	DEATHS = −82.882 + 1.607 RFPMS	RFPMS	0.0010
	+0.021 DENFLP	DENFLP	0.0094
3	DEATHS = −83.253 + 1.667 RFPMS	RFPMS	0.008
	+0.024 DENFLP	DENFLP	0.0059
	−0.115 DRAINA	DRAINA	0.2659
4	DEATHS = −81.251 + 2.292 RFPMS	RFPMS	0.0391
	+0.023 DENFLP	DENFLP	0.0115
	−0.083 DRAINA	DRAINA	0.5195
	−2.606 RAINFL	RAINFL	0.5307
5	DEATHS = −83.024 + 2.361 RFPMS	RFPMS	0.0400
	+0.021 DENFLP	DENFLP	0.0489
	−0.097 DRAINA	DRAINA	0.5661
	−2.971 RAINFAL	RAINFAL	0.5150
	+0.003 DENTOTA	DENTOTA	0.6667
6	DEATHS = −71.641 + 2.536 RFPMS	RFPMS	0.0349
	+0.016 DENFLP	DENFLP	0.0897
	−0.101 DRAINA	DRAINA	0.5964
	−2.328 RAINFA	RAINFA	0.5967
	−2.414 SLOPCH	SLOPCH	0.1281
	+0.728 SLOPBA	SLOPBA	0.1365
7	DEATHS = −63.577 + 2.974 RFPMS	RFPMS	0.0279
	+0.017 DENFLP	DENFLP	0.0840
	−0.106 DRAINA	DRAINA	0.6185
	−4.396 RAINFL	RAINFA	0.628
	−2.721 SLOPCH	SLOPCH	0.0998
	+1.079 SLOPBA	SLOPBA	0.0998
	−0.141 SLOPSI	SLOPSI	0.5933

TABLE IX (Continued)

No. of Best Variables	Equations	Variables	Observed Significant Level
8	DEATHS = -66.316 + 2.968 RFPMS	RFPMS	0.0320
	+0.019 DENFLP	DENFLP	0.1524
	-0.111 DRAINA	DRAINA	0.6176
	-4.352 RAINFA	RAINFA	0.5931
	+0.002 DENTOT	DENTOT	0.8227
	+1.069 SLOPBA	SLOPBA	0.1142
	-2.659 SLOPCH	SLOPCH	0.1234
	-0.140 SLOPSI	SLOPSI	0.5760

The minimum R-square improvement model was run on the previous listed eight variables. The results are much the same as the maximum R-square improvement model.

"Best" 1 variable

$$\text{Deaths} = -18.393 + (1.276)\ \text{RFPMS} \tag{4.4}$$

"Best" 2 variables

$$\text{Deaths} = -82.882 + (1.607)\ \text{RFPMS} + (0.021)\ \text{DENFLP} \tag{4.5}$$

"Best" 3 variables

$$\text{Deaths} = -83.252 + (1.667)\ \text{RFPMS} + (0.024)\ \text{DENFLP} + (-0.115)\ \text{DRAINA} \tag{4.6}$$

"Best" 4 variables

$$\text{Deaths} = -81.252 + (2.292)\ \text{RFPMS} + (0.023)\ \text{DENFLP} + (-0.083)\ \text{DRAINA} + (-2.606)\ \text{RAINFAL} \tag{4.7}$$

"Best" 5 variables

$$\text{Deaths} = -83.824 + (2.361)\ \text{RFPMS} + (0.021)\ \text{DENFLP} + (-0.097)\ \text{DRAINA} + (-2.771)\ \text{RAINFAL} + (0.003)\ \text{DENTOT} \tag{4.8}$$

"Best" 6 variables

$$\text{Deaths} = -71.641 + (2.536)\ \text{RFPMS} + (0.016)\ \text{DENFLP} + (-0.101)\ \text{DRAINA} + (-2.328)\ \text{RAINFAL} + (-2.414)\ \text{SLOPCH} + (0.728)\ \text{SLOPBA} \quad (4.9)$$

"Best" 7 variables

$$\text{Deaths} = -63.577 + (2.973)\ \text{RFPMS} + (0.017)\ \text{DENFLP} + (-0.106)\ \text{DRAINA} + (-4.396)\ \text{RAINFAL} + (-2.721)\ \text{SLOPCH} + (1.079)\ \text{SLOPBA} + (0.141)\ \text{SLOPSI} \quad (4.10)$$

"Best" 8 variables

$$\text{Deaths} = -66.316 + (2.968)\ \text{RFPMS} + (0.016)\ \text{DENFLP} + (-0.111)\ \text{DRAINA} + (-4.352)\ \text{RAINFAL} + (0.002)\ \text{DENTOT} + (1.069)\ \text{SLOPBA} + (-2.659)\ \text{SLOPCH} + (-0.140)\ \text{SLOPSI} \quad (4.11)$$

The equation developed through the "best" of six in the minimum R^2 selection was determined to be the most representative of the family of equations created. The "best" of six equations has as the independent variables; drainage area (DRAINA), amount of rainfall (RAINFA), the ratio of probable maximum rainfall to storm rainfall (RFPMS), density of flood plain (DENFL), slope of channel (SLOPCH), and slope of basin (SLOPBA). The selection was made this way due to (1) R^2 value of 0.56 and (2) the availability of source data.

Flash Flood Model

Application of the Flash Flood Model for the purpose of more realistic projection of flood flows is easily done. The Flash Flood Model is designed to solve many hydrologic problems when the data base is complete or partially complete. For this study measurements and calculations were made during field trips as if working in a laboratory on a miniature river basin. This study was, in fact, a laboratory research project on site for the creation of practical data. During the field trips it was found that many times certain basic measurements could not be obtained easily. As a result of this problem, several options were built into the program allowing the model to calculate a hard to determine parameter or to accept a specific input measurement. Items that are optional for entry in the Flash Flood Model are: time to peak, unit graph peak, flood stage, maximum probable storm and type of empirical equations to be used. There are many times when calculated data must be checked by historical information. One instance of the need of the selection capability is when, by local stream improvement, a natural flood stage has been revised due to the construction of a flow way.

The creation of the master files for Antecedent Precipitation Index (API) values (Data files TBA, TBB, TBC and TBD) makes it possible for their use by the design hydrologist. Through the use of these API files or tables, it is possible to create any soil moisture condition required of a design Engineer. The water balance characteristics of any hydrologic model are critical. The model must predict what the soil moisture is as closely as possible. In this Flash Flood Model the system of percolation, soil moisture, storage, drainage, and evaporation characteristics are represented in the master API files. All variables in the water cycle are important to the hydrologic process. The main element of this, or any other flow model, is that, by its use it is possible to forecast or determine what the basin streamflow will be from a particular storm. The very nature of a flash flood will minimize certain hydrologic parameters while maximizing other parameters.

In the Flash Flood Model the geographic API files allow the modeler to select the logical file, or if a particular condition exists, the modeler may theoretically move the basin 200 miles east or west.

The determination of the time to peak and unit graph may be done by the model, but if possible a site investigation should be made to establish what the local community uses for a flood stage. The engineer must be careful to tie in theory with the local datum base, as a forecast scheme that would forecast for an unknown bridge or non-local datum control condition could result in a disastrous situation rather than a good forecast. Many times two forecast schemes may be required for one community, one scheme for the natural creek bed in the rural areas, and one scheme for the improved channel section through town.

The Flash Flood Potential Scale, which is a subroutine output in the Flash Flood Model, is designed to present to local, state and Federal agencies what could occur from a flood caused by rains of a Probable Maximum Precipitation (PMP) Storm. This Flash Flood

Potential Scale is divided in values of one through ten. The scale includes conditions from no flood to catastrophic floods. The scale is determined in the model by calculation of the possible deaths that may occur from the PMP storm. The Flash Flood Model may also be run with rainfall less than from a PMP storm, and if this is done, then a death count related to the subject storm will be given.

In this research of a forecast scheme for the test communities in the states of New Mexico, Oklahoma and Texas the design was to develop the Flash Flood Potential Scale for the PMP storm. The basic data from the design basin was compiled into the data requirements, as shown in Figure 6.. A typical Flash Flood Potential Scale is shown in Table I. The Flash Flood Model was run and the resulting Flash Flood Potential Scale determinations are listed in Table X.

Flash Flood Potential Scales for each test community are listed in Appendix A.

A typical Flash Flood Potential Scale with calculated death count and Scale number is shown in Figure 18.

Flash Flood Forecasting schemes were developed for all design basins and are shown in Appendix B.

A typical Flash Flood Forecasting Scheme is shown in Figure 19.

TABLE X

SUMMARY OF FLASH FLOOD MODEL'S

POTENTIAL SCALE DETERMINATIONS

Location of Community	No. of Possible Deaths	Flash Flood Potential Scale Number
Cimarron, New Mexico	53	8
Clayton, New Mexico	76	8
Folsom, New Mexico	80	8
Raton, New Mexico	115	8
Springer, New Mexico	116	8
Tucumcari, New Mexico	125	8
Ute Park, New Mexico	104	8
Valmora, New Mexico	76	8
Watrous, New Mexico	112	8
Beaver, Oklahoma	0	6
Guymon, Oklahoma	61	8
Kenton, Oklahoma	117	8
Amarillo, Texas	27	6
Canadian, Texas	0	6
Palo Duro State Park, Texas	108	8
Tascosa, Texas	64	8

CIMARRON RIVER, CIMARRON, NEW MEXICO

EAGLE NEST LAKE TO CIMARRON

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROBABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 53

Figure 18. Typical Flash Flood Potential Scale, Cimarron, New Mexico

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 2

CIMARRON RIVER, CIMARRON, NEW MEXICO

EAGLE NEST LAKE TO CIMARRON
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.2 FT

FLOOD STAGE = 4.8 FT.
GAGE ZERO = 6400.00 FT.-MSL
TIME TO PEAK = 2.4 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.5	2.0	2.5	3.1	3.9	4.7	6.1	7.5	7.9	8.8	9.7
1.2	I	1.5	1.8	2.3	2.9	3.6	4.4	5.8	7.2	7.9	8.8	9.6
1.4	I	1.4	1.7	2.1	2.5	3.2	3.8	5.3	6.7	7.7	8.6	9.5
1.6	I	1.3	1.6	1.9	2.3	2.9	3.6	5.0	6.4	7.6	8.6	9.4
1.8	I	1.2	1.5	1.8	2.2	2.7	3.3	4.7	6.1	7.5	8.4	9.3
2.0	I	1.2	1.4	1.7	2.0	2.5	3.0	4.4	5.7	7.1	8.3	9.2
2.2	I	1.2	1.3	1.5	1.8	2.2	2.7	4.0	5.3	6.7	8.2	9.0
2.4	I	1.2	1.3	1.5	1.7	2.1	2.5	3.6	5.0	6.4	8.1	8.9
2.6	I	1.2	1.2	1.4	1.6	1.9	2.3	3.3	4.6	6.0	8.0	8.8
2.8	I	1.2	1.2	1.3	1.5	1.9	2.2	3.2	4.4	5.8	7.9	8.7
3.0	I	1.2	1.2	1.2	1.4	1.7	2.0	2.9	4.0	5.3	7.8	8.5
3.2	I	1.2	1.2	1.2	1.3	1.6	1.9	2.7	3.8	5.1	7.7	8.4
3.4	I	1.2	1.2	1.2	1.2	1.5	1.7	2.5	3.5	4.7	7.5	8.3
3.6	I	1.2	1.2	1.2	1.2	1.4	1.6	2.3	3.2	4.4	7.2	8.1
3.8	I	1.2	1.2	1.2	1.2	1.3	1.5	2.1	3.0	4.1	6.8	8.0
4.0	I	1.2	1.2	1.2	1.2	1.2	1.4	2.0	2.8	3.8	6.5	7.8
4.2	I	1.2	1.2	1.2	1.2	1.2	1.3	1.8	2.7	3.9	6.6	7.9
4.4	I	1.2	1.2	1.2	1.2	1.2	1.2	1.7	2.5	3.8	6.5	7.9
4.6	I	1.2	1.2	1.2	1.2	1.2	1.2	1.6	2.3	3.4	6.1	7.7
4.8	I	1.2	1.2	1.2	1.2	1.2	1.2	1.5	2.2	3.4	6.0	7.8
5.0	I	1.2	1.2	1.2	1.2	1.2	1.2	1.4	2.1	3.0	5.6	7.5

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

Figure 19. Flash Flood Forecasting Scheme Cimarron, New Mexico

The Flash Flood Model caculates unknown parameters and relists given known parameters in a format called the Pertinent Data Sheet. The Pertinent Data Sheet is calculated during each run of the Flash Flood Model. An example of the Pertinent Data Sheet is shown in Figure 20. During each run of the Flash Flood Model the computer will search the input data for dam break information. If data is found to operate the dam break routine, the Flash Flood Model will calculate the maximum flow from a complete washout of the dam or it will calculate a flow from a breached dam. In most cases a dam will fail by breach. The breach, in most situations, must be estimated in terms of width and depth. The Flash Flood Model calculates the breach flow in maximum flow at the dam face, and then will predict the height of the flood and travel time to the town downstream. See Figure 21 for an example of the dam break sheet.

CIMARRON RIVER, CIMARRON, NEW MEXICO

EAGLE NEST LAKE TO CIMARRON

PERTINENT DATA

DRAINAGE AREA = 98.20 SQUARE MILES

CHANNEL SLOPE = 88.0 FEET/MILE

OVERLAND SLOPE = 1100.0 FEET/MILE

MAXIMUM HEIGHT OF BASIN = 9038.0 FT MEAN SEA LEVEL

ZERO OF LOCATION = 6400.0 FEET MEAN SEA LEVEL

FLOOD STAGE = 4.8 FEET

FLOOD STAGE FLOW = 7030. CFS

FLOW DEPTH FROM 100 YEAR FLOOD = 12. FEET

100 YEAR FLOOD FLOW = 40000. CFS

PROBABLE MAXIMUN PRECIPITATION STORM = 24.00INCHES

DEPTH FROM PROBABLE MAXIMUN PRECIPITATION STORM = 22. FEET

TIME TO PEAK = 2.4 HOURS

UNIT GRAPH PEAK = 4300. CFS

PROBABLE MAXIMUM PRECIPITATION STORM FLOOD FLOW = 45800. CFS

NUNBER OF RAINFALL GAGES REQUIRED = 9

NUMBER OF RIVER STATIONS REQUIRED = 3

Figure 20. Pertinent Data Sheet, Cimarron, New Mexico

CIMARRON RIVER, CIMARRON, NEW MEXICO

EAGLE NEST LAKE TO CIMARRON

DAM BREAK DATA FOR THE BASIN

NAME OF DAM IS EAGLE NEST

NAME OF CITY DOWNSTREAM FROM DAM IS CIMARRON

SURFACE ACRES = 2768.

DEPTH OF THE WATER AT THE DAM = 89.00 FEET

RESERVOIR CAPACITY = 98540.7 ACRE-FEET

RESERVOIR LENGTH = 1.8 MILES

PEAK CFS FLOW OF TOTAL DAM BREAK = 5626000. CFS

RESERVOIR TIME TO PEAK AT SPILLWAY = 1.05 MINUTES

WEIR BREACH -- MOST PROBABLE WAY OF DAM FAILURE

WIDTH OF BREACH = 70.0 FEET

DEPTH OF BREACH = 60.0 FEET

PEAK FLOW AT BREACH = 37000. CFS

PEAK TIME IN MINUTES AT BREACH = 15.8 MINUTES

DOWN STREAM EFFECT FROM BREACH

STAGE AT CITY DOWN STREAM WILL BE NEAR 13.92 FEET

PEAK TRAVEL TIME TO CITY WILL BE = 1.2 HOURS

Figure 21. Dam Break Sheet, Eagle Nest Dam, New Mexico

MIT Catchment Model

The MIT Catchment sub-routine is used in the Flash Flood Model as a means of determining the unit graph storm or the peak flow from a particular storm. Its use is optional, either the peak flow and time to peak will be determined through hydrologic basin determination as shown in Chapter III, or the MIT Catchment through its more definite control of basin runoff characteristics. Whenever the user of the Flash Flood Model desires a more accurate determination of basin outflow than average utility control, the MIT Catchment Model is used for determination of flow hydrograph. See figure 22 for typical output from the MIT Catchment Model.

TYPICAL EXAMPLE
MIT CATCHMENT MODEL
DATA INPUT SUMMARY

```
CIMARRON RIVER, CIMARRON, NEW MEXICO

                         NUMBER OF SEGMENTS =    3
                              DT =  5.000 MINUTES
                OUTPUT SAMPLING INTERVAL =  5.00 MINUTES
                     NUMBER OF RAIN GAGES = 1
                               IOPT =  0
                        NUMBER OF STORMS =  1
                       NUMBER OF SEASONS =  0
                     INFILTRATION TYPE = SCS INFL
```

SEGMENT	UPSTREAM SEGMENTS	ADJACENT SEGMENTS	TYPE	IPR	NDX	LENGTH (FEET)	SLOPE	ROUGHNESS PARAMETER
OF1			5	1	10	7920.	0.2500	0.400
OF2			5	1	10	7920.	0.2500	0.400
SW3		OF1 OF2	3	1	100	100320.	0.0260	0.040

THIESSEN COEFFICIENTS FOR RAIN GAGE

SEGMENT	1	OTHER PARAMETERS		SCS CN
OF1	1.0	1.400	0.0	85.
OF2	1.0	1.400	0.0	85.
SW3	0.0	20.000	0.0	***

COMPUTATION SEQUENCE

INDEX	SEGMENT
1	OF1
2	OF2
3	SW3

KINEMATIC CHANNEL PARAMETERS

SEGMENT	ALPHA	M
OF1	1.488	1.670
OF2	1.488	1.670
SW3	2.094	1.330

Figure 22. Typical Example - MIT Catchment Model

TYPICAL EXAMPLE

MIT CATCHMENT MODEL

RAINFALL DATA SHEET

CIMARRON RIVER, CIMARRON, NEW MEXICO

TIME (MIN)	RAINFALL DATA INTENSITY (IN/HR) 1
60.00	4.00
120.00	11.00
180.00	6.00
240.00	3.00

Figure 22. (cont'd) MIT Kinematic Catchment Model

TYPICAL EXAMPLE
MIT CATCHMENT MODEL
OUTFLOW HYDROGRAPH

CIMARRON RIVER, CIMARRON, NEW MEXICO

TIME (MIN)	OUTFLOW HYDROGRAPHS FOR SEGMENTS OF1	OF2	SW3
5.00	0.0	0.0	0.0
10.00	0.00	0.00	0.07
15.00	0.00	0.00	1.59
20.00	0.01	0.01	11.58
25.00	0.02	0.02	47.51
30.00	0.03	0.03	140.06
35.00	0.04	0.04	334.19
40.00	0.06	0.06	689.16
45.00	0.09	0.09	1278.29
50.00	0.12	0.12	2188.36
55.00	0.15	0.15	3519.06
60.00	0.18	0.18	5382.38
65.00	0.30	0.30	8401.95
70.00	0.44	0.44	13588.00
75.00	0.61	0.61	21829.39
80.00	0.80	0.80	34138.04
85.00	1.01	1.01	51568.91
90.00	1.23	1.23	75082.06
95.00	1.48	1.48	105352.44
100.00	1.74	1.74	142547.12
105.00	1.99	1.99	186061.81
110.00	2.22	2.22	234408.87
115.00	2.41	2.41	285221.44
120.00	2.55	2.55	335594.44
125.00	2.50	2.50	380443.31
130.00	2.43	2.43	415319.06
135.00	2.34	2.34	439439.69
140.00	2.24	2.24	453284.31
145.00	2.14	2.14	458062.62
150.00	2.04	2.04	455379.56
155.00	1.96	1.96	447210.06
160.00	1.87	1.87	435425.31
165.00	1.80	1.80	421519.87
170.00	1.74	1.74	406795.31
175.00	1.69	1.69	392215.06
180.00	1.64	1.64	378390.50
185.00	1.54	1.54	364573.00
190.00	1.45	1.45	350042.56
195.00	1.36	1.36	335229.56
200.00	1.29	1.29	320440.50

Figure 22. (continued) MIT Kinematic Catchment Model

TYPICAL EXAMPLE
MIT CATCHMENT MODEL
OUTFLOW HYDROGRAPH

CIMARRON RIVER, CIMARRON, NEW MEXICO

TIME (MIN)	OUTFLOW HYDROGRAPHS FOR SEGMENTS OF1	OF2	SW3
205.00	1.23	1.23	305902.69
210.00	1.17	1.17	291793.94
215.00	1.12	1.12	278258.81
220.00	1.07	1.07	265413.75
225.00	1.03	1.03	253344.69
230.00	0.99	0.99	242105.69
235.00	0.96	0.96	231720.56
240.00	0.93	0.93	222189.69
245.00	0.84	0.84	212683.94
250.00	0.76	0.76	202504.56
255.00	0.70	0.70	191869.81
260.00	0.63	0.63	180974.50
265.00	0.58	0.58	169993.44
270.00	0.53	0.53	159085.69
275.00	0.48	0.48	148394.25
280.00	0.44	0.44	138044.12
285.00	0.40	0.40	128138.25
290.00	0.37	0.37	118754.69
295.00	0.34	0.34	109944.69
300.00	0.31	0.31	101734.19
305.00	0.29	0.29	94126.94
310.00	0.27	0.27	87109.62
315.00	0.25	0.25	80656.00
320.00	0.23	0.23	74732.62
325.00	0.21	0.21	69302.06
330.00	0.20	0.20	64325.63
335.00	0.18	0.18	59765.41
340.00	0.17	0.17	55585.66
345.00	0.16	0.16	51752.96
350.00	0.15	0.15	48236.52
355.00	0.14	0.14	45008.09
360.00	0.13	0.13	42042.00
365.00	0.12	0.12	39314.86
370.00	0.11	0.11	36805.45
375.00	0.11	0.11	34494.46
380.00	0.10	0.10	32364.37
385.00	0.09	0.09	30399.28
390.00	0.09	0.09	28584.69
395.00	0.08	0.08	26907.52
400.00	0.08	0.08	25355.85

Figure 22. (continued) MIT Kinematic Catchment Model

TYPICAL EXAMPLE
MIT CATCHMENT MODEL
OUTFLOW HYDROGRAPH

CIMARRON RIVER, CIMARRON, NEW MEXICO

TIME (MIN)	OUTFLOW HYDROGRAPHS FOR SEGMENTS OF1	OF2	SW3
405.00	0.07	0.07	23918.84
410.00	0.07	0.07	22586.68
415.00	0.07	0.07	21350.46
420.00	0.06	0.06	20202.09
425.00	0.06	0.06	19134.21
430.00	0.06	0.06	18140.15
435.00	0.05	0.05	17213.84
440.00	0.05	0.05	16349.77
445.00	0.05	0.05	15542.95
450.00	0.0[illegible]	0.05	14788.80
455.00	0.05	0.05	14083.18
460.00	0.04	0.04	13422.31
465.00	0.04	0.04	12802.75
470.00	0.04	0.04	12221.35
475.00	0.04	0.04	11675.27
480.00	0.04	0.04	11161.85
485.00	0.03	0.03	10678.71
490.00	0.03	0.03	10223.67
495.00	0.03	0.03	9794.71
500.00	0.03	0.03	9389.99
505.00	0.03	0.03	9007.82
510.00	0.03	0.03	8646.64
515.00	0.03	0.03	8305.05
520.00	0.03	0.03	7981.70
525.00	0.03	0.03	7675.41
530.00	0.02	0.02	7385.05
535.00	0.02	0.02	7109.59
540.00	0.02	0.02	6848.07
545.00	0.02	0.02	6599.62
550.00	0.02	0.02	6363.42
555.00	0.02	0.02	6138.73
560.00	0.02	0.02	5924.84
565.00	0.02	0.02	5721.09
570.00	0.02	0.02	5526.90
575.00	0.02	0.02	5341.70
580.00	0.02	0.02	5164.96
585.00	0.02	0.02	4996.20
590.00	0.02	0.02	4834.98
595.00	0.02	0.02	4680.87
600.00	0.02	0.02	4533.47

Figure 22. (continued) MIT Kinematic Catchment Model

CHAPTER V

RESULTS

Flash Flood Model

Death Potential Scale

The data test bed was supplied by the original twenty-five locations. Statistical analysis was made and results indicated that a projection of possible deaths that could occur, could indeed be made. Once the equation with the best fit was determined, an analysis was made to see just how the developed equation would forecast the source data. Forecast values were determined for each input data point. It is shown that the residual value was as high as 92 and as low as -52 (Table VI) for a plotting of the relationship between the forecast value and the observed value. The statistical equation was applied back against the original input data to determine the relationship between forecast residual and observed deaths, (Figures 23 and 24). The final statistical equation (best of six variables) is not the ultimate equation. It appears that the developed equation has a bias to under forecast.

To further test the statistical equation an additional set of death data was applied against the Flash Flood Model. The second set of data was compiled from storms in the southwest. Two of the new storms are from Oklahoma and two are from Colorado. See Table XII

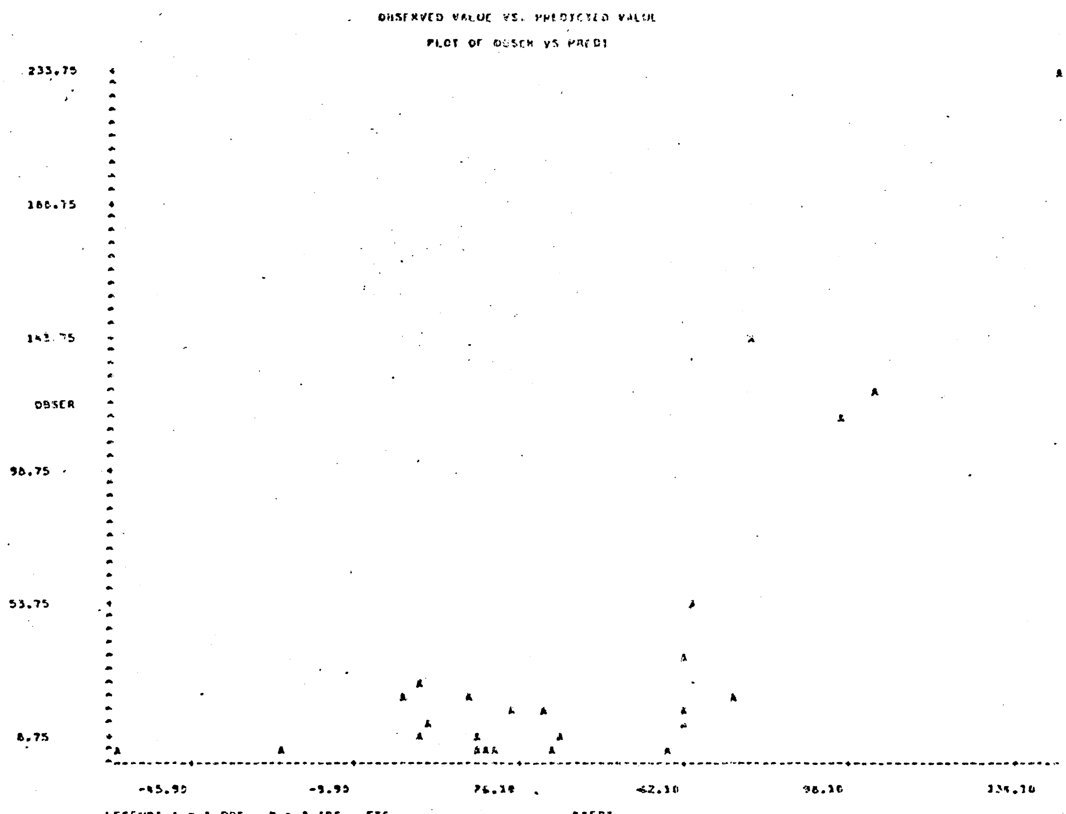

Figure 23. Observed Values vs. Predicted Value - Death Count

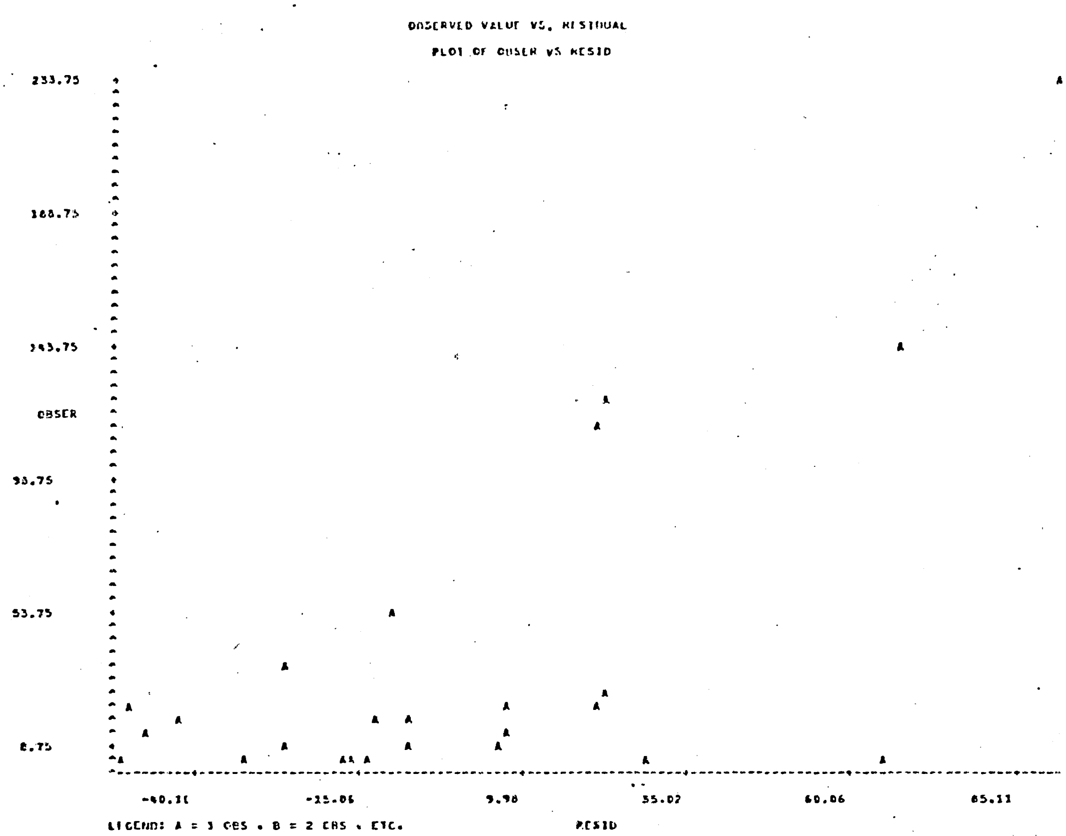

Figure 24. Observed Values vs. Residual - Death Count

TABLE XI

COMPARISON OF DEATHS

Station Location and Stream Name	Date	Observed No. of Deaths	Forecast No. of Deaths
Tulsa, Oklahoma Mingo Creek	June '76	3	4
Enid, Oklahoma Boggy Creek	Oct. '73	9	8
Pueblo, Colorado Fountain Creek	June '21	78	60
Colorado Scprings, Colorado, Monument Creek	May '35	18	22

for comparison data between reported deaths and forecast deaths. In the second set of data it shows that the confidence level is ± 25%, which is better than the original data set. The second set of storms shows further the worth of the Flash Flood Potential in that predictions are close and certainly do give an indication of how great a disaster might occur. As stated for the test data of the original set and now for this second set of data, it appears that the statistical equation may have a bias to under forecast the death count. In the second set, the forecast death count for the flood in Tulsa and Colorado Springs is over forecasted, but not to the extent it under forecasted the Enid and Pueblo floods.

The subroutine for the development of the potential death count was, in the beginning, designed as a tool whereby through its use a community could be pre-warned of the approximate death count that could occur from the PMP storm. The data will seldom reach the limit of the PMP storm so the Flash Flood Model will accept any storm rainfall and then give a potential death count.

Flood Forecasting Schemes

Through the utilization of the Antecedent Precipitation Index master files as shown in lines 11 through 96 of Figure 11, the Flash Flood Model makes it possible to forecast any rise in any stream. The forecast tables are dependent on basin parameters, allowing quick "look-up" forecasts of floods and which permit on-the-spot updating as the storm progresses.

To present the reliability and worth of the Flash Flood tables, a comparison of forecasts was made. (See Table XII). This table was compiled from recent rises in local streams over the past two years. The table lists the forecasts made by the Sacramento Model, the Existing Manual Model (the old data historic API method) and the Flash Flood Model. The Sacramento Model and Manual Model are currently used for public forecasts, the Flash Flood Model is to be used when time prohibits use of the big model and is to be used as a backup system. In the majority of the floods the Flash Flood Model was not checked or looked at until after the forecast was made. Many times the Flash Flood Model was not referred to at all. As stated, in the majority of cases, the Flash Flood Model was not referred to until the issuance of the forecast, but in the case of the two major differences, the Augusta, Kansas and Bartlesville, Oklahoma floods, the tables were used by the operational hydrologist. A statistical analysis was then run on the list of forecasts. The analysis of Variance Table indicated that the forecast of the Flash Flood Model holds 98% of the control of the true forecast, or the observed value.

The statistical analysis gave an equation:

$$\text{True Forecast} = (-1.167) + ((0.018)\ \text{non-flash flood model}) + ((0.999)\ \text{flash flood model}) \quad (5.1)$$

it was thus dictated to use 0.999% of the value of the Flash Flood Model and to use 0.018% of the non-Flash Flood Model schemes.

The Flash Flood Model will calculate the equipment needed to satisfy the data needs. The Model will also enable the hydrologist to predict dam breaks in terms of the flow at the breached dam and the stage and time of travel to the community downstream.

TABLE XII

COMPARISON OF FORECASTS

Station - Stream - State	Date	Method of Forecast: Sacramento Model Feet	Manual Model Feet	Flash Flood Model Feet	Observed Value Feet
Canadian, Canadian R. Ok.	5-77		8	9.4	9.05
Waurika, Beaver Cr. Ok.	5-77		873 msl	873 msl	873 msl
Beggs, Deep Fork R. Ok.	5-77	23		15	12.59
Sperry, Bird Cr. Ok	5-77	28		23.5	23.12
Owasso, Bird Cr. Ok.	5-77	30		24.5	24.95
Bartlesville, Caney R. Ok.	7-76	19		11	11.2
Augusta, Walnut R. Ks.	7-76		38	34.	33.8
El Dorado, Whitewater R. Ks.	7-76		26	24	23.5
Kingfisher, Uncle John C. Ok.	5-77		25	22	22.5
Kingfisher, Kingfisher C. Ok.	5-77		25	18	21.5
Copan, Caney R. Ok.	5-77	22		22	18.4
Ramona, Caney R. Ok.	5-77	25.5		26	23.5
Blackwell, Chikaskia R. Ok.	5-77		22	24	22.2
Murdock, Ninnescah R. Ks.	5-77		9.7	10	9.76
Blue, Blue R. Ok.	5-77		25	13.5	9.3
Caney, Caney R. Ok.	5-77		24	15.9	14.6

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

After analysis of 25 drainage basins by using the STEPWISE regression techniques relating deaths to eight drainage basin characteristics and climatic conditions, the following results were noted. The ratio of Rainfall to Probable Maximum Precipitation (RFPMS) was found to be the most significant in terms of both R^2 (coefficient of determination) and the observed significance level of the coefficient. Although the RFPMS was most significant, an equation developed in the minimum R^2 was used as it included six basin, population and climatic conditions. In this equation the variables RFPMS, Rainfall (RAINFL) and slope of channel (SLOPCH) were deemed more significant than the density of flood plain (DENFLP), drainage area (DRAINA) and slope of the basin (SLOPBA). The potential death count was determined for the new seventeen test basins. The calculated death count was then set against the step limits of flood potential scale and a scale number was determined for each basin.

Each of the seventèen test basins were investigated for flood stage, unit graph flow, 100 year flow stage and flow, depth of flow from Probable Maximum Precipitation Storm, the number of index rain gages and stream gages and where there is an upstream dam, the downstream time-to-peak and stage were determined. For each basin a set of flash flood tables were generated to further present to the city officials the flood potential of their community. (45)

An operational Flash Flood Model had never been developed in the United States, but with the continued community development in the flood plain some method of quick alert had to be developed. The Flash Flood Model is designed so that it can be used to create flood parameters for a community long before any flood occurs, or it may be used operationally during a flood.

The Flash Flood Potential Scale was developed from twenty-five original floods. The accuracy was tested against the original twenty-five locations and also against four additional locations. The Flash Flood Potential Scale should only be used as an indication or trend of the number of deaths which could occur from a particular storm.

Conclusions

The objective of this research was to create a way of predicting the possible deaths and damage that could occur due to the Probable Maximum Precipitation Storm. To enable practical application of the model, a Flood Potential Scale was developed to assist the hydrologist or layman in determining what relation a particular basin has to other basins of similar characteristics.

Through utilization of the Flash Flood Model on 17 test basins the model was found to be a most useful tool for the members of the community. Before, when a flood occurred in a basin, few had any idea of the great disaster that could befall a community. The Flash Flood Model will allow the City Engineer or Civil Defense Director of a local city to understand the magnitude of a flood which could occur.

The model will help to create individual data sets for many basins, which up to now were believed to be non-floodable.

The model will also help the responsible Federal, State, County or City officials in development of a flood plain. Now it can be presented to the community an estimate of what the ultimate, probable stage could be expected in a particular reach or at a specific location. Along with estimate of probable maximum stage, the model will determine the time-to-peak and unit graph peak, the 100-year flow and stage and for each location a flash flood table will be developed with varying initial stages. The Flash Flood Table will allow on the spot forecasting for any storm, at any initial antecedent precipitation index

The model will also treat the sudden dam break and will develop the flow wave and route the flow down stream in terms of stage and travel time.

The Flash Flood Model and Flash Flood Potential Scale is original in the basic hypothesis, in concept and application. Application is now being made by some Engineering firms.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

The following suggestions for future study would be useful for flash flood forecasting in the high plains and the entire United States.

1. Compile an ultra complete falsh flood vs deaths data set with 300 or more points covering 100 years of data.
2. Use a multiple regression technique to predict flows at different storm frequencies.
3. Use additional data input of miles of roads in flood plains, time of storm and time period since last major rise.
4. To investigate the resultant deaths of the same community or one similar in floods of ample warnings versus no warning at all.
5. To completely combine the momentum, kinematic and HEC-2 program into one conclusive basin design program.

BIBLIOGRAPHY

1. Beard, L. R., "Generalized Evaluation of Flash-Flood Potential." Center for Research in Water Resources, The University of Texas at Austin, June, 1975.

2. McCain, J. F. and Jarrett, R. D., "Manual for Estimating Flood Characteristics of Natural-Flow Streams in Colorado." Colorado Water Conservation Board, Technical Manual No. 1, Denver, Colorado (1976).

3. Sauer, V. B., "An Approach to Estimating Flood Frequency for Urban Areas in Oklahoma." U. S. Geological Survey, Water Resources Investigations 23-74 (July 1974).

4. Thomas, Jr., W. O., "Techniques for Estimating Flood Depths for Oklahoma Streams." U. S. Geological Survey, Water Resources Investigation 2-76 (April 1976).

5. Jordan, P. R. and Irza, T. J., "Kansas Streamflow Characteristics." State of Kansas, Technical Report No. 11, February (1975).

6. Hershfield, D. M., "Rainfall Frequency Atlas of the United States." National Weather Service, Technical Paper No. 40, May (1961).

7. Yarnell, D. L., "Rainfall-Frequency Data." Miscellaneous Publication No. 204, U. S. Department of Agriculture, Washington, D. C., (1935).

8. U. S. Weather Bureau, "Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1000 Square Miles and Durations of 6, 12, 24, and 48 Hours." Hydrometeorological Report No. 33, April (1956).

9. "National Weather Service River Forecast System Forecast Procedures." NOAA TECHNICAL MEMORANDUM NWS HYDRO 14. Department of Commerce (1972).

10. Crawford, N. H., and Linsley, R. K., "Digital Simulation in Hydrology." Stanford Watershed Model IV. Technical Report No. 39, Stanford University (1966).

11. Harley, B. M., Perkins, F. E., and Eagleson, P. S., "A Modular Distributed Model of Catchment Dynamics." MIT Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics. Report 113 December (1970).

12. Lighthill, M. J. and Whitham, G. B., "On Kinematic Waves - I. Flood Movement in Long Rivers."

13. Woolhiser, D. A. and Liggett, J. A., "Unsteady, One-Dimensional Flow over a Plane - the Rising Hydrograph." Water Resources Research, Vol. 3, No. 3, (1967).

14. Wooding, R. A., "A Hydraulic Model for Catchment--Stream Problem III. Comparison with Runoff Observations." J of Hydrology, Vol. 4, (1966).

15. U.S. Soil Conservation Service. "A Method for Estimating Volume and Rate of Runoff in Small Watersheds." SCS-TP-149 (Rev.), (1973).

16. Schaake, Jr., J. C., Leclerc, G. and Harley, B. M., "Evaluation and Control of Urban Runoff." ASCE Annual and National Environmental Engineering Meeting (1973).

17. Kriengsiri, P., "A Methodology for Estimating the Regional Flood Frequencies for Northeastern Thailand.", Unpublished Doctor's Dissertation, Oklahoma State University (1975).

18. Street & Torrie. Principles and Procedures of Statistics. New York: McGraw-Hill (1960).

19. Eichert, B. S., Water Surface Profiles. U.S. Army Corps of Engineers, Davis, California (October 1973).

20. "Hydrology." SCS National Engineering Handbook, Washington, D.C. USDA, (1972).

21. Chow, Ven te. Handbook of Applied Hydrology. New York: McGraw-Hill, (1964).

22. "Flow Through A Breached Dam." Military Hydrology Bulletin 9, Washington, D.C.: Dept. of the Army, (1957).

23. Wilson, C. and Iturbe, I. R., "Joint Usage of Rainfall-Runoff Models and Rainfall Generation Models.", MIT Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics. Report No. 4-36738 (1975).

24. Special Supplement, La Epoca, Weekly Newspaper, Folsom, New Mexico, August (1908).

25. "Natural Disaster Survey Report 72-1.", National Oceanic and Atmospheric Administration, Department of Commerce, August (1972).

26. Henz, J. F. and Scheetz, V. R., "The Big Thompson Flood of 1976 in Colorado.", Geophysical R/D Corporation and Donald O. Doehring, College of Forestry and Natural Resources, Colorado State University, December (1976).

27. "Natural Disaster Survey Report 76-1.", National Oceanic and Atmospheric Administration, Department of Commerce, October (1976).

28. "The Big Thompson Flood.", C. F. Boone, Publisher, Lubbock, Texas, (1976).

29. "The Big Thompson River Flood.", Colorado Water Conservation Board, Denver, Colorado, October (1976).

30. U.S. Weather Bureau "Climatological Data, National Summary (1951)

31. U.S. Weather Bureau "Climatological Data, National Summary (1953)

32. U.S. Weather Bureau "Climatological Data, National Summary (1957)

33. U.S. Weather Bureau "Climatological Data, National Summary (1958)

34. U.S. Weather Bureau "Climatological Data, National Summary (1961)

35. U.S. Weather Bureau "Climatological Data, National Summary (1962)

36. U.S. Weather Bureau "Climatological Data, National Summary (1965)

37. U.S. Weather Bureau "Climatological Data, National Summary (1966)

38. U.S. Weather Bureau "Climatological Data, National Summary (1969)

39. U.S. Weather Service "Climatological Data, National Summary (1970)

40. U.S. Weather Service "Climatological Data, National Summary (1972)

41. U.S. Weather Service "Climatological Data, National Summary (1973)

42. U.S. Weather Service "Climatological Data, National Summary (1974)

43. U.S. Weather Service "Climatological Data, National Summary (1975)

44. Service, Jolayne, <u>A User's Guide to the Statistical Analysis System</u>. North Carolina State University, Raleigh (August, 1972).

45. Sheridan, J., "Methods for Developing Flash Flood Forecasting Tables.", Unpublished thesis Oklahoma State University, (1975).

APPENDIX A

FLASH FLOOD POTENTIAL SCALES

PERICA CREEK, CLAYTON, NEW MEXICO

TOTAL LOCAL AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 76

DRY CIMARRON, FOLSOM, NEW MEaICO

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 80

RAILROAD CANYON, RATON, NEW MEXICO

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW:

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 115

CIMARRON RIVER, SPRINGER, NEW MEXICO

90 SQUARE MILES ABOVE SPRINGER, TOTAL = 2673

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 116

CONCHAS CANAL, TUCUMCARI, NEW MEXICO

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 125

CIMARRON RIVER, UTE PARK, NEW MEXICO

EAGLE NEST TO UTE PARK

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 104

WOLF CREEK, VALMORA, NEW MEXICO

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

MORA RIVER, WATROUS, NEW MEXICO

90 SQUARE MILES ABOVE WATROUS, TOTAL = 670

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 112

NORTH CANADIAN RIVER AT BEAVER, OKLAHOMA

LOCAL AREA, GUYMON TO BEAVER

FLOOD POTENTIAL IS ESTIMATED AT 6 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 0

NORTH CANIDIAN RIVER AT GUYMON, OKLAHOMA

LOCAL AREA, STATE HY 95 TO BEAVER

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROBABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 61

LOCAL CREEK, KENTON, OKLAHOMA

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW:

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 117

LOCAL CREEK, AMARILLO, TEXAS

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 6 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW:

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 27

CANADIAN RIVER, CANADIAN, TEXAS

BELOW SANFORD RESERVOIR

FLOOD POTENTIAL IS ESTIMATED AT 6 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROBABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 0

PALO DURO CANYON STATE PARK NR. CANYON, TEXAS

TOTAL DRAINAGE BASIN ABOVE GAGE

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW:

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT.

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 108

LOCAL CREEK, BOYS RANCH, TEXAS

TOTAL DRAINAGE AREA

FLOOD POTENTIAL IS ESTIMATED AT 8 OF A SCALE OF 1 TO 10

FLOOD POTENTIAL SCALE IS LISTED BELOW;

1 = NO SIGNIFICANT FLOODING.

2 = SOME STREET AND LOW LAND FLOODING.

3 = STREET AND SOME RESIDENTIAL FLOODING.

4 = MAJOR STREET AND RESIDENTIAL FLOODING.

5 = STREAM FLOODING AND PROPERTY LOSS, VERY LIGHT.

6 = STREAM FLOODING WITH CHANCE OF LOSS OF LIFE AND PROPERTY LOSS, LIGHT,

7 = STREAM FLOODING WITH PROPABLE LOSS OF LIFE (0 TO 50) AND PROPERTY LOSS, MODERATE.

8 = STREAM FLOODING WITH LOSS OF LIFE (50 TO 150) AND PROPERTY LOSS, MAJOR.

9 = STREAM FLOODING WITH LOSS OF LIFE (150 TO 400) AND PROPERTY LOSS, MAJOR.

10 = CATASTROPHIC FLOOD.

POSSIBLE DEATHS FROM PROBABLE MAX STORM WOULD BE 64

APPENDIX B

FLASH FLOOD FORECAST SCHEMES

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

PERICA CREEK, CLAYTON, NEW MEXICO

TOTAL LOCAL AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 0.7 FT

FLOOD STAGE = 2.7 FT.
GAGE ZERO = 4980.00 FT.-MSL
TIME TO PEAK = 1.8 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.3	2.3	3.9	5.3	6.1	6.9	8.4	9.3	9.6	10.4	11.2
1.2	I	1.2	2.0	3.2	5.0	5.8	6.6	8.1	9.2	9.6	10.4	11.1
1.4	I	1.0	1.7	2.5	3.9	5.3	6.0	7.6	9.0	9.5	10.3	11.0
1.6	I	0.9	1.5	2.2	3.4	5.1	5.8	7.2	8.8	9.4	10.2	10.9
1.8	I	0.7	1.2	1.9	2.8	4.5	5.4	6.9	8.4	9.3	10.1	10.8
2.0	I	0.7	1.1	1.6	2.3	3.7	5.2	6.5	8.0	9.2	10.0	10.7
2.2	I	0.7	0.9	1.4	2.0	3.0	4.5	6.1	7.6	9.0	9.9	10.6
2.4	I	0.7	0.8	1.2	1.7	2.5	3.9	5.8	7.2	8.7	9.8	10.5
2.6	I	0.7	0.7	1.0	1.5	2.2	3.3	5.4	6.8	8.3	9.7	10.4
2.8	I	0.7	0.7	0.9	1.4	2.1	3.0	5.4	6.6	8.2	9.6	10.3
3.0	I	0.7	0.7	0.7	1.1	1.6	2.4	5.1	6.2	7.6	9.5	10.2
3.2	I	0.7	0.7	0.7	0.9	1.5	2.1	4.5	6.0	7.3	9.4	10.1
3.4	I	0.7	0.7	0.7	0.7	1.2	1.8	3.7	5.6	6.9	9.3	9.9
3.6	I	0.7	0.7	0.7	0.7	1.0	1.6	3.2	5.4	6.6	9.2	9.8
3.8	I	0.7	0.7	0.7	0.7	0.8	1.3	2.7	5.1	6.3	9.1	9.7
4.0	I	0.7	0.7	0.7	0.7	0.7	1.1	2.3	4.8	6.0	8.9	9.5
4.2	I	0.7	0.7	0.7	0.7	0.7	0.9	2.0	4.6	6.1	9.0	9.6
4.4	I	0.7	0.7	0.7	0.7	0.7	0.7	1.7	3.8	5.9	8.9	9.7
4.6	I	0.7	0.7	0.7	0.7	0.7	0.7	1.5	3.3	5.6	8.4	9.5
4.8	I	0.7	0.7	0.7	0.7	0.7	0.7	1.3	3.0	5.5	8.3	9.5
5.0	I	0.7	0.7	0.7	0.7	0.7	0.7	1.2	2.6	5.2	7.9	9.3

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

DRY CIMARRON, FOLSOM, NEW MEXICO

TOTAL DRAINAGE AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.1 FT

FLOOD STAGE = 4.6 FT.
GAGE ZERO = 6390.00 FT.-MSL
TIME TO PEAK = 2.3 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.5	2.0	2.6	3.3	4.1	4.9	6.5	7.5	8.1	9.1	10.1
1.2	I	1.4	1.8	2.4	3.0	3.8	4.6	6.2	7.4	8.0	9.0	10.0
1.4	I	1.3	1.7	2.1	2.6	3.3	4.1	5.7	7.3	7.8	8.9	9.9
1.6	I	1.2	1.6	1.9	2.4	3.1	3.8	5.3	6.9	7.7	8.8	9.7
1.8	I	1.2	1.4	1.8	2.2	2.8	3.4	4.9	6.5	7.5	8.7	9.6
2.0	I	1.1	1.4	1.6	2.0	2.5	3.2	4.6	6.1	7.4	8.5	9.5
2.2	I	1.1	1.3	1.5	1.8	2.3	2.8	4.2	5.7	7.3	8.4	9.3
2.4	I	1.1	1.2	1.4	1.7	2.1	2.6	3.8	5.3	6.9	8.3	9.2
2.6	I	1.1	1.1	1.3	1.6	1.9	2.4	3.4	4.8	6.4	8.1	9.0
2.8	I	1.1	1.1	1.3	1.5	1.9	2.3	3.3	4.7	6.3	8.0	8.9
3.0	I	1.1	1.1	1.2	1.4	1.7	2.0	3.0	4.2	5.7	7.8	8.7
3.2	I	1.1	1.1	1.1	1.3	1.6	1.9	2.8	4.0	5.4	7.7	8.6
3.4	I	1.1	1.1	1.1	1.1	1.4	1.7	2.5	3.7	5.0	7.6	8.4
3.6	I	1.1	1.1	1.1	1.1	1.3	1.6	2.4	3.4	4.7	7.4	8.3
3.8	I	1.1	1.1	1.1	1.1	1.2	1.5	2.2	3.1	4.3	7.3	8.1
4.0	I	1.1	1.1	1.1	1.1	1.1	1.4	2.0	2.9	4.0	7.0	7.9
4.2	I	1.1	1.1	1.1	1.1	1.1	1.2	1.8	2.8	4.1	7.2	8.0
4.4	I	1.1	1.1	1.1	1.1	1.1	1.1	1.7	2.6	4.0	7.0	8.1
4.6	I	1.1	1.1	1.1	1.1	1.1	1.1	1.6	2.4	3.6	6.5	7.8
4.8	I	1.1	1.1	1.1	1.1	1.1	1.1	1.5	2.3	3.5	6.5	7.8
5.0	I	1.1	1.1	1.1	1.1	1.1	1.1	1.4	2.1	3.1	6.0	7.6

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

RAILROAD CANYON, RATON, NEW MEXICO

TOTAL DRAINAGE AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 0.7 FT

FLOOD STAGE = 2.9 FT.
GAGE ZERO = 6780.00 FT.-MSL
TIME TO PEAK = 1.7 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.2	1.9	2.8	4.1	5.4	5.9	7.0	8.0	8.9	9.9	10.3
1.2	I	1.1	1.7	2.4	3.5	5.1	5.7	6.8	7.8	8.8	9.8	10.3
1.4	I	1.0	1.5	2.1	2.8	4.1	5.4	6.4	7.5	8.5	9.7	10.2
1.6	I	0.9	1.3	1.9	2.5	3.7	5.1	6.2	7.2	8.3	9.7	10.2
1.8	I	0.8	1.1	1.6	2.2	3.1	4.4	5.9	7.0	8.0	9.6	10.1
2.0	I	0.7	1.0	1.4	1.9	2.7	3.8	5.7	6.7	7.8	9.6	10.0
2.2	I	0.7	0.9	1.3	1.7	2.3	3.1	5.5	6.4	7.5	9.5	9.9
2.4	I	0.7	0.8	1.1	1.5	2.1	2.8	5.1	6.2	7.2	9.3	9.9
2.6	I	0.7	0.7	1.0	1.3	1.8	2.5	4.4	5.9	6.9	9.0	9.8
2.8	I	0.7	0.7	0.9	1.2	1.8	2.4	4.2	5.8	6.8	8.9	9.8
3.0	I	0.7	0.7	0.7	3.0	1.4	2.0	3.6	5.5	6.4	6.6	9.7
3.2	I	0.7	0.7	0.7	0.9	1.3	1.8	3.1	5.3	6.2	8.4	9.6
3.4	I	0.7	0.7	0.7	0.7	1.1	1.6	2.7	4.8	6.0	8.1	9.5
3.6	I	0.7	0.7	0.7	0.7	1.0	1.4	2.4	4.3	5.8	7.8	9.3
3.8	I	0.7	0.7	0.7	0.7	0.8	1.2	2.2	3.8	5.6	7.5	9.0
4.0	I	0.7	0.7	0.7	0.7	0.7	1.1	2.0	3.3	5.4	7.3	8.7
4.2	I	0.7	0.7	0.7	0.7	0.7	0.9	1.7	3.2	5.4	7.4	8.9
4.4	I	0.7	0.7	0.7	0.7	0.7	0.7	1.5	2.8	5.3	7.3	9.0
4.6	I	0.7	0.7	0.7	0.7	0.7	0.7	1.3	2.5	4.8	7.0	8.5
4.8	I	0.7	0.7	0.7	0.7	0.7	0.7	1.2	2.3	4.6	6.9	8.6
5.0	I	0.7	0.7	0.7	0.7	0.7	0.7	1.1	2.1	3.8	6.6	8.1

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

CIMARRON RIVER, SPRINGER, NEW MEXICO

90 SQUARE MILES ABOVE SPRINGER, TOTAL = 2673
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.4 FT

FLOOD STAGE = 5.6 FT.
GAGE ZERO = 5770.00 FT.-MSL
TIME TO PEAK = 1.9 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	2.2	3.3	4.7	6.2	7.8	8.8	10.0	11.2	12.4	13.9	14.3
1.2	I	2.0	3.0	4.1	5.5	7.1	8.5	9.8	11.0	12.2	13.9	14.3
1.4	I	1.8	2.6	3.6	4.7	6.2	7.6	9.3	10.6	11.9	13.8	14.2
1.6	I	1.6	2.4	3.2	4.2	5.7	7.1	9.0	10.3	11.6	13.7	14.2
1.8	I	1.5	2.1	2.8	3.8	5.1	6.5	8.8	10.0	11.2	13.4	14.1
2.0	I	1.4	1.9	2.5	3.3	4.5	5.9	8.5	9.7	10.9	13.2	14.1
2.2	I	1.4	1.7	2.3	3.0	3.9	5.1	7.9	9.3	10.6	13.0	14.0
2.4	I	1.4	1.6	2.0	2.7	3.6	4.6	7.2	9.1	10.3	12.7	13.9
2.6	I	1.4	1.4	1.8	2.3	3.2	4.2	6.5	8.7	9.9	12.5	13.9
2.8	I	1.4	1.4	1.7	2.2	3.0	4.0	6.3	8.6	9.8	12.4	13.8
3.0	I	1.4	1.4	1.4	1.9	2.6	3.4	5.6	8.0	9.3	12.0	13.6
3.2	I	1.4	1.4	1.4	1.7	2.3	3.1	5.1	7.5	9.1	11.7	13.3
3.4	I	1.4	1.4	1.4	1.4	2.0	2.7	4.5	6.9	8.8	11.3	13.0
3.6	I	1.4	1.4	1.4	1.4	1.8	2.4	4.1	6.3	8.6	11.0	12.8
3.8	I	1.4	1.4	1.4	1.4	1.6	2.2	3.7	5.8	8.2	10.7	12.5
4.0	I	1.4	1.4	1.4	1.4	1.4	2.0	3.4	5.3	7.6	10.4	12.1
4.2	I	1.4	1.4	1.4	1.4	1.4	1.6	2.9	5.2	7.8	10.5	12.4
4.4	I	1.4	1.4	1.4	1.4	1.4	1.4	2.6	4.6	7.5	10.4	12.4
4.6	I	1.4	1.4	1.4	1.4	1.4	1.4	2.4	4.2	6.8	10.0	11.9
4.8	I	1.4	1.4	1.4	1.4	1.4	1.4	2.2	3.9	6.7	9.9	11.9
5.0	I	1.4	1.4	1.4	1.4	1.4	1.4	2.0	3.6	5.9	9.6	11.4

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 2

CONCHAS CANAL, TUCUMCARI, NEW MEXICO

TOTAL DRAINAGE AREA
- CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 0.7 FT

FLOOD STAGE = 2.9 FT.
GAGE ZERO = 4100.00 FT.-MSL
TIME TO PEAK = 2.3 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.8	3.5	5.6	6.7	8.0	9.2	10.0	10.7	11.3	12.2	12.3
1.2	I	1.6	2.8	5.1	6.2	7.5	8.8	9.9	10.6	11.2	12.2	12.3
1.4	I	1.2	2.3	4.0	5.6	6.7	7.9	9.7	10.4	11.0	12.1	12.3
1.6	I	1.0	2.0	3.2	5.3	6.4	7.5	9.6	10.2	10.9	12.1	12.3
1.8	I	0.8	1.6	2.6	4.5	5.9	7.0	9.2	10.0	10.7	12.0	12.2
2.0	I	0.7	1.4	2.2	3.5	5.5	6.5	8.7	9.9	10.5	11.9	12.2
2.2	I	0.7	1.1	1.9	2.8	4.8	5.9	8.1	9.7	10.4	11.7	12.2
2.4	I	0.7	0.9	1.6	2.4	4.0	5.6	7.5	9.6	10.2	11.5	12.2
2.6	I	0.7	0.7	1.2	2.0	3.2	5.2	7.0	9.1	10.0	11.3	12.2
2.8	I	0.7	0.7	1.1	1.8	2.9	4.8	6.8	8.9	9.9	11.3	12.2
3.0	I	0.7	0.7	0.8	1.4	2.3	3.6	6.3	8.2	9.7	11.1	12.1
3.2	I	0.7	0.7	0.7	1.1	2.0	2.9	5.9	7.8	9.6	10.9	11.9
3.4	I	0.7	0.7	0.7	0.7	1.6	2.5	5.5	7.3	9.3	10.7	11.7
3.6	I	0.7	0.7	0.7	0.7	1.2	2.1	5.1	6.8	8.8	10.5	11.5
3.8	I	0.7	0.7	0.7	0.7	1.0	1.8	4.3	6.4	8.4	10.4	11.3
4.0	I	0.7	0.7	0.7	0.7	0.7	1.5	3.5	6.1	7.9	10.2	11.1
4.2	I	0.7	0.7	0.7	0.7	0.7	1.0	2.7	6.0	8.0	10.3	11.3
4.4	I	0.7	0.7	0.7	0.7	0.7	0.7	2.4	5.6	7.8	10.3	11.3
4.6	I	0.7	0.7	0.7	0.7	0.7	0.7	2.0	5.3	7.2	10.1	11.0
4.8	I	0.7	0.7	0.7	0.7	0.7	0.7	1.8	4.8	7.1	10.0	11.0
5.0	I	0.7	0.7	0.7	0.7	0.7	0.7	1.5	4.1	6.5	9.8	10.8

* AVAILABLE FORM-LOCAL WEATHER SERVICE OFFICE.

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 2

CIMARRON RIVER, UTE PARK, NEW MEXICO

EAGLE NEST TO UTE PARK
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.0 FT

FLOOD STAGE = 4.1 FT.
GAGE ZERO = 7405.00 FT.-MSL
TIME TO PEAK = 1.6 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.4	2.1	2.8	3.6	4.6	5.7	7.1	7.7	8.4	9.8	10.9
1.2	I	1.4	1.9	2.5	3.2	4.2	5.3	6.9	7.6	8.3	9.7	10.8
1.4	I	1.2	1.7	2.2	2.8	3.6	4.6	6.6	7.4	8.1	9.5	10.6
1.6	I	1.1	1.5	2.0	2.6	3.3	4.2	6.1	7.2	7.9	9.4	10.5
1.8	I	1.1	1.4	1.8	2.3	3.0	3.8	5.7	7.0	7.8	9.2	10.4
2.0	I	1.0	1.3	1.6	2.1	2.7	3.5	5.2	6.9	7.6	9.0	10.2
2.2	I	1.0	1.2	1.5	1.9	2.4	3.0	4.7	6.7	7.4	8.8	10.0
2.4	I	1.0	1.1	1.4	1.7	2.2	2.8	4.3	6.2	7.2	8.7	9.9
2.6	I	1.0	1.0	1.2	1.5	2.0	2.5	3.8	5.6	7.0	8.5	9.6
2.8	I	1.0	1.0	1.2	1.5	1.9	2.4	3.7	5.4	6.9	8.4	9.6
3.0	I	1.0	1.0	1.1	1.3	1.6	2.1	3.3	4.8	6.7	8.1	9.3
3.2	I	1.0	1.0	1.0	1.2	1.5	1.9	3.0	4.5	6.2	8.0	9.1
3.4	I	1.0	1.0	1.0	1.0	1.4	1.7	2.7	4.1	5.8	7.8	8.9
3.6	I	1.0	1.0	1.0	1.0	1.2	1.6	2.5	3.7	5.3	7.6	8.7
3.8	I	1.0	1.0	1.0	1.0	1.1	1.4	2.3	3.4	4.9	7.4	8.5
4.0	I	1.0	1.0	1.0	1.0	1.0	1.3	2.1	3.1	4.5	7.3	8.2
4.2	I	1.0	1.0	1.0	1.0	1.0	1.1	1.8	3.0	4.7	7.3	8.4
4.4	I	1.0	1.0	1.0	1.0	1.0	1.0	1.7	2.7	4.5	7.3	8.4
4.6	I	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.5	4.0	7.1	8.1
4.8	I	1.0	1.0	1.0	1.0	1.0	1.0	1.4	2.4	3.9	7.0	8.1
5.0	I	1.0	1.0	1.0	1.0	1.0	1.0	1.3	2.2	3.4	6.8	7.8

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

WOLF CREEK, VALMORA, NEW MEXICO

TOTAL DRAINAGE AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.4 FT

FLOOD STAGE = 5.8 FT.
GAGE ZERO = 6315.00 FT.-MSL
TIME TO PEAK = 3.0 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.9	2.6	3.4	4.3	5.4	6.3	8.1	9.0	9.7	10.9	12.1
1.2	I	1.8	2.4	3.0	3.9	4.9	6.0	7.8	8.9	9.5	10.8	12.0
1.4	I	1.7	2.1	2.7	3.4	4.3	5.3	7.1	8.7	9.4	10.6	11.8
1.6	I	1.6	2.0	2.5	3.1	4.0	4.9	6.7	8.6	9.2	10.5	11.7
1.8	I	1.5	1.8	2.3	2.8	3.6	4.5	6.3	8.1	9.0	10.4	11.5
2.0	I	1.4	1.7	2.1	2.6	3.3	4.1	6.0	7.7	8.9	10.2	11.3
2.2	I	1.4	1.6	1.9	2.3	2.9	3.6	5.4	7.2	8.7	10.0	11.2
2.4	I	1.4	1.5	1.8	2.2	2.7	3.3	5.0	6.8	8.5	9.9	11.0
2.6	I	1.4	1.4	1.7	2.0	2.5	3.1	4.5	6.2	8.0	9.7	10.8
2.8	I	1.4	1.4	1.6	1.9	2.4	3.0	4.4	6.1	7.8	9.6	10.7
3.0	I	1.4	1.4	1.5	1.7	2.1	2.6	3.9	5.5	7.2	9.4	10.5
3.2	I	1.4	1.4	1.4	1.6	2.0	2.4	3.6	5.2	6.8	9.3	10.3
3.4	I	1.4	1.4	1.4	1.4	1.8	2.2	3.3	4.8	6.4	9.1	10.1
3.6	I	1.4	1.4	1.4	1.4	1.7	2.0	3.0	4.4	6.1	8.9	9.9
3.8	I	1.4	1.4	1.4	1.4	1.6	1.9	2.8	4.0	5.7	8.7	9.7
4.0	I	1.4	1.4	1.4	1.4	1.4	1.8	2.6	3.8	5.2	8.6	9.5
4.2	I	1.4	1.4	1.4	1.4	1.4	1.6	2.3	3.6	5.4	8.6	9.6
4.4	I	1.4	1.4	1.4	1.4	1.4	1.4	2.2	3.3	5.2	8.6	9.7
4.6	I	1.4	1.4	1.4	1.4	1.4	1.4	2.0	3.1	4.7	8.1	9.4
4.8	I	1.4	1.4	1.4	1.4	1.4	1.4	1.9	2.9	4.6	8.1	9.4
5.0	I	1.4	1.4	1.4	1.4	1.4	1.4	1.8	2.7	4.1	7.5	9.1

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF N MEXICO

FORECAST ZONE 1

MORA RIVER, WATROUS, NEW MEXICO

90 SQUARE MILES ABOVE WATROUS, TOTAL = 670
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.4 FT

FLOOD STAGE = 5.5 FT.
GAGE ZERO = 6450.00 FT.-MSL
TIME TO PEAK = 3.2 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	1.9	2.7	3.7	4.7	6.0	7.1	8.6	9.4	10.2	11.8	13.0
1.2	I	1.8	2.5	3.3	4.3	5.5	6.6	8.5	9.3	10.1	11.7	12.9
1.4	I	1.6	2.2	2.9	3.7	4.8	5.9	8.1	9.0	9.9	11.5	12.7
1.6	I	1.5	2.0	2.6	3.4	4.4	5.5	7.6	8.8	9.7	11.3	12.6
1.8	I	1.4	1.8	2.4	3.0	4.0	5.0	7.1	8.6	9.5	11.1	12.5
2.0	I	1.4	1.7	2.1	2.7	3.6	4.5	6.6	8.4	9.3	10.9	12.3
2.2	I	1.4	1.6	2.0	2.5	3.1	4.0	6.0	8.2	9.0	10.7	12.1
2.4	I	1.4	1.5	1.8	2.2	2.9	3.6	5.6	7.6	8.8	10.5	11.9
2.6	I	1.4	1.4	1.6	2.0	2.6	3.3	5.0	7.0	8.6	10.3	11.7
2.8	I	1.4	1.4	1.6	1.9	2.5	3.2	4.8	6.8	8.5	10.2	11.6
3.0	I	1.4	1.4	1.4	1.7	2.2	2.8	4.3	6.1	8.1	9.9	11.3
3.2	I	1.4	1.4	1.4	1.6	2.0	2.5	4.0	5.8	7.7	9.7	11.1
3.4	I	1.4	1.4	1.4	1.4	1.8	2.3	3.6	5.3	7.2	9.5	10.8
3.6	I	1.4	1.4	1.4	1.4	1.6	2.1	3.3	4.9	6.7	9.3	10.5
3.8	I	1.4	1.4	1.4	1.4	1.5	1.9	3.0	4.5	6.3	9.1	10.3
4.0	I	1.4	1.4	1.4	1.4	1.4	1.8	2.7	4.1	5.8	8.9	10.0
4.2	I	1.4	1.4	1.4	1.4	1.4	1.5	2.4	4.0	6.0	8.9	10.2
4.4	I	1.4	1.4	1.4	1.4	1.4	1.4	2.2	3.6	5.8	8.9	10.3
4.6	I	1.4	1.4	1.4	1.4	1.4	1.4	2.0	3.3	5.3	8.6	9.9
4.8	I	1.4	1.4	1.4	1.4	1.4	1.4	1.9	3.1	5.2	8.6	9.9
5.0	I	1.4	1.4	1.4	1.4	1.4	1.4	1.8	2.9	4.5	8.4	9.5

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF OKLAHOMA

FORECAST ZONE 20

NORTH CANADIAN RIVER AT BEAVER, OKLAHOMA

LOCAL AREA, GUYMON TO BEAVER
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 11.3 FT

FLOOD STAGE = 15.0 FT.
GAGE ZERO = 2368.00 FT.-MSL
TIME TO PEAK = 8.9 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	11.8	12.5	13.3	14.3	15.2	15.6	16.6	17.5	18.3	19.2	20.0
1.2	I	11.7	12.3	13.0	13.9	15.0	15.5	16.4	17.3	18.2	19.1	19.9
1.4	I	11.5	12.0	12.6	13.3	14.3	15.2	16.1	17.0	18.0	19.0	19.8
1.6	I	11.4	11.9	12.4	13.1	14.0	15.0	15.9	16.8	17.7	18.9	19.7
1.8	I	11.3	11.7	12.2	12.8	13.6	14.5	15.7	16.6	17.5	18.8	19.6
2.0	I	11.3	11.6	12.0	12.5	13.2	14.1	15.5	16.3	17.3	18.7	19.5
2.2	I	11.3	11.5	11.8	12.2	12.9	13.6	15.2	16.1	17.0	18.6	19.4
2.4	I	11.3	11.4	11.7	12.1	12.6	13.3	15.0	15.9	16.8	18.5	19.2
2.6	I	11.3	11.3	11.5	11.8	12.4	13.0	14.5	15.6	16.5	18.4	19.1
2.8	I	11.3	11.3	11.5	11.8	12.3	12.9	14.4	15.5	16.4	18.3	19.1
3.0	I	11.3	11.3	11.3	11.6	12.0	12.5	13.9	15.3	16.1	18.0	18.9
3.2	I	11.3	11.3	11.3	11.4	11.8	12.3	13.6	15.1	15.9	17.8	18.8
3.4	I	11.3	11.3	11.3	11.3	11.7	12.1	13.2	14.8	15.7	17.5	18.6
3.6	I	11.3	11.3	11.3	11.3	11.5	11.9	13.0	14.4	15.5	17.3	18.5
3.8	I	11.3	11.3	11.3	11.3	11.4	11.8	12.7	14.0	15.3	17.1	18.4
4.0	I	11.3	11.3	11.3	11.3	11.3	11.6	12.5	13.7	15.1	16.8	18.2
4.2	I	11.3	11.3	11.3	11.3	11.3	11.4	12.2	13.6	15.2	16.9	18.3
4.4	I	11.3	11.3	11.3	11.3	11.3	11.3	12.0	13.3	15.1	16.9	18.3
4.6	I	11.3	11.3	11.3	11.3	11.3	11.3	11.9	13.0	14.8	16.6	18.0
4.8	I	11.3	11.3	11.3	11.3	11.3	11.3	11.8	12.9	14.7	16.5	18.0
5.0	I	11.3	11.3	11.3	11.3	11.3	11.3	11.6	12.7	14.1	16.2	17.6

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF OKLAHOMA

FORECAST ZONE 21

NORTH CANIDIAN RIVER AT GUYMON, OKLAHOMA

LOCAL AREA, STATE HY 95 TO BEAVER
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.7 FT

FLOOD STAGE = 6.9 FT.
GAGE ZERO = 2970.00 FT.-MSL
TIME TO PEAK = 4.4 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	2.1	2.7	3.3	4.1	5.0	5.9	7.6	8.9	10.0	11.1	12.0
1.2	I	2.0	2.5	3.1	3.7	4.6	5.6	7.3	8.7	9.9	11.0	11.9
1.4	I	1.9	2.3	2.8	3.3	4.1	4.9	6.8	8.2	9.6	10.8	11.8
1.6	I	1.8	2.2	2.6	3.1	3.8	4.6	6.4	7.9	9.3	10.7	11.7
1.8	I	1.8	2.1	2.4	2.9	3.6	4.3	5.9	7.6	9.0	10.6	11.5
2.0	I	1.7	2.0	2.3	2.7	3.3	3.9	5.5	7.2	8.6	10.5	11.4
2.2	I	1.7	1.9	2.1	2.5	3.0	3.6	5.1	6.8	8.2	10.3	11.3
2.4	I	1.7	1.8	2.0	2.3	2.8	3.3	4.7	6.4	7.9	10.2	11.1
2.6	I	1.7	1.7	1.9	2.2	2.6	3.1	4.3	5.8	7.5	10.1	11.0
2.8	I	1.7	1.7	1.9	2.1	2.5	3.0	4.2	5.7	7.3	10.0	10.9
3.0	I	1.7	1.7	1.8	2.0	2.3	2.7	3.8	5.2	6.8	9.8	10.7
3.2	I	1.7	1.7	1.7	1.9	2.2	2.5	3.6	4.9	6.4	9.4	10.6
3.4	I	1.7	1.7	1.7	1.7	2.0	2.4	3.3	4.5	6.0	9.0	10.4
3.6	I	1.7	1.7	1.7	1.7	1.9	2.2	3.1	4.2	5.6	8.7	10.2
3.8	I	1.7	1.7	1.7	1.7	1.8	2.1	2.9	3.9	5.3	8.3	10.1
4.0	I	1.7	1.7	1.7	1.7	1.7	2.0	2.7	3.7	4.9	8.0	9.9
4.2	I	1.7	1.7	1.7	1.7	1.7	1.8	2.5	3.6	5.0	8.1	10.0
4.4	I	1.7	1.7	1.7	1.7	1.7	1.7	2.3	3.3	4.8	8.0	10.0
4.6	I	1.7	1.7	1.7	1.7	1.7	1.7	2.2	3.1	4.5	7.6	9.7
4.8	I	1.7	1.7	1.7	1.7	1.7	1.7	2.1	3.0	4.4	7.5	9.7
5.0	I	1.7	1.7	1.7	1.7	1.7	1.7	2.0	2.8	3.9	7.1	9.1

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF OKLAHOMA

FORECAST ZONE 21

LOCAL CREEK, KENTON, OKLAHOMA

TOTAL DRAINAGE AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.9 FT

FLOOD STAGE = 3.8 FT.
GAGE ZERO = 4290.00 FT.-MSL
TIME TO PEAK = 1.9 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	3.0	4.6	6.5	7.3	8.3	9.3	10.8	11.3	11.8	12.7	13.5
1.2	I	2.8	4.1	6.0	6.9	7.9	8.9	10.8	11.2	11.7	12.7	13.5
1.4	I	2.4	3.5	5.1	6.5	7.3	8.2	10.1	11.1	11.6	12.5	13.4
1.6	I	2.2	3.2	4.5	6.1	7.0	7.9	9.7	11.0	11.4	12.4	13.3
1.8	I	2.0	2.8	3.9	5.4	6.7	7.5	9.3	10.8	11.3	12.3	13.2
2.0	I	1.9	2.6	3.4	4.6	6.4	7.1	8.9	10.7	11.2	12.2	13.1
2.2	I	1.9	2.3	3.1	4.1	5.7	6.7	8.4	10.2	11.1	12.1	12.9
2.4	I	1.9	2.1	2.8	3.6	5.1	6.4	7.9	9.7	[illegible]	12.0	12.8
2.6	I	1.9	1.9	2.4	3.2	4.4	6.0	7.5	9.2	10.8	11.8	12.6
2.8	I	1.9	1.9	2.3	3.0	4.2	5.7	7.4	9.0	10.8	11.8	12.6
3.0	I	1.9	1.9	1.9	2.6	3.5	4.8	7.0	8.5	10.2	11.6	12.4
3.2	I	1.9	1.9	1.9	2.3	3.2	4.2	6.7	8.1	9.8	11.5	12.3
3.4	I	1.9	1.9	1.9	1.9	2.8	3.7	6.4	7.7	9.4	11.3	12.1
3.6	I	1.9	1.9	1.9	1.9	2.4	3.3	6.0	7.4	9.0	11.2	12.0
3.8	I	1.9	1.9	1.9	1.9	2.2	3.0	5.3	7.1	8.6	11.1	11.8
4.0	I	1.9	1.9	1.9	1.9	1.9	2.7	4.7	6.8	8.2	11.0	11.7
4.2	I	1.9	1.9	1.9	1.9	1.9	2.2	4.0	6.7	8.3	11.0	11.8
4.4	I	1.9	1.9	1.9	1.9	1.9	1.9	3.6	6.4	8.1	11.0	11.8
4.6	I	1.9	1.9	1.9	1.9	1.9	1.9	3.2	6.1	7.7	10.8	11.6
4.8	I	1.9	1.9	1.9	1.9	1.9	1.9	3.0	5.7	7.6	10.8	11.6
5.0	I	1.9	1.9	1.9	1.9	1.9	1.9	2.7	5.1	7.1	10.5	11.4

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF TEXAS

FORECAST ZONE 1

CANADIAN RIVER, CANADIAN, TEXAS

BELOW SANFORD RESERVOIR
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 8.5 FT

FLOOD STAGE = 17.1 FT.
GAGE ZERO = 701.50 FT.-MSL
TIME TO PEAK = 7.0 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	8.9	9.4	10.0	10.7	11.5	12.4	14.1	15.8	17.2	18.3	19.4
1.2	I	8.8	9.2	9.8	10.4	11.2	12.0	13.8	15.5	17.1	18.3	19.3
1.4	I	8.7	9.1	9.5	10.0	10.7	11.5	13.2	14.9	16.7	18.1	19.1
1.6	I	8.6	9.0	9.3	9.8	10.5	11.2	12.8	14.5	16.3	18.0	19.0
1.8	I	8.6	8.8	9.2	9.6	10.2	10.9	12.4	14.1	15.9	17.9	18.9
2.0	I	8.5	8.8	9.0	9.4	9.9	10.6	12.0	13.7	15.4	17.7	18.7
2.2	I	8.5	8.7	8.9	9.2	9.7	10.2	11.6	13.2	14.9	17.6	18.6
2.4	I	8.5	8.6	8.8	9.1	9.5	10.0	11.2	12.8	14.5	17.4	18.4
2.6	I	8.5	8.5	8.7	9.0	9.3	9.8	10.9	12.3	14.0	17.3	18.2
2.8	I	8.5	8.5	8.7	8.9	9.3	9.7	10.8	12.1	13.8	17.2	18.2
3.0	I	8.5	8.5	8.6	8.8	9.0	9.4	10.4	11.7	13.2	16.9	17.9
3.2	I	8.5	8.5	8.5	8.7	9.0	9.3	10.2	11.4	12.8	16.5	17.8
3.4	I	8.5	8.5	8.5	8.5	8.8	9.1	9.9	11.1	12.4	15.9	17.6
3.6	I	8.5	8.5	8.5	8.5	8.7	9.0	9.8	10.8	12.1	15.5	17.4
3.8	I	8.5	8.5	8.5	8.5	8.6	8.9	9.6	10.5	11.8	15.0	17.3
4.0	I	8.5	8.5	8.5	8.5	8.5	8.8	9.4	10.3	11.4	14.6	17.1
4.2	I	8.5	8.5	8.5	8.5	8.5	8.6	9.2	10.2	11.5	14.8	17.2
4.4	I	8.5	8.5	8.5	8.5	8.5	8.5	9.1	10.0	11.4	14.6	17.2
4.6	I	8.5	8.5	8.5	8.5	8.5	8.5	9.0	9.8	11.0	14.1	16.8
4.8	I	8.5	8.5	8.5	8.5	8.5	8.5	8.9	9.7	11.0	14.0	16.8
5.0	I	8.5	8.5	8.5	8.5	8.5	8.5	8.8	9.5	10.5	13.5	16.0

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

FLASH FLOOD FORECASTING TABLE

STATE OF TEXAS

FORECAST ZONE 4

PALO DURO CANYON STATE PARK NR. CANYON, TEXAS

TOTAL DRAINAGE BASIN ABOVE GAGE
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 0.7 FT

FLOOD STAGE = 3.0 FT.
GAGE ZERO = 2780.00 FT.-MSL
TIME TO PEAK = 2.8 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	0.9	1.4	1.9	2.6	3.5	4.5	6.6	8.4	9.1	10.6	11.8
1.2	I	0.8	1.2	1.7	2.3	3.2	4.1	6.2	8.2	9.0	10.4	11.7
1.4	I	0.7	1.1	1.5	2.1	2.9	3.7	5.8	7.7	8.8	10.3	11.5
1.6	I	0.7	1.0	1.4	1.9	2.6	3.4	5.4	7.4	8.7	10.2	11.4
1.8	I	0.7	0.9	1.2	1.6	2.2	2.9	4.7	6.7	8.4	9.9	11.1
2.0	I	0.7	0.8	1.0	1.4	1.9	2.6	4.1	6.1	8.1	9.7	10.9
2.2	I	0.7	0.7	0.9	1.3	1.7	2.3	3.9	5.9	7.9	9.6	10.8
2.4	I	0.7	0.7	0.7	1.0	1.5	2.1	3.7	5.9	7.8	9.5	10.8
2.6	I	0.7	0.7	0.7	1.0	1.4	1.9	3.2	4.9	6.7	9.2	10.4
2.8	I	0.7	0.7	0.7	0.8	1.2	1.6	2.8	4.4	6.2	9.0	10.1
3.0	I	0.7	0.7	0.7	0.7	1.0	1.4	2.5	4.0	5.8	8.8	9.9
3.2	I	0.7	0.7	0.7	0.7	0.8	1.2	1.6	3.6	5.4	8.6	9.7
3.4	I	0.7	0.7	0.7	0.7	0.7	1.1	2.0	3.3	5.0	8.4	9.5
3.6	I	0.7	0.7	0.7	0.7	0.7	0.9	1.8	3.2	4.8	8.4	9.5
3.8	I	0.7	0.7	0.7	0.7	0.7	0.8	1.6	2.9	4.5	8.3	9.4
4.0	I	0.7	0.7	0.7	0.7	0.7	0.7	1.4	2.6	4.2	8.0	9.2
4.2	I	0.7	0.7	0.7	0.7	0.7	0.7	1.2	2.3	4.1	7.9	9.3
4.4	I	0.7	0.7	0.7	0.7	0.7	0.7	1.0	2.0	3.4	6.8	8.7
4.6	I	0.7	0.7	0.7	0.7	0.7	0.7	0.9	1.8	3.1	6.6	8.7
4.8	I	0.7	0.7	0.7	0.7	0.7	0.7	0.8	1.6	2.9	6.2	8.5
5.0	I	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.4	2.6	6.0	8.4

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE.

FLASH FLOOD FORECASTING TABLE

STATE OF TEXAS

FORECAST ZONE 3

LOCAL CREEK, BOYS RANCH, TEXAS

TOTAL DRAINAGE AREA
CREST GAGE HEIGHT IN FEET

INITIAL STAGE = 1.2 FT

FLOOD STAGE = 5.0 FT.
GAGE ZERO = 3180.00 FT.-MSL
TIME TO PEAK = 2.5 HOURS

FLASH FLOOD GUIDANCE VALUES*		INCHES OF RAINFALL IN 3 HOURS										
		0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0
1.0	I	2.2	3.6	5.2	6.9	8.0	8.7	10.1	11.4	12.4	13.0	13.6
1.2	I	2.0	3.2	4.6	6.1	7.8	8.4	9.8	11.2	12.4	13.0	13.6
1.4	I	1.7	2.7	3.9	5.2	6.9	8.0	9.4	10.8	12.0	12.9	13.5
1.6	I	1.5	2.4	3.4	4.7	6.3	7.7	9.0	10.5	11.8	12.8	13.4
1.8	I	1.3	2.0	3.0	4.2	5.7	7.3	8.7	10.1	11.5	12.8	13.3
2.0	I	1.2	1.8	2.6	3.6	5.0	6.6	8.4	9.8	11.2	12.7	13.2
2.2	I	1.2	1.6	2.3	3.1	4.3	5.7	8.1	9.4	10.8	12.6	13.1
2.4	I	1.2	1.4	2.0	2.8	3.9	5.2	7.8	9.0	10.4	12.5	13.1
2.6	I	1.2	1.2	1.7	2.4	3.4	4.6	7.3	8.6	10.0	12.4	13.0
2.8	I	1.2	1.2	1.6	2.2	3.2	4.4	7.1	8.5	9.9	12.4	12.9
3.0	I	1.2	1.2	1.3	1.8	2.6	3.7	6.3	8.1	9.4	12.1	12.8
3.2	I	1.2	1.2	1.2	1.6	2.4	3.3	5.7	7.9	9.1	11.9	12.7
3.4	I	1.2	1.2	1.2	1.2	2.0	2.9	5.0	7.6	8.8	11.5	12.6
3.6	I	1.2	1.2	1.2	1.2	1.7	2.5	4.6	7.1	8.5	11.2	12.5
3.8	I	1.2	1.2	1.2	1.2	1.5	2.2	4.1	6.5	8.2	10.9	12.4
4.0	I	1.2	1.2	1.2	1.2	1.2	1.9	3.6	5.9	7.9	10.6	12.3
4.2	I	1.2	1.2	1.2	1.2	1.2	1.5	3.1	5.7	8.0	10.7	12.4
4.4	I	1.2	1.2	1.2	1.2	1.2	1.2	2.7	5.1	7.9	10.6	12.4
4.6	I	1.2	1.2	1.2	1.2	1.2	1.2	2.4	4.6	7.6	10.1	12.1
4.8	I	1.2	1.2	1.2	1.2	1.2	1.2	2.2	4.3	7.6	10.1	12.1
5.0	I	1.2	1.2	1.2	1.2	1.2	1.2	2.0	3.9	6.5	9.6	11.6

* AVAILABLE FORM LOCAL WEATHER SERVICE OFFICE

VITA

John Francis Sheridan

Candidate for the Degree of

Doctor of Philosophy

Thesis: A METHODOLOGY FOR DETERMINING FLASH FLOOD FORECASTING SYSTEMS FOR A COMMUNITY

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Biographical:

Personal Data: Born in Natick, Massachusetts, April 23, 1929, the son of Thomas J. and Margaret L. Sheridan. Married to Jo Ann Dearston 1953, two sons, John H. T. and Jeffery J. Sheridan.

Education: Graduated from Natick High School, Natick, Massachusetts, in 1946; received a Bachelor of Science degree in Petroleum Engineering from the University of Tulsa, 1953; completed the requirements for the Master of Science degree December, 1975, from Oklahoma State University, Stillwater. Completer the requirements for the Doctor of Philosophy degree in Civil Engineering at Oklahoma State University, Stillwater, in July, 1977.

Professional Experience: For the period 1953 through 1961 worked in the fields of Petroleum, Mechanical and Civil Engineering. Since 1961 have worked as a Hydrologist with the National Weather Service, River Forecast Center, Tulsa, Oklahoma.

Professional Organizations: Student member of American Society of Petroleum Engineers; Registered Engineer, State of Oklahoma, Registered Land Surveyor, State of Oklahoma, Sigma XI and Chi Epsilon.