RUNOFF PARAMETERS APPLIED TO THE COUNCIL CREEK BASIN OF PAYNE COUNTY, OKLAHOMA

By

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PAYNE COUNTY, OKLAHOMA

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CHAPTER I

INTRODUCTION

Fresh water is one requirement of modern man which may be expected to continue to increase in demand as long as man experiences a growth in population or technology. The two major sources of fresh water are the waters found on the surface of the land, known as surface water, and that found below the surface in a condition of complete saturation of the soil, known as ground water.

Ground water is dependent upon the surface water as its source of replenishment by infiltration. Fresh surface water relies completely upon precipitation as its ultimate source. Both ground and surface water may become contaminated, either by the activities of modern society or by natural processes. When this occurs, the most common and by far the cheapest method of returning the quality of the water to a usable condition is by the natural evaporation and subsequent precipitation process.

This process, when all the aspects of evaporation, precipitation, and water movement, both above and over the land and sea are considered, is called the hydrologic cycle. The part of the hydrologic cycle taking place over the land masses produces the readily usable fresh water supplies. This is the phase of the hydrologic cycle, known as the runoff cycle, which must be better understood if full advantage is to be taken of the available fresh water resources.

The runoff cycle consists of five phases, or soil conditions. These five phases are discussed in Chapter II, but for now the five phases can be considered to be a general description of precipitation, evaporation, infiltration, runoff, and interflow, the flow of water below the surface but above the saturated zone.

The factors affecting the runoff cycle are many and complex, but may generally be divided into two large catagories; these are climatic and physiographic. The physiographic conditions of an area are its combined physical and geological characteristics. Some areas change drastically over a period of a few years, mostly due to urbanization, agricultural expansion, or industrial development. However, some natural phenomena may result in the rapid alteration of the physical appearance of an area. For this study, an area in north central Oklahoma (Figure 1-1) was chosen. The area has remained reasonably constant in its physiographical characteristics over the six-year study period from 1954 to 1959. The area is known as the Council Creek Basin, located in Payne County, Oklahoma. A basin or drainage basin is an area consisting of the entire area from which the runoff from precipitation contributes to the flow of the stream.

If the geological characteristics of a basin remain constant and the physical characteristics can be considered to vary with the season, then the variations in the runoff cycle may be described as a function of the climate and the season. In Chapter II, climatic conditions will be discussed. The climate will be seen to determine various characteristics of the basin, which in turn control the runoff cycle.

These basin characteristics, vegetal cover, soil moisture, etc., are extremely difficult to measure. Thus, this study of the runoff

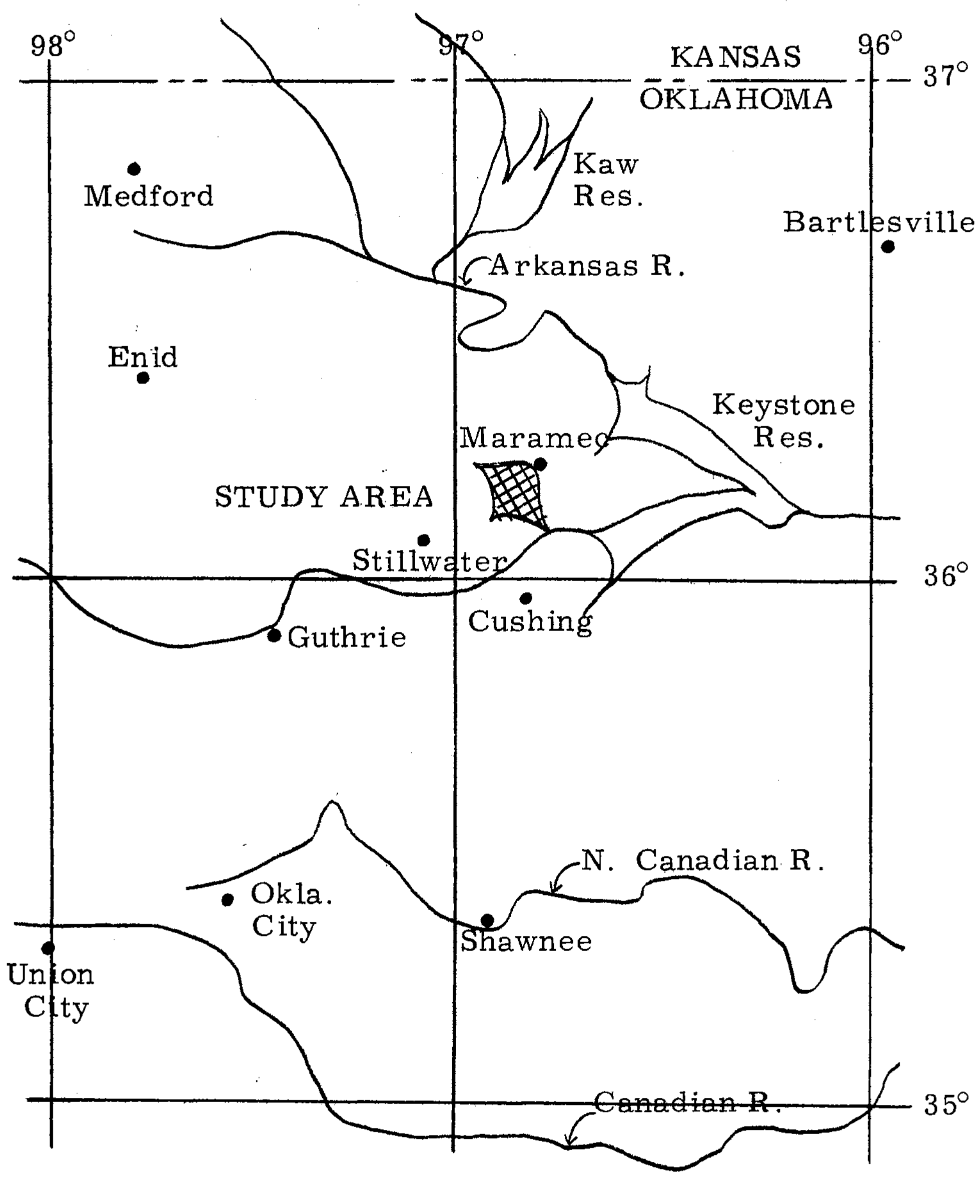

Figure 1.1. Location Map

cycle will not attempt to quantitatively describe these weather-related basin characteristics, but rather will deal exclusively with the weather conditions themselves. This is a reasonable alternative to the quantitative description of the basin characteristics resulting from climatic variations.

The study consists of a series of seven computer programs designed to determine what, if any, effect rainfall amount, duration, areal distribution, antecedent rainfall, antecedent temperature, and season have on the runoff cycle. Each was studied separately and in conjunction with the other parameters. These parameters were chosen because they control the climatic characteristics of the basin, and because of the ease and the frequency of which they are measured. All basin characteristics which are not dependent upon these parameters are considered to remain constant or to have little effect on the runoff cycle.

Listing of the seven programs may be found in Appendix A. A short explanation of each program precedes each program. One program similar to the general flow chart in Appendix B may be used to obtain the same data obtained from the seven programs. A series of programs was used in this paper to facilitate the study of the individual parameters.

The study period in each year is only 300 days. Runoff conditions during January and February were not considered because of periodic freezing. The water is in the form of ice and snow during parts of these winter months, and interflow is hampered by the periodic freezing. Relationships developed for the runoff cycle during the rest of the year are not applicable under these circumstances. Although March 1 is the first day considered in the study of the runoff cycle, thirty days of rainfall and temperature records prior to March 1 are supplied to the computer to develop the antecedent conditions. Thus, thirty days prior to March 1, either January 30 or 31, is day one in the computer programs listed in Appendix A.

Appendix C is a listing of the days and week numbers used by the computer, and the corresponding month and day of the calendar year.

The methods outlined in this study will reduce the necessity to rely on empirical equations to predict runoff. Runoff predictions can be made based on relationships developed from historical data, and based on theoretically sound assumptions.

CHAPTER II

LITERATURE SURVEY AND THEORY

Literature Survey

When water reaches the earth as rain, several paths are open for it to follow. By following one or more of these paths, the water will eventually return to the atmosphere. The moisture may return immediately to the atmosphere as evaporation when reaching the surface, or even before reaching the ground. Rain may be intercepted by vegetation and not reach the ground, or it may be held in small depressions in the ground surface to await evaporation or infiltration into the soil under the force of gravity. The moisture held by the soil below the surface but above the level of saturation, known as the groundwater table, is referred to as field moisture (13). That part of the field moisture which is held indefinitely by the soil grains and is not subject to gravity drainage is called the field capacity. If the field moisture is greater than the field capacity, the excess will flow slowly downward and laterally to the water table or to an outlet on the surface at a lower elevation. When the water table rises to a level above the ground surface, water will flow from the ground and will once more be subject to evaporation. The water may then flow overland or be a part of the channel flow, possibly to return again to the ground systems at a different location.

Field moisture may also be taken up by the plant roots and returned to the atmosphere via transpiration. When the field moisture is thus reduced to a level below the field capacity, a field moisture deficiency equal to the difference is observed.

When the rainfall exceeds the interception and surface depression storage capacity, and the intensity of the rainfall is greater than the infiltration rate into the soil, overland flow occurs, Overland flow carries the water to larger storage basins and to stream channels to be eventually transported to the seas. Part of the water will be evaporated on the journey and, where the stream channel is above the water table, part will enter the soil to become field moisture and groundwater.

The amount of rain which follows each of the above pathways is dependent on the climatic and physiographic characteristics of the drainage basin before, during, and after the rainstorm.

The above pathways taken by the rainfall between precipitation and evaporation, and the time periods associated with each, have been described in a variety of ways. Hoyt (6) refers to the five-phase runoff cycle, which describes the time periods and soil conditions before, during, and after a rainstorm. The first phase consists of the rainless period prior to the initial rainfall. The length of the period and the severity of the weather conditions, temperature, wind velocity, etc., are major factors in determining the length of the second phase or initial period of rain. During this phase, the demands of interception, initial infiltration, and the filling of the small surface depressions are greater than the rainfall. With the filling of the local depressions, infiltration continues, but if the rain continues at an intensity greater than the infiltration rate, phase three is reached. Water begins flowing overland and as interflow to the stream channels. Field moisture capacity is exceeded in the upper soil, water moves down through the soil to the water table, and laterally toward a lower elevation outlet. This combined downward and lateral movement through the soil is known as the soil transmission rates. As the upper soil becomes saturated, infiltration will be limited by the transmission rates. During phase three, infiltration rates begin decreasing because of this limiting factor.

Phase four brings the satisfying of all surface storage. Infiltration continues to decrease as the rate of infiltration approaches the transmission through the soil. The water table may begin to rise during this phase. Rainfall in excess of the infiltration rates takes the form of overland flow to the channels and lakes. The third and fourth phase together are referred to as the effective rainfall, and is that part of the total rainfall which is responsible for runoff.

The fifth stage is the transitory period between the termination of the effective rainfall and the time when the conditions of the first phase are reached. Surface storage becomes depleted, channel storage decreases as overland flow ceases, followed by the cessation of interflow. The water table may rise initially, but spring, effluent streams, and transpiration will act to cause a decline in the level of the saturated zone.

The runoff cycle may be described in another manner. Wisler and Brater (13) divide the rainfall period into three stages: the initial period, the net supply interval, and the risidual rain. The initial period, or stage, lasts until overland flow begins, corresponding to the second phase of the runoff cycle. The net supply interval, or second stage, is the time period commencing with the start of overland flow and lasting until near the end of the storm, when the rainfall intensity has decreased to a rate less than the infiltration rates. This last stage is known as the risidual rain. The stage of the storm refers to one of the three parts of the storm described by Wisler and Brater. The phase is the term usually used in this study. It always refers to Hoyt's runoff cycle.

The first stage is dependent upon the physiographic characteristics, topography, soil type, etc., of the drainage basin, the extent of the first phase of the runoff cycle, and the climatic conditions including the type of vegetal cover. Research in Germany (4) has shown the interception loss in wooded areas to be much greater than for any other type of cover. Cover is also a factor in soil moisture, since transpiration is a major cause in the reduction of field moisture. The type of cover largely determines the rate of moisture loss from the soil due to evaporation as well as transpiration rates (11).

Four classifications (2) of climatic characteristics must be considered in the investigation of the runoff cycle: precipitation, interception, evaporation, and transpiration. A description of precipitation may include form, type, intensity, duration, time distribution, frequency, direction of storm movement, antecedent precipitation, and soil moisture. Interception, the result of vegetal cover, will vary with the season and the length and intensity of the storm. Evaporation depends upon the physical characteristics of the basin and on the weather condtions--temperature, wind velocity and direction, and atmosphere pressure. Transpiration is also dependent upon the type of cover and weather conditions.

Physiographic conditions may be divided into two general physical categories (2): basin and channel characteristics. Basin characteristics include size, shape, slope, elevation, stream density, land use, vegetation, soil types, permeability, and topographic conditions. Channel characteristics consist of carrying and storage capacity.

The climatic and physiographic conditions of a basin are not independent of each other. The parameters which define one also affect several basin characteristics of the other. A simpler though perhaps less accurate approach to acquiring rainfall-runoff relationships would be to use fewer but less inter-dependent variables. These could be relief, soil infiltration, vegetal cover, and surface storage (1). These four parameters will be influenced by all the factors which affect the climatic and physiographic conditions.

A study of the runoff cycle should use those parameters which can be readily measured and are applicable to the cycle. Any study of rainfall-runoff relationships must be based on historical data; thus, the study is limited to the natural phenomenon which has been observed and recorded. Any one event can only be observed once and does not repeat itself (2). Therefore, the parameters selected must be restricted to those easily measured and routinely recorded data. From this historical data, a rainfall-runoff relationship may be developed. From a plot of runoff versus rainfall, a linear relationship can be obtained (10).

One factor which has been proven reliable in predicting the runoff is the date or week of the year (9), when it is used in conjunction with rainfall amount, intensity, and antecedent moisture conditions.

Three general methods of making soil moisture condition determinations (7) are: the number of days since the last rainfall, the discharge at the beginning of a storm, and antecedent precipitation. The first method is very insensitive and has not been used with any marked success. The second method is good in humid and semi-humid regions if used in conjunction with the season. However, it does not reflect changes caused by rains during the previous week. Antecedent precipitation has been proven effective when used with the season of the year or with temperature.

One method of measuring the antecedent precipitation is

$$I = b_1P_1 + b_2P_2 + \ldots + b_iP_i$$

where

I = antecedent precipitation

P = precipitation of i^{th} day prior

b = function of i, usually taken as 1/i.

By using the mean temperature as a parameter, Lanbein et al. (8) have shown a satisfactory relationship between annual rainfall and run-off. Hopkins and Hackett (5) investigated antecedent temperatures for single storms using the temperature index to correlate season, elevation, and latitude. They found a good correlation exists with mean temperature, but not with either maximum or minimum temperatures. The parameter they suggested using for antecedent temperature is the Antecedent Temperature Index (ATI). The ATI for any week of the year is defined as

$$ATI = 0.9ATI\,(\text{prev. week}) + 0.1\overline{T}$$

where $\overline{T}$ is the previous week's average mean temperature.

In evaluating the seasonal parameter, Linsley and Kohler (9) suggest using the week number. Rainfall amount and duration are the last two parameters to be considered. These parameters, together with the antecedent temperature index, antecedent precipitation, and areal distribution should be adequate to establish a relevant relationship between rainfall and runoff for a basin whose physiographic characteristics have not drastically changed over the testing period.

Theory

The second phase of the runoff cycle, the initial rainfall, was said to be a function of the weather conditions preceding the event, the season, and the physiographic characteristics of the runoff area. The weather conditions are a quantitative description of the first phase of the runoff cycle. The two most important weather parameters affecting the second phase are antecedent precipitation and antecedent temperature. The quantity of rain required to satisfy the demands of the second phase of the runoff cycle, the initial rainfall requirements or, more simply, the I. R., is a function of the antecedent precipitation, antecedent temperature, season, and the physical characteristics of the basin or areal distribution of rain over the basin. Figure 2.1 is a plot of rainfall versus runoff for the Council Creek Basin. The data points were taken from six years of records, two years are shown; 1956 is represented by "o" and 1957 is represented by "x". The dotted line represents a runoff of one inch per inch of rainfall. If a first-order curve is passed through the plotted points, the resulting equation is

$$\text{Runoff} = .2 \times \text{Rainfall} - 0.14. \qquad (2.1)$$

This curve was visually estimated to obtain a first approximation of the rainfall-runoff relationship. The values of runoff and rainfall are in inches. The more general form of the equation is

$$\text{Runoff} = B \times \text{Rainfall} + C. \qquad (2.2)$$

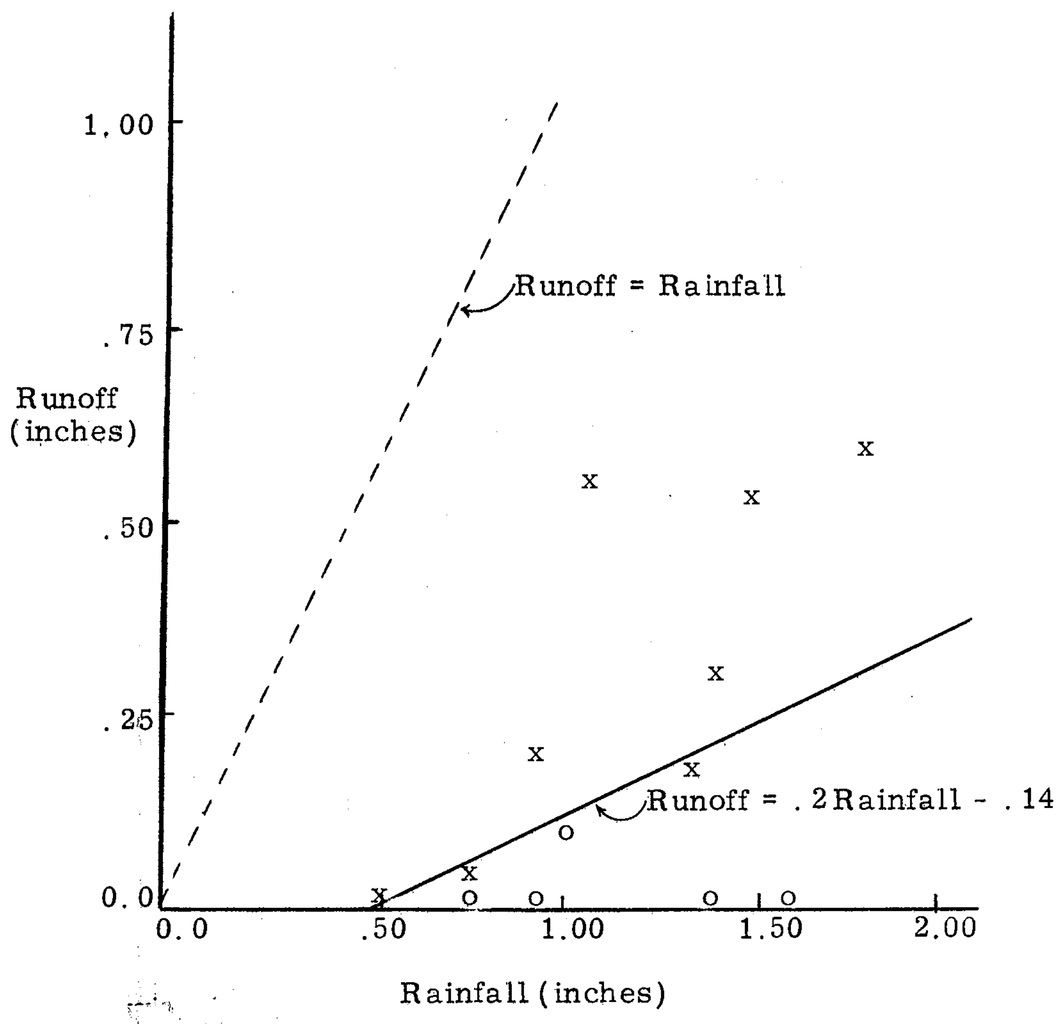

Figure 2.1. Rainfall-Runoff Curve

C is always a negative number (see Figure 2.2). In this figure, I.R. is the initial rainfall requirement and DIFF represents the effect of antecedent precipitation on the runoff curve. If the values of B and C are not considered to remain constant, but to vary with the antecedent conditions, then an accurate value of runoff could be predicted for any storm for which the antecedent conditions are known.

The initial rainfall requirement is represented on the graph as the point where the runoff curve crosses the rainfall axis, or where the runoff equals zero. From Equation (2.2)

$$\text{Runoff} = O = B \times I.R. + C \tag{2.3}$$

where

B = slope of runoff curve

C = y-intercept of runoff curve

and

$$I.R. = -C/B \tag{2.4}$$

where I.R. is the Initial Rainfall.

B, the slope of the rainfall-runoff curve, represents the fraction of the effective rainfall that becomes runoff. Earlier in this chapter, it was stated that this fraction is limited by the transmission rates of the soil. Of the parameters chosen to study in relation with the runoff cycle, the season, temperature, areal distribution, and duration can all be expected to influence B.

Duration is expected to have little effect on the second phase of the runoff cycle. However, its effect on the value of B was investigated using the sixth program (Appendix A). Correction factors for different durations were calculated. These values were used to adjust the predicted runoff using first the entire rainfall, Equation (2.3), and then

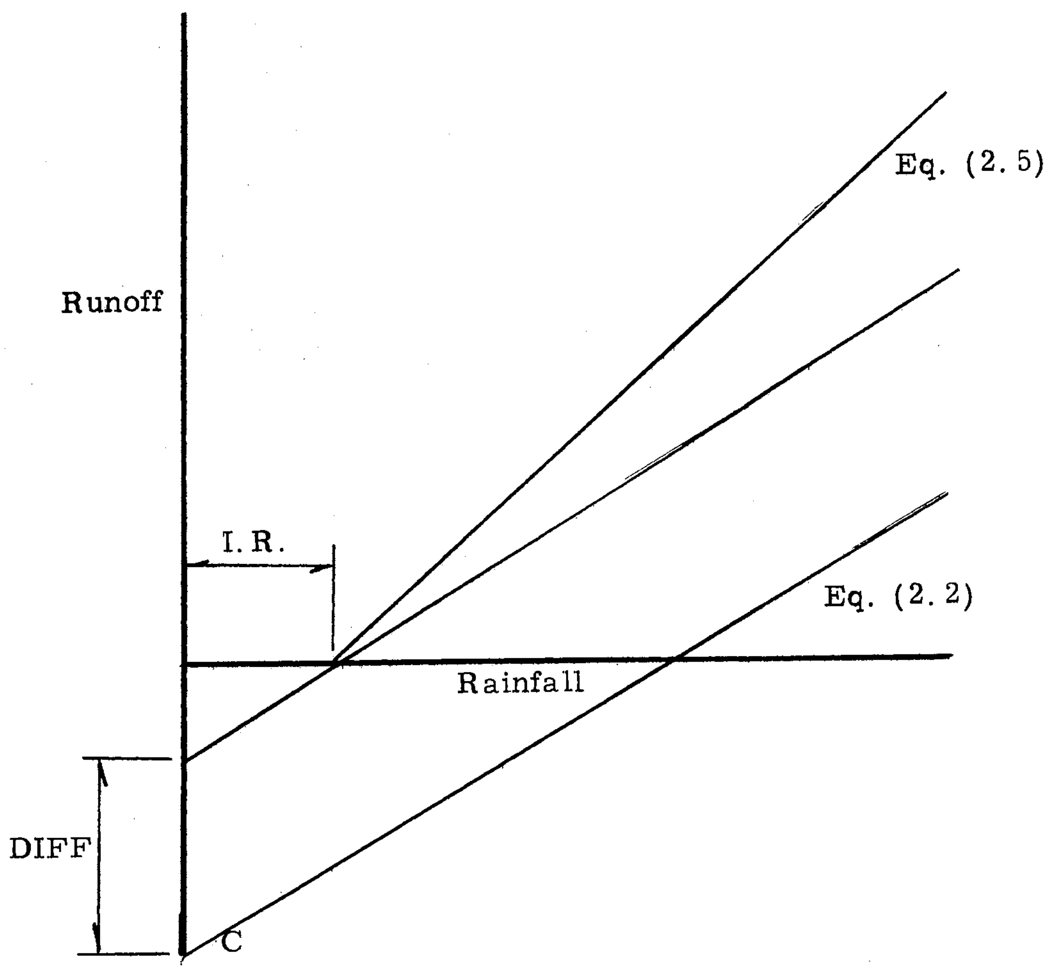

Figure 2.2. Theoretical Equations

only the effective rainfall (E.R.). Adjustments to the effective rainfall gave the better results. The adjusted values of B for duration to be used with the effective rainfall is noted as B'. The theoretical runoff equation thus becomes

$$\text{Runoff} = B' \times E.R. \tag{2.5}$$

where

$$B' = B \times F \tag{2.6}$$

F is the correction factor for the duration of the storm.

$$E.R. = \text{Rainfall} - I.R. \tag{2.7}$$

where

E.R. = effective rainfall

I.R. = initial rainfall

B' = slope of the runoff curve adjusted for the duration of the storm.

Values of B and C were calculated for eight ranges of the antecedent temperature index (ATI), and for different seasons of the year (see Programs Three and Four in Appendix A). The best results were obtained by averaging the resultant B's and C's. Allowing BT and CT to represent the values calculated using the ATI, and BS and CS to represent the constants calculated for the various seasons, Equation (2.4) becomes

$$I.R. = \left(\frac{CT + CS}{BT + BS}\right) \tag{2.8}$$

and Equation (2.6) becomes

$$B' = \frac{1}{2}(BT + BS) \times F \tag{2.9}$$

where

BT = slope of runoff curve using the ATI

BS = slope of runoff curve using the seasonal variation

CT = y-intercept of the runoff curve using the ATI

CS = y-intercept of the runoff curve using the seasonal variation

F = correction factor for the duration of the storm.

Antecedent precipitation affects the initial rainfall requirement, but is expected to have little effect on the slope of the runoff curve. Thus the runoff curve can be adjusted for antecedent precipitation by adjusting the value of C. In the fifth program (Appendix A), a linear relationship was established between the adjustment of C and the antecedent precipitation.

$$\text{DIFF} = \text{Slope} \times \text{ANPR} - \text{CONS} \qquad (2.10)$$

where

DIFF = adjustment of runoff curve due to antecedent precipitation

Slope = slope of adjustment curve

ANPR = antecedent precipitation in inches per day

CONS = y-intercept on the adjustment curve.

Equation (2.8) now becomes

$$\text{I.R.} = \left(\frac{\frac{1}{2}(\text{CT} + \text{CS}) - \text{DIFF}}{\frac{1}{2}(\text{BT} + \text{BS})} \right) \qquad (2.11)$$

Areal distribution will affect both the initial rainfall requirements, by the varying amount of local storage, and because of the differing transmission rates in the basin, the slope of the runoff curve. If AD represents the change in runoff due to the rainfall distribution, and the runoff is equal to the effective rainfall times B', then from Equations (2.7), (2.9), and (2.10)

$$\text{Runoff} = AD \times B' \times (\text{Rainfall} - I.R.) \qquad (2.12)$$

where

AD = areal distribution correction factor.

During part of the summer, the slope of the runoff curve, B, becomes very small. This causes C to become small. Thus, if the antecedent precipitation is large, which is very unlikely in the summer, DIFF could become greater than $\frac{1}{2}(CT + CS)$. This results in a positive C and a negative I. R. To correct for this, DIFF is never allowed to exceed $-\frac{1}{4}(CS + CT)$.

All calculations are made using station flows. The stream flow is equal to the sum of each of the station flows multiplied by the fraction of the total basin area each basin represents.

CHAPTER III

THE STUDY AREA

Council Creek is an intermittently flowing stream in north central Oklahoma. It is located 36° latitude and 97° longitude in eastern Payne County. The gaged drainage basin is 30.2 square miles in area, with an outlet altitude of 838 feet, where it drains into the Cimarron River. Figure 2.1 is a map showing the location of the basin; Figure 3.1 shows the general area around Council Creek. The three towns shown in the map have reporting weather stations whose data were used in this study. The three stations (Stillwater, Maramec, and Cushing) were used to develop a Thiessen map of the basin, Figure 3.2. In a Thiessen map, any rain reported at one station is assumed to have fallen uniformly over the entire area represented by that station. In this report, the term station area means the Thiessen area represented by that station. Also, area one or station one is the same as the Stillwater station area and represents 26 percent of the total basin area. Area two refers to the Maramec area and area three to Cushing, and represent 52 and 22 percent of the total basin, respectively.

The economy of the area is based on agriculture; thus the physical features of the land have remained relatively constant for the testing period. The area is characterized by low rolling hills and relatively flat valleys.

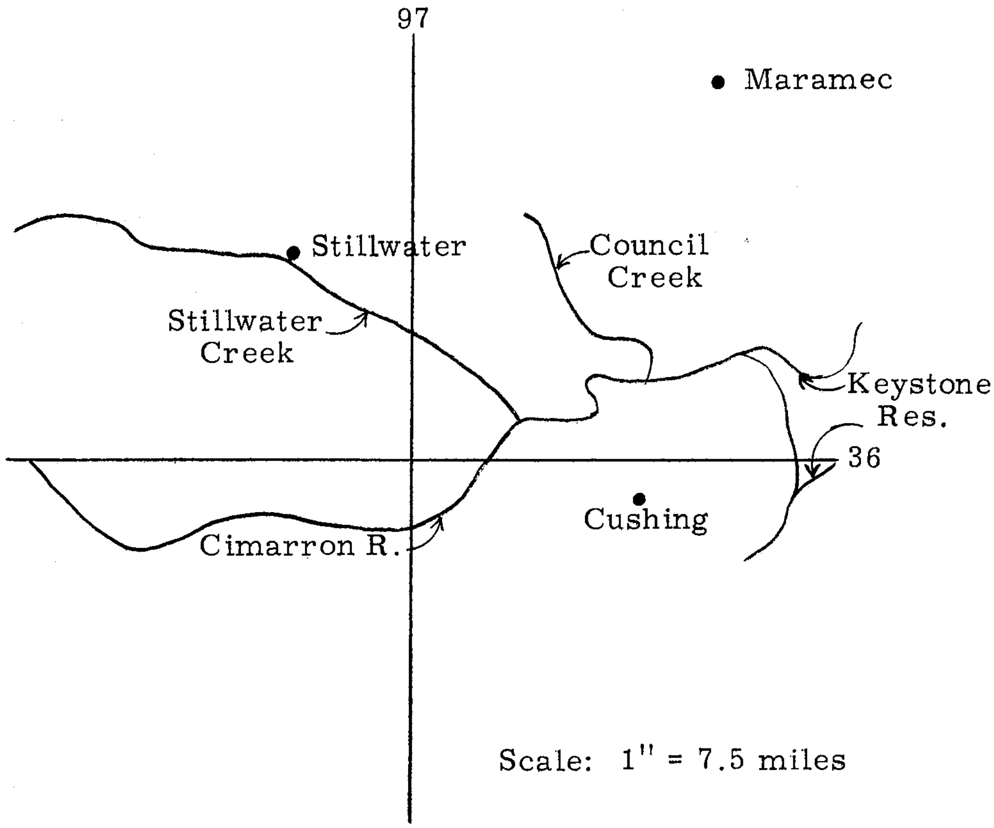

Figure 3.1. Area Map

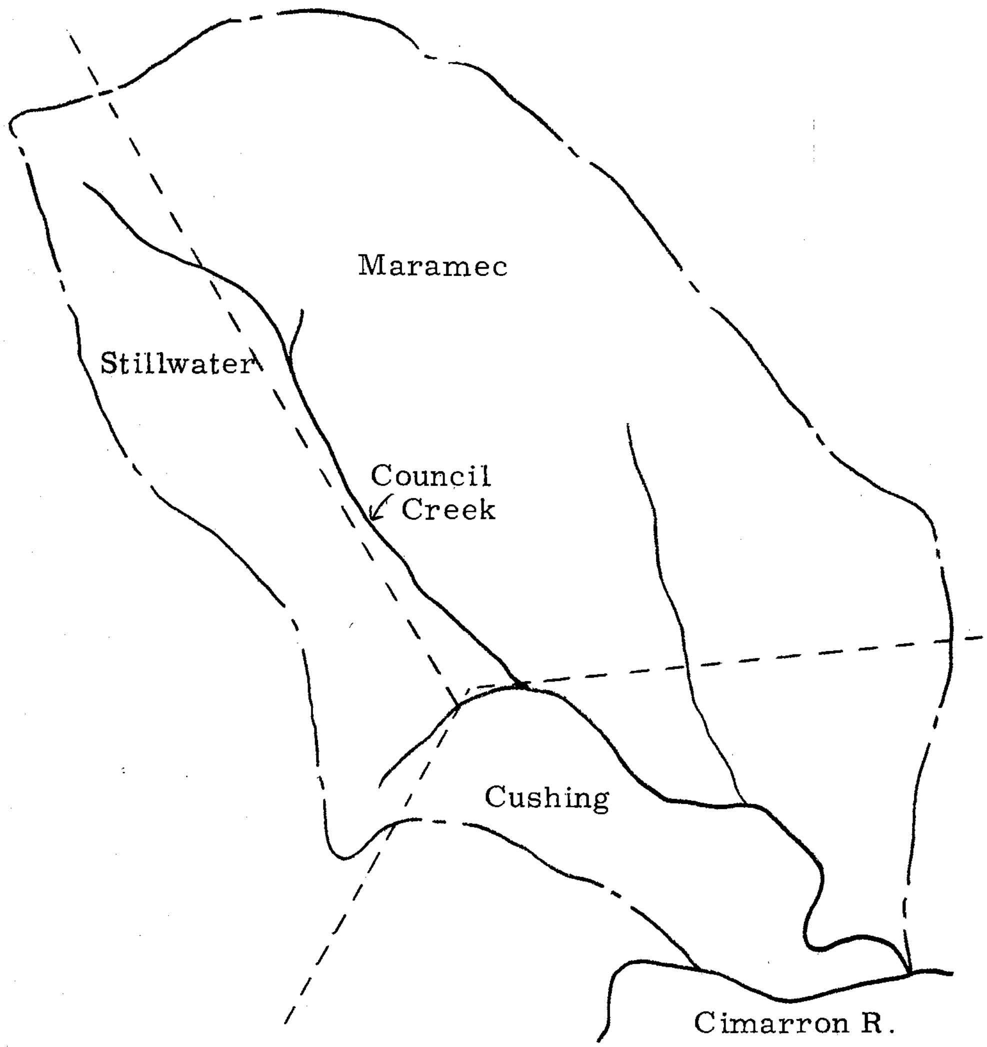

Figure 3. 2. Thiessen Map

Geologically, the area is considered part of the Northeast Oklahoma Platform (3). The geological formations consist of alternate layers of sandstone and shale. The shale is gray to greenish gray in color, silty, and micaceous in composition. The sandstones are of three types, all of which are fine to medium grained and well cemented. Thus the permeability varies over the basin. The areas of sand would have high infiltration rates, while the presence of large quantities of shale may restrict infiltration elsewhere. The fine grained, well cemented sandstone aquifers are not highly permeable, nor do they have high transmission rates.

CHAPTER IV

THE METHOD OF ANALYSIS AND RESULTS

Antecedent Precipitation

Figure 2.1 is a plot of the typical rainfall-runoff relationship. The data points, marked "x" and "o", were picked at random from the events occurring in the Council Creek Basin during two years: 1957 (x), a year when the precipitation was greater than normal and 1956 (o), a drought year. The runoff during the dry year is nearly always below the level of runoff from similar size storms occurring during the wet year. This is a very strong indication that the antecedent precipitation will greatly affect the rainfall-runoff relationship. Also, the spread of the plotted points for the dry year is much less than for the wet year.

A straight line visually passed through the plotted data points gives the first approximation of the rainfall-runoff relationship:

$$\text{Runoff} = 0.2 \times \text{Rainfall} - 0.14 \qquad (4.1)$$

Runoff and Rainfall are in inches. The runoff inch is the volume of flow which would occur if an average of one inch of water would run off the total drainage area. In discussing the station areas, a volume of one inch would be different for each area, but the average volume of runoff produced per area would be the same.

The points plotted for the wet year are widely scattered and fall both far above and below the curve. All events in 1956 fall below the line. This curve will be referred to as the theoretical runoff curve, and values calculated using the equation of the curve will be called the theoretical or predicted runoff.

As can readily be seen from Figure 2.1, any attempt to estimate runoff on the basis of rainfall amount alone would be a hopeless task. However, from the figure, it can also be seen that events during the wet year generally produce larger runoffs than similar events during a dry year. If this is assumed to be the result of a higher antecedent precipitation, then the relationship between the theoretical runoff curve (Equation (4.1)) and antecedent precipitation would be a logical starting place.

The definition of antecedent precipitation is

$$I = b_1P_1 + b_2P_2 + \dots + b_iP_i \qquad (4.2)$$

Let b_i equal 1/i, where i is the number of days prior to the event. As i increases, b_i will decrease until the term b_iP_i becomes insignificant for any reasonable value of P_i. For practical purposes, the upper limit of i was set at 30. For rainfalls in excess of three inches occurring just more than 30 days prior to the event, an error in the calculated value of antecedent precipitation of about 0.1 results. The calculated values for the weather stations in the Council Creek Basin range from less than one-hundreth to more than two and one-half inches per day.

The first computer program, Appendix A, was written to find each storm which produced a significant amount of runoff, or a storm of significant size to have produced significant theoretical runoff. The antecedent precipitation for each storm and station area was calculated. Total rainfall and duration, and the day the storm began for each station in the basin were found and the total runoff from the basin for each storm was calculated. The runoff was divided into three values, each representing the runoff from one of the areas. These areas represent the Stillwater, Maramec, and Cushing regions shown on the Thiessen map in Figure 3. 2. The separation of the stream flow into the three area flows was accomplished by dividing the flows according to the area each represents on the Thiessen map, but weighing the area flows in accordance with the respective rainfalls at each station. For further clarification, see Appendix A.

The values for rainfall, runoff, and antecedent precipitation for each storm and station were read into the fifth program. Theoretical runoff values were calculated for each storm. The difference between the theoretical or predicted runoff and the calculated station flows was taken and paired with the antecedent precipitation for that storm. These pairs of numbers represent the plotted data points on a graph of the runoff variation from the theoretical values versus antecedent precipitation. The variation curve was assumed to be a first-order equation. The program then calculated the equation of the curve using the method of least squares (12).

The method of least squares is the process of passing a curve through various points, such that the sum of the squares of the variances of each of the points from the curve is less than is the sum of the squares of the variances from any other curve of the same order. Values calculated from this equation will be referred to as the theoretical runoff difference.

The program now had values for the total rain and antecedent precipitation for each storm and station, and two equations for the conversion of this data into expected values of runoff. Runoff was calculated for each storm by subtracting the theoretical runoff difference from the theoretical runoff.

Table I shows the results of adjusting the theoretical runoff equation using antecedent precipitation. The predicted values of runoff for two years (1956, a drought year and 1957, a wet year) are shown. These results were converted from the actual printouts which gave the results as area flows. These flows were converted to stream flows for the table. In the table, "Rain" is the total rainfall for each storm in inches; "Flow" is the volumetric runoff in inches; "Theor" is the theoretical runoff in inches calculated from the theoretical runoff equation (Equation (4.1)); "ANPR" is the antecedent precipitation in inches per day; and "ADJA" is the adjusted theoretical runoff value, or the value obtained after subtracting the theoretical runoff difference from the theoretical runoff. All values are Thiessen averages. The printout included one page of output for each year of input. One page is shown as typical results.

In Figure 2.1, it is seen that a much larger scattering in the data points occurred in the wet year than in the dry year. Less favorable results in wet years using the antecedent precipitation factor are to be expected. Table I confirms this assumption. The error is especially noticeable at the beginning of the year when the adjusted flow is too low.

During this time of year, the temperature is lower and the evaporation rate is less than during the summer. This results in the soil moisture being retained longer and the vegetal cover differing from what exists during the rest of the year. Thus, the second factor to be studied should be either antecedent temperature or season. In Chapter II, the antecedent temperature index, ATI, was found to be a function

TABLE I

ANTECEDENT PRECIPITATION

Month	Day	Rain	Flow	Theor	ANPR	ADJA
1956						
Feb	18	0.67	0.0	0.278	0.007	0.0
May	10	1.85	0.014	0.552	0.045	0.027
May	22	0.56	0.0	0.224	0.381	0.0
May	27	1.75	0.110	0.546	0.487	0.181
Jun	25	0.79	0.0	0.297	0.282	0.0
Jul	2	0.76	0.015	0.298	0.147	0.0
Oct	11	0.53	0.0	0.181	0.005	0.0
Oct	27	0.68	0.0	0.250	0.009	0.0
Nov	1	0.82	0.0	0.233	0.126	0.0
Dec	5	0.54	0.0	0.220	0.057	0.0
1957						
Mar	18	0.68	0.0	0.255	0.081	0.0
Mar	27	0.91	0.017	0.329	0.183	0.0
Mar	30	0.93	0.031	0.335	0.486	0.0
Apr	14	1.97	0.461	0.607	0.196	0.119
Apr	17	0.84	0.307	1.017	1.424	0.534
Apr	19	1.27	0.391	0.513	1.477	0.376
Apr	27	2.26	0.098	0.889	0.700	0.343
May	5	0.91	0.205	0.327	0.679	0.008
May	8	0.81	0.253	0.594	0.829	0.323
May	10	1.02	0.234	0.358	1.394	0.373
May	13	2.32	0.027	0.695	0.863	0.406
May	15	0.95	0.080	0.339	1.297	0.970
May	17	3.66	2.161	1.928	1.000	0.506
May	21	1.93	0.099	0.576	2.069	1.792
May	28	1.69	0.088	0.517	1.831	0.631
Jun	5	2.58	0.781	0.761	0.948	0.510

of the season when mean temperatures were used to calculate it. So the next parameter to be used in the development of the rainfall-runoff relationship will be the ATI.

Antecedent Temperature Index (ATI)

Table II shows the ATI distribution for 1956 and 1957. The table corresponds to the output of the second program, Appendix A. Figure 4.1 is a graph of the ATI from February to December for 1956, 1957, and for the average of the six years of record. The peak values of ATI seem to occur during or very near the 35th week, which corresponds to the middle of September. The values of ATI are lower for 1957 than the average, reflecting the higher precipitation and, consequently, a larger number of days of cloud cover. A measurement of the ATI is not an accurate substitute for the season, but the location on the ATI curve is a close approximation. Also, the variation of the ATI from its normal values for the time of year offers an advantage in its use over the seasonal values. If the ATI is higher than normal, vegetal cover may suffer and less soil moisture will be present. This reduction in cover is ignored if the seasonal parameter is used by itself. Conversely, a lower than normal ATI reflects a higher soil moisture and a thicker vegetal cover.

An attempt to develop a relationship between ATI and the theoretical runoff curve similar to the one developed for antecedent precipitation was unsuccessful. This was due to the rainfall distribution for this area. The bulk of the year's precipitation falls during the late spring. Thus, rains during the early spring do not result in large runoffs because of the low soil moisture. The normally expected low

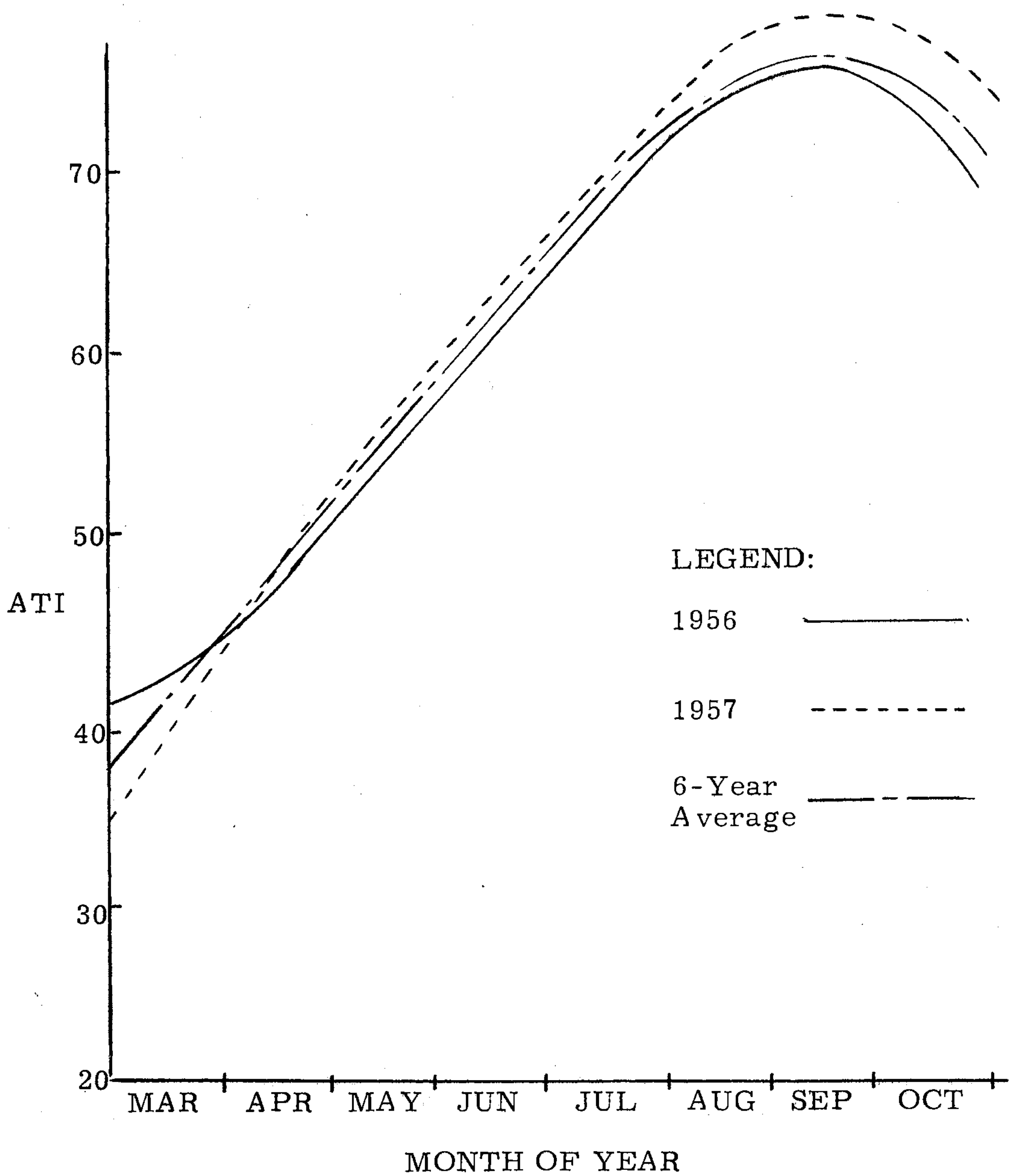

Figure 4.1. ATI Curve

TABLE II

ANTECEDENT TEMPERATURE INDEX (ATI)

Month	Day	Week No.	ATI 1956	ATI 1957	6-Year Average
Feb	6	2	26.9	36.0	37.4
Feb	20	4	29.7	38.8	38.4
Mar	2	6	34.8	39.6	40.1
Mar	16	8	37.2	41.9	41.9
Mar	30	10	41.5	43.7	43.9
Apr	13	12	44.7	44.9	46.6
Apr	27	14	47.6	48.8	50.5
May	11	16	52.7	52.2	53.7
May	25	18	56.5	55.3	56.7
Jun	8	20	59.8	58.7	60.2
Jun	22	22	63.6	61.7	63.6
Jul	6	24	67.3	65.6	67.0
Jul	20	26	70.6	69.5	70.5
Aug	3	28	73.7	72.3	73.1
Aug	17	30	76.7	74.0	75.0
Aug	31	32	78.0	75.5	76.5
Sep	14	34	78.7	74.8	76.6
Sep	28	36	78.5	73.5	76.6
Oct	12	38	77.6	71.7	75.4
Oct	26	40	75.0	67.7	71.5
Nov	9	42	70.7	64.5	67.1
Nov	23	44	66.5	60.8	64.5
Dec	7	46	62.1	57.9	60.1

moisture conditions of the summer and fall due to the higher temperatures are made even less by the scarcity of rain. However, in the late spring, soil moisture is high due to the higher antecedent precipitation. Also, the late spring storms generally produce greater amounts of rainfall, and the heavier rains usually produce runoff amounts closer to the theoretical runoff curve than the lighter rains.

The net result is a much larger predicted runoff for high and low values of ATI than actually occur. Moderate values of ATI are associated with actual runoff greater than the predicted values. This makes a first-order relationship impossible to develop. A second-order equation was also found to be unreliable. Adjusting the theoretical values with the known antecedent precipitation relationship did not improve the results. It was then decided not to modify the rainfall-runoff relationship, but to develop entirely new theoretical runoff equations for several ranges in the ATI.

Eight ranges in the ATI were used; the lowest was for all values below 40, the highest for all values above 70. The six middle ranges were each given a range of five degrees. The same data was read into this program as for the antecedent precipitation, except that ATI values were input instead of antecedent precipitation. The least squares method was again used, this time to calculate the curves on a plot of runoff versus rainfall for each of the ranges of ATI. These new equations were used to predict the runoff. The program made all calculations and printed out all results in terms of the station flows (Program Three in Appendix A). These station flows were converted into stream flows for Table III. Results for 1956 and 1957 are shown in the table. The column headings are the same as before, except that ADJT is the

TABLE III

RUNOFF PREDICTIONS USING ANTE-
CEDENT TEMPERATURE

Month	Day	Rain	Flow	Theor	ADJT	ATI
1956						
Mar	18	0.67	0.0	0.278	0.008	37.2
May	10	1.85	0.014	0.552	0.100	49.6
May	22	0.56	0.0	0.224	0.0	54.9
May	27	1.76	0.109	0.545	0.331	56.5
Jun	25	0.79	0.0	0.303	0.047	63.6
Jul	2	0.76	0.015	0.298	0.032	65.6
Oct	11	0.53	0.0	0.180	0.010	78.1
Oct	27	0.68	0.0	0.250	0.010	75.0
Nov	1	0.82	0.0	0.248	0.023	75.0
Dec	5	0.54	0.0	0.221	0.016	64.5
1957						
Mar	18	0.68	0.0	0.255	0.051	41.9
Mar	27	0.91	0.017	0.335	0.163	42.4
Mar	30	0.93	0.031	0.341	0.171	43.7
Apr	14	1.97	0.461	0.599	0.535	44.9
Apr	17	0.84	0.307	0.320	0.167	44.9
Apr	19	1.27	0.391	0.414	0.292	44.9
Apr	27	2.26	0.098	0.695	0.156	48.8
May	5	0.91	0.205	0.329	0.040	50.4
May	8	1.96	0.253	0.591	0.383	50.4
May	10	1.02	0.234	0.358	0.078	50.4
May	13	2.32	0.027	0.695	0.505	52.2
May	15	0.95	0.080	0.340	0.035	52.2
May	17	3.66	2.161	1.735	1.879	52.2
May	21	1.93	0.099	0.583	0.409	54.0
May	28	1.69	0.088	0.523	0.265	55.3
Jun	5	2.58	0.781	0.566	0.048	56.5

new predicted runoff values based on the ATI and ATI is included instead of antecedent precipitation.

The results again show slightly better results for the dry year than for the wet year. But the results are generally good, showing an easily developed relationship to exist between the antecedent temperature and the rainfall-runoff curve. As may have been expected, the predicted runoffs for the early spring and summer are not as good as for the late spring. The soil moisture is lower during these periods than the ATI is able to show by itself. Also, a larger number of events during April and May makes the results for these two months statistically more reliable.

Now that the two relationships have been developed, one to define the theoretical runoff curve using the ATI, and the other to modify the existing curve with respect to antecedent precipitation, it is time to test the interaction of the two parameters. This means modifying the antecedent precipitation program to accept the eight equations dependent on ATI and redeveloping the theoretical runoff difference equation.

Combined Antecedent Parameters

From Chapter II, the theoretical runoff equation (Equation (2. 2)) is

$$\text{Runoff} = B \times \text{Rainfall} + C.$$

Eight values of B and C were calculated for the various ranges of ATI. These values were read into the Antecedent Precipitation program and used to calculate the new theoretical runoff. The theoretical, or predicted, runoff will now mean the runoff calculated from the theoretical runoff equation using the constants calculated for the ATI ranges.

The theoretical runoff was adjusted as before, using the least squares method to find the new theoretical runoff difference equation. The results are shown in Table IV. As before, the results for 1957 are less reliable than for the dryer year. Using the ATI as a substitute for the seasonal fluctuations may be partially responsible. The values of ATI used in May and June of 1957 corresponded to those of a month earlier in 1956. The seasonal variation cannot be totally accounted for by the use of the ATI. In the next section, seasonal variation is treated, by itself and in conjunction with ATI.

Seasonal Variation

The seasonal variation was approached using the same procedure as was used with the antecedent temperature, the fourth program in Appendix A. The year was divided into seven-week segments. For each time period, a new value for B and C were found for the theoretical runoff curve. These values were averaged with the values calculated from the ATI program to give a combined seasonal and temperature runoff equation. Table V shows the results: Column "ADJS" is the results using seasonal constants only; "Theor" represents the results using the original equation (Equation (4.1)); and "ADJT" is the results using the average of the ATI and seasonal variation.

Combining the two equations brings good net results. The late summer and fall predictions show similar results using either method. For 1957, early spring predictions are generally better with the seasonal method, while late April and May give better results using the ATI calculations. Because of the stabilizing effect of the two theoretical

TABLE IV

COMBINED ANTECEDENT PARAMETERS

Month	Day	Rain	Flow	Theor	ADJA	ATI
1956						
Mar	18	0.67	0.0	0.008	0.0	37.2
May	10	1.85	0.014	0.100	0.0	49.6
May	22	0.56	0.0	0.0	0.0	54.9
May	27	1.76	0.109	0.331	0.119	56.5
Jun	25	0.79	0.0	0.047	0.0	63.6
Jul	2	0.76	0.015	0.032	0.0	65.6
Oct	11	0.53	0.0	0.010	0.0	78.1
Oct	27	0.68	0.0	0.010	0.0	75.0
Nov	1	0.82	0.0	0.023	0.0	75.0
Dec	5	0.54	0.0	0.016	0.0	64.5
1957						
Mar	18	0.68	0.0	0.051	0.0	41.9
Mar	27	0.91	0.017	0.163	0.0	42.4
Mar	30	0.93	0.031	0.171	0.0	43.7
Apr	14	1.97	0.461	0.535	0.193	44.9
Apr	17	0.84	0.307	0.167	0.126	44.9
Apr	19	1.27	0.391	0.292	0.314	44.9
Apr	27	2.26	0.098	0.156	0.700	48.8
May	5	0.91	0.205	0.040	0.0	50.4
May	8	1.96	0.253	0.383	0.221	50.4
May	10	1.02	0.234	0.078	0.053	50.4
May	13	2.32	0.027	0.505	0.862	52.2
May	15	0.95	0 080	0.035	0.031	52.2
May	17	3.66	2.161	1.879	1.676	52.2
May	21	1.93	0.099	0.409	0.771	54.0
May	28	1.69	0.088	0.265	0.363	55.3
Jun	5	2.58	0.781	0.566	0.948	56.5

TABLE V

SEASONAL VARIATION AND ANTECEDENT TEMPERATURE

Month	Day	Rain	Flow	Theor	ADJS	ADJT	ATI
1956							
Mar	18	0.67	0.0	0.278	0.014	0.010	37.2
May	10	1.85	0.014	0.552	0.272	0.188	49.6
May	22	0.56	0.0	0.224	0.0	0.0	54.9
May	27	1.76	0.109	0.545	0.328	0.317	56.5
Jun	25	0.79	0.0	0.303	0.016	0.015	63.6
Jul	2	0.76	0.015	0.298	0.015	0.022	65.6
Oct	11	0.53	0.0	0.180	0.010	0.010	78.1
Oct	27	0.68	0.0	0.250	0.010	0.010	75.0
Nov	1	0.82	0.0	0.248	0.021	0.021	75.0
Dec	5	0.54	0.0	0.221	0.006	0.007	64.5
1957							
Mar	18	0.68	0.0	0.255	0.009	0.036	41.9
Mar	27	0.91	0.017	0.335	0.026	0.095	42.4
Mar	30	0.93	0.031	0.341	0.028	0.100	43.7
Apr	14	1.97	0.461	0.599	0.302	0.430	44.9
Apr	17	0.84	0.307	0.320	0.142	0.052	44.9
Apr	19	1.27	0.391	0.414	0.191	0.241	44.9
Apr	27	2.26	0.098	0.695	0.357	0.259	48.8
May	5	0.91	0.205	0.329	0.142	0.075	50.4
May	8	1.96	0.253	0.591	0.289	0.337	50.4
May	10	1.02	0.234	0.358	0.142	0.108	50.4
May	13	2.32	0.027	0.695	0.407	0.406	52.2
May	15	0.95	0.080	0.340	0.014	0.021	52.2
May	17	3.66	2.161	1.735	1.000	1.945	52.2
May	21	1.93	0.099	0.583	0.373	0.373	54.0
May	28	1.69	0.088	0.523	0.243	0.255	55.3
Jun	5	2.58	0.781	0.566	0.622	0.594	56.5

equations on each other, the average of the two calculated values will be used in all future theoretical runoff predictions.

Duration

Corrections for storm duration were made by changing the slope of the runoff curve. Reliable results were not obtained until the predicted runoff values were first adjusted for antecedent precipitation. The reasons for this can be seen by noting that most of the summer storms are of short duration. Because of the low antecedent precipitation, these storms produce little or no runoff, whereas storms of similar size and duration produce sizable stream flows in May.

The correction factors were calculated by classifying all storms into three categories: less than 24 hours, between one and two days duration, and longer than two days. The predicted values for all the storms in each category were summed and divided into the total actual flows of the three durations. The resulting correction factors, called F, were multiplied by each storm's total rainfall to give the new predicted flows. The program was then modified to multiply each storm's effective rainfall by the correction factor. This second procedure was found to give the better results when the correction for antecedent precipitation was not allowed to reduce the initial rainfall requirement by more than one-half. The duration program is the sixth one in Appendix A.

Areal Distribution

Each of the four preceding programs are based on the estimated station flows. One of the assumptions made in calculating the station flows is that a storm would produce the same runoff anywhere in the basin. In the last program in Appendix A, adjustments are made for the different runoff characteristics of the three station areas. In this program, the actual stream flow is used in conjunction with the calculated area flows. Whereas all of the other programs can be applied to a basin with any number of weather stations, this program was written to handle only a three-station basin. A correction factor, AD, was calculated for each station. The totals of all the predicted flows for the testing period were summed for each station. The total actual stream flows for all the storms in the testing period were summed. The sum of all the predicted flows should equal the sum of the actual stream flows. The difference between the predicted total and the actual total can be reduced by the station correction factors. Thus,

$$TSF = AD(1) \times Flow(1) + AD(2) \times Flow(2) + AD(3) \times Flow(3)$$

where

TSF = Total Stream Flow

AD = Areal Distribution correction factor

Flow = Predicted area runoff.

Subscripts 1, 2, and 3, respectively, represent the Stillwater, Maramec, and Cushing Thiessen areas. AD(2) and AD(3) were assumed to be equal to one, and a temporary value of AD(1) was calculated. Temporary values of AD(2) and AD(3) were calculated in a similar manner. Then AD(1) was found from the following equation:

$$AD(1) = 1 - (1 - (AD(1)) \times (AD(1)/TAD).$$

TAD is the sum of AD(1), AD(2), and AD(3). AD(2) and AD(3) are found in the same manner. The calculated values of AD are shown in Appendix A.

Summary

Theoretically, the rainfall-runoff curve should follow the straight line relationship:

$$\text{Runoff} = B \times \text{Rainfall} + C \qquad (4.3)$$

The C term, in conjunction with B, defines the initial rainfall requirement, I.R. This is the quantity of rain required to fill the local depressions, satisfy interception demands, and saturate the upper layer of soil. The I.R. area of Figure 2.2 corresponds to phase two of the runoff cycle. All the parameters controlling the second phase of the runoff cycle can be accounted for if good values of B and C are found. With rainfall in excess of the I.R., the runoff is dependent on B alone. The slope of the line represents the percent of the rainfall which reaches the stream quickly as overland flow. The remaining fraction inflitrates into the ground, is evaporated, or becomes interflow, to reach the stream later. As the intensity of the storm increases, the runoff fraction in turn increases.

The values of B and C are considered to be largely dependent upon the time of year, and a function of the antecedent temperature, represented as ATI. Table II and Figure 4.1 show the ATI for two years, 1956 and 1957. If temperature is a factor in the runoff cycle, largely because of its effect on evaporation rates and variations in the vegetal cover of an area from the norm for the season, then the computed values of B and C should produce values of the I.R. which show this. Table VI shows values of I.R. calculated for three ranges of the antecedent temperature index using the third computer program. All factors other than rainfall amount and antecedent temperature are considered constant in this program. A scarcity of data for the other ranges resulted in their exclusion from the table.

TABLE VI

INITIAL RAINFALL (ATI)

Antecedent Temperature Index (ATI)	Initial Rainfall (I. R.)
40 - 45	.23
45 - 50	.20
50 - 55	.66

The seasonal variations again represent cover, temperature, and evaporation rates. Other climatic factors, such as the rainfall distribution during the year, are incorporated in the seasonal variations more than in the antecedent temperature. An area's type of vegetation remains predominately a function of the season, although the ATI will determine its condition. This is especially true of an agricultural region. The ATI should be a more reliable substitute for evaporation rates and soil moisture because of the mutual effect of cloudy and rainy days on the three parameters. Initial rainfall, calculated with the fourth program and holding everything constant except rainfall amount and time of year, is shown in Table VII for three five-week periods.

TABLE VII

INITIAL RAINFALL (SEASON)

Days	Initial Rainfall
Mar 5 - Apr 8	0.20
Apr 9 - May 13	0.32
May 14 - Jun 18	0.54

A scarcity of runoff producing storms in the summer and fall again make results for the rest of the year quantitatively meaningless. Qualitatively, it can be said that only the very heavy storms will produce runoff during the summer and fall unless the ATI is much lower than normal; in other words, the yearly rainfall is higher than the average.

Antecedent precipitation was not considered to be a factor in the determination of the slope of the curve, B, or in the fraction of effective rainfall which becomes runoff. Instead, it is used to correct the values of C, and with a constant slope, to indirectly determine the adjusted initial rainfall requirement. The theoretical difference equation was calculated using the fifth program (Appendix A) and the previously calculated relationships based on antecedent temperature and season were found to be

$$DIFF = -0.0952 \times ANPR + 0.0403$$

where ANPR is the Antecedent Precipitation. This is the value added to the theoretical runoff equation to calculate the expected runoff. The horizontal intercept, when DIFF is zero, occurs at an antecedent precipitation value of 0.425. Values above this reduce the I. R. while lower values produce higher values of the initial rainfall. During the summer, B is generally very small. As a result, the absolute value of C is smaller than in the spring. During the wet years, the antecedent precipitation will at times be high enough to cause a corrected value of C to become positive. C must be restricted to negative values. If the B and C values are accurate, this would imply that the antecedent precipitation will have little effect above a certain level, which varies with the season. The value of DIFF is limited to values which do not decrease the initial rainfall by more than one-half in the programs. The B and C values for the summer are probably not as reliable as for the spring, because of the rarity of events.

The drought year, 1956, produced no large storm when the antecedent precipitation value was 0.600 or higher. Only three storms during the 300 days of the investigated year produced measurable runoff. Of these, the largest was the storm of May 31, whose total runoff was less than seven percent of the total rainfall. Using the ATI theoretical runoff curve and adjusting it with the theoretical difference equation, a value of 0.60 inches is found to be needed to meet the initial rainfall requirement. This implies that the percent of the effective rainfall which ran off is about ten percent. This is higher than expected for late May, but the short duration of that storm may be the reason.

The effect of duration is largely on the slope of part of the theoretical runoff curve representing the effective rainfall. Initial ranfall requirements remain basically the same. The amount of infiltration will vary with the time required to fill local depressions, but infiltration is a small quantity during this phase compared to the amount needed to fill the depressions and saturate the top layers of soil. For slow rains of long duration, after the initial rainfall requirements are met, runoff may be very small if the infiltration rate of the area approaches the rainfall intensity.

However, for areal distribution, the first, or initial, rainfall stage of a storm may be more important, although the slope of the effective rainfall portion of the curve may be affected. The physical features will greatly determine the local storage, although this may also be dependent on season, and is in agricultural areas. Areal distribution is important if infiltration rates vary in the basin. This can happen if the amount of relief varies in the different station areas and the permeability and type of vegetal cover are dissimilar. The correction factors for the three areas are shown in Table VIII. These values show that even in the smaller basins with relatively uniform geophysical characteristics, runoff will vary according to areal distribution.

TABLE VIII

AREA DISTRIBUTION CORRECTION FACTORS

Station	Correction
Stillwater	0.93
Maramec	0.96
Cushing	0.91

Only three durations were considered: less than one day, between one and two days, and longer than two days. The results are shown in Table IX. Fractional values were calculated for the three durations, and these were used to adjust the slope of the effective rainfall section of the theoretical runoff curve. Theoretically, the slope should be increased for short duration storms and decreased for storms of longer duration. A higher value for the longest duration than for the second longest duration may be caused by the infiltration rates approaching the soil transmission rates.

TABLE IX

DURATION CORRECTION FACTORS

Duration (Days)	Fraction
less than one	1.21
one to two	0.53
greater than two	0.78

CHAPTER V

CONCLUSIONS AND REMARKS

There are many methods of runoff prediction in use today. Most are empirical in nature and attempt to describe runoff by use of constants which must be estimated. Usually, these formulas are independent of the climatic conditions--antecedent temperature, antecedent precipitation, and season. As can be seen from this study, these three factors have a very great effect on the amount of runoff from any rainfall. An attempt to estimate runoff from rainfall without considering antecedent precipitation and either or both season and antecedent temperature will net very questionable results. Of course, this study was made for an area where these parameters radically alter the climatic and physical characteristics of the basin. Other areas may not have so extreme a range in temperature, and may have relatively uniform rainfall during all seasons. The effects of these three parameters may then not be as critical.

The quantity of flow may not be as important as the rate or stage of stream flow in some cases. However, if a unit hydrograph of a drainage basin is known, the stream flow can be found at any time. The unit hydrograph is a measure of stream flow versus time, such that the quantity of flow represented as the area under the curve is equal to one inch of runoff. For flows other than one inch, every point on the unit hydrograph is multiplied by the actual flow in inches. The unit hydrograph can be obtained by actual time measurements of stream flow after a storm, or if the runoff data is unavailable, an adequate hydrograph may be obtained from one of the equations which defines the unit hydrograph in terms of the basin's physical features and the duration of the storm.

Runoff prediction has two major purposes. The flow rate, which can be converted into the stage of the stream, is used in flood warnings. The time factor involved would make flood warnings on a basin the size of Council Creek impractical. However, larger basins are comprised of subbasins. The runoff may be predicted more accurately in these small basins. Then these smaller flows, and their resultant hydrographs, may be routed down the larger stream to predict flood stages and to control the storage in reservoirs. Reservoir storage is related to flood control in many cases, but is also important in regulating downstream channel flows and withdrawal rates.

The programs discussed in this study developed relationships between the rainfall-runoff curve and various measurable climatic factors. To do this, it was necessary to have extensive records of the basin. But runoff data is not available for most basins of this size--30 square miles. If it is desirable to be able to predict runoff for this type of basin, then the relationships calculated from histroical data must be obtainable by some other method. It may be possible to develop the theoretical difference equation for antecedent precipitation by knowledge of soil types, and it could be practical to apply relationships obtained for one basin to a similar basin. It may also be possible to apply the results of this study to other streams in the region, such as

Stillwater Creek. The feasibility of this type of study should certainly be investigated.

The basic relationship between rainfall and runoff is a function of both the season and antecedent temperature. Antecedent precipitation alters the basic rainfall-runoff relationship by changing the initial rainfall requirement. The maximum alteration of the initial rainfall due to antecedent precipitation is dependent on the season and antecedent precipitation. The effect of storm duration is most felt during the effective rainfall stage of the storm. Areal distribution's effect on runoff is dependent on both the physical characteristics of the drainage basin and the antecedent weather conditions of various parts of the basin.

This research was performed to show that basic relationships can be found between the routinely measured weather conditions and the runoff cycle. The dependence of the runoff cycle on each parameter is too complex to have been completely evaluated in this report. But a relationship has been shown using the season, antecedent temperature and precipitation, storm duration, and areal distribution. It is hoped that an increasing knowledge of the runoff cycle will accelerate the research of each factor involved, and continue the attempt to blend the knowledge of each of the factors into a qualitative description of the runoff cycle.

A SELECTED BIBLIOGRAPHY

(1) Chorley, Richard J. Introduction to Geographical Hydrology. New York: Barnes and Noble, 1971.

(2) Chow, Ven Te. Handbook of Applied Hydrology. New York: McGraw-Hill Book Company, 1954, Section 14.

(3) Cole, J. Glenn. "East Flank of the Nemaha Ridge." Shale Shaker, Vol. 19, No. 8 (April, 1969), 134-146.

(4) Geiger, Rudolf. The Climate Near the Ground. Cambridge, Mass.: Harvard University Press, 1957.

(5) Hopkins, Charles D. and Dale O. Hackett. "Average Antecedent Temperature as a Factor in Predicting Runoff from Storm Rainfall." Journal of Geophysical Research, Vol. 66, No. 10 (September, 1961), 3313-3318.

(6) Hoyt, W. G. "Outline of Runoff Cycle." Engineering Technical Bulletin 27, No. 142 (1942), 57-69.

(7) Kohler, M. A. and R. K. Linsley. "Predicting the Runoff from Storm Rainfall." Weather Bureau Research Paper No. 34, September, 1951.

(8) Langbein, Walter B. et al. "Annual Runoff in the United States." U. S. Geological Survey Circular 52, June, 1949.

(9) Linsley, R. K., Jr., M. A. Kohler, and J. L. H. Paulhus. Hydrology for Engineers. New York: McGraw-Hill Book Company, Inc., 1958.

(10) Miller, Clayton R. "Runoff Volumes for Small Urban Watersheds." Water Resources Research, Vol. 8, No. 2 (April, 1972), 426-434.

(11) Ramser, C. E. "Runoff from Small Agricultural Areas." Journal of Agricultural Research, Vol. 34, No. 9 (May, 1927), 797-805.

(12) Snedecor, George W. and William G. Cochran. Statistical Methods. Iowa City, Iowa: Iowa State University Press, 1967.

(13) Wisler, C. O. and E F. Brater. Hydrology. New York: John Wiley and Sons, Inc., 1959.

APPENDIX A

COMPUTER PROGRAMS FOR FINDING RUNOFF PARAMETERS

In Appendix A is a listing of seven programs. Each program is preceded by a brief description of any peculiarities of that program. Following each program is a sample of the output. The same data deck was used for the last five programs except that for the last four programs the runoff parameters calculated by the preceding programs are included. Because of the method of calculation used in one program, runoff from storms producing no runoff was input as 0.001 inch. Since rainfall was only recorded to the nearest 0.01 inch, any resulting error is insignificant.

Program One

Separation of Storms

The first program is used to divide daily stream flow and rainfall records for one year into total rainfall and duration for individual storms. The antecedent precipitation for each storm is also calculated for a period of thirty days prior to the start of each storm. Runoff for any one storm is assumed to be the total stream flow following the storm until the stream flow reaches the level of the calculated baseflow, or for a period of not more than eight days, minus the calculated baseflow for the period of runoff. If a second storm occurs before the end of the eight days, then the first storm's runoff is assumed to last until the increase in runoff.

When the stream flow for two consecutive days differs by less than a quantity (XM), which is read in as data, the baseflow of those days is the average of the flows. On days when the baseflow cannot be calculated in this manner, the baseflow is assumed to vary linearly between two days for which the baseflow is calculated.

```
$JOB *****************,TIME=30 JOE FEHRING
      DIMENSION PREC(5,366),RO(366),CON(5),BF(366),L(5),LDUR(5),
     A DUR(5),FLOW(5),FLIN(5),ANPR(5),RAIN(5),FRAC(5),STA(5)
      READ(5,10) JYEAR,LSTA,LREC,BSF,XM,XN,A
   10 FORMAT(5X,3I5,3F5.2,F10.2)
      WRITE(6,20) JYEAR
   20 FORMAT(1H1,///23X7HYEAR =   ,I5//)
      PRINT 80
   80 FORMAT(26X43HFLOW - DURATION - ANTECEDENT PRECIPITATION   )
         LPLUS=LSTA+1
      READ(5,30) (STA(I),I=1,LPLUS)
   30 FORMAT(9F8.3)
         DO 15 I=1,LPLUS
         CON(I)=.5*A*STA(I)*640./12.
      WRITE(6,60) I,CON(I)
   15 CONTINUE
   60 FORMAT(//22X16H  STA       CON    ,/5(26X,I5,F10.3))
      WRITE(6,40)
   40 FORMAT(//23X3HDAY,4X3HSTA,4X3HDUR,6X4HRAIN,6X4HFLOW,6X4HANPR/)
C           PRECIPITATION CONVERSION
      READ(5,100) ((PREC(I,K), I=1,LSTA), K=1,LREC)
  100 FORMAT(5X,9F8.2)
      READ(5,300) (RO(I), I=1,LREC)
  300 FORMAT(8F10.2)
  130    DO 140 I=1,LREC
         PREC(LPLUS,I)=0.0
         DO 140 K=1,LSTA
         PREC(LPLUS,I)=PREC(LPLUS,I)+STA(K)*PREC(K,I)
  140 CONTINUE
  310    BF(30)=BSF
         M=30
         DO 380 LF=30,LREC
         IF(ABS(RO(LF)-RO(LF-1)).LE.XM) GO TO 340
         GO TO 380
  340    BF(LF)=(RO(LF)+RO(LF-1))/2.
         IF(M.LT.LF-1) GO TO 350
         M=LF
         GO TO 380
  350    DO 360 K=M,LF
         BF(K)=(RO(LF)+RO(M))/2.
  360 CONTINUE
         M=LF
  380 CONTINUE
C           LOCATE START OF INCREASED FLOW
         IDAY=32
  410    IF(IDAY.GE.LREC-8) GO TO 2110
         LSTAGE=0
         IF(RO(IDAY).GE.RO(IDAY-1)+XM) GO TO 510
         IF(PREC(LPLUS,IDAY-1).GT.XN*2.) GO TO 910
         IDAY=IDAY+1
         GO TO 410
C           AREAL DISTRIBUTION (L)
  510    LDAY=IDAY-2
         ID=IDAY
         N=IDAY+1
  520    DO 550 JK=1,LPLUS
         L(JK)=-1
         DO 530 KJ=1,4
         IF(PREC(JK,LDAY+KJ).GT.XN) GO TO 532
         L(JK)=L(JK)+1
  530 CONTINUE
  532    LDUR(JK)=1
         LB=LDAY+KJ
         DO 540 KJ=1,5
         IF(PREC(JK,LB+KJ).LE.XN) GO TO 550
         LDUR(JK)=LDUR(JK)+1
  540 CONTINUE
  550 CONTINUE
  560    DO 580 IJ=1,LPLUS
         ANPR(IJ)=0.0
         DO 580 II=1,30
         LD=ID-II+L(IJ)
         ANPR(IJ)=ANPR(IJ)+(1./II)*PREC(IJ,LD)
  580 CONTINUE
C           CALCULATION OF TOTAL FLOW (FLOW(LPLUS))
         DO 630 I=1,LPLUS
         KA=ID+L(I)
         KB=KA+LDUR(I)
         RAIN(I)=PREC(I,KA)
  630 CONTINUE
         DO 650 I=1,LPLUS
         DO 640 JA=KA,KB
         RAIN(I)=RAIN(I)+PREC(I,JA+1)
         IF(RO(JA+2).GT.RO(JA+1).AND.RO(JA+1).LT.RO(JA)) GO TO 650
  640 CONTINUE
  650 CONTINUE
         LL=N+8
         FLOW(LPLUS)=RO(ID)
         DO 720 I=N,LL
         IF(RO(I).GT.RO(I-1).AND.RO(I-1).LT.RO(I-2)) GO TO 740
         IF(RO(I).LE.BF(I)) GO TO 730
         FLOW(LPLUS)=FLOW(LPLUS)+RO(I)
  720 CONTINUE
  730    DUR(LPLUS)=I-1-ID
         FLOW(LPLUS)=FLOW(LPLUS)-BF(IDAY)*DUR(LPLUS)
         LLL=0
         GO TO 750
  740    LLL=1
  750    DO 760 K=1,LSTA
         IF(RAIN(LPLUS).LE.0.) GO TO 830
         FRAC(K)=(RAIN(K)/RAIN(LPLUS))*LSTA
  760 CONTINUE
         TOTAL=0.0
         DO 770 K=1,LSTA
         TOTAL=TOTAL+FRAC(K)*STA(K)*A
  770 CONTINUE
         FLIN(LPLUS)=FLOW(LPLUS)/CON(LPLUS)
         DO 780 K=1,LSTA
         FLOW(K)=FRAC(K)*STA(K)*A*FLOW(LPLUS)/TOTAL
         FLIN(K)=FLOW(K)/CON(K)
  780 CONTINUE
C           PRINT RESULTS
         LSTAGE=LSTAGE+1
      WRITE(6,200) ID,LSTAGE,LDUR(LPLUS),RAIN(LPLUS),FLIN(LPLUS),
     A ANPR(LPLUS)
         DO 820 K=1,LSTA
      WRITE(6,400) K,LDUR(K),RAIN(K),FLIN(K),ANPR(K)
  820 CONTINUE
  200 FORMAT(/19X,3I7,3F10.3)
  400 FORMAT(26X,2I7,3F10.3)
```

```
 830     IDAY=I
         IF(IDAY.GE.LREC-8) GO TO 2110
         IF(LLL.EQ.0) GO TO 410
         LDAY=IDAY
         N=IDAY+1
         FLOW(LPLUS)=RO(I-1)
         ID=N-1
         GO TO 520
C           DROUGHT CONDITIONS
 910     ID=IDAY-1
         LD=ID
         DO 920 I=1,4
         IF(RO(ID+1).GE.RO(ID)+XM) GO TO 930
         ID=ID+1
 920 CONTINUE
 930      DO 950 K=1,LPLUS
         LDUR(K)=0
         RAIN(K)=PREC(K,LD)
         DO 940 I=LD,ID
         IF(PREC(K,I).LE.XN) GO TO 950
         LDUR(K)=LDUR(K)+1
 940 CONTINUE
 950 CONTINUE
         DO 960 K=1,LPLUS
 960 CONTINUE
         DO 980 IJ=1,LPLUS
         ANPR(IJ)=0.0
         DO 980 II=1,30
         LD=IDAY-II-1
         ANPR(IJ)=ANPR(IJ)+(1./II)*PREC(IJ,LD)
 980 CONTINUE
     WRITE(6,600) IDAY,LDUR(LPLUS),RAIN(LPLUS),ANPR(LPLUS)
 600 FORMAT(/23XI3,10X,I4,F10.3,10X,F10.3)
         DO 1020 K=1,LSTA
     WRITE(6,800) K,LDUR(K),RAIN(K),ANPR(K)
 800 FORMAT(26X,2I7,F10.3,10X,F10.3)
1020 CONTINUE
         IDAY=ID+2
         GO TO 410
2110 PRINT 1000
1000 FORMAT(1H1)
     STOP
     END

$ENTRY
```

YEAR = 1956

FLOW - DURATION - ANTECEDENT PRECIPITATION

STA	CON
1	177.173
2	418.773
3	209.387
4	805.333

DAY	STA	DUR	RAIN	FLOW	ANPR
52		1	0.652		0.007
	1	1	0.540		0.008
	2	1	0.750		0.007
	3	1	0.550		0.007
106		2	1.240		0.046
	1	2	1.440		0.035
	2	2	1.000		0.051
	3	2	1.550		0.047
117		1	0.574		0.498
	1	1	0.670		0.563
	2	3	0.750		0.452
	3	0	0.140		0.533
122	1	1	1.777	0.111	0.490
	1	1	0.610	0.038	0.419
	2	1	2.660	0.166	0.524
	3	1	1.000	0.062	0.481
151		1	0.813		0.282
	1	1	0.400		0.254
	2	1	0.940		0.300
	3	1	0.910		0.271
158	1	1	0.760	0.015	0.161
	1	1	0.900	0.018	0.120
	2	1	0.790	0.015	0.153
	3	1	0.580	0.011	0.214
259		2	0.632		0.010
	1	1	0.960		0.002

After storm runoff is calculated for the basin, the flow is divided into station or area flows. The basin rainfall is calculated by the Thiessen method. A quantity, called FRAC, is calculated for each area to be equal to the rainfall for that area times the total number of areas, divided by the basin rainfall. A second value, TOTAL, is calculated as the sum of each value of FRAC times the total area each value represents. Each area flow is then assumed to be equal to the value of FRAC times the area that station represents, divided by the quantity, TOTAL.

A definition of terms used in the first program follows.

Definitions

A	–	Area of basin in square miles
ANPR	–	Antecedent Precipitation
BF	–	Base Flow of stream
BSF	–	Assumed base flow for the beginning of the year
CON	–	Conversion from seconds-feet-days to inches of rainfall
FRAC	–	Conversion from stream flow to area flow
IDAY	–	Day storm begins
IYEAR	–	Year of record
KA	–	First day of runoff
KB	–	Last day of runoff
LDUR	–	Duration of storm
LPLUS	–	As a subscript, it represents basin values
LREC	–	Days of record
LSTA	–	Number of weather stations
PREC	–	Daily precipitation at each station

RAIN — Total rainfall for one storm

RO — Daily stream flow

XM — Minimum change in stream flow considered by the program

XN — Minimum daily rainfall considered (0.3 in.).

Program Two

Antecedent Temperature Index

The second program is used to calculate the ATI. Any number of years of record may be read into the program. The ATI is calculated and printed for each year before the second year's records are entered. The mean daily temperature for the days of record comprise the data. The first week's average temperature is calculated. The ATI for the first two weeks are assumed to be equal to this value. The ATI's for the next three weeks are calculated using the ATI definition,

ATI = .9ATI(Prev. week) + .1 Avg. Temp. (Prev. week).

The ATI for the first week is then adjusted by subtracting one fourth of the difference between the first and fifth weeks' ATI. This value is the result of assuming a linear variation in the ATI over this period. The ATI for the rest of the year is calculated based on this adjusted value.

Definitions of the terms used in the program follow. Terms not defined are the same as in the first program.

Definitions

ATEMP — Average weekly temperature

ATI — Antecedent Temperature Index

```
$JOB ****************,TIME=30              JOE FEHRING
C          ANTECEDENT TEMPERATURE INDEX (ATI)
C          ATI=.9ATI(PREV.WEEK)+.1 AVG. TEMP (PREV.WEEK)
      DIMENSION TEMP(366),ATI(52)
      READ(5,100) NN
         DO 910 I=1,NN
  100 FORMAT(5X,2I5)
  300 FORMAT(5X,15F5.0)
      READ(5,100) JYEAR,LREC
      READ(5,300) (TEMP(L), L=1,LREC)
         ATEMP=0.0
C          AVERAGE TEMPERATURE FOR FIRST WEEK
         DO 110 J=1,7
         ATEMP=ATEMP+TEMP(J)
  110 CONTINUE
         FTEMP=ATEMP/7.
C          ESTABLISH FIRST WEEKS ATI
         ATI(1)=FTEMP
         ATI(2)=FTEMP
         ATEMP=0.0
         DO 140 K=3,5
         DO 130 J=1,7
         ATEMP=ATEMP+TEMP((K-2)*7+J)
  130 CONTINUE
      ATEMP=ATEMP/7
         ATI(K)=.9*ATI(K-1)+.1*ATEMP
  140 CONTINUE
         ATI(1)=ATI(1)-.25*(ATI(5)-ATI(1))
C          ATI FOR REST OF YEAR
         ATI(2)=.9*ATI(1)+.1*FTEMP
         NRWK=LREC/7
         DO 240 K=3,NRWK
         ATEMP=0.0
         DO 230 J=1,7
         ATEMP=ATEMP+TEMP((K-2)*7+J)
  230 CONTINUE
         ATI(K)=.9*ATI(K-1)+.1*ATEMP/7
  240 CONTINUE
         N=NRWK/2
  310 WRITE(6,200) JYEAR
         DO 320 K=1,N
         M=(K-1)*7+1
         KN=K+N
         MN=M+7*N
      WRITE(6,400) M,K,ATI(K),MN,KN,ATI(KN)
  320 CONTINUE
      PRINT 600
  200 FORMAT(1H1/////20X7HYEAR =   ,I4//20X3HDAY,5X,4HWEEK,6X,
     A 3HATI,10X,3HDAY,5X,4HWEEK,6X,3HATI/)
  400 FORMAT(10X,2(10X,I3,6X,I2,5X,F5.1))
  600 FORMAT(1H1)
  910 CONTINUE
      STOP
      END

$ENTRY
```

YEAR = 1956

DAY	WEEK	ATI	DAY	WEEK	ATI
1	1	26.7	162	24	67.3
8	2	26.9	169	25	69.3
15	3	28.4	176	26	70.6
22	4	29.7	183	27	72.1
29	5	32.3	190	28	73.7
36	6	34.8	197	29	75.5
43	7	36.4	204	30	76.7
50	8	37.2	211	31	77.2
57	9	38.9	218	32	78.0
64	10	41.5	225	33	77.9
71	11	43.0	232	34	78.7
78	12	44.7	239	35	78.9
85	13	45.6	246	36	78.5
92	14	47.6	253	37	78.1
99	15	49.6	260	38	77.6
106	16	52.7	267	39	76.3
113	17	54.9	274	40	75.0
120	18	56.5	281	41	73.0
127	19	58.1	288	42	70.7
134	20	59.8	295	43	69.0
141	21	61.6	302	44	66.5
148	22	63.6	309	45	64.5
155	23	65.6	316	46	62.1

FTEMP – Assumed ATI for the first two weeks

NN – Number of years of record entered

NRWK – Number of weeks of record

TEMP – Daily mean temperature.

Program Three

Antecedent Temperature Index Constants

For this program and for all of the following programs, the same basic data deck is used. On each card is punched the year, day, station number, station flow, rainfall for the station, duration, antecedent precipitation, and antecedent temperature index (ATI). The day, station number, rainfall, and the ATI are read into this program to develop the theoretical runoff equations for the eight ranges of ATI. Storms for several years of record are separated according to the ATI at the beginning of the storm. Assuming a linear relationship between runoff and rainfall, the theoretical runoff equation is

$$\text{Runoff} = B \times \text{Rainfall} + C.$$

B and C can be calculated by the least squares method using the following equations:

$$B = \frac{A\Sigma(\text{Rainfall} \times \text{Runoff}) - \Sigma \text{Rainfall} \times \Sigma \text{Runoff}}{A\Sigma \text{Rainfall}^2 - (\Sigma \text{Rainfall})^2}$$

and

$$C = \frac{\Sigma \text{Rainfall}^2 \times \Sigma \text{Runoff} - \Sigma \text{Rainfall} \times \Sigma(\text{Rainfall} \times \text{Runoff})}{A\Sigma \text{Rainfall}^2 - (\Sigma \text{Rainfall})^2}$$

This program calculates B and C using the above equations for eight ranges of ATI, and prints these values as well as a table to show the results of using this method. A definition of terms follows.

```
$JOB *****************,TIME=30 JOE FEHRING
C          ANTECEDENT TEMPERATURE INDEX CONSTANTS
      DIMENSION ID(8,50),RAIN(8,50),FLIN(8,50),NI(8),ADJT(8,50),J(8),
     B SUMB(8),SUMC(8),SUMBC(8),SUMBB(8),
     A LS(9,50),THEOR(9,50),ATI(9,50),A(8),B(8),C(8)
      READ(5,100) N,(NI(I),I=1,N)
  100 FORMAT(5X,15I5)
         READ(5,300) LSTA,AA,BB,CC
  300 FORMAT(5X,I5,7F10.3)
C          INPUT
         DO 140 I=1,N
         J(I)=0
         DO 130 K=1,50
      READ(5,500) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),ATI(I,K)
  500 FORMAT(10X,2I5,5X,2F10.3,10X,F10.3)
         IF(ID(I,K).EQ.0) GO TO 140
         J(I)=J(I)+1
  130 CONTINUE
  140 CONTINUE
C          CALCULATION OF CONSTANTS
         DO 320 I=1,8
         SUMB(I)=0.
         SUMC(I)=0.
         SUMBC(I)=0.
         SUMBB(I)=0.
         A(I)=0.
         B(I)=0.
         C(I)=0.
  320 CONTINUE
         DO 490 I=1,N
         JA=J(I)
         DO 490 K=1,JA
         IF(ATI(I,K).GE.40.) GO TO 420
         A(1)=A(1)+1.
         SUMB(1)=SUMB(1)+RAIN(I,K)
         SUMC(1)=SUMC(1)+FLIN(I,K)
         SUMBC(1)=SUMBC(1)+RAIN(I,K)*FLIN(I,K)
         SUMBB(1)=SUMBB(1)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  420    IF(ATI(I,K).GE.45.) GO TO 430
         A(2)=A(2)+1.
         SUMB(2)=SUMB(2)+RAIN(I,K)
         SUMC(2)=SUMC(2)+FLIN(I,K)
         SUMBC(2)=SUMBC(2)+RAIN(I,K)*FLIN(I,K)
         SUMBB(2)=SUMBB(2)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  430    IF(ATI(I,K).GE.50.) GO TO 440
         A(3)=A(3)+1.
         SUMB(3)=SUMB(3)+RAIN(I,K)
         SUMC(3)=SUMC(3)+FLIN(I,K)
         SUMBC(3)=SUMBC(3)+RAIN(I,K)*FLIN(I,K)
         SUMBB(3)=SUMBB(3)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  440    IF(ATI(I,K).GE.55.) GO TO 450
         A(4)=A(4)+1.
         SUMB(4)=SUMB(4)+RAIN(I,K)
         SUMC(4)=SUMC(4)+FLIN(I,K)
         SUMBC(4)=SUMBC(4)+RAIN(I,K)*FLIN(I,K)
         SUMBB(4)=SUMBB(4)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  450    IF(ATI(I,K).GE.60.) GO TO 460
         A(5)=A(5)+1.
         SUMB(5)=SUMB(5)+RAIN(I,K)
         SUMC(5)=SUMC(5)+FLIN(I,K)
         SUMBC(5)=SUMBC(5)+RAIN(I,K)*FLIN(I,K)
         SUMBB(5)=SUMBB(5)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  460    IF(ATI(I,K).GE.65) GO TO 470
         A(6)=A(6)+1.
         SUMB(6)=SUMB(6)+RAIN(I,K)
         SUMC(6)=SUMC(6)+FLIN(I,K)
         SUMBC(6)=SUMBC(6)+RAIN(I,K)*FLIN(I,K)
         SUMBB(6)=SUMBB(6)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  470    IF(ATI(I,K).GE.70.) GO TO 480
         A(7)=A(7)+1.
         SUMB(7)=SUMB(7)+RAIN(I,K)
         SUMC(7)=SUMC(7)+FLIN(I,K)
         SUMBC(7)=SUMBC(7)+RAIN(I,K)*FLIN(I,K)
         SUMBB(7)=SUMBB(7)+RAIN(I,K)*RAIN(I,K)
         GO TO 490
  480    A(8)=A(8)+1.
         SUMB(8)=SUMB(8)+RAIN(I,K)
         SUMC(8)=SUMC(8)+FLIN(I,K)
         SUMBC(8)=SUMBC(8)+RAIN(I,K)*FLIN(I,K)
         SUMBB(8)=SUMBB(8)+RAIN(I,K)*RAIN(I,K)
  490 CONTINUE
         DO 530 IJ=1,8
         IF(A(IJ).LE.0.) GO TO 520
         DENOM=A(IJ)*SUMBB(IJ)-SUMB(IJ)*SUMB(IJ)
         B(IJ)=(A(IJ)*SUMBC(IJ)-SUMB(IJ)*SUMC(IJ))/DENOM
         C(IJ)=(SUMBB(IJ)*SUMC(IJ)-SUMB(IJ)*SUMBC(IJ))/DENOM
         IF(B(IJ).GT.0.) GO TO 530
  520    B(IJ)=0.2
         C(IJ)=-.135
  530 CONTINUE
         DO 690 I=1,N
         JA=J(I)
         DO 690 K=1,JA
         ADJT(I,K)=AA*RAIN(I,K)**2+BB*RAIN(I,K)+CC
         IF(ADJT(I,K).GT.0.) GO TO 610
         ADJT(I,K)=0.0
  610    IF(ATI(I,K).GE.40.) GO TO 620
         THEOR(I,K)=B(1)*RAIN(I,K)+C(1)
         GO TO 690
  620    IF(ATI(I,K).GE.45.) GO TO 630
         THEOR(I,K)=B(2)*RAIN(I,K)+C(2)
         GO TO 690
  630    IF(ATI(I,K).GE.50.) GO TO 640
         THEOR(I,K)=B(3)*RAIN(I,K)+C(3)
         GO TO 690
  640    IF(ATI(I,K).GE.55.) GO TO 650
         THEOR(I,K)=B(4)*RAIN(I,K)+C(4)
         GO TO 690
  650    IF(ATI(I,K).GE.60.) GO TO 660
         THEOR(I,K)=B(5)*RAIN(I,K)+C(5)
         GO TO 690
  660    IF(ATI(I,K).GE.65.) GO TO 670
         THEOR(I,K)=B(6)*RAIN(I,K)+C(6)
         GO TO 690
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 670     IF(ATI(I,K).GE.70.) GO TO 680
         THEOR(I,K)=B(7)*RAIN(I,K)+C(7)
         GO TO 690
 680     THEOR(I,K)=B(8)*RAIN(I,K)+C(8)
 690  CONTINUE
C           PRINTOUT
         DO 740 I=1,N
      WRITE(6,200) NI(I)
 200  FORMAT(1H1///20X7HYEAR =   ,I4//20X62HDAY     STA       RAIN       FLO
     AW      THEOR       ADJT        ATI    )
         JA=J(I)
        DO 740 K=1,JA
         IF(THEOR(I,K).GT.0.) GO TO 710
         THEOR(I,K)=0.0
 710  WRITE(6,400) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),ADJT(I,K),
     A THEOR(I,K),ATI(I,K)
 400  FORMAT(16X,2I7,4F10.3,F10.1)
 740  CONTINUE
         PRINT 600
 600  FORMAT(1H1////20X1HI,6X,1HB,10X,1HC//)
         DO 820 I=1,8
      WRITE(6,800) I,B(I),C(I)
 800  FORMAT(20X,I1.2F10.4)
 820  CONTINUE
      PRINT 1000
1000  FORMAT(1H1)
      STOP
      END

$ENTRY
```

I	B	C
1	0.0269	-0.0009
2	0.2133	-0.0486
3	0.0310	-0.0062
4	0.2837	-0.1903
5	0.2284	-0.0342
6	0.1940	-0.0460
7	0.2000	-0.1350
8	0.0818	-0.0624

Definitions

A	–	Number of storms during each ATI range
ADJT	–	Predicted runoff using Equation (2.1)
B	–	Slope of runoff curve calculated using the ATI
BB	–	Assumed slope of runoff curve
C	–	y-intercept of runoff curve calculated using the ATI
CC	–	Assumed y-intercept of runoff curve
J	–	Number of storms during any year
N	–	Number of years of record
NI	–	Year of record
SUMB	–	Sum of rainfalls during one range of ATI
SUMBB	–	Sum of squares of rainfalls during one range of ATI
SUMBC	–	Sum of rainfalls times runoffs for one range of ATI
SUMC	–	Sum of runoffs for one range of ATI
THEOR	–	Predicted runoff using Equation (2.1).

Program Four

Seasonal Variation

This program is similar to the third program in procedure. The same data is read into the program except that the eight values of B and C calculated for the ATI ranges, referred to as BT and CT, are also entered. The year is divided into seven segments, each one approximately five weeks long. New values of B and C are calculated using the least squares method and signified as BS and CS. These values are printed at the end of the program. Values of the predicted runoffs calculated using Equation (2.1), the seasonal values based on

```
$JOB ******************,TIME=30,PAGES=16        JOE FEHRING
C           SEASONAL VARIATION
      DIMENSION ID(8,50),LS(8,50),RAIN(8,50),FLIN(8,50),ATI(8,50),
     A BS(7),CS(7),BT(8),CT(8),THEOR(8,50),ADJS(8,50),ADJT(8,50),M(7)
     B  ,J(8),NI(8),SUMR(8),SUMF(8),SUMRF(8),SUMRR(8)
         READ(5,100) N,(NI(I),I=1,N)
  100 FORMAT(5X,15I5)
         READ(5,300) LSTA,AA,BB,CC
  300 FORMAT(5X,I5,7F10.3)
      READ(5,700) (BT(I),CT(I),I=1,8)
  700 FORMAT(10X,2F10.4)
         DO 140 I=1,N
         J(I)=0
         DO 130 K=1,50
         READ(5,500) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),ATI(I,K)
         IF(ID(I,K).EQ.0) GO TO 140
         J(I)=J(I)+1
         THEOR(I,K)=AA*RAIN(I,K)**2+BB*RAIN(I,K)+CC
         IF(THEOR(I,K).GE.0.) GO TO 130
         THEOR(I,K)=0.
  130 CONTINUE
  140 CONTINUE
  500 FORMAT(10X,2I5,5X,2F10.3,10X,F10.3)
         DO 220 K=1,7
         SUMR(K)=0.
         SUMF(K)=0.
         SUMRF(K)=0.
         SUMRR(K)=0.
         BS(K)=0.
         CS(K)=0.
         M(K)=0
  220 CONTINUE
         DO 390 I=1,N
         JA=J(I)
         DO 390 K=1,JA
         IF(ID(I,K).GE.71) GO TO 320
         KK=1
         GO TO 380
  320    IF(ID(I,K).GE.106) GO TO 330
         KK=2
         GO TO 380
  330    IF(ID(I,K).GE.141) GO TO 340
         KK=3
         GO TO 380
  340    IF(ID(I,K).GE.176) GO TO 350
         KK=4
         GO TO 380
  350    IF(ID(I,K).GE.211) GO TO 360
         KK=5
         GO TO 380
  360    IF(ID(I,K).GE.246) GO TO 370
         KK=6
         GO TO 380
  370    KK=7
  380 CALL SEASON(SUMR(KK),SUMF(KK),SUMRF(KK),SUMRR(KK),RAIN(I,K),
     A FLIN(I,K),M(KK))
  390 CONTINUE
         DO 640 K=1,7
         IF(M(K).EQ.0) GO TO 630
         DENOM=M(K)*SUMRR(K)-SUMR(K)*SUMR(K)
         BS(K)=(M(K)*SUMRF(K)-SUMR(K)*SUMF(K))/DENOM
         CS(K)=(SUMRR(K)*SUMF(K)-SUMR(K)*SUMRF(K))/DENOM
         GO TO 640
  630    BS(K)=0.2
         CS(K)=-0.135
  640 CONTINUE
         DO 495 I=1,N
         JA=J(I)
         DO 495 K=1,JA
         IF(ID(I,K).GE.71) GO TO 420
         KK=1
         GO TO 450
  420    IF(ID(I,K).GE.106) GO TO 425
         KK=2
         GO TO 450
  425    IF(ID(I,K).GE.141) GO TO 430
         KK=3
         GO TO 450
  430    IF(ID(I,K).GE.176) GO TO 435
         KK=4
         GO TO 450
  435    IF(ID(1,K).GE.211) GO TO 440
         KK=5
         GO TO 450
  440    IF(ID(1,K).GE.246) GO TO 445
         KK=6
         GO TO 450
  445    KK=7
  450    IF(ATI(I,K).GE.40.) GO TO 455
         KL=1
         GO TO 490
  455    IF(ATI(I,K).GE.45.) GO TO 460
         KL=2
         GO TO 490
  460    IF(ATI(I,K).GE.50.) GO TO 465
         KL=3
         GO TO 490
  465    IF(ATI(I,K).GE.55.) GO TO 470
         KL=4
         GO TO 490
  470    IF(ATI(I,K).GE.60.) GO TO 475
         KL=5
         GO TO 490
  475    IF(ATI(I,K).GE.65.) GO TO 480
         KL=6
         GO TO 490
  480    IF(ATI(I,K).GE.70.) GO TO 485
         KL=7
         GO TO 490
  485    KL=8
  490    ADJS(I,K)=AA*RAIN(I,K)**2+BS(KK)*RAIN(I,K)+CS(KK)
         ADJT(I,K)=(AA*RAIN(I,K)**2+BT(KL)*RAIN(I,K)+CT(KL)+ADJS(I,K))/2
  495 CONTINUE
         DO 740 I=1,N
      WRITE(6,200) NI(I)
  200 FORMAT(1H1////20X7HYEAR =   ,I4///20X,58HDAY    STA     RAIN     FLOW
     A  THEOR     ADJS     ADJT     ATI     )
         JA=J(I)
         DO 740 K=1,JA
         IF(ADJS(I,K).GE.0.) GO TO 720
```

```
      ADJS(I,K)=0.0
720   IF(ADJT(I,K).GE.0.) GO TO 730
      ADJT(I,K)=0.0
730 WRITE(6,400) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),THEOR(I,K),
   A ADJS(I,K),ADJT(I,K),ATI(I,K)
400 FORMAT(17X,2I6,5F8.3,F7.1)
740 CONTINUE
    PRINT 600
    WRITE(6,800) (I,BS(I),CS(I), I=1,7)
600 FORMAT(1H1////20X1HI,10X,2HBS,8X,2HCS//)
800 FORMAT(20X,I1,5X,2F10.4)
    STOP
    END

    SUBROUTINE SEASON(SUMR,SUMF,SUMRF,SUMRR,RAIN,FLIN,M)
      SUMR=SUMR+RAIN
      M=M+1
      SUMF=SUMF+FLIN
      SUMRF=SUMRF+RAIN*FLIN
      SUMRR=SUMRR+RAIN*RAIN
    RETURN
    END

$ENTRY
```

YEAR = 1956

DAY	STA	RAIN	FLOW	THEOR	ADJS	ADJT	ATI
52	1	0.652	0.001	0.272	0.063	0.043	37.2
52	2	0.750	0.001	0.293	0.078	0.053	37.2
52	3	0.550	0.001	0.250	0.049	0.034	37.2
105	1	1.980	0.015	0.590	0.276	0.195	49.6
105	2	1.440	0.011	0.454	0.189	0.129	49.6
105	3	2.560	0.020	0.745	0.378	0.275	49.6
117	1	0.670	0.001	0.276	0.046	0.026	54.9
117	2	0.750	0.001	0.293	0.071	0.051	54.9
122	1	0.610	0.038	0.263	0.027	0.069	56.5
122	2	2.660	0.166	0.773	0.726	0.703	56.5
122	3	1.000	0.062	0.350	0.150	0.180	56.5
151	1	0.400	0.001	0.217	0.052	0.043	63.6
151	2	0.940	0.001	0.336	0.193	0.171	63.6
151	3	0.910	0.001	0.329	0.185	0.164	63.6
158	1	0.900	0.018	0.327	0.182	0.120	65.6
158	2	0.790	0.015	0.302	0.153	0.093	65.6
158	3	0.580	0.011	0.256	0.098	0.042	65.6
259	1	0.960	0.001	0.341	0.015	0.023	78.1
259	3	1.280	0.001	0.416	0.026	0.047	78.1
275	1	0.850	0.001	0.316	0.012	0.015	75.0
275	2	0.890	0.001	0.325	0.013	0.018	75.0
280	1	1.740	0.001	0.528	0.047	0.086	75.0
280	3	1.650	0.001	0.506	0.043	0.078	75.0
314	1	0.520	0.001	0.243	0.005	0.000	75.0
314	2	0.770	0.001	0.298	0.010	0.061	64.5

BS and CS and the average values calculated using both the ATI and seasonal values, are printed out under the column headings THEOR, ADJS, and ADJT, respectively. Definitions used in this program which differ from previous definitions or appear for the first time are listed below.

Definitions

ADJS – Predicted runoff using season only
ADJT – Average predicted runoff using season and ATI
BS – Slope of runoff curve using the season
BT – Slope of runoff curve using the ATI
CS – y-intercept of runoff curve using the season
CT – y-intercept of runoff curve using the ATI
M – Number of storms during one season
SUMF – Sum of flows during one season
SUMR – Sum of rainfalls during one season
SUMRF – Sum of rainfalls times flows during one season
SUMRR – Sum of square of runoffs during one season.

Program Five

Antecedent Precipitation

The listing which follows is the final form of the program. It includes the use of the B and C values calculated in the previous two programs. Thus, it differs from the program used to calculate the data in Table I, which was converted from the program utilizing only Equation (4.1). The difference between the predicted runoff and actual runoff is

```
$JOB *****************,TIME=30 JOE FEHRING
C          ANTECEDENT PRECIPITATION
      DIMENSION DIFF(8,50),ID(8,50),RAIN(8,50),FLIN(8,50),ADJA(8,50),
     A ANPR(8,50),J(8),LS(8,50),THEOR(8,50),NI(8),ATI(8,50),B(8),C(8)
     B ,BS(8),CS(8)
      READ(5,100) N,(NI(I),I=1,N)
  100 FORMAT(5X,I5I5)
      READ(5,300) LSTA,AA
      READ(5,700) (B(I),C(I),BS(I),CS(I), I=1,8)
  300 FORMAT(5X,I5,7F10.3)
  700 FORMAT(10X,4F10.4)
         DO 140 I=1,N
         J(I)=0
         DO 130 K=1,50
C          INPUT
      READ(5,500) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),ANPR(I,K)
     A,ATI(I,K)
  500 FORMAT(10X,2I5,5X,5F10.3)
         IF(ID(I,K).EQ.0) GO TO 140
         J(I)=J(I)+1
  610    IF(ATI(I,K).GE.40.) GO TO 620
         THEOR(I,K)=B(1)*RAIN(I,K)+C(1)
         GO TO 690
  620    IF(ATI(I,K).GE.45.) GO TO 630
         THEOR(I,K)=B(2)*RAIN(I,K)+C(2)
         GO TO 690
  630    IF(ATI(I,K).GE.50.) GO TO 640
         THEOR(I,K)=B(3)*RAIN(I,K)+C(3)
         GO TO 690
  640    IF(ATI(I,K).GE.55.) GO TO 650
         THEOR(I,K)=B(4)*RAIN(I,K)+C(4)
         GO TO 690
  650    IF(ATI(I,K).GE.60.) GO TO 660
         THEOR(I,K)=B(5)*RAIN(I,K)+C(5)
         GO TO 690
  660    IF(ATI(I,K).GE.65.) GO TO 670
         THEOR(I,K)=B(6)*RAIN(I,K)+C(6)
  670    IF(ATI(I,K).GE.70.) GO TO 680
         THEOR(I,K)=B(7)*RAIN(I,K)+C(7)
         GO TO 690
  680    THEOR(I,K)=B(8)*RAIN(I,K)+C(8)
  690 CONTINUE
         IF(ID(I,K).GE.71) GO TO 320
         KK=1
         GO TO 380
  320    IF(ID(I,K).GE.106) GO TO 330
         KK=2
         GO TO 380
  330    IF(ID(I,K).GE.141) GO TO 340
         KK=3
         GO TO 380
  340    IF(ID(I,K).GE.176) GO TO 350
         KK=4
         GO TO 380
  350    IF(ID(I,K).GE.211) GO TO 360
         KK=5
         GO TO 380
  360    IF(ID(I,K).GE.246) GO TO 370
         KK=6
         GO TO 380
  370    KK=7
  380    THEOR(I,K)=(THEOR(I,K)+BS(KK)*RAIN(I,K)+CS(KK))/2.
         IF(THEOR(I,K).GT.0.) GO TO 120
         THEOR(I,K)=0.0
  120 DIFF(I,K)=THEOR(I,K)-FLIN(I,K)
  130 CONTINUE
  140 CONTINUE
C           CALCULATION OF CONSTANTS
         SUMD=0.0
         SUMA=0.0
         SUMDA=0.0
         SUMDD=0.0
         M=0
         DO 440 I=1,N
         JA=J(I)
         M=M+JA
         DO 440 K=I,JA
         SUMD=SUMD+ANPR(I,K)
         SUMA=SUMA+DIFF(I,K)
         SUMDA=SUMDA+DIFF(I,K)*ANPR(I,K)
         SUMDD=SUMDD+ANPR(I,K)*ANPR(I,K)
  440 CONTINUE
         DENOM=M*SUMDD-SUMD*SUMD
         SLO=(M*SUMDA-SUMD*SUMA)/DENOM
         BIN=(SUMDD*SUMA-SUMD*SUMDA)/DENOM
         DO 540 I=1,N
         JA=J(I)
         DO 540 K=1,JA
         ADJA(I,K)=THEOR(I,K)-(ANPR(I,K)*SLO+BIN)
         IF(ADJA(I,K).GT.0.) GO TO 540
         ADJA(I,K)=0.0
  540 CONTINUE
         DO 740 I=1,N
      WRITE(6,200) NI(I)
  200 FORMAT(1H1////20X7HYEAR =  ,I4///20X58HDAY    STA     RAIN     FLOW
     A THEOR     ANPR     ADJA     ATI    )
         JA=J(I)
         DO 740 K=1,JA
      WRITE(6,400) ID(I,K),LS(I,K),RAIN(I,K),FLIN(I,K),THEOR(I,K),
     A ANPR(I,K),ADJA(I,K),ATI(I,K)
  400 FORMAT(17X,2I6,5F8.3,F7.1)
  740 CONTINUE
      WRITE(6,600) SLO,BIN
  600 FORMAT(1H1///20X7HSLO  =  ,F8.4//20X7HBIN  =  ,F8.4/1H1)
      STOP
      END

$ENTRY
```

YEAR = 1957

DAY	STA	RAIN	FLOW	THEOR	ANPR	ADJA	ATI
52	1	0.610	0.001	0.067	0.073	0.033	41.9
52	2	0.510	0.001	0.050	0.108	0.020	41.9
52	3	0.700	0.001	0.082	0.028	0.044	41.9
61	1	0.660	0.013	0.075	0.180	0.052	42.4
61	2	0.920	0.018	0.119	0.219	0.100	42.4
61	3	1.150	0.023	0.159	0.144	0.132	42.4
64	1	0.580	0.020	0.061	0.402	0.059	43.7
64	2	0.930	0.032	0.121	0.526	0.131	43.7
64	3	1.330	0.045	0.189	0.492	0.196	43.7
79	1	0.680	0.161	0.086	0.151	0.060	44.9
79	2	2.570	0.610	0.393	0.214	0.373	44.9
79	3	2.090	0.496	0.315	0.252	0.299	44.9
82	1	1.860	0.683	0.278	0.484	0.283	44.9
82	2	0.300	0.110	0.024	1.998	0.174	44.9
82	3	0.910	0.334	0.123	1.181	0.195	44.9
84	1	1.530	0.473	0.224	1.195	0.297	44.9
84	2	1.160	0.358	0.164	1.752	0.290	44.9
84	3	1.230	0.380	0.175	1.112	0.241	44.9
92	1	2.630	0.119	0.184	0.562	0.198	48.8
92	2	2.490	0.113	0.174	0.792	0.210	48.8
92	3	1.830	0.083	0.127	0.638	0.148	48.8
100	1	0.840	0.192	0.070	0.513	0.079	50.4
100	2	0.700	0.160	0.043	0.852	0.083	50.4
100	3	1.420	0.325	0.185	0.557	0.198	50.4
103	1	0.810	0.105	0.064	0.513	0.073	50.4
103	2	2.460	0.318	0.391	1.040	0.450	50.4
103	3	2.150	0.278	0.330	0.707	0.357	50.4
105	1	1.600	0.368	0.221	0.513	0.229	50.4
105	2	0.960	0.220	0.094	1.710	0.217	50.4
105	3	0.500	0.115	0.003	1.685	0.123	50.4
108	1	2.650	0.031	0.589	0.513	0.598	52.2
108	2	1.840	0.022	0.356	1.107	0.421	52.2
108	3	3.080	0.036	0.713	0.791	0.748	52.2
110	1	0.780	0.065	0.051	1.487	0.152	52.2
110	2	0.920	0.077	0.091	1.107	0.156	52.2
110	3	1.240	0.103	0.183	1.619	0.297	52.2
112	1	7.450	2.943	1.971	0.963	2.022	52.2
112	2	5.920	2.339	1.530	0.977	1.583	52.2
112	3	2.130	0.841	0.440	1.110	0.505	52.2

YEAR = 1957

DAY	STA	RAIN	FLOW	THEOR	ANPR	ADJA	ATI
116	1	0.800	0.041	0.057	2.450	0.250	54.0
116	2	2.600	0.132	0.575	2.274	0.751	54.0
116	3	1.670	0.085	0.307	1.115	0.373	54.0
123	1	1.300	0.060	0.243	2.681	0.458	55.3
123	2	2.050	0.094	0.438	1.600	0.550	55.3
123	3	1.300	0.060	0.243	1.380	0.334	55.3
131	1	3.880	1.206	0.914	0.996	0.968	56.5
131	2	1.980	0.616	0.420	1.023	0.477	56.5
131	3	2.480	0.717	0.550	0.717	0.578	56.5
134	1	0.320	0.225	0.000	1.771	0.128	58.7
134	2	1.110	0.780	0.193	1.321	0.279	58.7
134	3	1.360	0.956	0.258	1.587	0.369	58.7
140	1	2.250	1.103	0.490	0.790	0.525	58.7
140	2	1.100	0.539	0.191	0.872	0.233	58.7
140	3	0.680	0.333	0.081	0.813	0.119	58.7
144	1	4.620	1.592	0.929	1.055	0.990	60.6
144	2	1.760	0.606	0.298	0.767	0.330	60.6
144	3	1.490	0.513	0.238	0.681	0.262	60.6
148	1	0.370	0.019	0.000	1.389	0.092	61.7
148	2	0.790	0.040	0.083	1.123	0.150	61.7
148	3	1.300	0.066	0.196	0.775	0.229	61.7
153	1	0.860	0.450	0.099	0.979	0.152	61.7
153	2	1.100	0.575	0.152	0.858	0.193	61.7
153	3	1.160	0.606	0.165	0.921	0.212	61.7
188	1	0.450	0.001	0.000	0.015	0.000	71.2
188	2	1.010	0.001	0.047	0.007	0.007	71.2
188	3	0.670	0.001	0.002	0.000	0.000	71.2
200	1	0.480	0.002	0.000	0.054	0.000	73.4
200	2	0.810	0.004	0.020	0.261	0.005	73.4
226	1	3.440	0.015	0.210	0.267	0.195	75.3
226	2	3.160	0.014	0.187	0.168	0.163	75.3
226	3	3.240	0.015	0.194	0.272	0.179	75.3
229	1	5.640	0.530	0.391	0.758	0.423	75.3
229	2	2.590	0.243	0.140	0.859	0.182	75.3
229	3	6.060	0.569	0.426	0.834	0.465	75.3
267	2	0.790	0.001	0.002	0.136	0.000	70.1
267	3	1.120	0.001	0.015	0.330	0.007	70.1

considered to be linearly dependent upon the antecedent precipitation. The equation of the difference is calculated by the least squares method, as outlined in the third program. Definitions of this program follow.

Definitions

ADD – Correct for antecedent precipitation

ADJA – Predicted runoff adjusted for antecedent precipitation

BIN – y-intercept on the runoff difference equation

DIFF – Difference between the predicted and actual runoffs

SLO – Slope of the runoff difference equation

SUMA – Sum of DIFF for all storms

SUMD – Sum of antecedent precipitation for all storms

SUMDA – Sum of DIFF times antecedent precipitation for all storms

SUMDD – Sum of the square of the antecedent precipitations

THEOR – Predicted runoff ignoring the antecedent precipitation.

Program Six

Duration Constants

For this program, the day, station, rainfall amount, duration, flow, antecedent temperature index, and antecedent precipitation are read into the computer along with the constants calculated from the three previous programs. Runoff predictions are made using these constants. The initial rainfall is calculated, restricting any reduction due to antecedent precipitation to one half the unadjusted value. For each storm, the slope on the runoff curve is found by taking the average

```
$JOB *****************,TIME=30 JOE FEHRING
C          DURATION CONSTANTS
C
      DIMENSION ID(8,40),RAIN(8,40),FLIN(8,40),ANPR(8,40),J(8),LS(8,40),
     A THEOR(8,40),NI(8),ATI(8,40),B(8),C(8),BS(8),CS(8),F(4),FS(4),
     B ADJD(8,40),STA(4),KI(8),LDUR(8,40),FIR(8,40),FRB(8,40)
      READ(5,100) N,(NI(I),I=1,N)
  100 FORMAT(5X,15I5)
         READ(5,300) LSTA
      READ(5,700) SLO,BIN
         LPLUS=LSTA+1
      READ(5,700) (STA(I), I=1,LPLUS)
      READ(5,700) (B(I),C(I),BS(I),CS(I), I=1,8)
  300 FORMAT(5X,I5,7F10.3)
  700 FORMAT(10X,4F10.4)
         A=STA(LPLUS)
         DO 140 I=1,N
         J(I)=0
         DO 130 K=1,50
C          INPUT
      READ(5,500) ID(I,K),LS(I,K),LDUR(I,K),RAIN(I,K),FLIN(I,K),
     A ANPR(I,K),ATI(I,K)
  500 FORMAT(10X,3I5,5F10.3)
C
C          CALCULATIONS USING CONSTANTS FROM PREVIOUS PROGRAMS
         IF(ID(I,K).EQ.0) GO TO 140
         J(I)=J(I)+1
  610    IF(ATI(I,K).GE.40.) GO TO 620
         KL=1
         GO TO 690
  620    IF(ATI(I,K).GE.45.) GO TO 630
         KL=2
         GO TO 690
  630    IF(ATI(I,K).GE.50.) GO TO 640
         KL=3
         GO TO 690
  640    IF(ATI(I,K).GE.55.) GO TO 650
         KL=4
         GO TO 690
  650    IF(ATI(I,K).GE.60.) GO TO 660
         KL=5
         GO TO 690
  660    IF(ATI(I,K).GE.65.) GO TO 670
         KL=6
         GO TO 690
  670    IF(ATI(I,K).GE.70.) GO TO 680
         KL=7
         GO TO 690
  680    KL=8
  690 CONTINUE
         IF(ID(I,K).GE.71) GO TO 320
         KK=1
         GO TO 380
  320    IF(ID(I,K).GE.106) GO TO 330
         KK=2
         GO TO 380
  330    IF(ID(I,K).GE.141) GO TO 340
         KK=3
         GO TO 380
  340    IF(ID(I,K).GE.176) GO TO 350
         KK=4
         GO TO 380
  350    IF(ID(I,K).GE.211) GO TO 360
         KK=5
         GO TO 380
  360    IF(ID(I,K).GE.246) GO TO 370
         KK=6
         GO TO 380
  370    KK=7
  380    FRB(I,K)=(BS(KK)+B(KL))/2.
         THEOR(I,K)=FRB(I,K)*RAIN(I,K)+(C(KL)+
     A CS(KK))/2.-(SLO*ANPR(I,K)+BIN)
         FIR(I,K)=(-(CS(KK)+C(KL))/2.-(SLO*ANPR(I,K)+BIN))/(BS(KK)+
     A B(KL))/2.
        CHECK=-.5*((CS(KK)+C(KL))/(BS(KK)+B(KL)))
         IF(FIR(I,K).GT.CHECK) GO TO 385
         FIR(I,K)=CHECK
  385    IF(THEOR(I,K).GT.0.) GO TO 130
         THEOR(I,K)=0.0
  130 CONTINUE
  140 CONTINUE
C
C          CALCULATION OF FRACTIONAL VALUES
         L1=0
         L2=0
         L3=0
         DO 420 I=1,3
         F(I)=0.0
         FS(I)=0.0
  420 CONTINUE
         DO 460 I=1,N
         JA=J(I)
         DO 460 K=1,JA
         IF(LDUR(I,K)-2) 430,440,450
  430    L1=L1+1
         F(1)=F(1)+THEOR(I,K)
         FS(1)=FS(1)+FLIN(I,K)
         GO TO 460
  440    L2=L2+1
         F(2)=F(2)+THEOR(I,K)
         FS(2)=FS(2)+FLIN(I,K)
         GO TO 460
  450    L3=L3+1
         F(3)=F(3)+THEOR(I,K)
         FS(3)=FS(3)+FLIN(I,K)
  460 CONTINUE
         F(1)=F(1)/FS(1)
         F(2)=F(2)/FS(2)
         F(3)=F(3)/FS(3)
         F(4)=F(3)
         DO 560 I=1,N
         JA=J(I)
         DO 560 K=1,JA
         ADJD(I,K)=FRB(I,K)*(RAIN(I,K)-FIR(I,K))/F(LDUR(I,K))
  560 CONTINUE
         DO 740 I=1,N
         JA=J(I)
      WRITE(6,200) NI(I)
  200 FORMAT(1H1////20X7HYEAR =  ,I4///20X58HDAY   STA   DUR       RAIN
     A     FLOW      THEOR       ADJD    )
```

DIFF = -1.0195

TAD = 2.3874

I	AD
1	0.9283
2	0.9590
3	0.9149

of the slopes calculated using the season and the antecedent temperature index. For each of three durations, a ratio, F, is found of the sum of the predicted flows to the sum of the actual flows. The new predicted runoff is found by multiplying the slope of the curve by the effective rainfall and dividing by the adjustment factor, F. The effective rainfall is simply the total rainfall minus the initial rainfall.

Definitions

ADJD – Predicted runoff, adjusted for duration

B – Slope of runoff curve using ATI

C – y-intercept of runoff curve using ATI

CHECK – One half of the initial rainfall

F – Correction factor for duration

FIR – Initial Rainfall

FRB – Slope of runoff curve using both season and ATI

FS – Sum of the flows for any duration, used to calculate F.

Program Seven

Areal Distribution

This program was written specifically for a basin with three reporting weather stations. The predicted area runoffs are calculated using the same procedure as in the sixth program. The predicted area flows should equal the actual basin flow. The program sums each of the predicted area flows, and each of the sums multiplied by the individual station's correction factor, –AD, is set equal to the sum of the actual basin flow. Two of the values of AD are set equal to one, and

```
$JOB ******************,TIME=30 JOE FEHRING
C          AREAL DISTRIBUTION CONSTANTS
C
      DIMENSION ID(8,40),RAIN(8,40),FLIN(8,40),ANPR(8,40),J(8),LS(8,40),
     A THEOR(8,40),NI(8),ATI(8,40),B(8),C(8),BS(8),CS(8),F(4),FS(4),
     B ADJD(8,40),STA(4),KI(8),LDUR(8,40),FIR(8,40),FRB(8,40)
     C ,AD(3),RT(3)
      READ(5,100) N,(NI(I),I=1,N)
  100 FORMAT(5X,15I5)
      READ(5,300) LSTA,AA
      READ(5,700) SLO,BIN
         LPLUS=LSTA+1
      READ(5,700) (STA(I), I=1,LPLUS)
      READ(5,700) (B(I),C(I),BS(I),CS(I), I=1,8)
  300 FORMAT(5X,I5,7F10.3)
  700 FORMAT(10X,4F10.4)
         A=STA(LPLUS)
         DO 140 I=1,N
         J(I)=0
         DO 130 K=1,50
C          INPUT
      READ(5,500) ID(I,K),LS(I,K),LDUR(I,K),RAIN(I,K),FLIN(I,K),
     A ANPR(I,K),ATI(I,K)
  500 FORMAT(10X,3I5,5F10.3)
C
C          CALCULATIONS USING CONSTANTS FROM PREVIOUS PROGRAMS
         IF(ID(I,K).EQ.0) GO TO 140
         J(I)=J(I)+1
  610    IF(ATI(I,K).GE.40.) GO TO 620
         KL=1
         GO TO 690
  620    IF(ATI(I,K).GE.45.) GO TO 630
         KL=2
         GO TO 690
  630    IF(ATI(I,K).GE.50.) GO TO 640
         KL=3
         GO TO 690
  640    IF(ATI(I,K).GE.55.) GO TO 650
         KL=4
         GO TO 690
  650    IF(ATI(I,K).GE.60.) GO TO 660
         KL=5
         GO TO 690
  660    IF(ATI(I,K).GE.65.) GO TO 670
         KL=6
         GO TO 690
  670    IF(ATI(I,K).GE.70.) GO TO 680
         KL=7
         GO TO 690
  680    KL=8
  690 CONTINUE
         IF(ID(I,K).GE.71) GO TO 320
         KK=1
         GO TO 380
  320    IF(ID(I,K).GE.106) GO TO 330
         KK=2
         GO TO 380
  330    IF(ID(I,K).GE.141) GO TO 340
         KK=3
         GO TO 380
  340    IF(ID(I,K).GE.176) GO TO 350
         KK=4
         GO TO 380
  350    IF(ID(I,K).GE.211) GO TO 360
         KK=5
         GO TO 380
  360    IF(ID(I,K).GE.246) GO TO 370
         KK=6
         GO TO 380
  370    KK=7
  380    FRB(I,K)=(BS(KK)+B(KL))/2.
         THEOR(I,K)=FRB(I,K)*RAIN(I,K)+(C(KL)+
     A CS(KK))/2.-(SLO*ANPR(I,K)+BIN)
         FIR(I,K)=(-(CS(KK)+C(KL))/2.-(SLO*ANPR(I,K)+BIN))/(BS(KK)+
     A B(KL))/2.
         CHECK=-.5*((CS(KK)+C(KL))/(BS(KK)+B(KL)))
         IF(FIR(I,K).GT.CHECK) GO TO 385
         FIR(I,K)=CHECK
  385    IF(THEOR(I,K).GT.0.) GO TO 130
         THEOR(I,K)=0.0
  130 CONTINUE
  140 CONTINUE
C
C          STATION CONSTANTS
         DO 810 I=1,3
         AD(I)=0.
         RT(I)=0.
  810 CONTINUE
         RTS=0.
         DO 850 I=1,N
         JA=J(I)
         DO 850 K=1,JA
         RTS=RTS+FLIN(I,K)*STA(LS(I,K))
         IF(LS(I,K)-2) 820,830,840
  820    RT(1)=RT(1)+THEOR(I,K)
         GO TO 850
  830    RT(2)=RT(2)+THEOR(I,K)
         GO TO 850
  840    RT(3)=RT(3)+THEOR(I,K)
  850 CONTINUE
         AD(1)=(RTS-RT(2)*STA(2)-RT(3)*STA(3))/(RT(1)*STA(1))
         AD(2)=(RTS-RT(1)*STA(1)-RT(3)*STA(3))/(RT(2)*STA(2))
         AD(3)=(RTS-RT(1)*STA(1)-RT(2)*STA(2))/(RT(3)*STA(3))
         TAD=AD(1)+AD(2)+AD(3)
         DIFF=RTS-RT(1)*STA(1)-RT(2)*STA(2)-RT(3)*STA(3)
         DO 860 K=1,3
         AD(K)=1.0+(AD(K)-1.0)*(AD(K)/TAD)
  860 CONTINUE
      WRITE(6,600) DIFF,TAD, (I,AD(I), I=1,3)
  600 FORMAT(1H1///20X,7HDIFF =   ,F10.4//20X,7HTAD   =   ,F10.4///20X,1HI,
     A 10X,2HAD/3(20XI1,5X,F10.4/)/1H1)
      STOP
      END

$ENTRY
```

```
      DO 740 K=1,JA
      WRITE(6,400) ID(I,K),LS(I,K),LDUR(I,K),RAIN(I,K),FLIN(I,K),
     A THEOR(I,K),ADJD(I,K)
  400 FORMAT(17X,3I6,4F10.3)
  740 CONTINUE
      WRITE(6,1800) (I,F(I), I=1,3)
 1800 FORMAT(1H1////24X1HI,10X,1HF/3(24X,I1,5X,F10.4/))
      PRINT 2000
 2000 FORMAT(1H1)
      STOP
      END

$ENTRY
```

YEAR = 1957

DAY	STA	DUR	RAIN	FLOW	THEOR	ADJD
52	1	1	0.610	0.001	0.033	0.103
52	2	1	0.510	0.001	0.020	0.083
52	3	2	0.700	0.001	0.044	0.053
61	1	2	0.660	0.013	0.052	0.049
61	2	2	0.920	0.018	0.100	0.073
61	3	1	1.150	0.023	0.132	0.215
64	1	1	0.580	0.020	0.059	0.097
64	2	2	0.930	0.032	0.131	0.074
64	3	2	1.330	0.045	0.196	0.109
79	1	1	0.680	0.161	0.060	0.119
79	2	4	2.570	0.610	0.373	0.317
79	3	2	2.090	0.496	0.299	0.172
82	1	1	1.860	0.683	0.283	0.352
82	2	2	0.300	0.110	0.174	0.003
82	3	1	0.910	0.334	0.195	0.150
84	1	1	1.530	0.473	0.297	0.272
84	2	1	1.160	0.358	0.290	0.183
84	3	1	1.230	0.380	0.241	0.215
92	1	1	2.630	0.119	0.198	0.223
92	2	2	2.490	0.113	0.210	0.089
92	3	3	1.830	0.083	0.148	0.098
100	1	2	0.840	0.192	0.079	0.062
100	2	1	0.700	0.160	0.083	0.110
100	3	1	1.420	0.325	0.198	0.283
103	1	2	0.810	0.105	0.073	0.059
103	2	3	2.460	0.318	0.450	0.343
103	3	3	2.150	0.278	0.357	0.295
105	1	3	1.600	0.368	0.229	0.210
105	2	2	0.960	0.220	0.217	0.071
105	3	1	0.500	0.115	0.123	0.055
108	1	3	2.650	0.031	0.598	0.528
108	2	1	1.840	0.022	0.421	0.537
108	3	2	3.080	0.036	0.748	0.420
110	1	1	0.780	0.065	0.152	0.167
110	2	1	0.920	0.077	0.156	0.216
110	3	1	1.240	0.103	0.297	0.328
112	1	1	7.450	2.943	2.022	2.495
112	2	1	5.920	2.339	1.583	1.961
112	3	1	2.130	0.841	0.505	0.638

the third value of AD is calculated. This is repeated until all three values of AD are found. The final values of AD are found by the equation

$$AD_k = 1 - (AD_k - 1) \times \frac{AD_k}{TAD} .$$

k assumes the values one, two and three, representing the respective Thiessen areas: Stillwater, Maramec, and Cushing.

Definitions

AD – Areal Distribution correction factor

DIFF – Total difference between predicted and actual basin flow

RT – Sum of predicted runoffs for individual stations

RTS – Sum of actual basin runoff

TAD – Sum of the three values of RT.

APPENDIX B

GENERAL FLOW CHART

Appendix B is a general flow chart to be followed in calculating the rainfall-runoff relationships using only one program. Comments pertaining to any step are boxed in dotted lines and placed to the right of that step. References are made to the programs listed in Appendix A.

Definitions

- A – Area of basin in square miles
- AD – Areal Distribution correction factor
- ANPR – Antecedent Precipitation in inches per day
- ATI – Antecedent Temperature Index
- BIN – y-intercept on runoff difference curve for antecedent precipitation
- BS – Slope of runoff curve calculated using seasonal variation
- BSF – Assumed baseflow at the start of the year
- BT – Slope of runoff curve using the ATI
- CON – Conversion factor for area flow from seconds-feet-days to inches of runoff
- CS – y-intercept of runoff curve calculated using the seasonal variation
- CT – y-intercept of runoff curve calculated using the ATI
- DIFF – Difference between predicted and actual runoff due to antecedent precipitation
- F – Correction factor for duration
- FLIN – Flow in inches
- FLOW – Flow in seconds-feet-days
- FRB – Slope of runoff curve using both the ATI and season

FRC	y-intercept of runoff curve using both the ATI and season
ID	Day the storm began
LDUR	Duration of the storm
LPLUS	As a subscript, it refers to basin values
LREC	Days of record for one year
LSTA	Weather reporting stations
N	Number of years of record
PREC	Daily Precipitation
RO	Stream Runoff
SLO	Slope of runoff difference curve for antecedent precipitation
TEMP	Mean daily Temperature
THEOR	Theoretical or predicted runoff
XM	Minimum runoff considered in the program
XN	Minimum rainfall considered in the program.

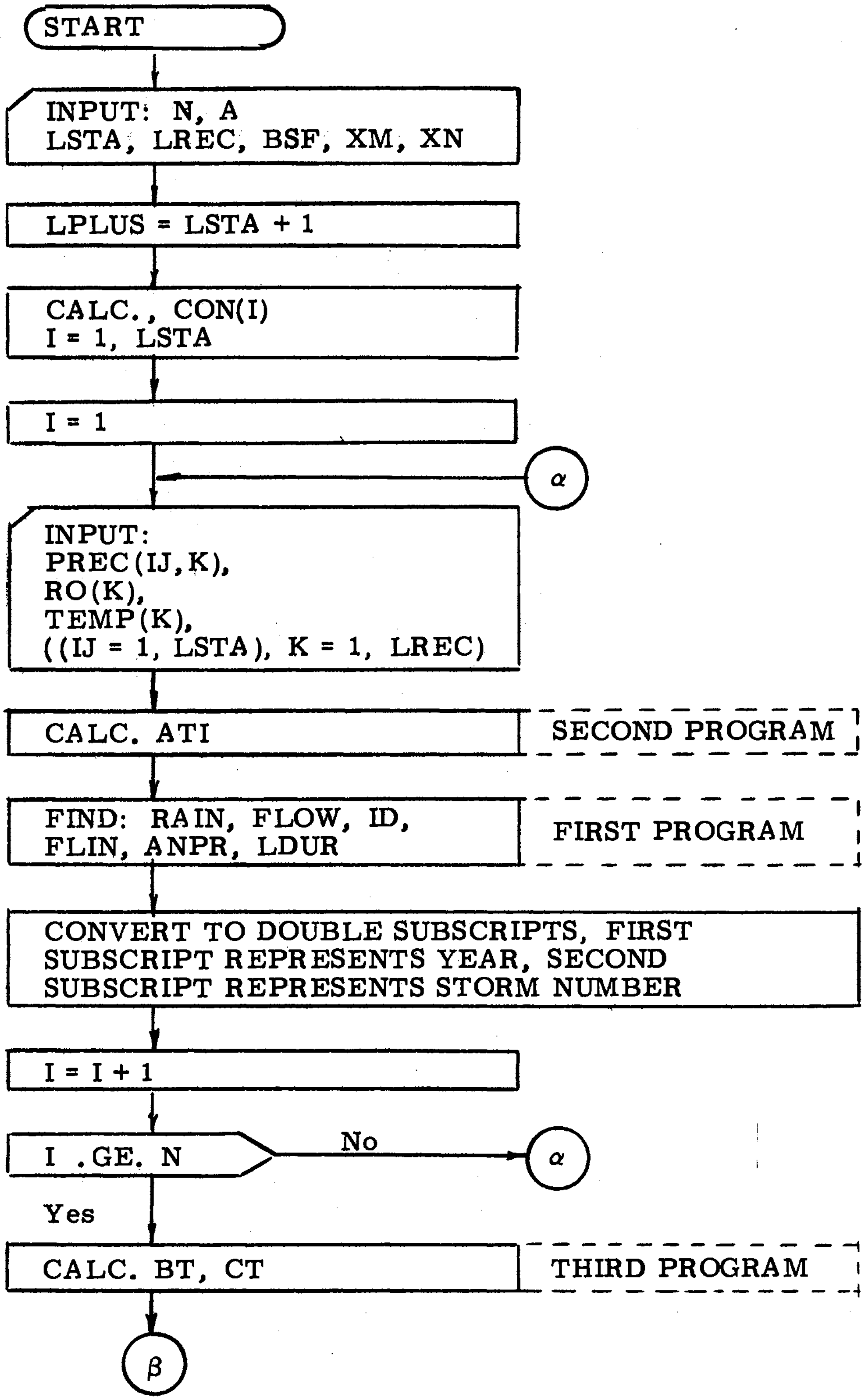

Figure B.1. General Flow Chart

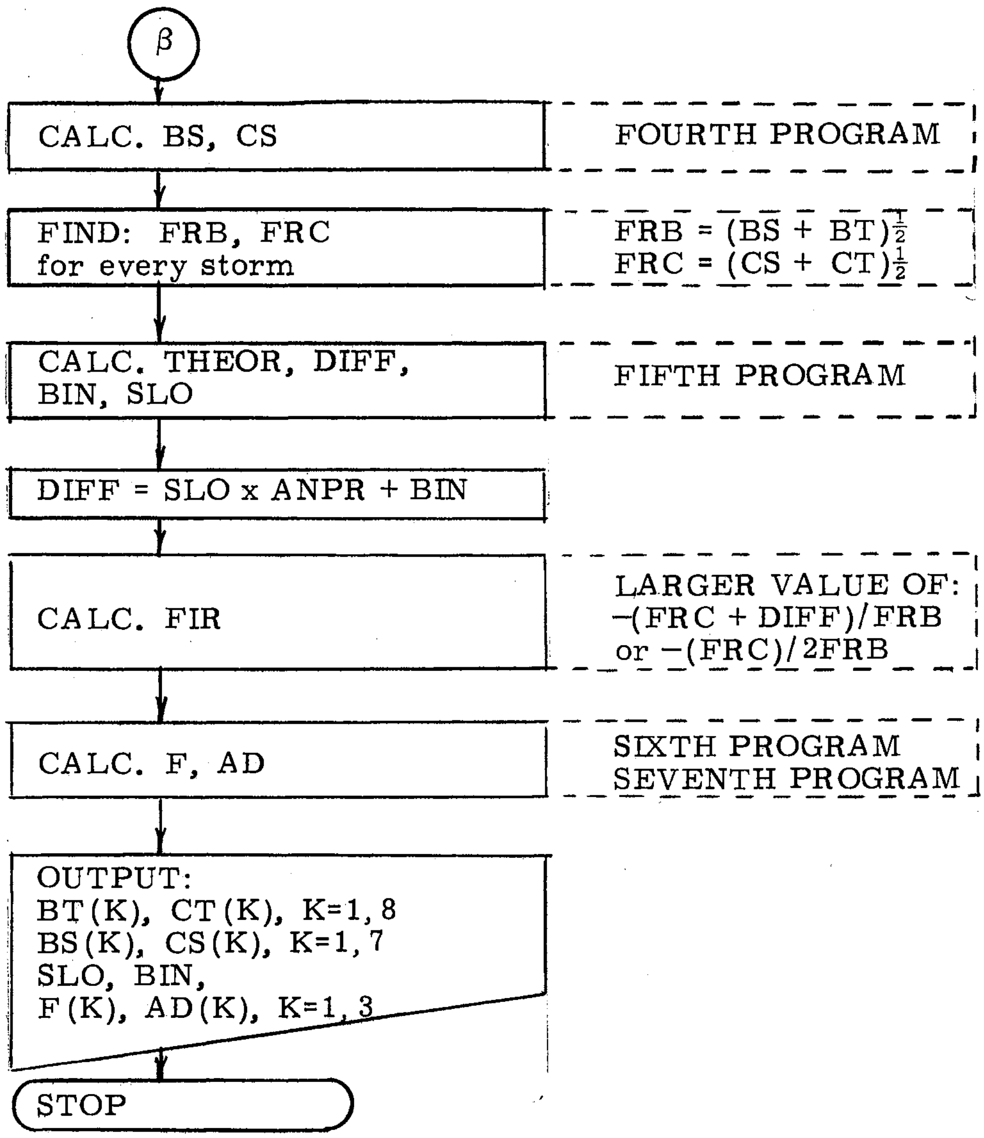

Figure B.1. General Flow Chart (Continued)

APPENDIX C

INTERPRETATION OF COMPUTER PRINTOUTS

Appendix C is furnished to aid the reader in interpreting the computer printouts. The term used by the programs, IDAY, is printed with the corresponding calendar date for non-leap years. In a leap year, IDAY 1 corresponds to January 31 instead of January 30. Thus March 1 is IDAY 31 for all years. The days shown are the first day of the weeks numbered.

TABLE X

INTERPRETATION OF COMPUTER PRINTOUTS

Month	Day	IDay	Week	Month	Day	IDay	Week
Jan	30	1	1	Jul	17	169	25
Feb	6	8	2	Jul	24	176	26
Feb	13	15	3	Jul	31	183	27
Feb	20	22	4	Aug	7	190	28
Feb	27	29	5	Aug	14	197	29
Mar	6	36	6	Aug	21	204	30
Mar	13	43	7	Aug	28	211	31
Mar	20	50	8	Sep	4	218	32
Mar	27	57	9	Sep	11	225	33
Apr	3	64	10	Sep	18	232	34
Apr	10	71	11	Sep	25	239	35
Apr	17	78	12	Oct	2	246	36
Apr	24	85	13	Oct	9	253	37
May	1	92	14	Oct	16	260	38
May	8	99	15	Oct	23	267	39
May	15	106	16	Oct	30	274	40
May	22	113	17	Nov	6	281	41
May	29	120	18	Nov	13	288	42
Jun	5	127	19	Nov	20	295	43
Jun	12	134	20	Nov	27	302	44
Jun	19	141	21	Dec	4	309	45
Jun	26	148	22	Dec	11	316	46
Jul	3	155	23	Dec	18	323	47
Jul	10	172	24	Dec	25	330	48

VITA

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