ANNUAL TOTALS AND TEMPORAL DISTRIBUTION OF CATTLE FEEDLOT RUNOFF IN KANSAS

by

FREDERICK GORDON BERGSRUD

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Approved by:

G. H. Larson

Major Professor

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INTRODUCTION

One of the major problems of the cattle feeding industry is waste management and disposal. One portion of this problem is the rainfall runoff from the feedlots. Feedlot runoff has been shown to carry pollutants from the feedlots. It has been further shown that these pollutants can and do end up in contaminating concentrations in Kansas rivers and streams.

The early studies of cattle manure dealt with quality and composition. Taiganides and Hazen (1) have compiled them into average data. Geldreich *et al*. (2, 3) studied total coliform and developed the fecal coliform: fecal streptococcus ratio. Witzel *et al*. (4) collected barn slurry and made quantitative measurements of both fecal coliform and fecal streptococci.

Miner (5) described cattle feedlot runoff as a high strength organic waste ranging from 1.25 to 7 times as strong as that of domestic sewage based on Biochemical Oxygen Demand (BOD). Smith and Miner (6) found that adverse conditions developed below several Kansas feedlots following rainfall. Smith (7) in another study reported that 15 of 27 fish kills in Kansas during 1964 were believed to be caused primarily by runoff from commercial cattle feedlots.

These studies document the need for the treatment of the runoff before it enters a natural watercourse. Miner (5) states that the first phase in a treatment scheme may be expected to be a runoff collection structure. For this structure to be safe, economical and efficient, its design must be based on several factors. Factors that will need to be considered include the total annual runoff, the inflow rate, the variation and temporal distribution of the inflow, transport and storage losses, and the management of the runoff accumulation in the collection structure.

PURPOSE

The purpose of this study was to establish a procedure for determining the total annual runoff, the inflow rates, and the temporal distribution of runoff from a cattle feedlot. It was supposed that by using available methods for describing the runoff producing characteristics of feedlots and combining this with daily precipitation records that cumulative runoff curves could be obtained.

The specific objectives were:

1. To establish a system for determining total annual runoff, its inflow rate and its temporal distribution;
2. To analyze data using this system; and,
3. To examine the data to determine the range and distribution of occurrences.

REVIEW OF LITERATURE

Factors Affecting Runoff

Runoff as used in this study refers to surface runoff only. Frevert, et al. (8) state that the factors affecting runoff may be divided into those factors associated with the precipitation and those factors associated with the watershed.

Precipitation Factors

Rainfall duration, intensity and areal distribution influence the rate and volume of runoff (8). Each factor affects runoff independently as well as in combination with one or both of the other factors. Precipitation data is presently being recorded at 290 stations in Kansas and is reported in a monthly publication of the U.S. Department of Commerce (9). Daily precipitation records are available for 24 stations for periods exceeding 50 years. Data from these stations has been used in several studies. Bark (10) reported the weekly precipitation amounts including weekly normals for the 24 stations. The stated purpose of this study was to encourage the use of shorter periods for the summarization of data. In another study, Bark (11) developed tables on the percent chance of receiving rainfall amounts varying from 0.10 inches to 2.80 inches of rain in a one week period. Feyerherm and Bark (12) studied the probabilities of sequences of wet and dry days in Kansas. The Kansas State Board of Agriculture (13) reported the average number of days of rains of different intensities in each month for a 50 year period beginning in 1896. Rainfall Frequency Maps for selected durations and return periods have also been published (14). Copley *et al.* (15) studied the relationship of runoff to rainfall intensity and total rainfall per storm. This data which is shown in Table I summarized the results of eight years of study on bare plots at Statesville, North Carolina. The study showed that generally the proportion of runoff increased with both total storm amount and storm intensity.

TABLE I

EFFECT OF RAINFALL AMOUNTS AND INTENSITIES ON RUNOFF

Rainfall Amount Groups Inches	Per Cent Total Rainfall	Per Cent Total Runoff
0-1	28.7	22.5
1-2	33.2	36.3
2-3	28.2	28.5
3 or more	9.9	12.8

TABLE I (continued)

Rainfall Intensity Groups Inches Per Hour	Per Cent Total Rainfall	Per Cent Total Runoff
0-1.5	43.7	26.4
1.5-3.0	32.4	36.8
3.0-4.5	17.2	26.6
4.5 or More	6.7	10.3

Watershed Factors

Watershed factors affecting runoff are listed by Kohnke and Bertrand (16) as being soil, size of drainage area, plant cover, and management practices. They further state that the effects of these factors are so complex that, even though all of them are known, it is possible to calculate only very approximately the resulting runoff conditions.

Even though an accurate prediction is not possible, it has still been necessary to develop methods to estimate both annual runoff and peak runoff. Kohnke and Bertrand (16) mention two methods as being used frequently to determine peak runoff rates. These are the "rational method" and Cook's method.

Frevert et al. (17) p. 60 considers the "rational method" to be a great oversimplification of a complicated process. It is, however, considered to be sufficiently accurate to be used in the design of relatively inexpensive projects.

Cook's method is more widely used in the estimation of runoff from small agricultural areas. It is based on a system of assigning numbers to the characteristics of a watershed that affect runoff. These characteristics are designated in four categories; relief, soil infiltration, vegetal cover, and surface storage. Hydrologists with the United States Soil Conservation Service have developed a system for determining runoff when the rainfall is known. This method is reported in their Hydrology Guide (18). It uses two variables, a hydrologic soil-cover complex number and antecedent rainfall. This method was selected for use in this study to describe the runoff characteristics of a cattle feedlot and is reported on more fully in a later section.

SCOPE AND PROCEDURE

Scope

The study included data from twelve stations in Kansas. These stations were used because their daily precipitation records had been stored on IBM magnetic tape. The stations gave good areal distribution of the state and represented the full range of annual precipitation totals. This range for Kansas is from slightly under 16 inches to just over 40 inches per year. The geographical location of these stations and the normal annual precipitation lines have been shown in Plate 1. Each station was studied for a period of 30 years from March 1, 1931 through February 27, 1960. Feyerherm and Bark (12) state that precipitation patterns from the past 30 to 50 years are a good basis for forecasts of the next 30 to 50 years.

The precipitation records were stored on magnetic tape by climatological week number. Week numbers start with week one beginning on March 1 and week 52 beginning on February 21. Using this system, the dates of February 28 and 29 are omitted. The advantages of starting on March 1 are in avoiding the confusion of leap year and by omitting the dates of February 28 and 29 each day of the year always falls in the same week number.

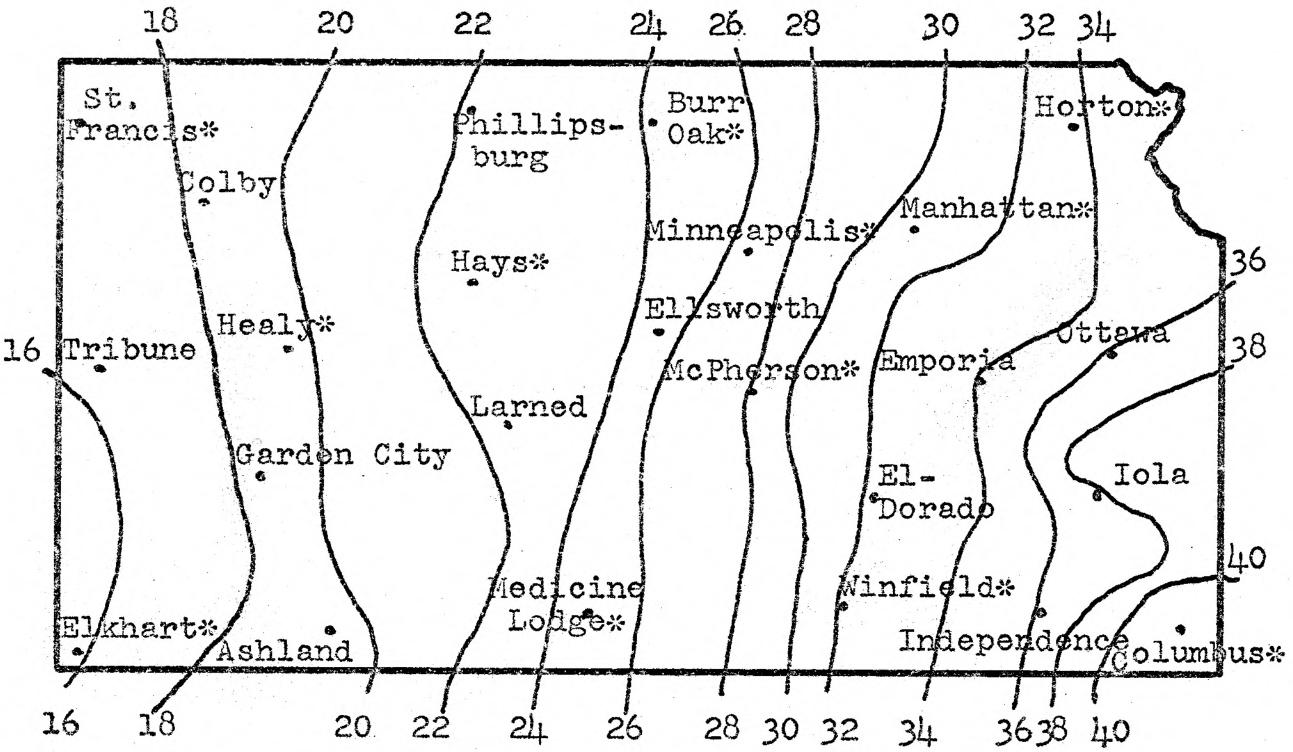
As was stated earlier, the method chosen to describe the runoff producing characteristics of the watershed was the soil cover complex number. This number for a watershed is arrived at from a table which has been reproduced here as Table II, pages 10 and 11. The watershed may be subdivided and a weighted value for the entire watershed calculated from the subdivision values.

The factors shown in the soil cover complex table are: land use or cover; treatment or practice; hydrologic condition

EXPLANATION OF PLATE 1

Geographical location of weather bureau stations for which data is available on magnetic tape. Normal annual precipitation is also shown in inches.

PLATE 1



*Stations Used in Study

TABLE II

RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL-COVER COMPLEXES

COVER			Hydrologic Soil Group			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Fallow	Straight Row	-----	77	86	91	94
Row Crops	Straight Row	Poor	72	81	88	91
	" "	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	" and Terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small Grain	Straight Row	Poor	65	76	84	88
	" "	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	"	Good	61	73	81	84
	" and Terraced	Poor	61	72	79	82
	" " "	Good	59	70	78	81
Close-seeded Legumes 1/ or Rotation Meadow	Straight Row	Poor	66	77	85	89
	"	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	" and Terraced	Poor	63	73	80	83
	" and "	Good	51	67	76	80

Pasture or Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		----	74	84	90	92

1/ Close-drilled or broadcast.

2/ Including right-of-way.

Source: Soil Conservation Service National Engineering Handbook, Section 4, Hydrology, U.S.D.A., Washington, D. C., August 1964, 9.2

of soil cover; and, hydrologic soil groups A, B, C, or D.

The soil groups are defined as follows:

Group A--Includes deep soils with very little silt and clay; also, deep, rapidly permeable loess.

Group B--Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration even after wetting.

Group C--Comprises shallow soils and soils containing considerable clay and colloid, though less than those of Group D. The group has below-average infiltration after pre-saturation.

Group D--Includes mostly clays of high swelling percent; but, the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

The selection of a soil cover complex number was done by an empirical approach to each of the four factors.

Factor 1--Land Use or Cover
The only possible selection from those listed was the fallow condition. This was true for either a surfaced or unsurfaced lot. The condition, roads, hardsurface might have been more applicable to the surfaced lot if the right of way had not been included.

Factor 2--Treatment or Practice
Having selected the fallow condition for Factor 1, no selection is available for this factor.

Factor 3--Hydrologic Condition of Soil Cover
Same as Factor 2.

Factor 4--Hydrologic Soil Group
For a surfaced lot, Group D, the group with the highest runoff potential was selected. For an unsurfaced lot the group selected as representative of most feedlots was Group C.

The selection of a value for Factor 4 for unsurfaced lots may vary with the original soil properties at the feedlot location, the age of the feedlot, the number of head per acre of feedlot, and the management practices of the feedlot operator. The original soil characteristics of the feedlot site will certainly be modified to some degree as a result of the deposition of cattle excreta on the surface and the compaction of the surface by the animals hooves. Zimmerman (19) reported that ponds built on permeable soils could be treated with heavy manure applications and light compaction with sheepsfoot rollers to reduce water losses.

Using the factors selected through the empirical approach, the soil cover complex numbers arrived at were 91 and 94 for the unsurfaced and surfaced lots respectively. Miner (5) in his study plotted runoff quantity as a function of rainfall and selected a soil cover complex number which gave the best fit to his plot. The numbers he selected were identical to those arrived at empirically.

Only the soil cover complex number for unsurfaced lots was used in this study. It was selected because the majority of lots in Kansas are unsurfaced except for feeding and watering areas.

No adjustment was made in the soil cover complex number for antecedent moisture conditions. Those selected empirically were based on an average antecedent moisture condition. Miner (5) did not state an antecedent moisture condition for his graphical solution. If the selected number, 91, was adjusted to dry conditions, the number would be 80. If adjusted to wet conditions, it would be 98. (18)

Plates 2 and 3, pages 16 and 18, show the rainfall-runoff relationship for soil cover complex numbers from 30 to 100. These graphs were interpolated to arrive at the figures for a soil cover complex number of 91 which are shown in Table III, page 19.

Procedure

The data analysis was performed by an IBM 360 computer. The computer program used is reproduced in the appendix. The procedure was:

Step 1--Read daily precipitation. Start with Station 1, Week 1 beginning on March 1, 1931.

Step 2--Read runoff as a function of daily precipitation from Table III on page 19 for Soil Cover Complex number of 91.

Step 3--Repeat steps 1 and 2 to complete climatological week.

Step 4--Print total of runoff for climatological week.

Step 5--Print cumulative sum of weekly runoffs.

Step 6--Repeat steps 1 through 5 for 52 weeks.

Step 7--Print annual runoff and annual precipitation totals.

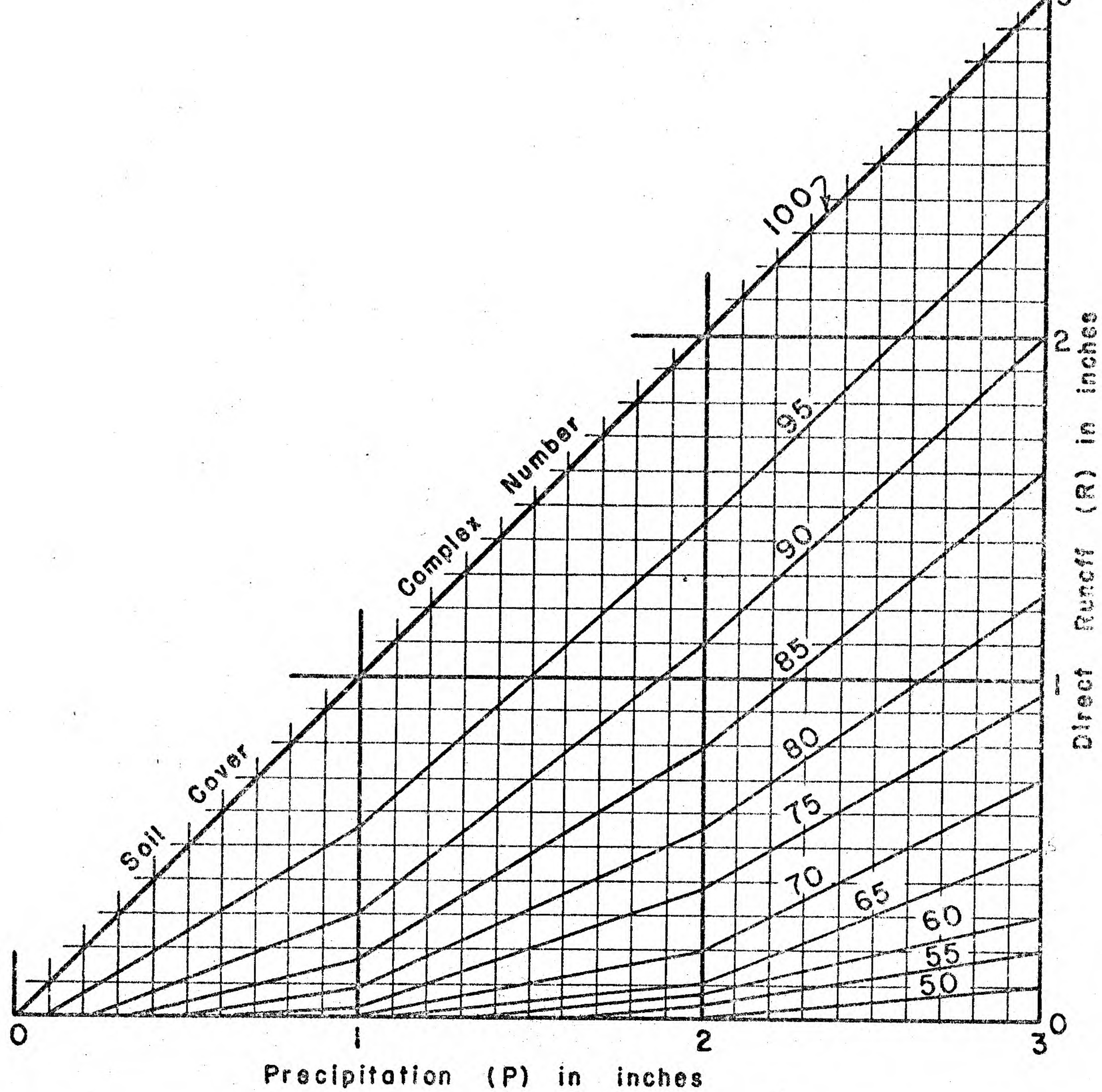
Step 8--Repeat Steps 1 through 7 for succeeding years until 30-year period is completed for Station 1.

Step 9--Group annual runoff totals into five groups as follows: six highest, six upper intermediate, six middle, six lower intermediate, and six lowest.

EXPLANATION OF PLATE 2

Relationship between precipitation and runoff for range of soil cover complex numbers.

PLATE 2



Soil Cover Complex Number
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
Precipitation (P) in inches
Direct Runoff (R) in inches

EXPLANATION OF PLATE 3

Relationship between precipitation and runoff for range of soil cover complex numbers. (continued)

PLATE 3

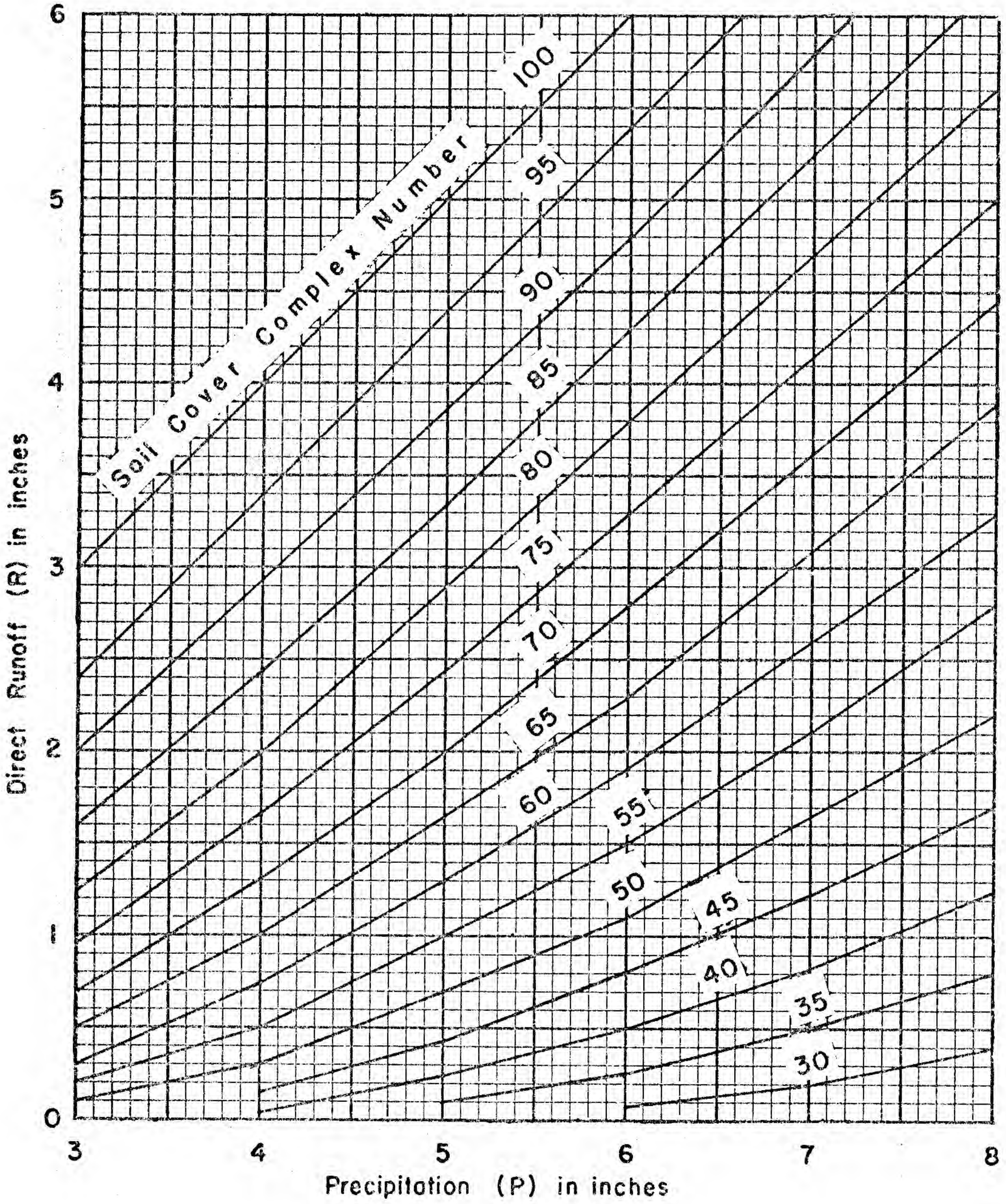

Soil Cover Complex Number
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
Direct Runoff (R) in inches
0
1
2
3
4
5
6
Precipitation (P) in inches
3
4
5
6
7
8

TABLE III

RUNOFF AS A FUNCTION OF RAINFALL BASED ON A SOIL COVER COMPLEX NUMBER OF NINETY-ONE

RAINFALL IN INCHES	RUNOFF IN INCHES	RAINFALL IN INCHES	RUNOFF IN INCHES
0.00 - 0.18	0.00	3.06 - 3.15	2.17
0.18 - 0.25	0.01	3.16 - 3.25	2.26
0.26 - 0.35	0.05	3.26 - 3.35	2.35
0.36 - 0.45	0.09	3.36 - 3.45	2.45
0.46 - 0.55	0.12	3.46 - 3.55	2.54
0.56 - 0.65	0.17	3.56 - 3.65	2.64
0.66 - 0.75	0.21	3.66 - 3.75	2.73
0.76 - 0.85	0.25	3.76 - 3.85	2.83
0.86 - 0.95	0.30	3.86 - 3.95	2.92
0.96 - 1.05	0.35	3.96 - 4.05	3.02
1.06 - 1.15	0.43	4.06 - 4.15	3.11
1.16 - 1.25	0.51	4.16 - 4.25	3.21
1.26 - 1.35	0.59	4.26 - 4.35	3.30
1.36 - 1.45	0.67	4.36 - 4.45	3.40
1.46 - 1.55	0.76	4.46 - 4.55	3.49
1.56 - 1.65	0.84	4.56 - 4.65	3.59
1.66 - 1.75	0.92	4.66 - 4.75	3.68
1.76 - 1.85	1.01	4.76 - 4.85	3.78
1.86 - 1.95	1.09	4.86 - 4.95	3.87
1.96 - 2.05	1.17	4.96 - 5.05	3.97
2.06 - 2.15	1.26	5.06 - 5.15	4.06
2.16 - 2.25	1.35	5.16 - 5.25	4.16
2.26 - 2.35	1.44	5.26 - 5.35	4.25
2.36 - 2.45	1.53	5.36 - 5.45	4.35
2.46 - 2.55	1.62	5.46 - 5.55	4.44
2.56 - 2.65	1.71	5.56 - 5.65	4.54
2.66 - 2.75	1.80	5.66 - 5.75	4.63
2.76 - 2.85	1.89	5.76 - 5.85	4.73
2.86 - 2.95	1.98	5.86 - 5.95	4.82
2.96 - 3.05	2.07	5.96 - 6.00*	4.92
		Any additional rainfall - 100% runoff	

*Runoff for rainfall exceeding 6.00 inches is computed as follows: Runoff = 4.92 plus (Rainfall - 6.00 inches).

Step 10-Plot each year in the first group from Step 9 on one graph with climatological week as abcissa and runoff in inches as ordinate.

Step 11-Repeat Step 10 for the four other groups from Step 9.

Step 12-Repeat Steps 1 through 11 for the other 11 stations.

The data was originally recorded on standard IBM magnetic tapes. Bark and Plant (20) have described the manner in which the data has been stored. A total of eight tapes were used with each tape containing three data sets for the total of 24 stations.

Two major problems were encountered in taking the data from the tapes. The first was that the original program did not take into consideration the possibility of missing data or a blank spot in the data field. The tapes had been checked for missing data but a representative value had not in all cases been inserted. Bark and Plant (20) in discussing this stated, "In general, where such a condition occurred, it occurred for a long period in the climatological records." Walker (21) who had worked with the tapes provided a sub-routine written in machine language that enabled this difficulty to be overcome.

The use of the tapes with missing data could have introduced error into the study. There are two reasons, however, which indicate that it probably did not introduce significant error. One reason was that the abnormal endings of a station run without the sub-routine usually occurred prior to March 1, 1931, where this study began. The other reason is that if the data is generally missing for long periods this would be obvious in the results and all stations were checked for this possibility.

The second problem encountered was that the tapes were originally prepared for use with an IBM 1401 computer. There were, therefore, double tape marks separating the data sets. In order to overcome this, it was necessary to change the data set designation from the standard for data sets Number 2 and 3. To obtain data set Number 2, data set Number 3 had to be requested. To obtain data set Number 3, data set Number 5 had to be requested.

With the above difficulties overcome, it was possible to obtain records from twelve stations for this study which gave good areal distribution. Several stations not reported in the study would still not give complete results for the period desired.

RESULTS

Definitions

Several items that are used repeatedly in the following discussion are defined as follows:

Range. The maximum and minimum values of any parameter.

Normal. The average value of a parameter for the thirty year period studied.

Eighty Per Cent Chance Occurrence. A value which is greater than or equal to the values which occurred in twenty-four out of the thirty years studied.

Peak Weekly Runoff. The largest amount of runoff that occurred in a single week during a climatological year. The thirty values of peak weekly runoff shown in the figures for each station represent therefore one value from each of the thirty years studied which does not necessarily correspond to the thirty highest peak weekly runoffs since several large weekly runoffs may have occurred in one year.

Climatological Year. A 52-week period beginning on March 1, of one calendar year and ending on February 27 of the succeeding year. For discussion purposes, a climatological year is identified by using the calendar year in which it begins. For example, climatological year 1950 begins on March 1, 1950, and ends on February 27, 1951.

Climatological Week. A seven day period which throughout the thirty year period always contains the same calendar date. Climatological week one always begins on March 1, and ends on March 7, and the weeks are numbered consecutively from that point with week 52 beginning on February 21 and ending on February 27. As mentioned earlier in this report, the use of 52 climatological weeks in a climatological year means that the dates February 28, and February 29, are omitted.

Mean Weighted Value. Mean weighted value was used only with Peak Weekly Runoff. It was computed by taking the number of occurrences for each runoff interval times the mid-point of the interval, obtaining a sum over all intervals, and dividing the sum by the total number of occurrences. The total number of occurrences equals thirty in all cases since thirty years were studied.

STATION DATA

Burr Oak

Annual precipitation varied at the Burr Oak Station from 12.11 inches to 41.52 inches. The normal precipitation was 25.14 inches. Annual runoff varied from 2.01 inches to 15.81 inches and the normal runoff was 8.01 inches. Plate 4 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 5 on page 28 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. This plate actually represents a closed cycle. The

EXPLANATION OF PLATE 4

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Burr Oak Station.

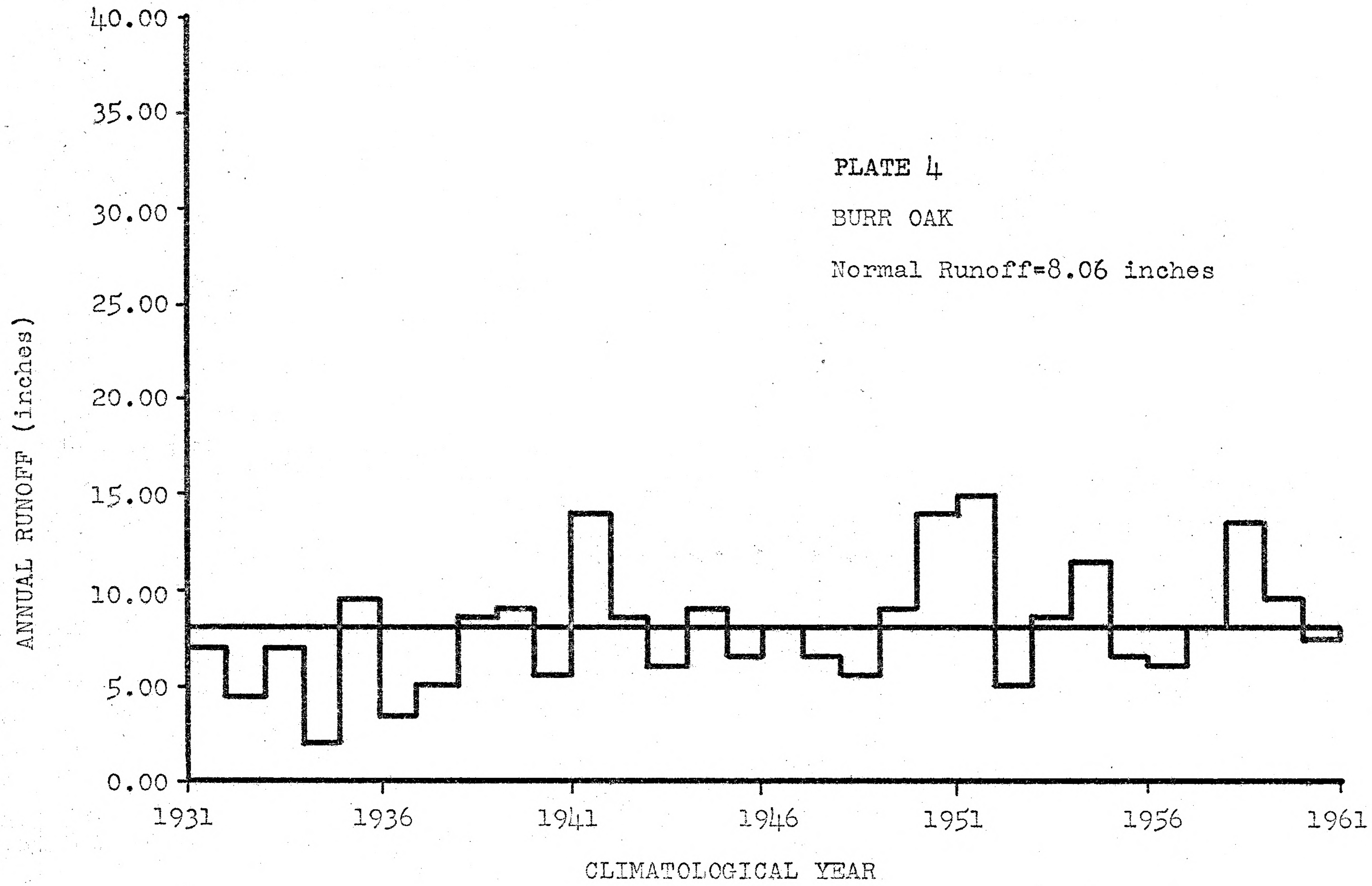


PLATE 4
BURR OAK
Normal Runoff=8.06 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

climatological week numbers identify the end of the week. That is, the point on the abcissa denoting climatological week four includes the runoff for week four or runoff from March 1 through March 28. Viewed in this manner, it can be seen that no significant runoff occurred from climatological weeks 33 through 48 or the period beginning on October 11 and ending on January 30. Beginning with week 49 or January 31, runoff of 0.50 inches or more occurred during every four week interval during the year until the cycle was ended on October 10. The maximum runoff accumulation occurred between week 13 and week 17 (May 24 to June 20) when 2.50 inches or more than twenty-five per cent of the total of 9.45 inches occurred. The second highest accumulation period occurred between week 25 and week 29 (August 16 to September 12) when 2.00 inches accumulated.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 6. In eighty per cent of the years, the peak weekly runoff was less than 3.00 inches and in ninety per cent of the years, less than 3.50 inches. The mean weighted value of peak weekly runoff for the station was 1.98 inches.

Columbus

Annual precipitation varied at the Columbus station from 21.91 inches to 56.44 inches. The normal precipitation

EXPLANATION OF PLATE 5

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Burr Oak Station.

EXPLANATION OF PLATE 6

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Burr Oak Station.

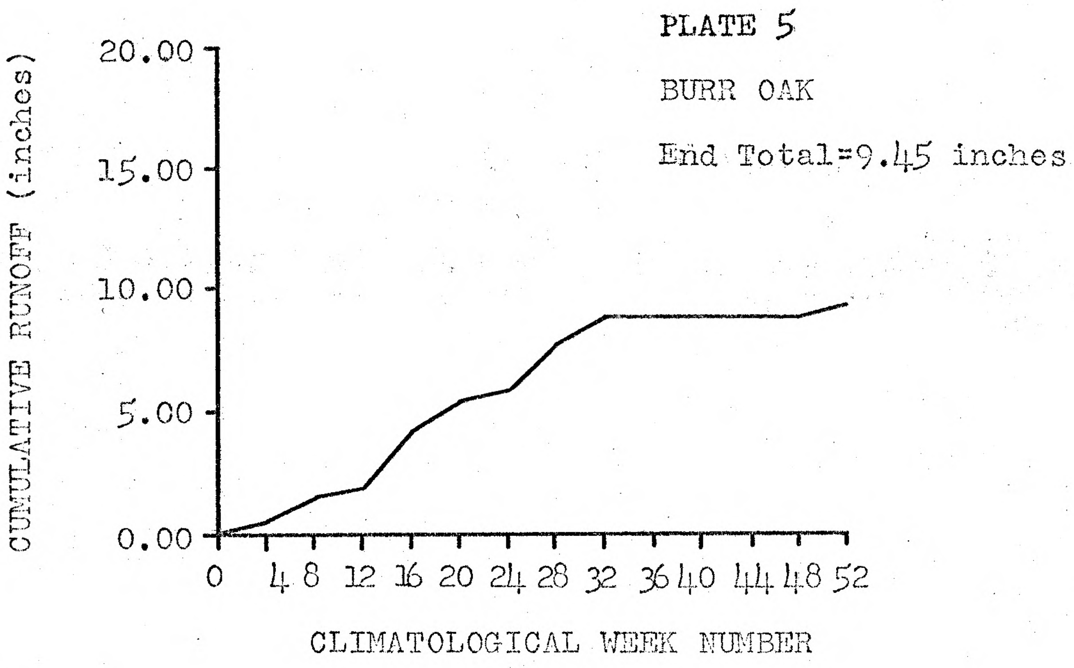


PLATE 5
BURR OAK
End Total=9.45 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

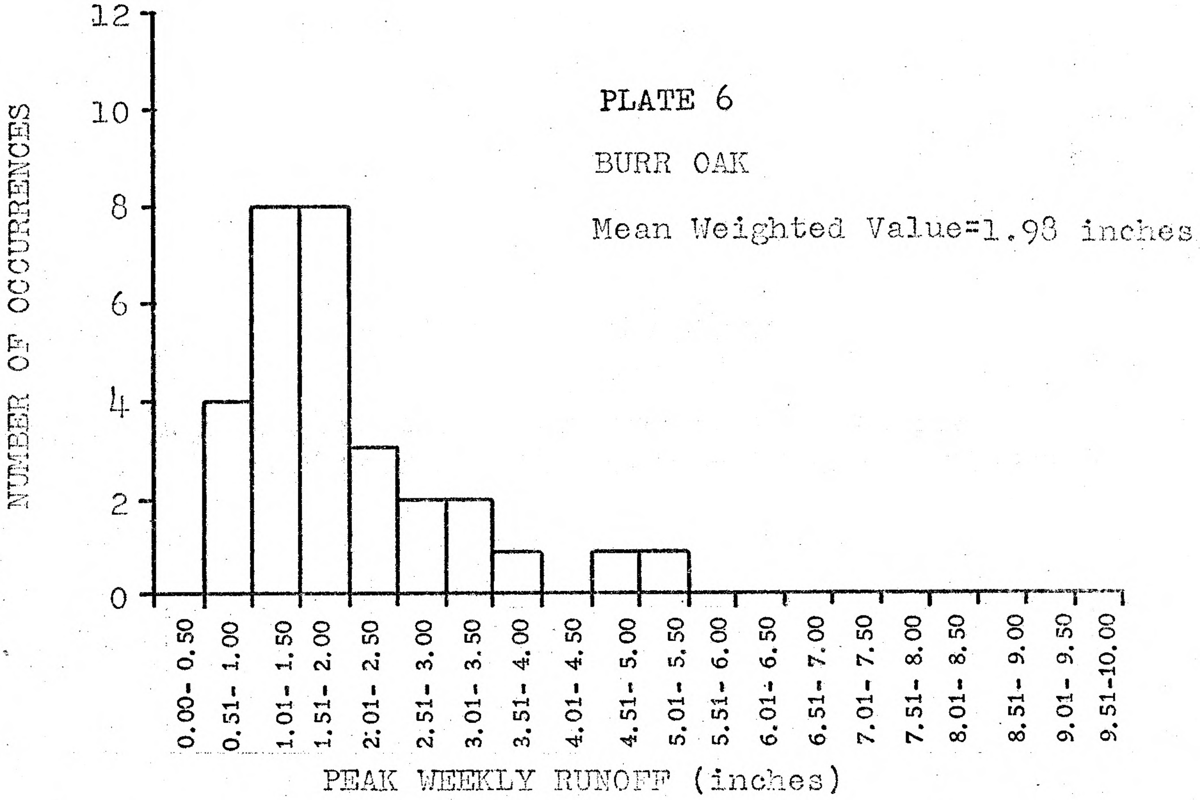


PLATE 6
BURR OAK
Mean Weighted Value=1.98 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

was 39.38 inches. Annual runoff varied from 5.47 inches to 25.11 inches and the normal runoff was 14.55 inches. Plate 7 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 8 on page 33 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. At this station, runoff began to accumulate at point 0 or in week one which begins on March 1. Runoff of 0.50 inches or more occurred during every four week period from that time until the end of week 44 or January 2. From January 3 to February 27, no significant runoff occurred. The maximum runoff accumulation, 3.00 inches, occurred between week 17 and week 21 (June 21 to July 18). The second highest accumulation rate was 2.00 inches in a four week period. This rate occurred between week 9 and week 17 (April 26 to June 20), week 25 and week 29 (August 16 to September 12) and week 33 and week 37 (October 11 to November 7).

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 9 on page 33. In eighty per cent of the years, the peak weekly runoff value did not exceed 3.50 inches and in ninety per cent of the years, it did not exceed 5.00 inches. Two large peak weekly runoff values occurred at this station. The largest was 9.53 inches which occurred in week 17 (June 21 - 27) in 1948 and the second largest was 7.27 inches which

EXPLANATION OF PLATE 7

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Columbus Station.

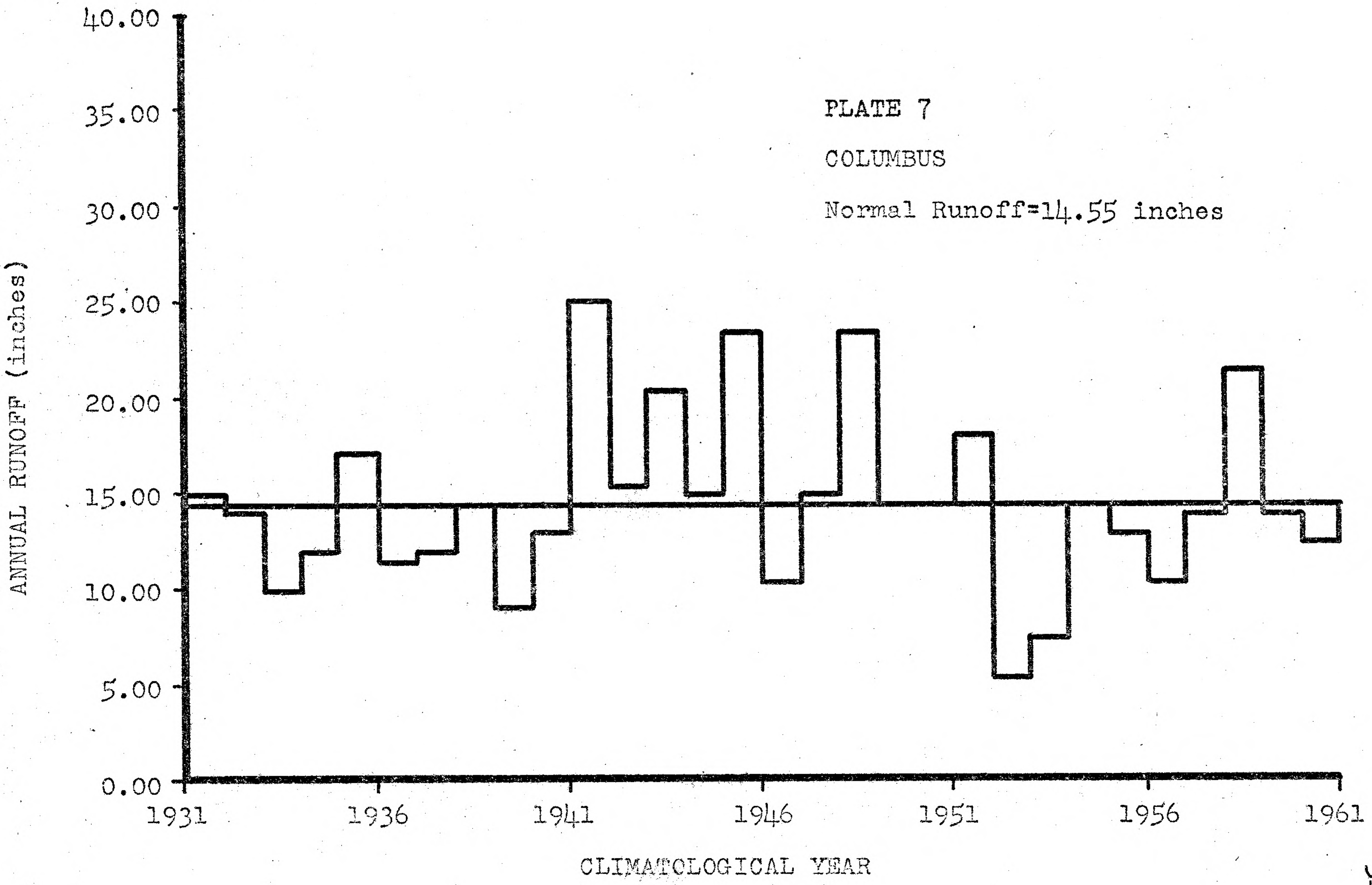


PLATE 7
COLUMBUS
Normal Runoff=14.55 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

EXPLANATION OF PLATE 8

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Columbus Station.

EXPLANATION OF PLATE 9

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Columbus Station.

PLATE 8

COLUMBUS

End Total=16.92 inches

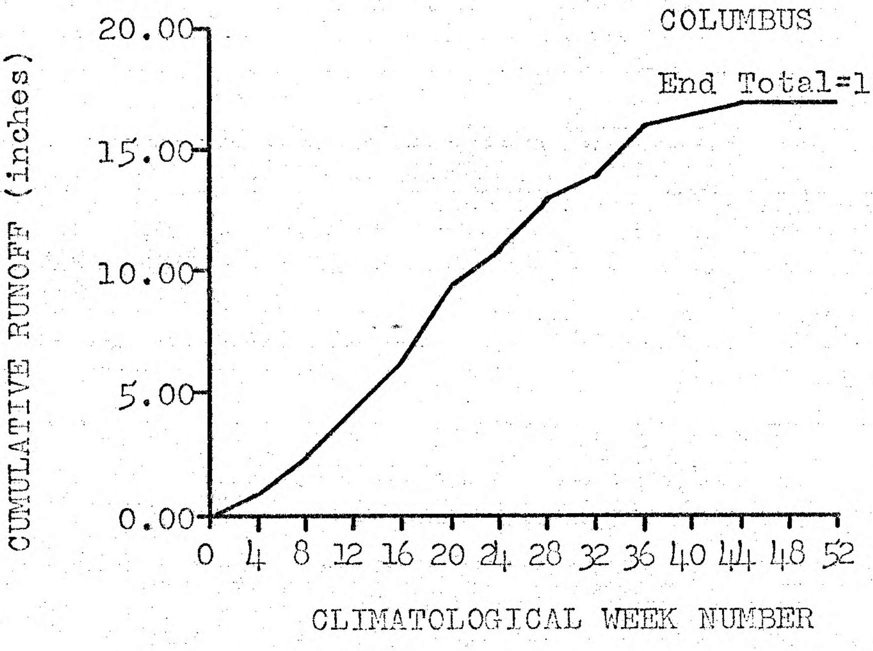
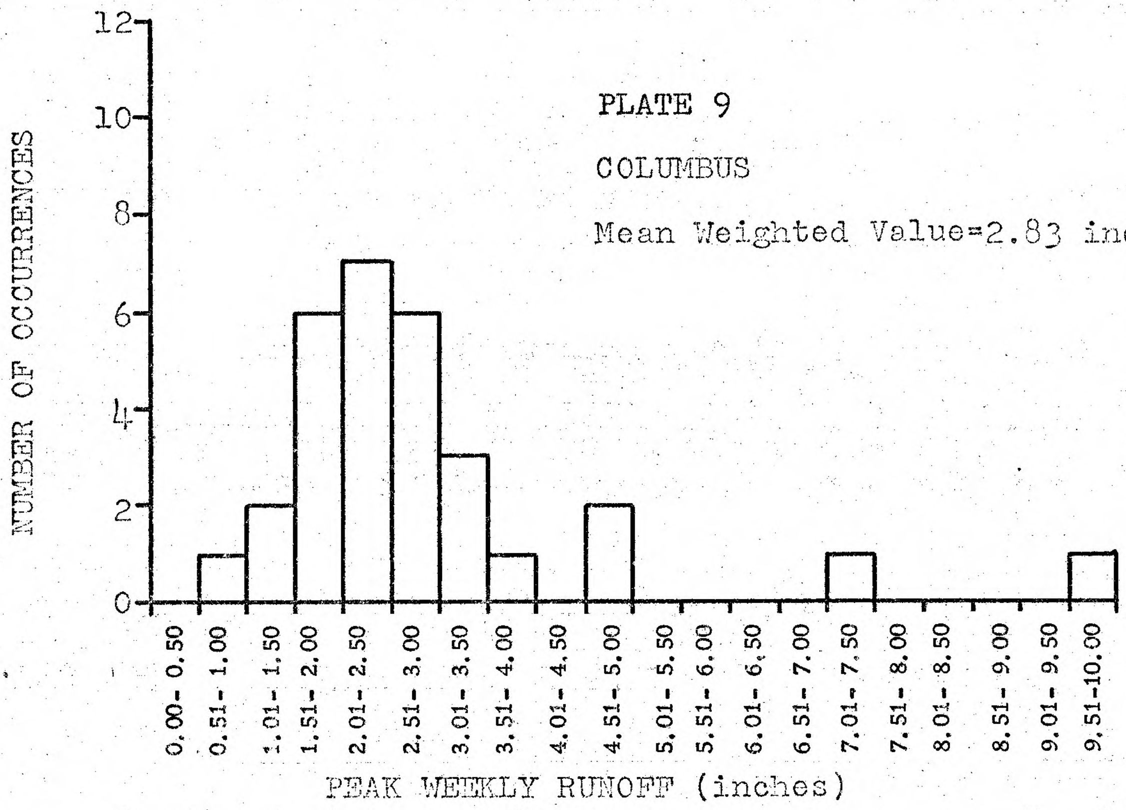


PLATE 9

COLUMBUS

Mean Weighted Value=2.83 inches



occurred in week 12 (May 17 - 23) in 1943. The mean weighted value of peak weekly runoff for the entire period was 2.83 inches. The mean weighted value excluding the two values considered to be unusually large was 2.42 inches.

Elkhart

Annual precipitation varied at the Elkhart Station from 7.46 inches to 29.47 inches. The normal precipitation was 17.46 inches. Annual runoff varied from 1.93 inches to 11.76 inches and the normal runoff was 5.48 inches. Plate 10 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 11 on page 39 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff began to accumulate at this station in the fifth week (March 29). This was the latest point in the calendar year for any of the stations studied. Runoff of 0.50 inches or more occurred in all four week periods from the starting point through the 32nd week (October 11) and occurred again in the 37th through the 40th week (November 8 through December 5). The maximum four week runoff accumulation was 1.50 inches which occurred in the period from week 21 through week 24 (July 19 through August 15). During

EXPLANATION OF PLATE 10

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Elkhart Station.

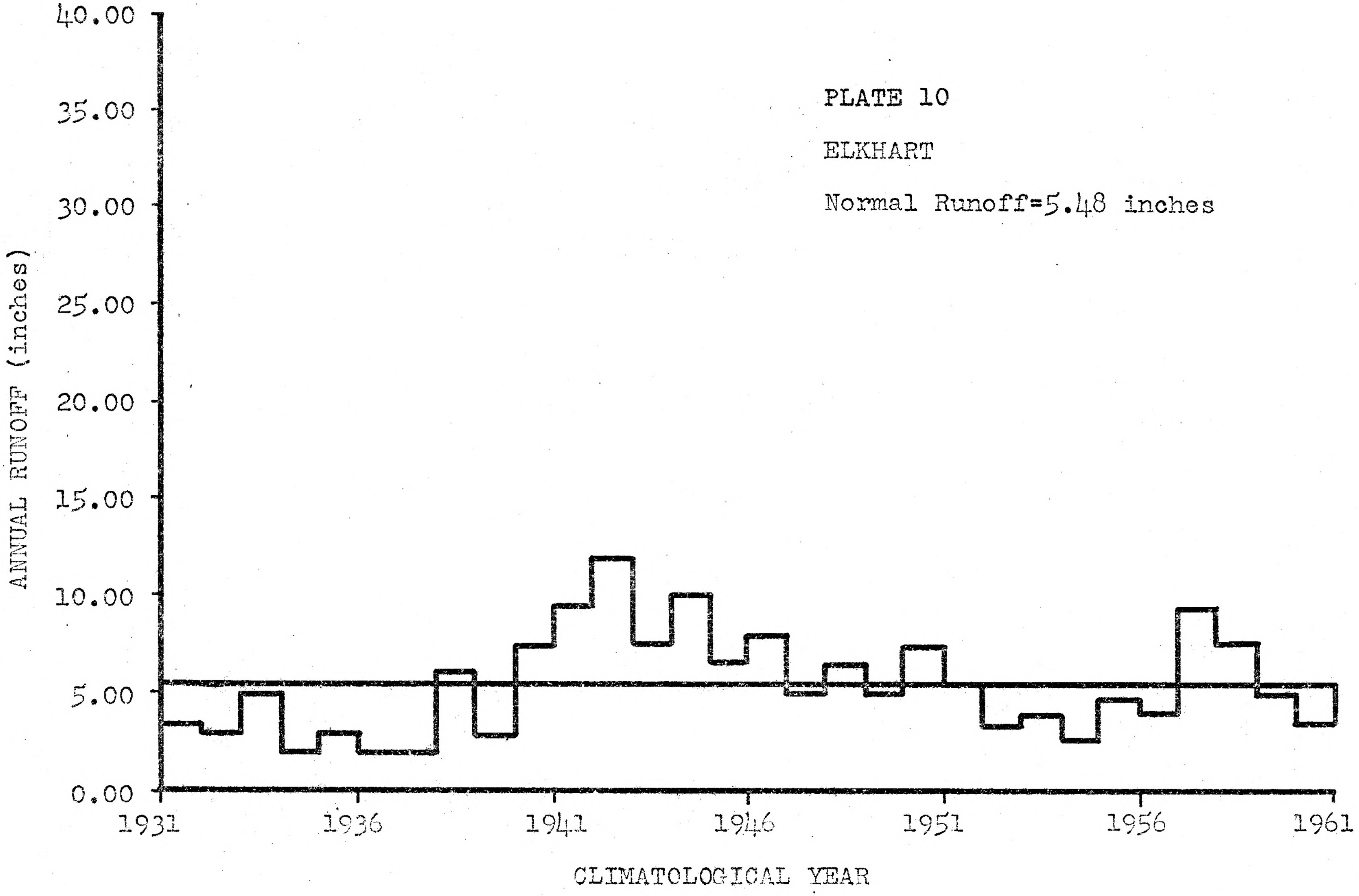


PLATE 10
ELKHART
Normal Runoff=5.48 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

the period from week five through week 24 (March 29 through August 15), 5.50 inches of the eighty per cent chance occurrence total of 7.68 inches accumulated.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 12. In eighty per cent of the years, peak weekly runoff did not exceed 2.50 inches and in ninety per cent did not exceed 3.00 inches. The mean weighted value of peak weekly runoff was 1.63 inches.

Hays

Annual precipitation at the Hays station varied from 8.28 inches to 41.58 inches. The normal precipitation was 22.82 inches. The annual runoff range was 1.88 inches to 16.77 inches and the normal runoff was 7.34 inches. Plate 13 on page 41 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 14 on page 44 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. The first significant runoff of the calendar year occurred at this station in the period from week 45 through week 48 (January 3 through January 30). No significant runoff occurred in the next four-week period. Beginning with week one (March 1) runoff of 0.50 inches or more occurred in all four week periods through week 32 (October 10). No

EXPLANATION OF PLATE 11

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Elkhart Station.

EXPLANATION OF PLATE 12

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Elkhart Station.

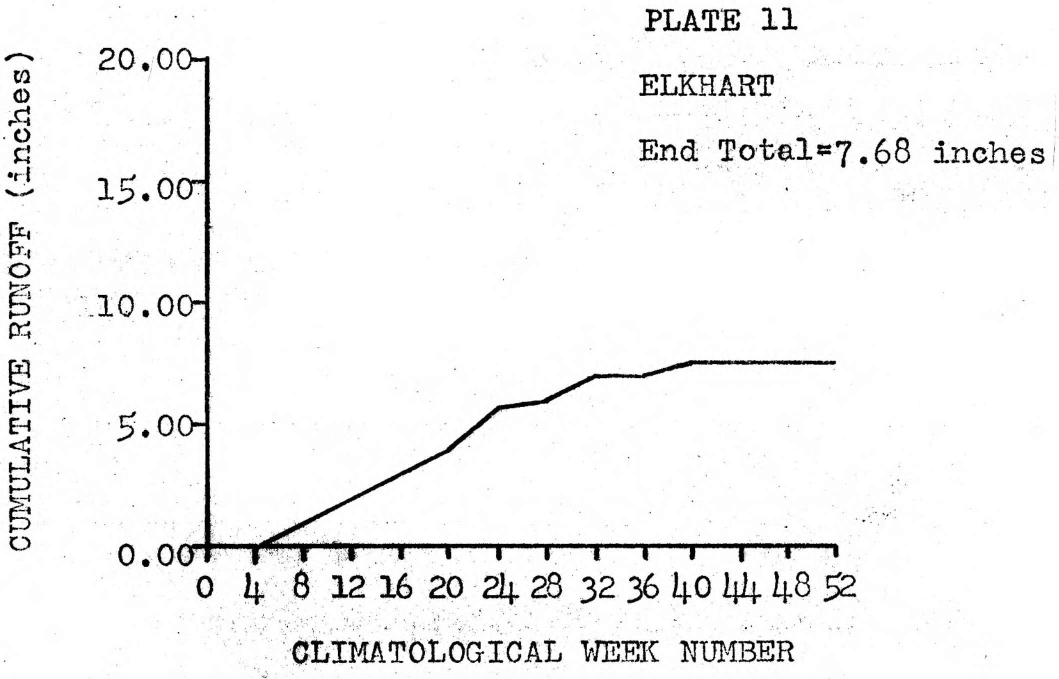


PLATE 11
ELKHART
End Total=7.68 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

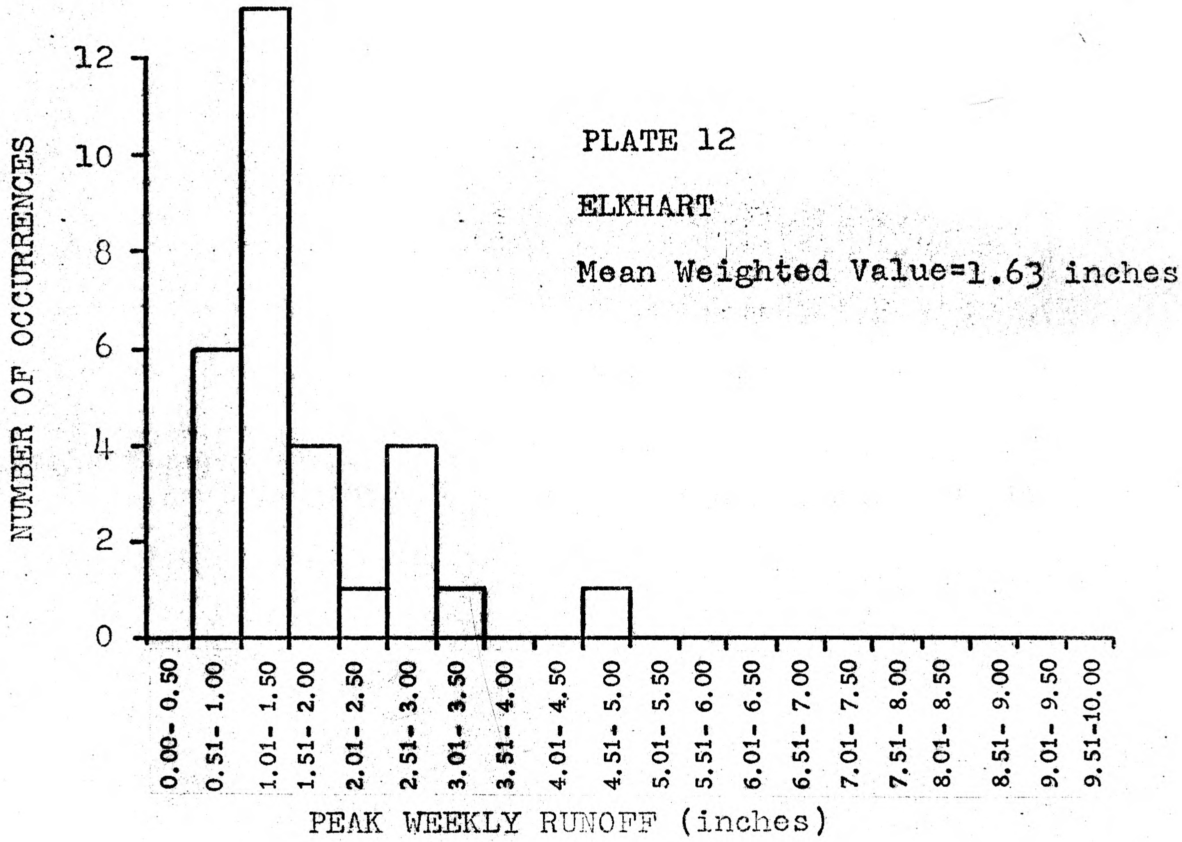


PLATE 12
ELKHART
Mean Weighted Value=1.63 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

EXPLANATION OF PLATE 13

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Hays Station.

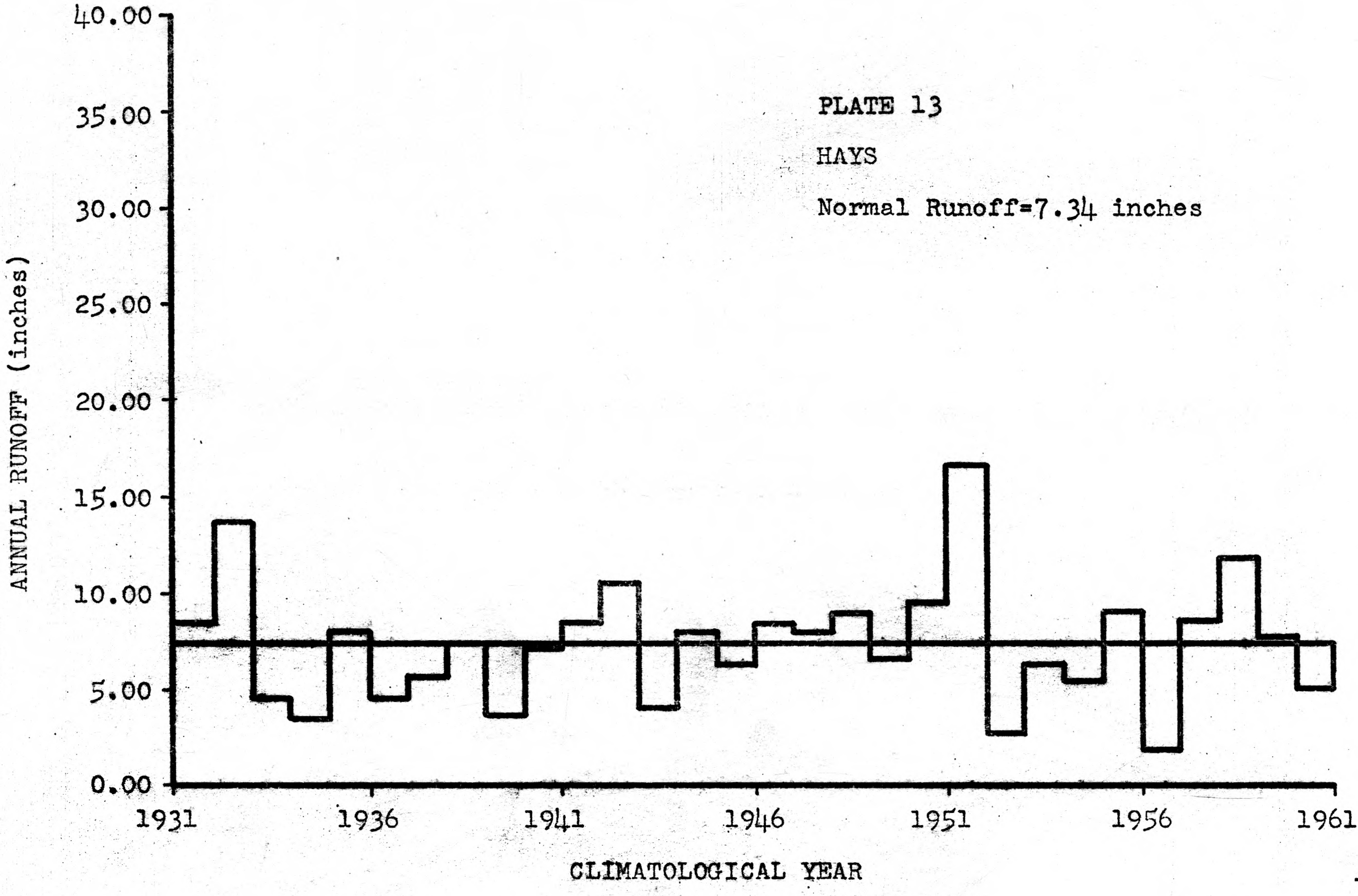


PLATE 13
HAYS
Normal Runoff=7.34 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

significant runoff occurred between weeks 33 and 45 (October 11 through January 2). The maximum runoff accumulation was 3.00 inches which occurred in weeks 13 through 16 (May 24 through June 20). This period accounted for more than one third of the eighty per cent chance occurrence runoff total (3.00 inches out of 8.87 inches).

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 15. In eighty per cent of the years, the peak weekly runoff did not exceed 3.00 inches and in ninety per cent of the years it did not exceed 3.50 inches. The mean weighted value of peak weekly runoff at this station was 1.88 inches.

Healy

Annual precipitation varied at the Healy station from 8.28 inches to 30.34 inches. The normal precipitation was 18.51 inches. Annual runoff varied from 1.56 inches to 10.83 inches and the normal runoff was 5.39 inches. Plate 16 on page 46 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 17 on page 49 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff accumulation of 0.50 inches or more began at this station as for the preceding station at week one (March 1). The accumulation of runoff continued to the end of week 36

EXPLANATION OF PLATE 14

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Hays Station.

EXPLANATION OF PLATE 15

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Hays Station.

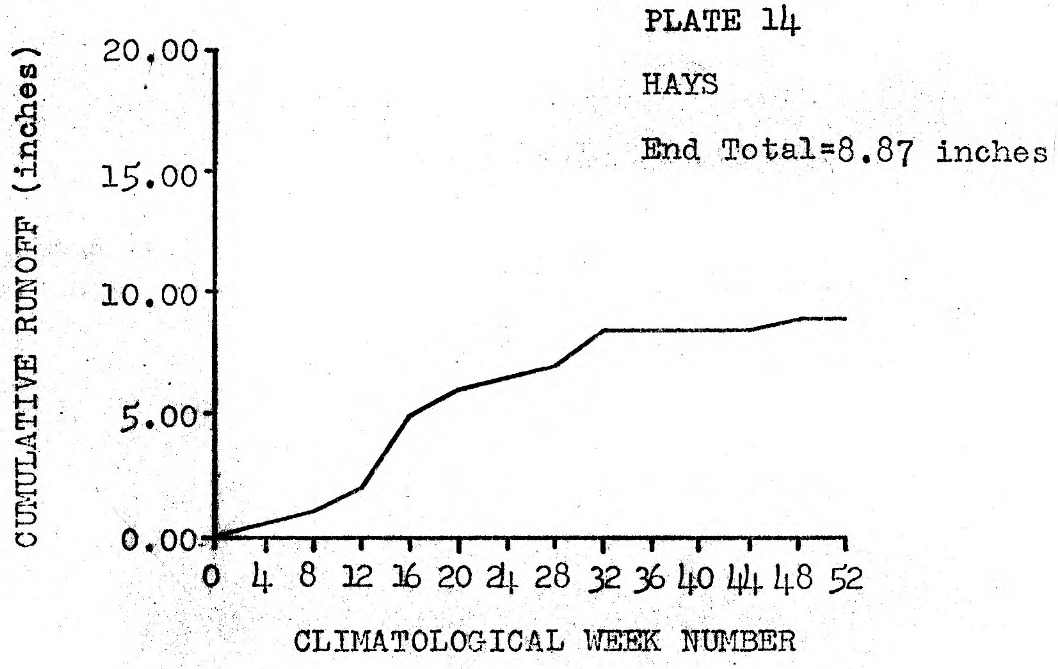


PLATE 14
HAYS
End Total=8.87 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

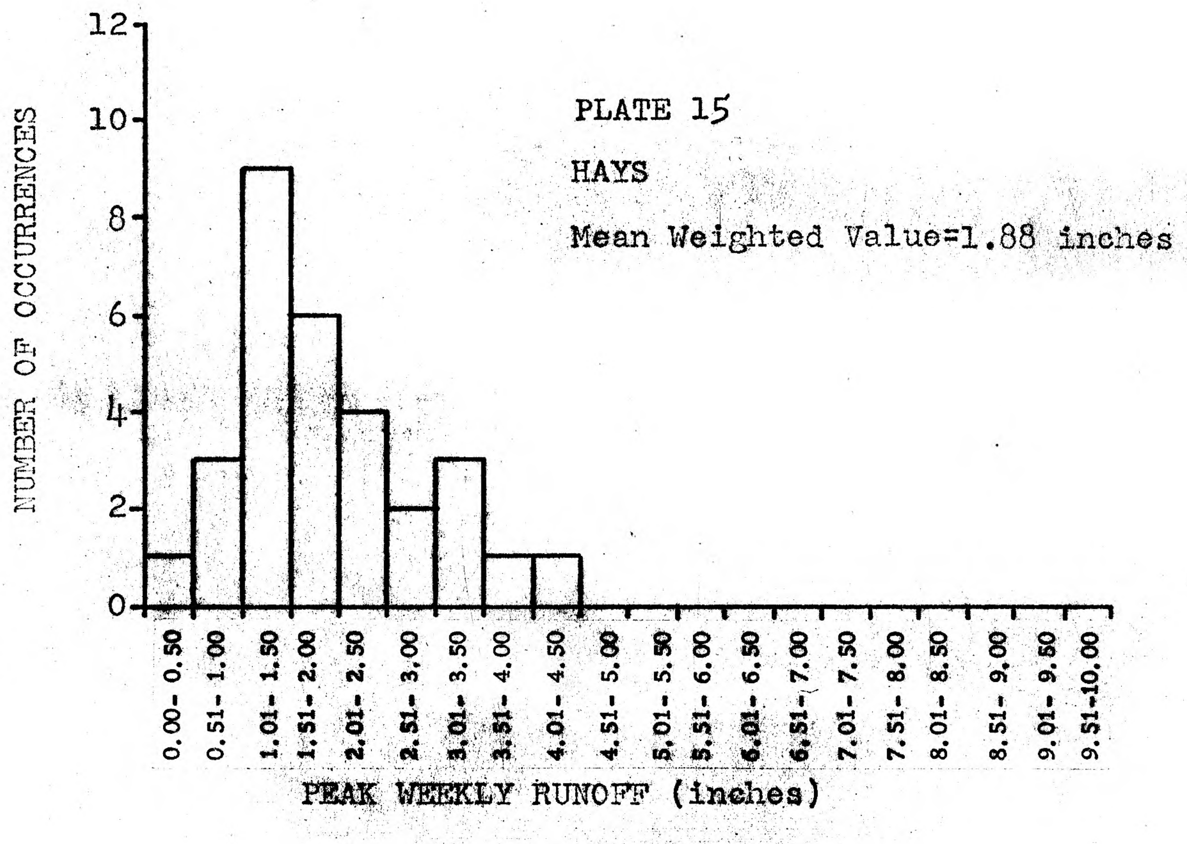


PLATE 15
HAYS
Mean Weighted Value=1.88 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

EXPLANATION OF PLATE 16

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Healy Station.

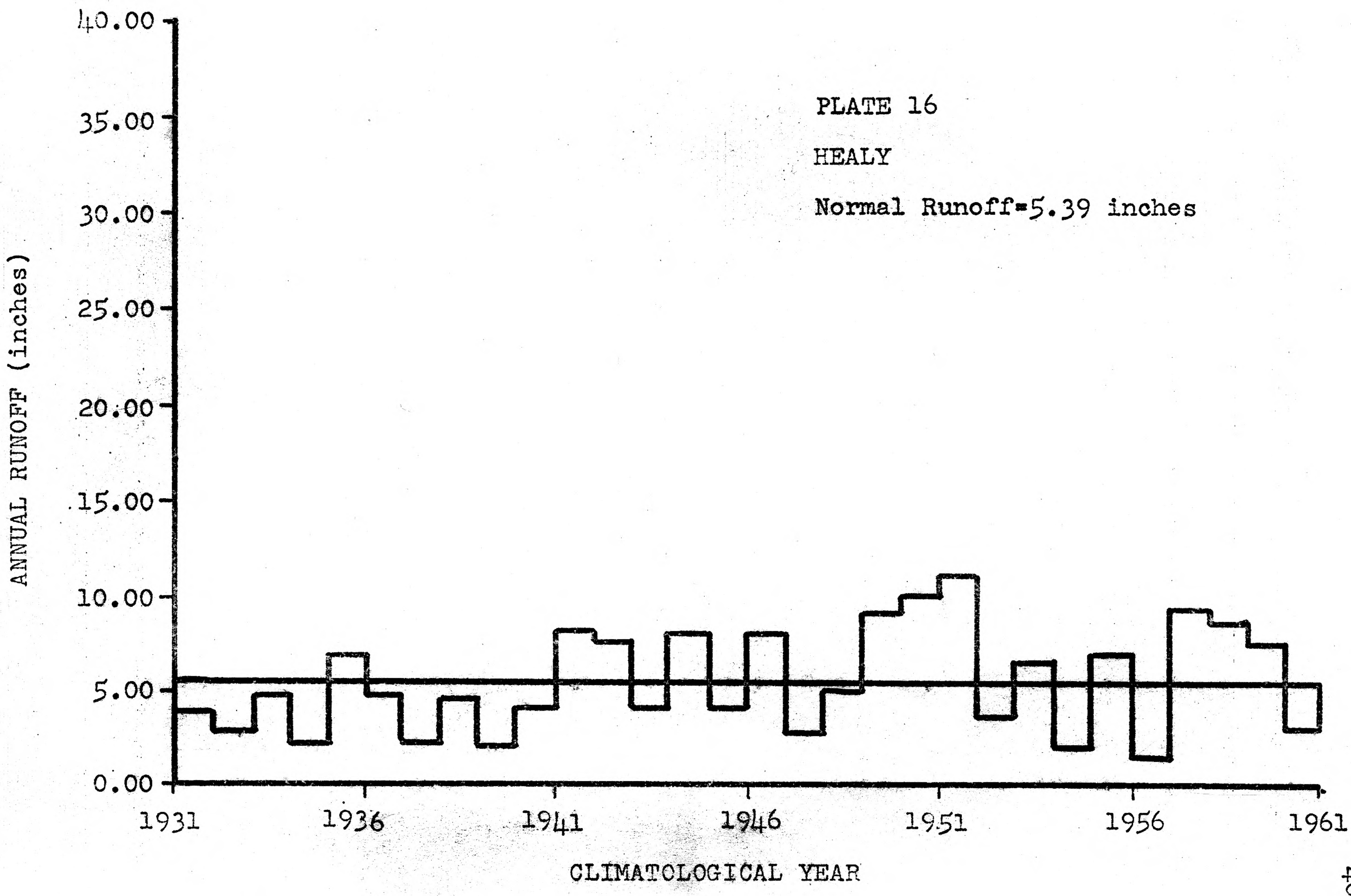


PLATE 16
HEALY
Normal Runoff=5.39 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

(November 7). No significant runoff occurred from week 37 (November 8) through week 52 (February 27). The maximum rate of accumulation was 1.50 inches in a four week period. This occurred in a twelve week period from week 9 through week 20 (April 26 through July 18). The total accumulation of 4.50 inches in this period represents over fifty per cent of the total eighty per cent chance occurrence runoff of 8.06 inches.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 18 on page 49. In eighty per cent of the years, the peak weekly runoff was less than or equal to 2.00 inches and in ninety per cent of the years, it did not exceed 2.50 inches. The mean weighted value of peak weekly runoff was 1.37 inches.

Horton

The range of annual precipitation at the Horton station was from 20.03 inches to 61.65 inches. The normal precipitation was 34.44 inches. Annual runoff varied from 5.55 inches to 25.49 inches with a normal of 12.20 inches. Plate 19 on page 51 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

EXPLANATION OF PLATE 17

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Healy Station.

EXPLANATION OF PLATE 18

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Healy Station.

PLATE 17

HEALY

End Total=8.06 inches

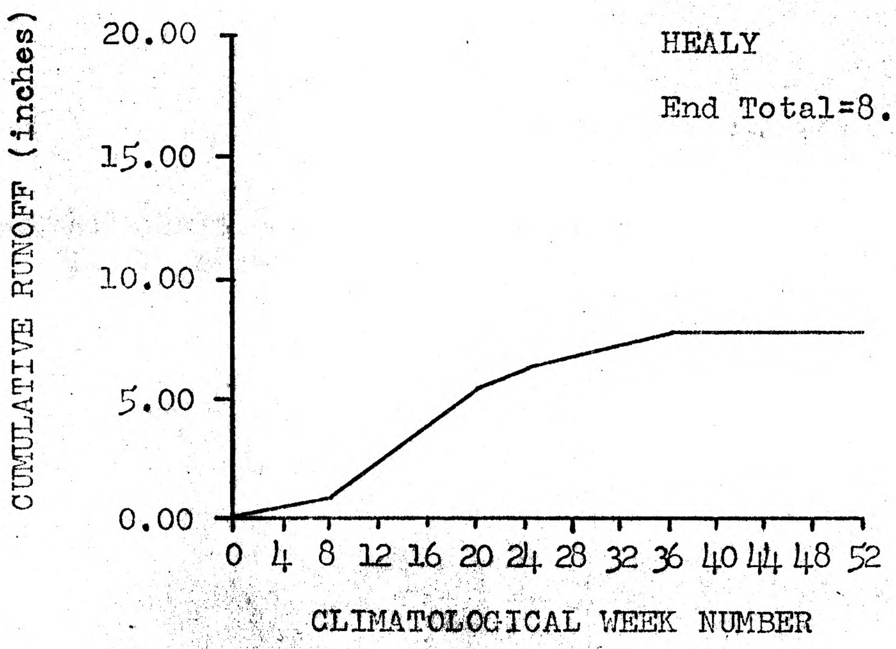
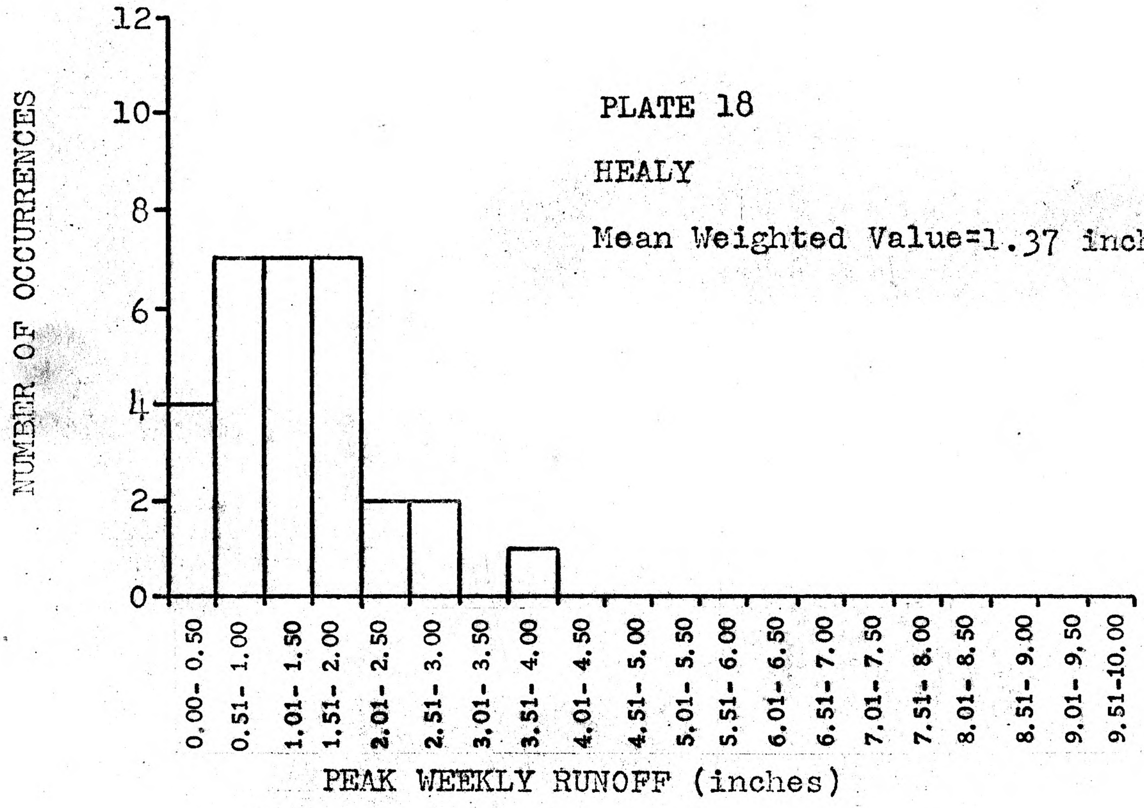


PLATE 18

HEALY

Mean Weighted Value=1.37 inches



EXPLANATION OF PLATE 19

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Horton Station.

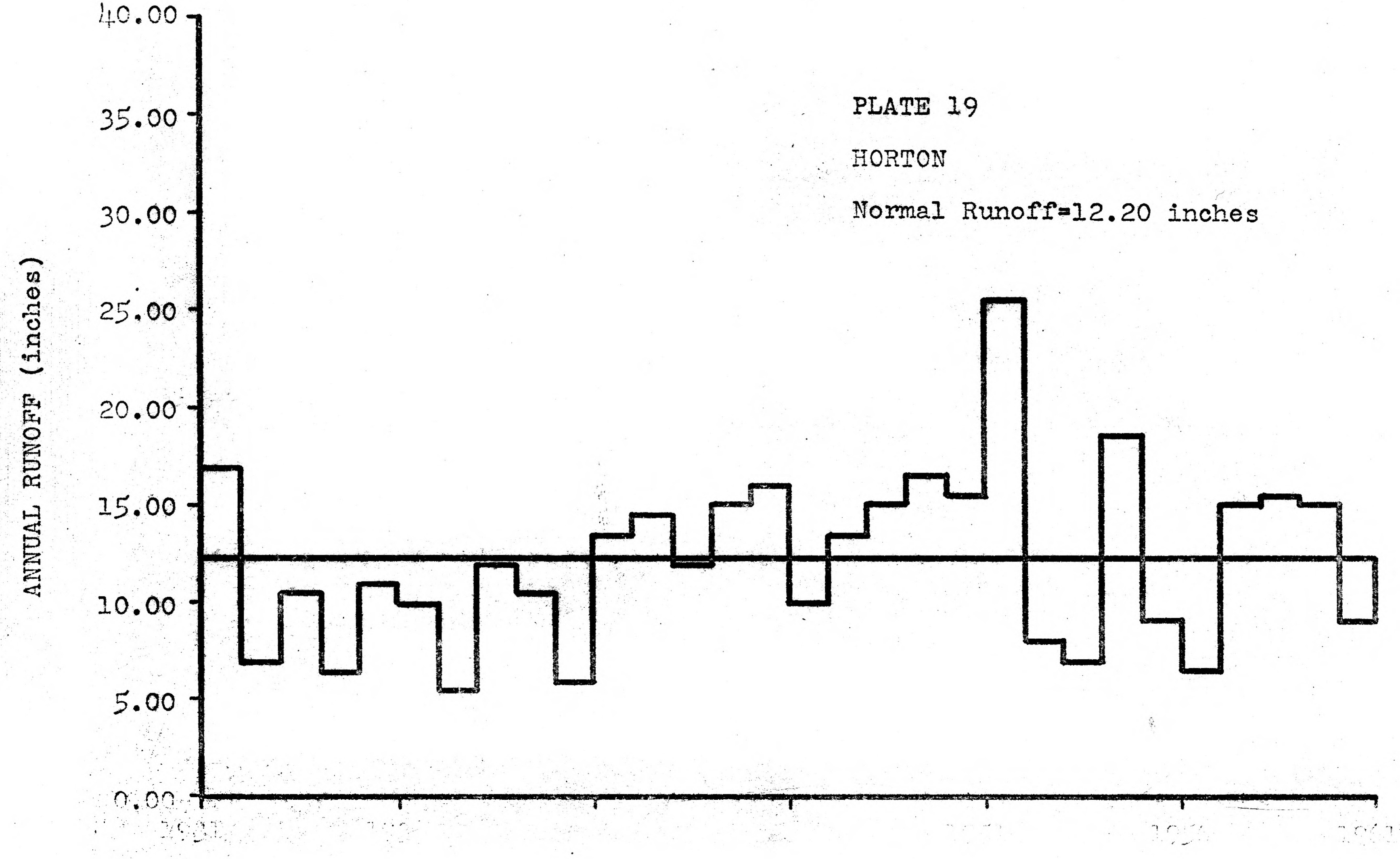


PLATE 19
HORTON
Normal Runoff=12.20 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00

Plate 20 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff accumulation began at week 49 (January 31) and equaled or exceeded 0.50 inches in every four week period until the end of week 40 (December 5). From the beginning of week 41 (December 6) to the end of week 48 (January 30) no significant runoff occurred. The maximum runoff increase in any four week period was 3.00 inches and occurred in week 13 through week 16 (May 24 through June 20). The second largest increase was 2.5 inches in the four weeks immediately following (June 21 through July 18). The entire eight week period (May 24 through July 18) contributed more than one third of the eighty per cent chance occurrence total which was 15.32 inches.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 21. In eighty per cent of the years, the peak weekly runoff was 3.50 inches or less and in ninety per cent of the years it was 4.00 inches or less. The mean weighted value of peak weekly runoff was 2.52 inches.

Manhattan

Annual precipitation at the Manhattan station varied from 19.15 inches to 58.93 inches. Normal precipitation

EXPLANATION OF PLATE 20

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Horton Station.

EXPLANATION OF PLATE 21

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Horton Station.

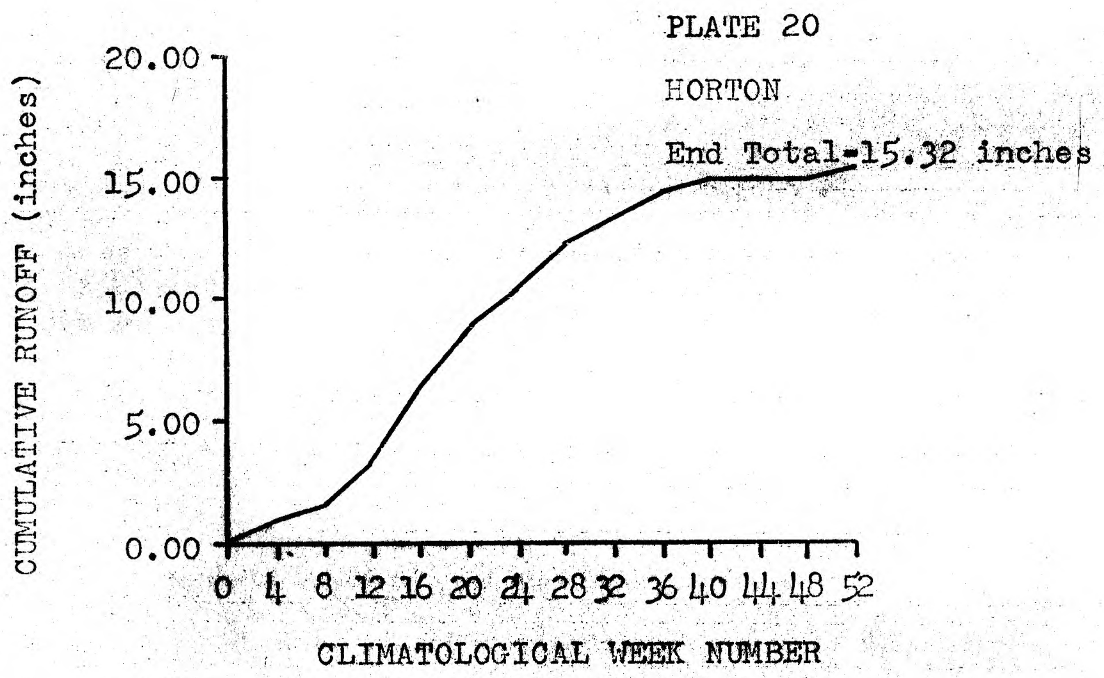


PLATE 20
HORTON
End Total=15.32 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

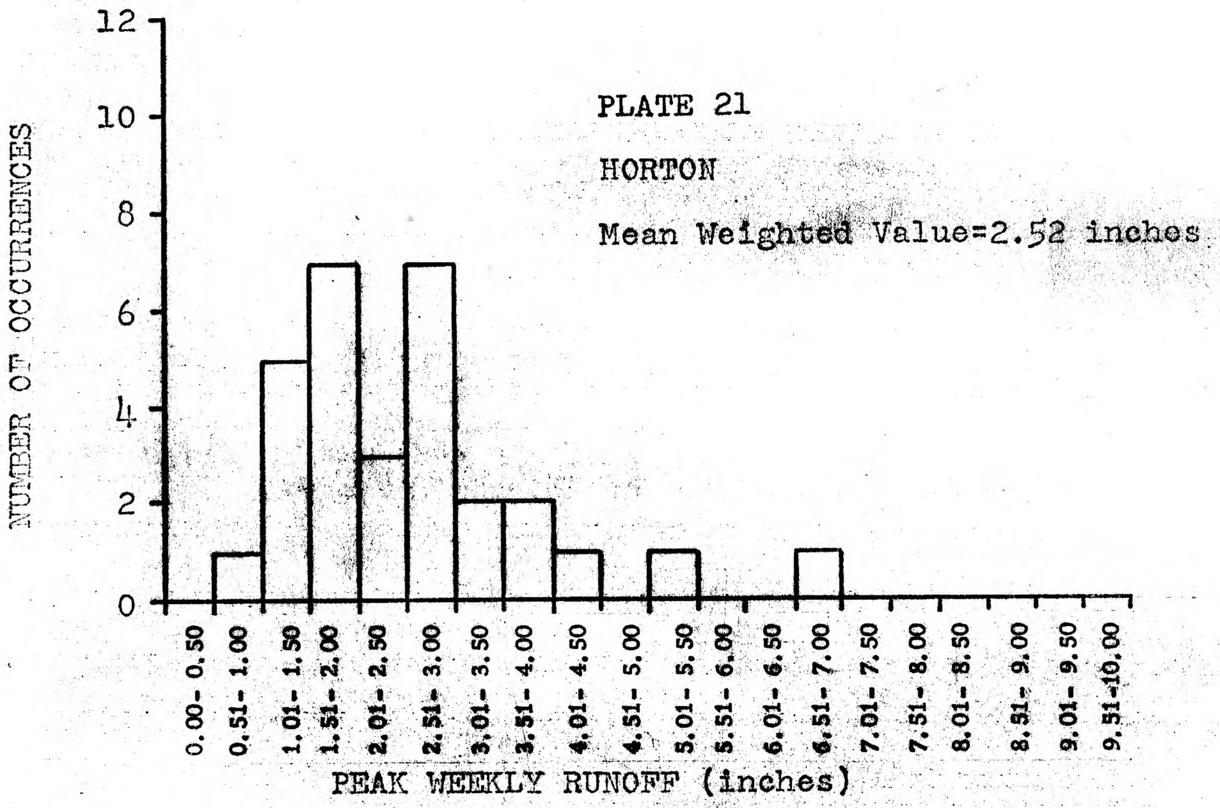


PLATE 21
HORTON
Mean Weighted Value=2.52 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

was 31.93 inches. Annual runoff varied from 4.39 inches to 24.35 inches and the normal was 11.54 inches. Plate 22 shows the total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 23 on page 59 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff of 0.50 inches or more for a four week period began at week one and continued through week 32 (October 10). The largest accumulation of runoff in any four week period was 3.00 inches. This occurred twice: from week 17 through week 20 (June 21 through July 18) and from week 25 through week 28 (August 16 through September 12). The second largest accumulation was 2.50 inches in the four week period from week 13 through week 16 (May 24 through June 20). These three high runoff periods combined produced 8.50 inches of runoff or approximately sixty per cent of the eighty per cent chance occurrence total of 14.18 inches.

The frequency of occurrence of peak weekly runoff amounts in one half inch increments is shown in Plate 24 on page 59. In eighty per cent of the years, the peak weekly runoff did not exceed 3.50 inches and in ninety per cent of the years did not exceed 4.00 inches. The mean weighted value of peak weekly runoff at Manhattan was 2.68 inches.

EXPLANATION OF PLATE 22

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Manhattan Station.

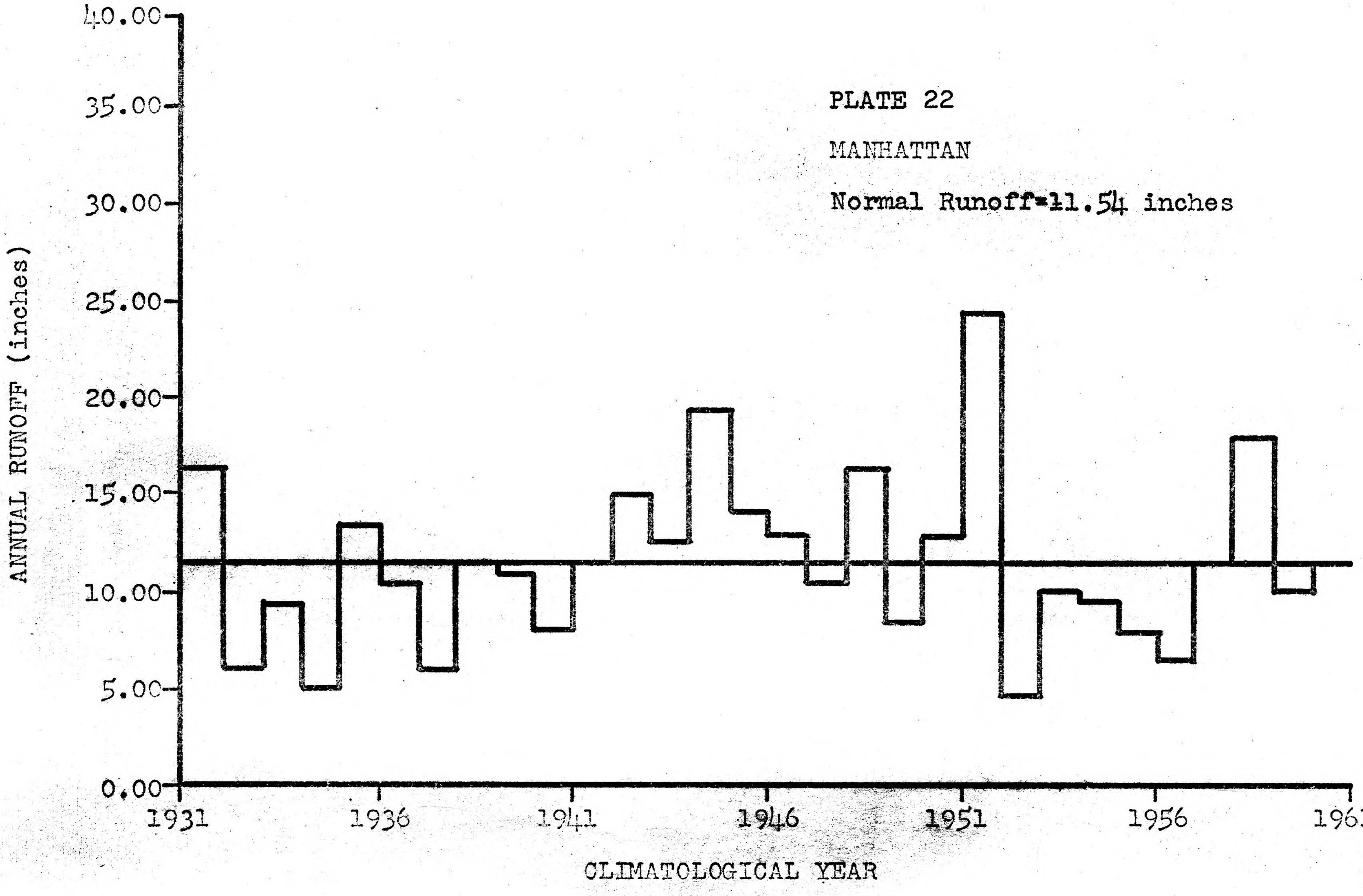


PLATE 22
MANHATTAN
Normal Runoff=11.54 inches
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANNUAL RUNOFF (inches)
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

EXPLANATION OF PLATE 23

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Manhattan Station.

EXPLANATION OF PLATE 24

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Manhattan Station.

PLATE 23

MANHATTAN

End Total=14.18 inches

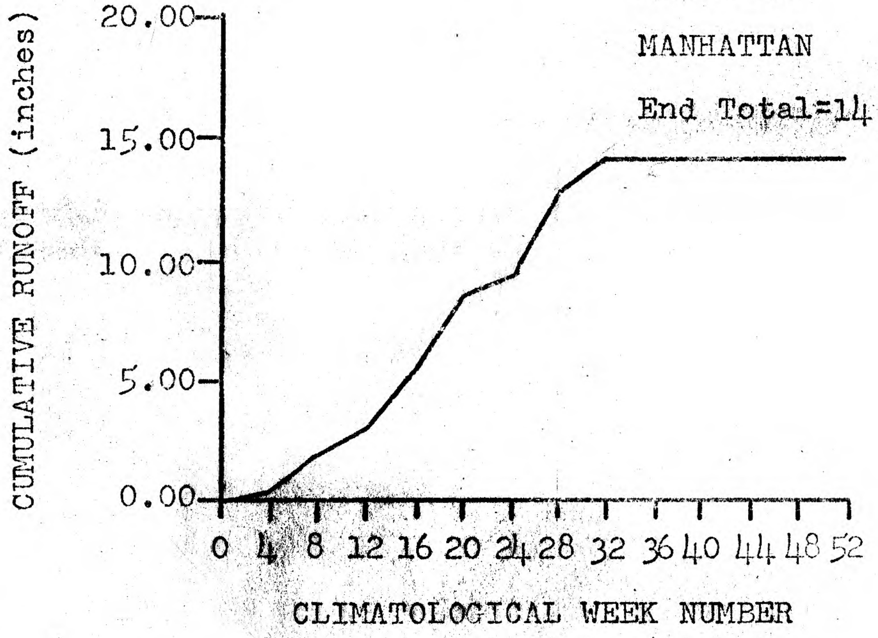
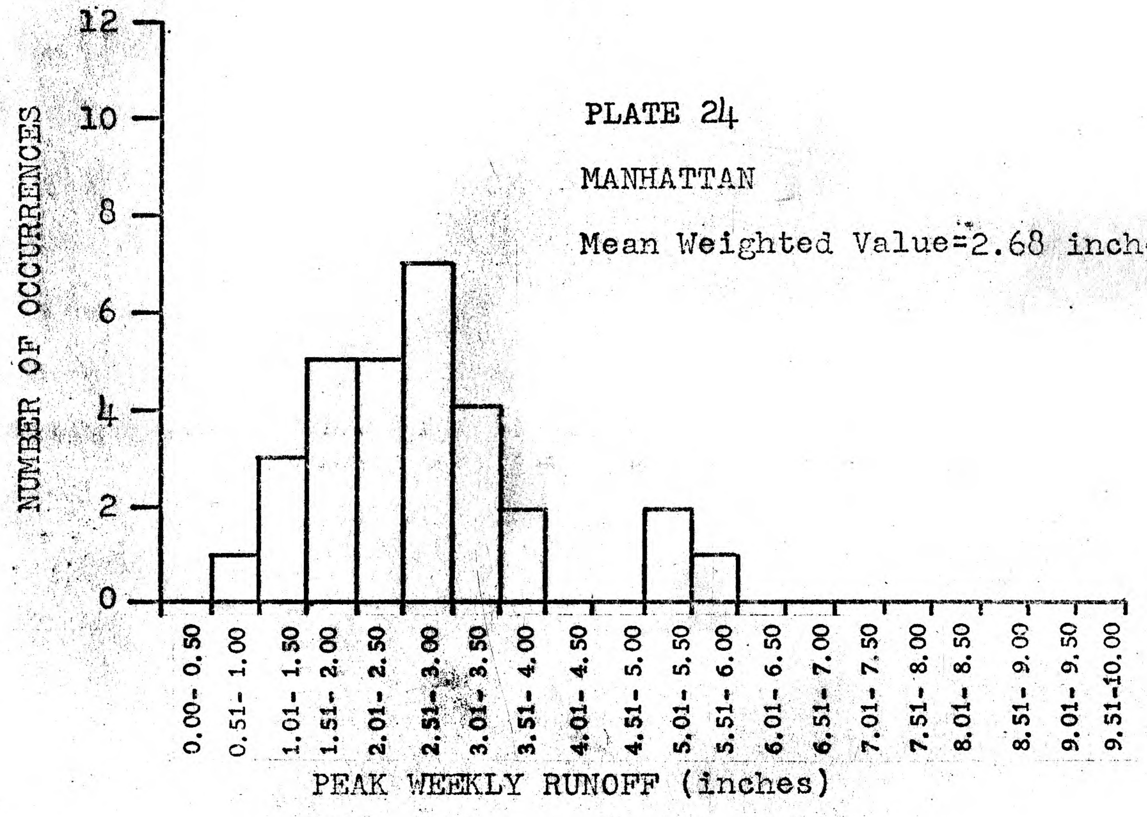


PLATE 24

MANHATTAN

Mean Weighted Value=2.68 inches



McPherson

Annual precipitation varied from 14.84 to 48.03 inches at the McPherson station. Normal precipitation was 27.31 inches. Annual runoff varied from 3.67 inches to 18.50 inches and the normal runoff was 8.98 inches. Plate 25 shows the total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 26 on page 64 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff of 0.50 inches or more began at week 49 (January 31) and occurred in all four week periods through week 36 (November 7). No significant runoff occurred from week 37 through week 48 (November 8 through January 30). The largest accumulation of runoff in any four week period was 2.50 inches. This occurred in weeks nine through twelve (April 26 through May 23). The second largest accumulation was 1.50 inches which occurred over three four week intervals from week 17 through week 28 (June 21 through September 12). The period from week nine through week 28 (April 26 through September 12) accounted for 8.00 inches, or approximately seventy-five per cent of the eighty per cent chance occurrence total of 12.34 inches.

The frequency of occurrence of peak weekly runoff amounts in one half inch increments is shown in Plate 27 on

EXPLANATION OF PLATE 25

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. McPherson Station.

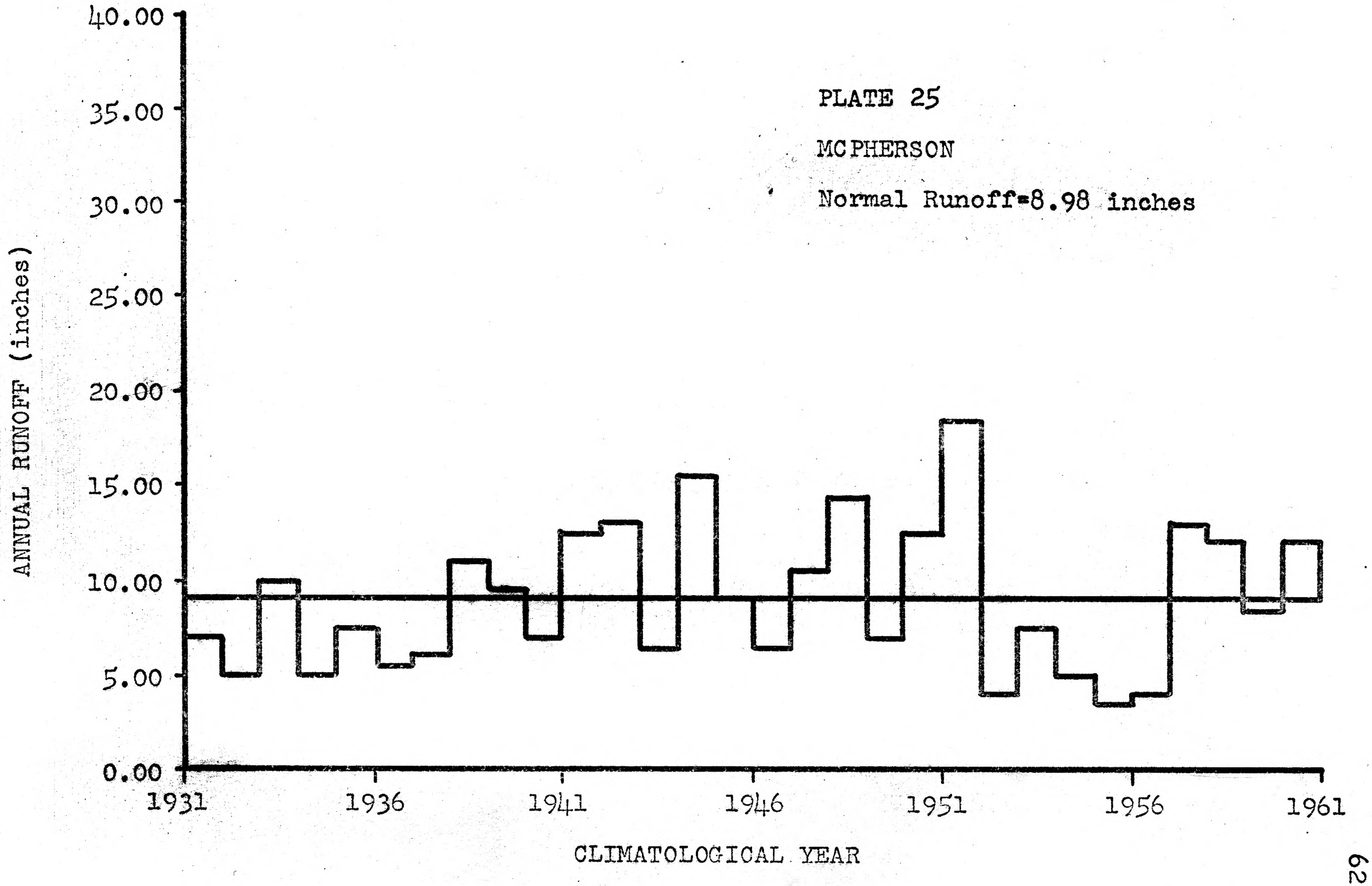


PLATE 25
MCPHERSON
Normal Runoff=8.98 inches
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANNUAL RUNOFF (inches)
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

EXPLANATION OF PLATE 26

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. McPherson Station.

EXPLANATION OF PLATE 27

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. McPherson Station.

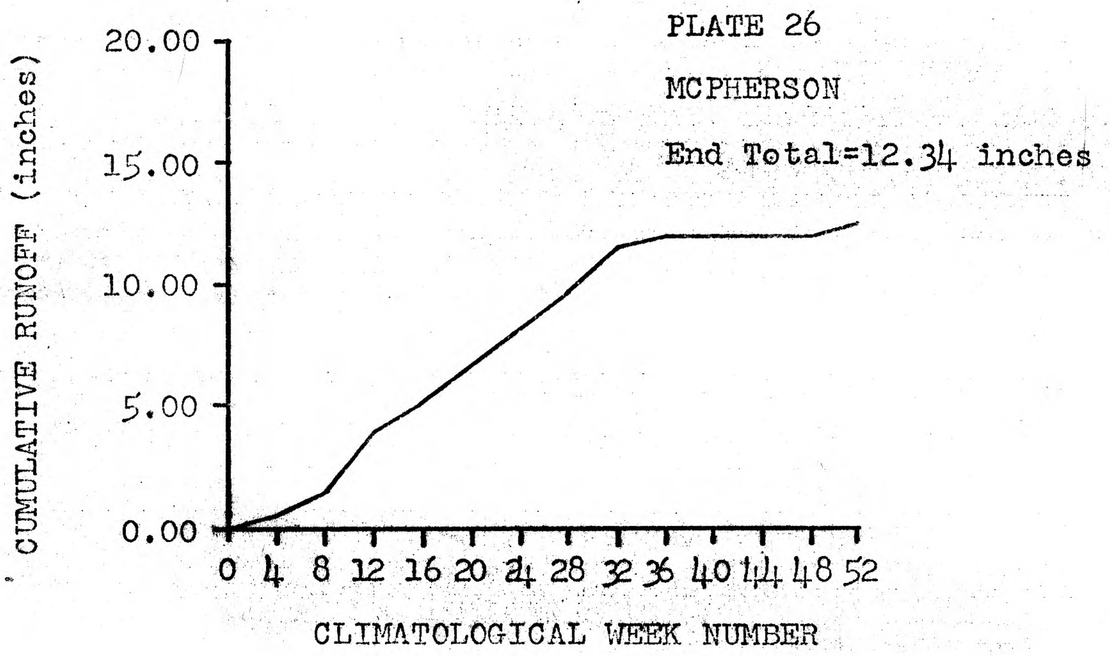


PLATE 26
MCPHERSON
End Total=12.34 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

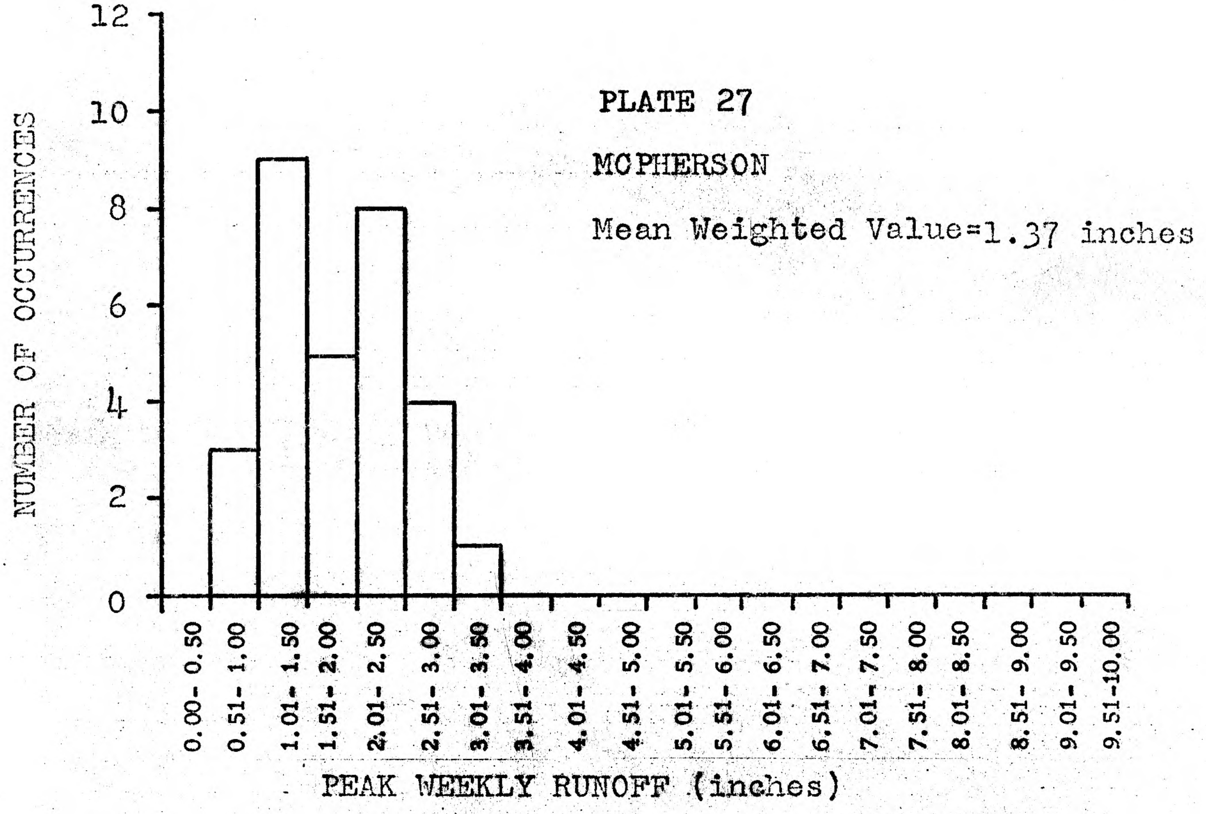


PLATE 27
MCPHERSON
Mean Weighted Value=1.37 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

page 64. In eighty per cent of the years, the peak weekly runoff did not exceed 2.50 inches and in ninety per cent of the years it did not exceed 3.00 inches. Only once did peak weekly runoff exceed 3.00 inches in the thirty year period. It occurred in 1944 when 3.05 inches of runoff occurred in week six (April 5 through April 11). The mean weighted value of peak weekly runoff was 1.82 inches.

Medicine Lodge

Annual precipitation ranged from 12.54 to 41.36 inches at the Medicine Lodge station. Normal precipitation was 25.02 inches. Annual runoff varied from 3.09 to 16.78 inches and the normal runoff was 8.85 inches. Plate 28 shows the total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 29 on page 70 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. This station had two periods during which runoff was less than 0.50 inches. They were from week 29 through week 32 (September 13 through October 10) and from week 41 through week 48 (December 6 through January 30). All other four week periods showed runoff accumulations of 0.50 inches or more. The largest amount of runoff accumulation in any four week period was 2.00 inches. It occurred in three consecutive periods beginning with week 9 and continuing through week 20

EXPLANATION OF PLATE 28

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Medicine Lodge Station.

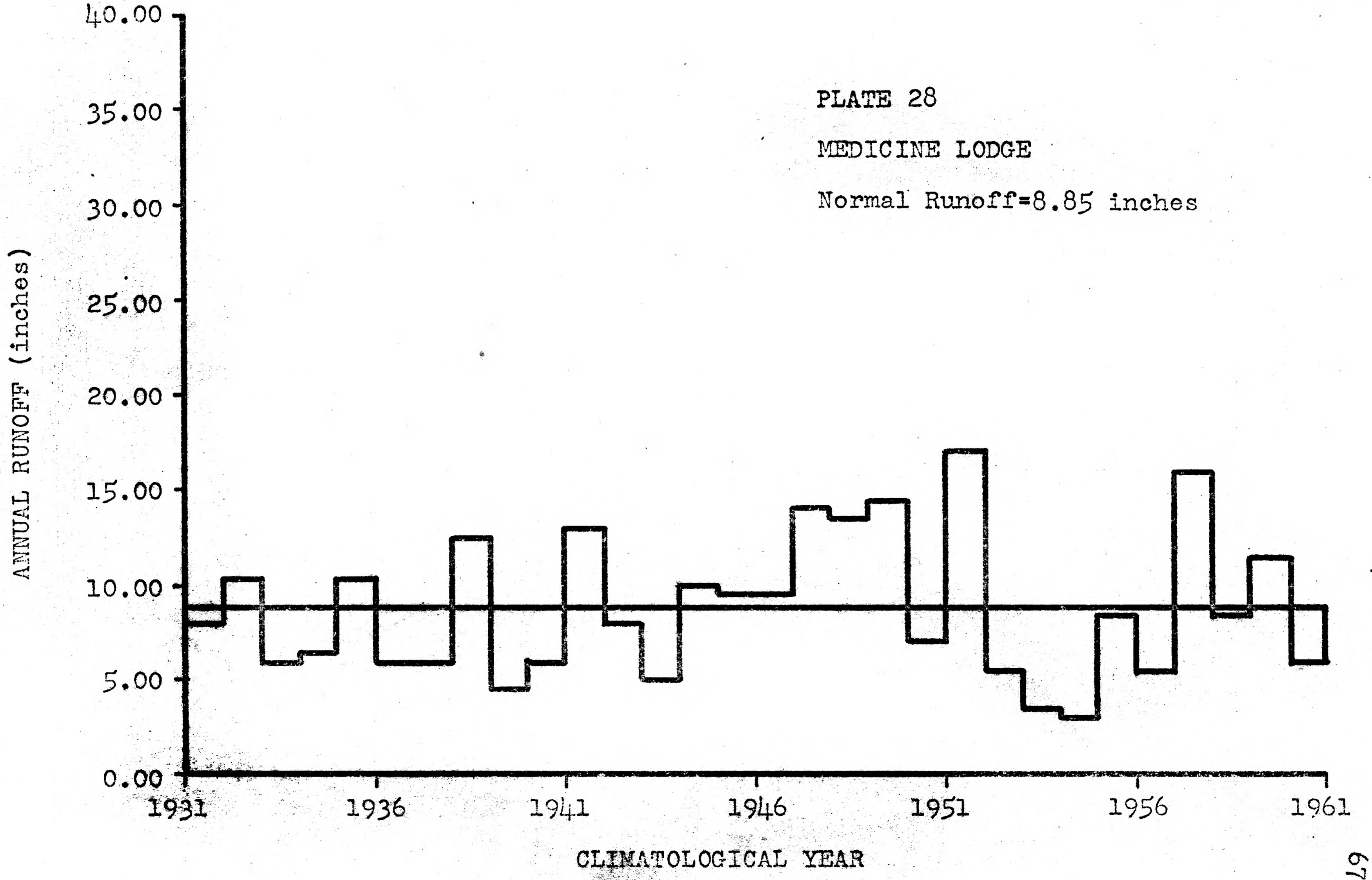


PLATE 28
MEDICINE LODGE
Normal Runoff=8.85 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

(April 26 through July 18). This twelve week period accounted for almost fifty per cent of the eighty per cent chance occurrence total runoff of 12.44 inches. An unusual characteristic appeared in the accumulation at this station in the 1.50 inches appearing from week 37 to week 40 (November 8 through December 5). No other station showed an increase of more than 0.50 inches at this time of the year.

The frequency of occurrence of peak weekly runoff amounts in one half inch increments is shown in Plate 30. In eighty per cent of the years, peak weekly runoff did not exceed 3.00 inches and in ninety per cent of the years it did not exceed 3.50 inches. The mean weighted value of peak weekly runoff was 2.07 inches.

Minneapolis

Annual precipitation varied from 15.19 inches to 54.22 inches at the Minneapolis station. Normal precipitation was 27.06 inches. Annual runoff varied from 3.42 inches to 22.94 inches and the normal runoff was 9.45 inches. Plate 31 on page 72 shows the total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 32 on page 75 is a plot of eighty per cent chance occurrence temporal distribution of cumulative runoff.

EXPLANATION OF PLATE 29

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Medicine Lodge Station.

EXPLANATION OF PLATE 30

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Medicine Lodge Station.

PLATE 29

MEDICINE LODGE

End Total-12.44 inches

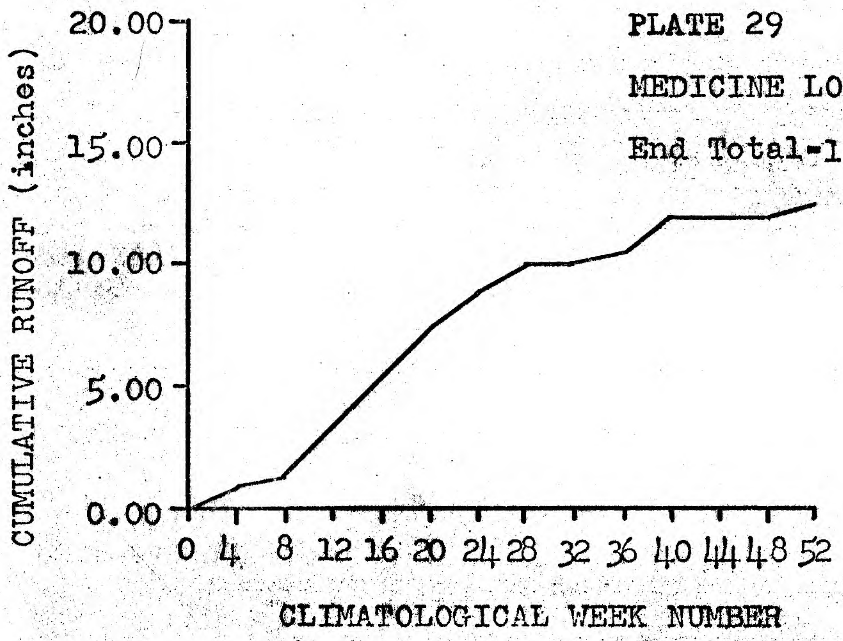
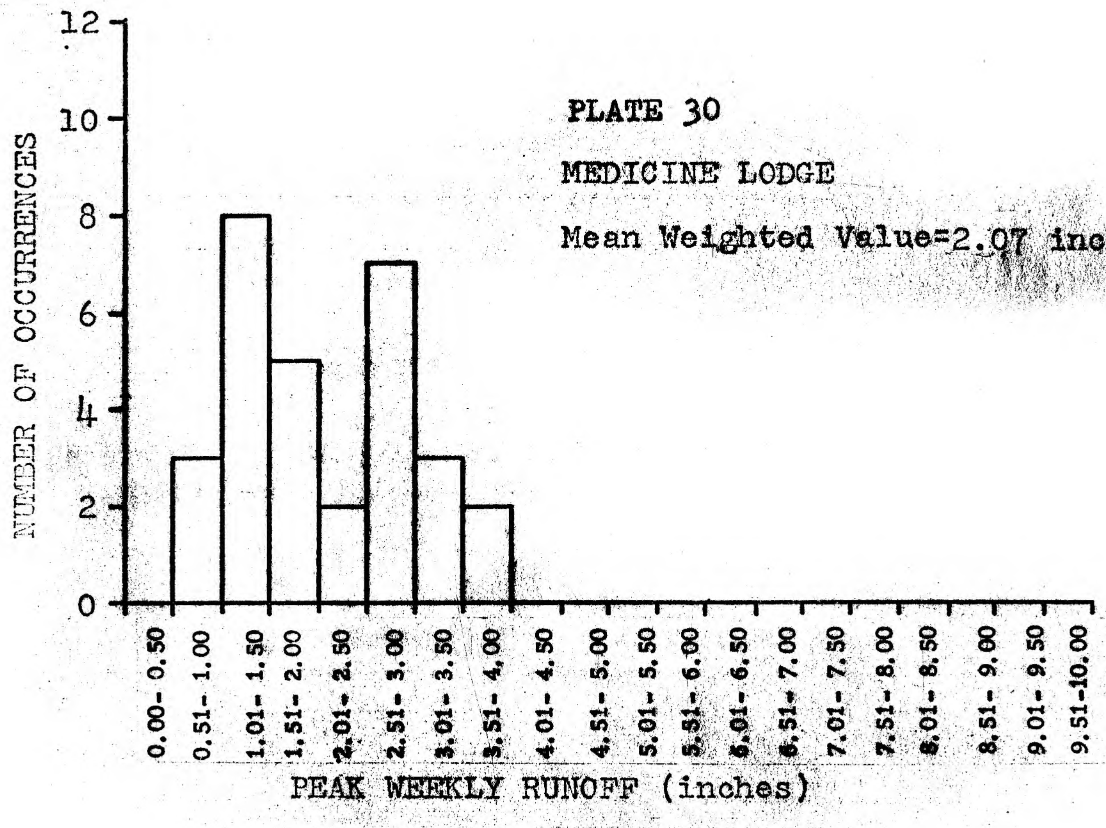


PLATE 30

MEDICINE LODGE

Mean Weighted Value=2.07 inches



EXPLANATION OF PLATE 31

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Minneapolis Station.

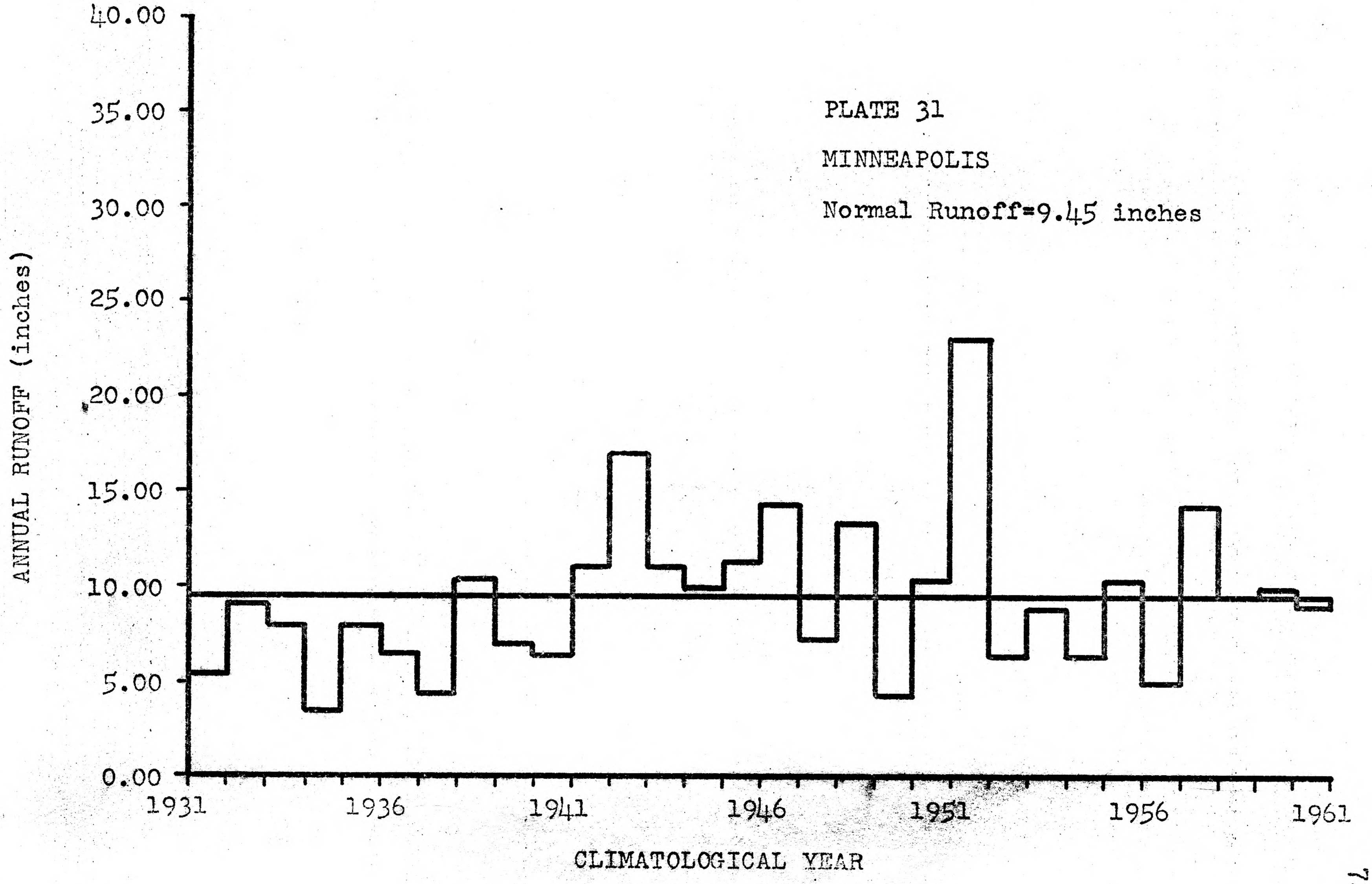


PLATE 31
MINNEAPOLIS
Normal Runoff=9.45 inches
ANNUAL RUNOFF (inches)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

This station like the preceding station has two periods of runoff accumulation less than 0.50 inches. For this station the periods are: week 33 through week 40 (October 11 through December 5) and week 45 through week 52 (January 3 to February 27). All other four week periods show increases of 0.50 inches or more with the maximum increase being 2.50 inches. The maximum increase occurred in weeks 13 through 16 (May 24 through June 20). The second highest accumulation rate was 1.50 inches which occurred from week 17 through week 28 (June 21 through September 12). These four periods or 16 weeks accounted for 7.00 inches of the eighty per cent chance occurrence total of 10.83 inches.

The frequency of occurrence of peak weekly runoff amounts in one half inch increments is shown in Plate 33. In eighty per cent of the years peak weekly runoff did not exceed 3.00 inches and in ninety per cent of the years, it did not exceed 3.50 inches. The mean weighted value of peak weekly runoff for the station was 2.21 inches.

St. Francis

Annual precipitation at the St. Francis station varied from 10.86 inches to 30.07 inches. The normal precipitation was 18.55 inches. Annual runoff varied from 1.92 inches to 9.95 inches. The normal runoff was 5.00 inches which was the

EXPLANATION OF PLATE 32

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Minneapolis Station.

EXPLANATION OF PLATE 33

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Minneapolis Station.

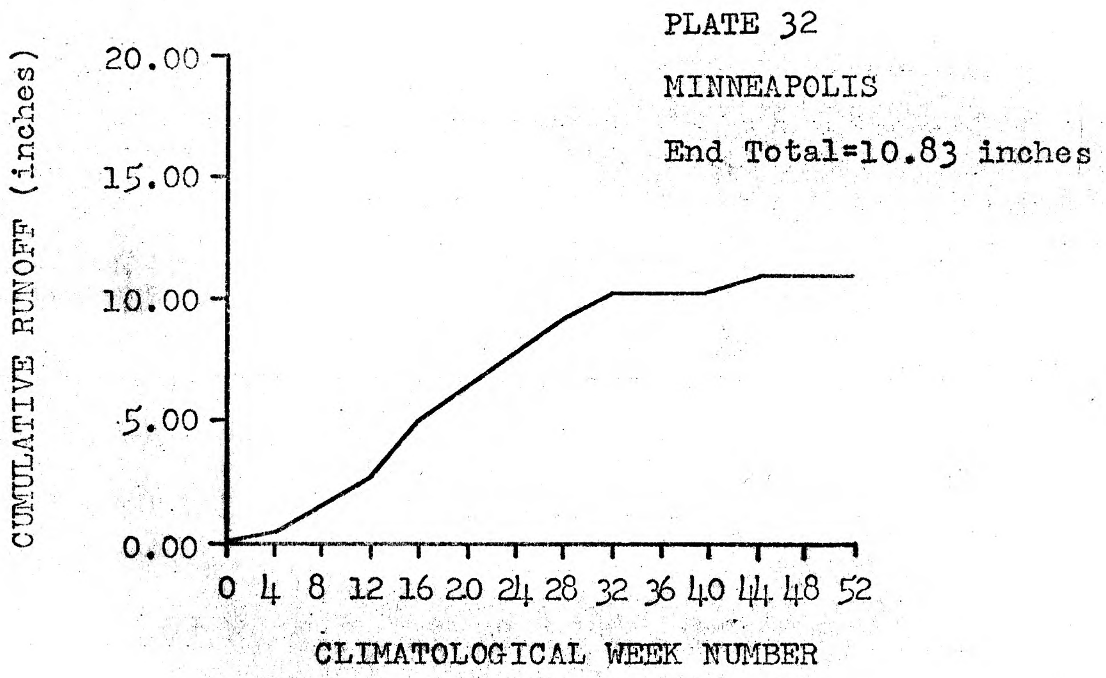


PLATE 32
MINNEAPOLIS
End Total=10.83 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

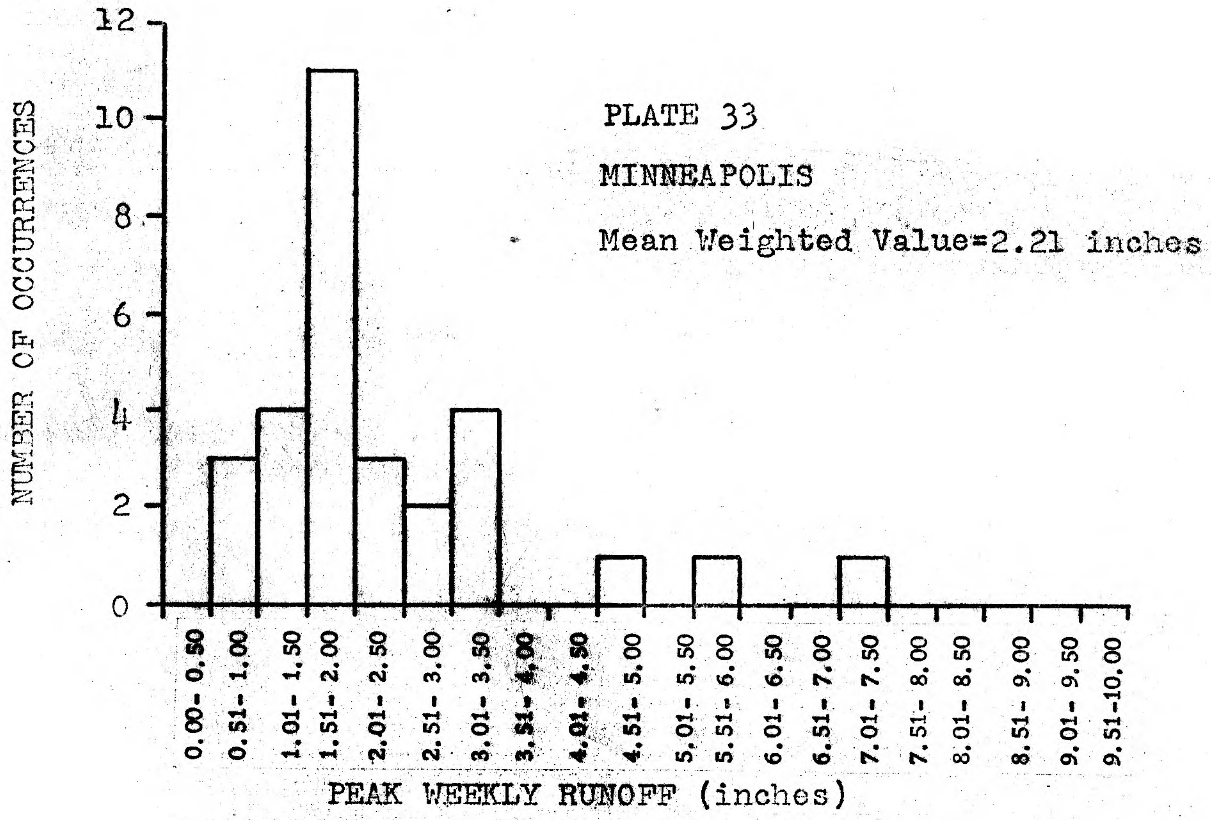


PLATE 33
MINNEAPOLIS
Mean Weighted Value=2.21 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

smallest normal encountered in the study. Plate 34 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 35 on page 80 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff began to accumulate at week one (March 1) and continued through week 36 (November 7) in increments of 0.50 inches or more per four week period. No significant runoff occurred from week 37 through week 52 (November 8 through February 27). The maximum runoff accumulation was 1.50 inches in any four week period. This rate occurred twice: from week 13 through week 16 (May 24 through June 20) and from week 25 through week 28 (August 16 through September 12). These two periods accounted for approximately forty per cent of the eighty per cent chance occurrence total runoff of 7.60 inches.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 36 on page 80. In eighty per cent of the years, peak weekly runoff did not exceed 2.50 inches and in none of the years studied did it exceed 3.00 inches. The mean weighted value of peak weekly runoff at this station was 1.27 which was the smallest value encountered in this study.

EXPLANATION OF PLATE 34

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. St. Francis Station.

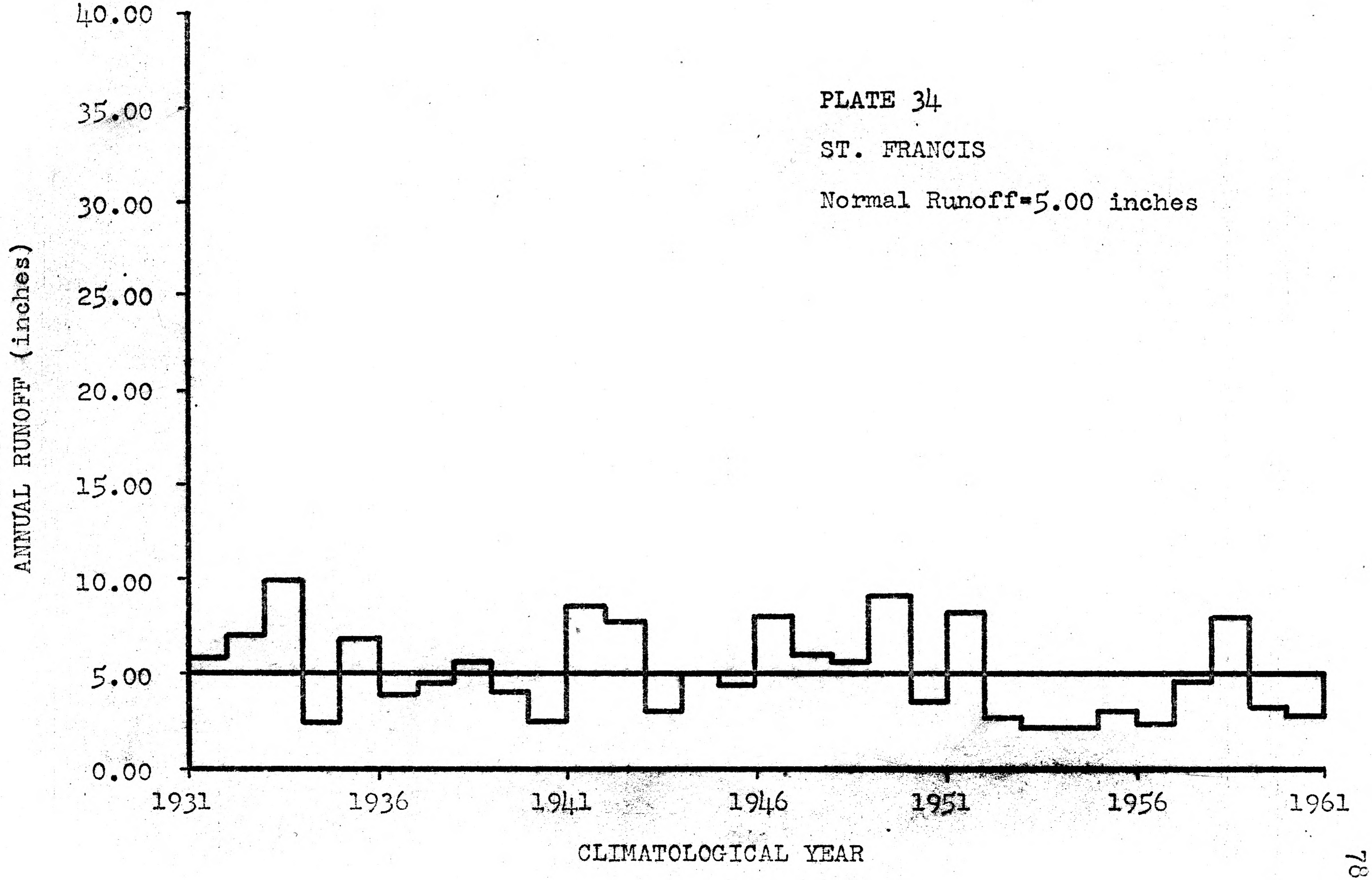


PLATE 34
ST. FRANCIS
Normal Runoff=5.00 inches
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANNUAL RUNOFF (inches)
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

EXPLANATION OF PLATE 35

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. St. Francis Station.

EXPLANATION OF PLATE 36

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. St. Francis Station.

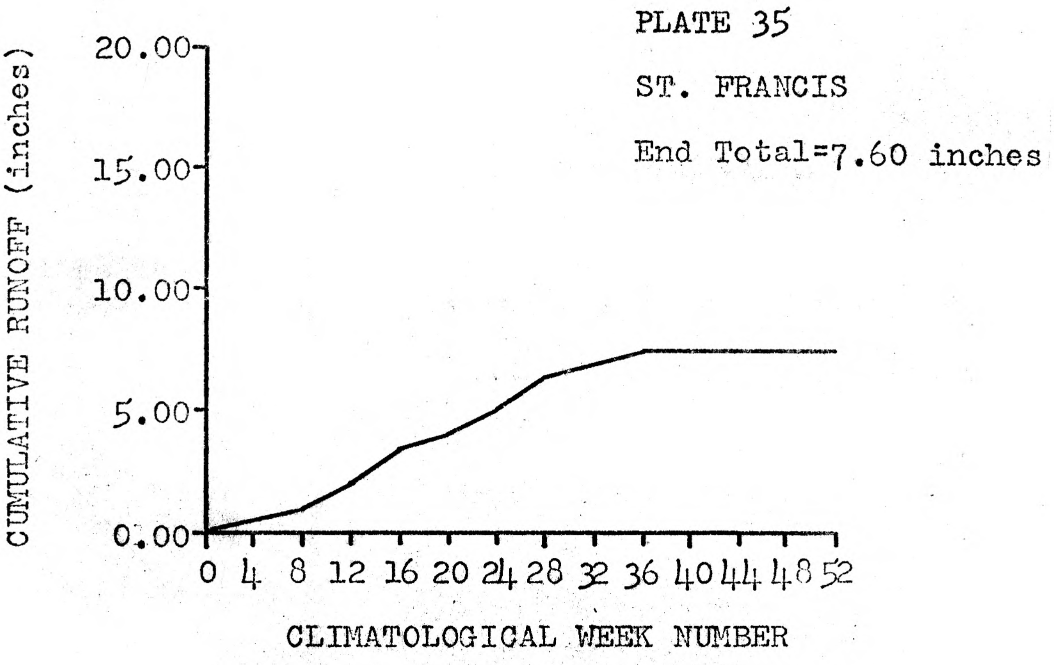


PLATE 35
ST. FRANCIS
End Total=7.60 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

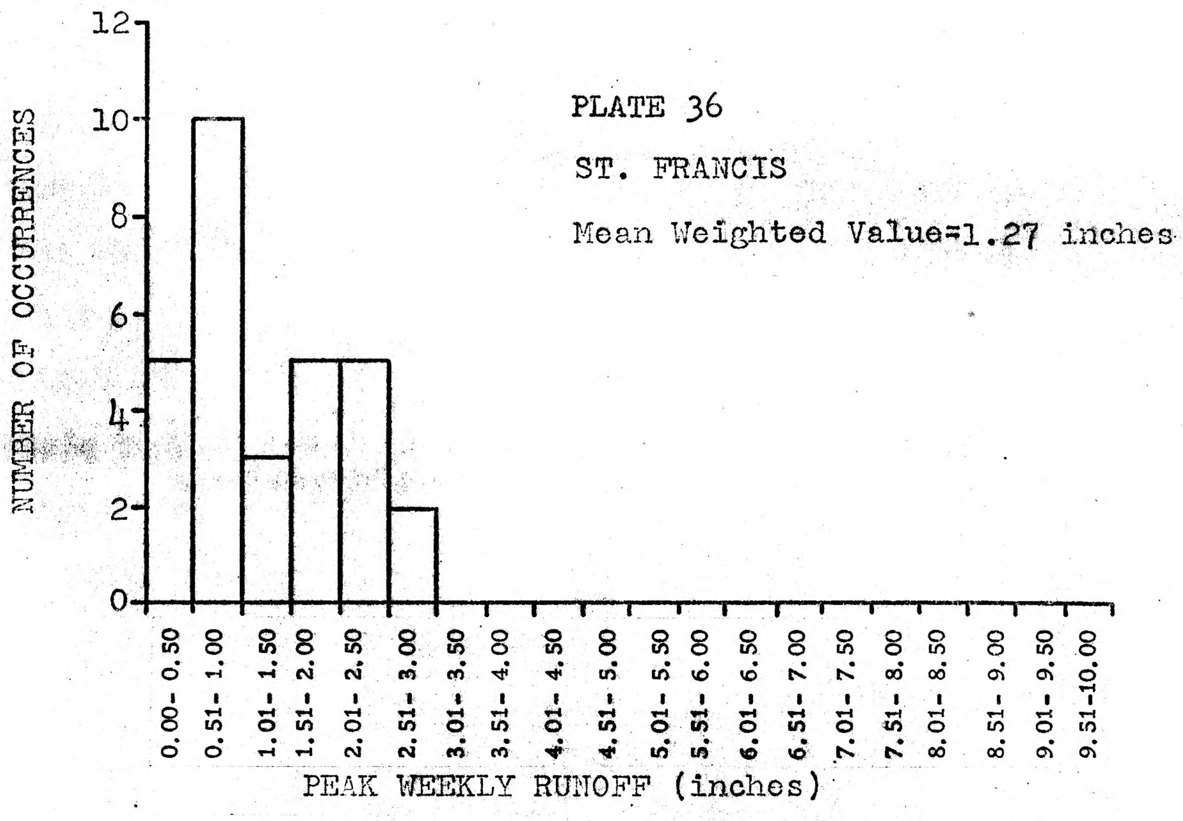


PLATE 36
ST. FRANCIS
Mean Weighted Value=1.27 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

Winfield

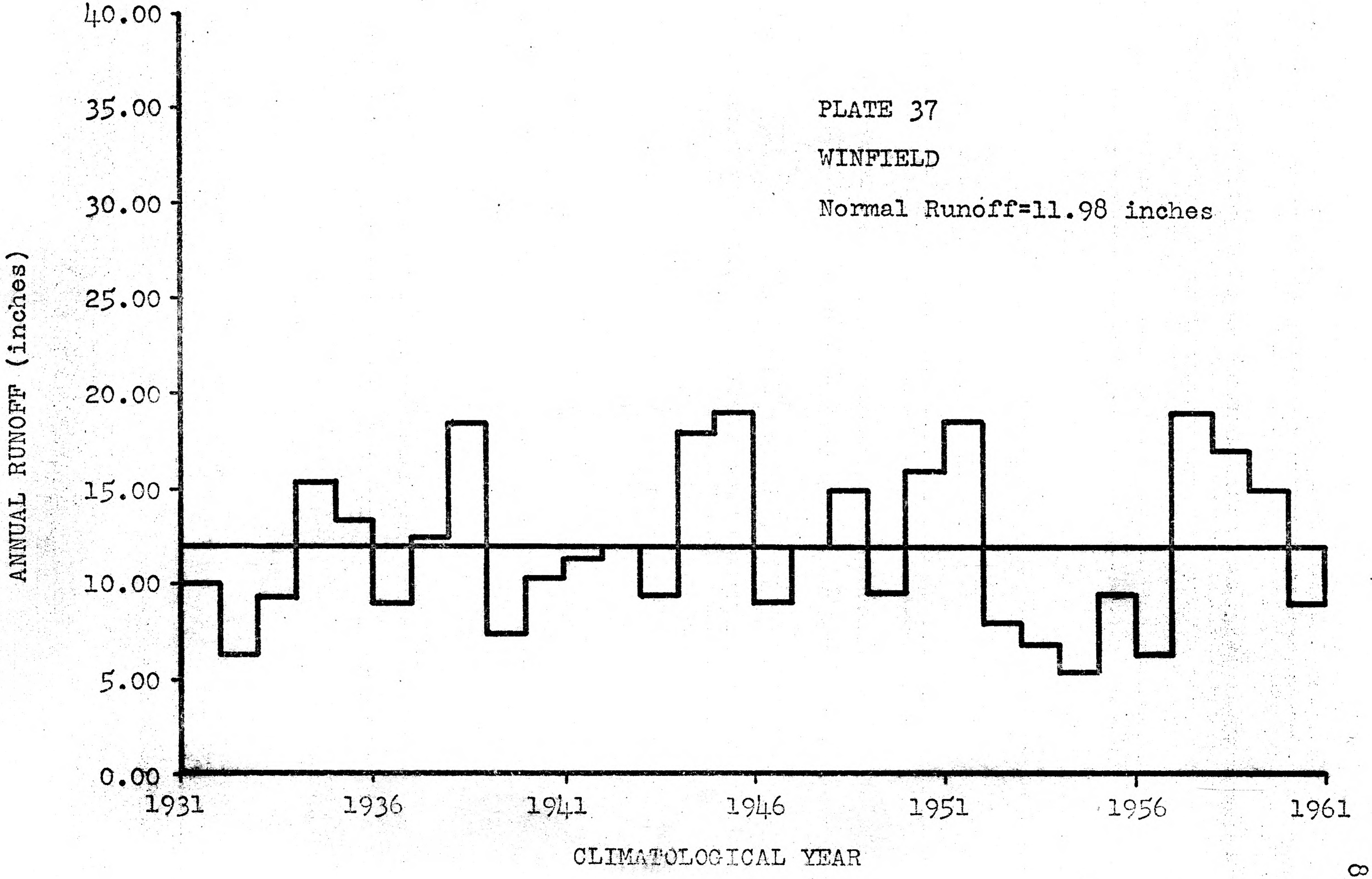
Annual precipitation varied at the Winfield station from 19.85 inches to 46.95 inches. The normal precipitation was 31.81 inches. Annual runoff varied from 6.25 inches to 19.16 inches and the normal runoff was 11.98 inches. Plate 37 shows total annual runoff for each climatological year plotted in relationship to the normal runoff line.

Plate 38 on page 85 is a plot of the eighty per cent chance occurrence temporal distribution of cumulative runoff. Runoff accumulation began at this station in week 45 (January 3) and continued through week 24 (August 15) in amounts of 0.50 inches or more per period. No significant runoff occurred in weeks 25 through 28 (August 16 through September 12). The period from week 29 through week 32 (September 13 through October 10) showed an increase of 4.00 inches which was the largest for this station. From week 33 through week 44 (October 11 through January 2) no significant runoff occurred. The largest accumulation mentioned above occurred, therefore, between two periods of no significant increase. This type of accumulation did not appear at any other station. No explanation for it is apparent from an examination of the data.

The frequency of occurrence of peak weekly runoff values in one half inch increments is shown in Plate 39 on

EXPLANATION OF PLATE 37

Total annual runoff for climatological years 1931 - 1960 plotted about the normal line. Winfield Station.


40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
ANNUAL RUNOFF (inches)
PLATE 37
WINFIELD
Normal Runoff=11.98 inches
1931
1936
1941
1946
1951
1956
1961
CLIMATOLOGICAL YEAR

EXPLANATION OF PLATE 38

Eighty per cent chance occurrence temporal distribution of cumulative runoff plotted at four week intervals. Winfield Station.

EXPLANATION OF PLATE 39

Frequency of occurrence of peak weekly runoff plotted in one half inch intervals. Winfield Station.

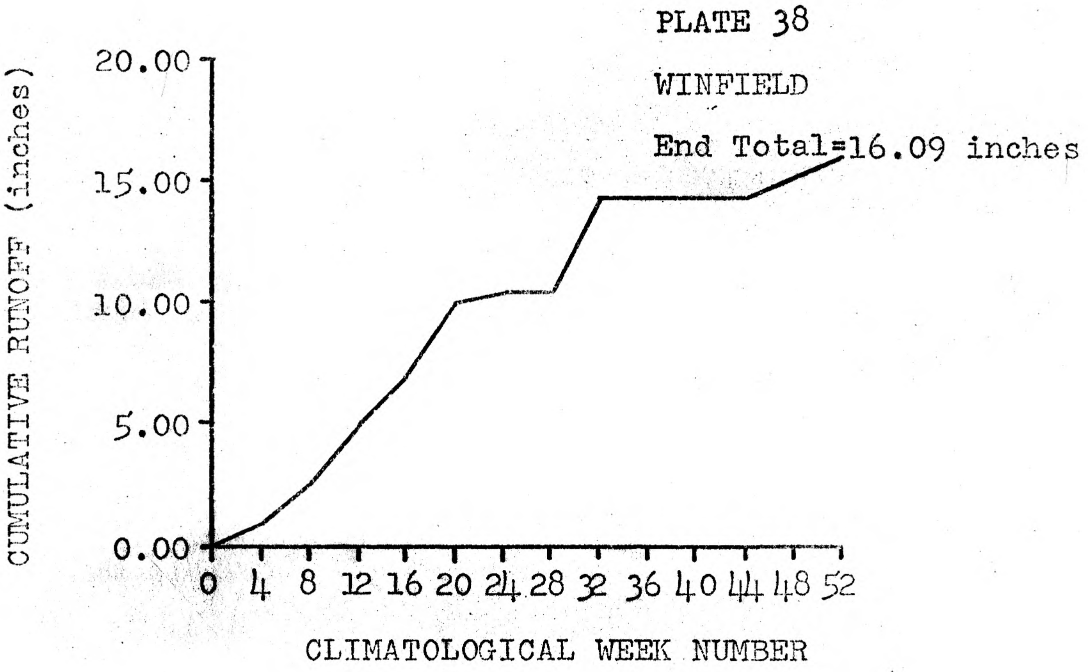


PLATE 38
WINFIELD
End Total=16.09 inches
CUMULATIVE RUNOFF (inches)
20.00
15.00
10.00
5.00
0.00
0 4 8 12 16 20 24 28 32 36 40 44 48 52
CLIMATOLOGICAL WEEK NUMBER

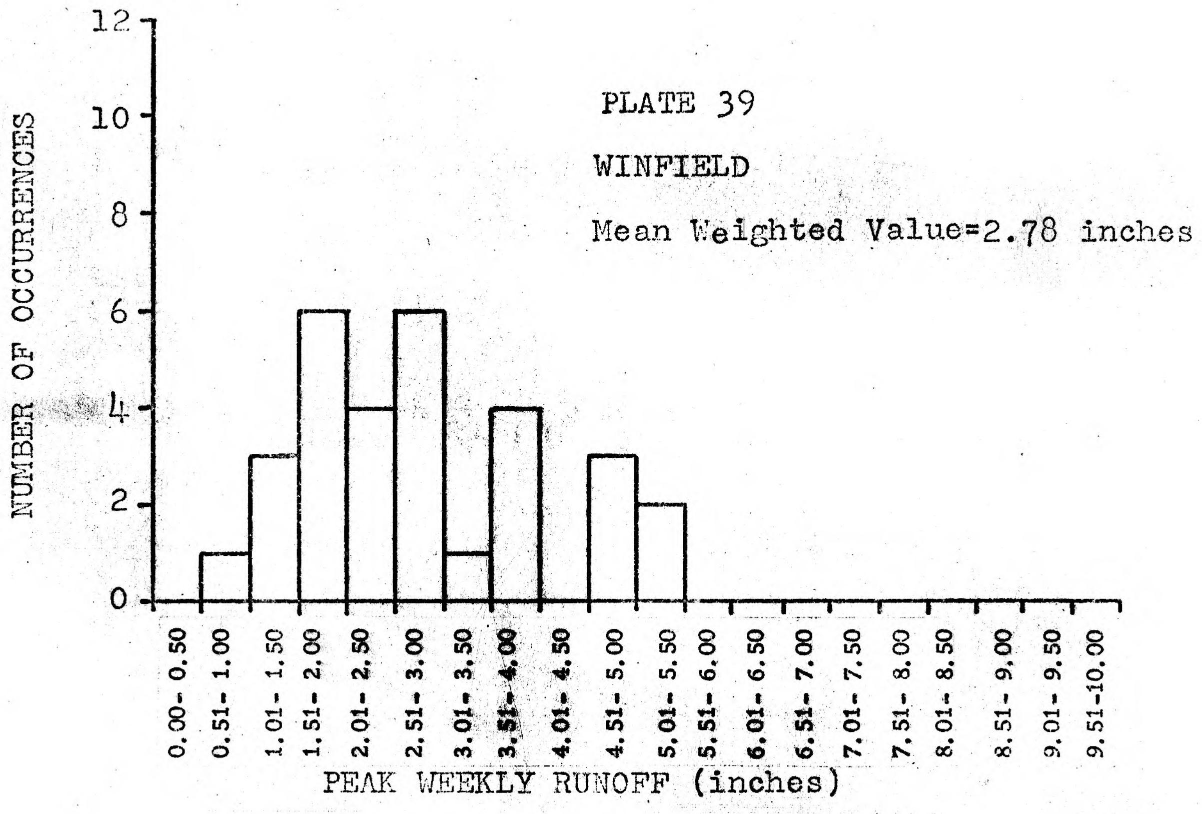


PLATE 39
WINFIELD
Mean Weighted Value=2.78 inches
NUMBER OF OCCURRENCES
12
10
8
6
4
2
0
0.00- 0.50
0.51- 1.00
1.01- 1.50
1.51- 2.00
2.01- 2.50
2.51- 3.00
3.01- 3.50
3.51- 4.00
4.01- 4.50
4.51- 5.00
5.01- 5.50
5.51- 6.00
6.01- 6.50
6.51- 7.00
7.01- 7.50
7.51- 8.00
8.01- 8.50
8.51- 9.00
9.01- 9.50
9.51-10.00
PEAK WEEKLY RUNOFF (inches)

page 85. In eighty per cent of the years, peak weekly runoff did not exceed 4.00 inches and in ninety per cent of the years, it did not exceed 5.00 inches. The mean weighted value of peak weekly runoff was 2.78 inches.

SUMMARY

A summary of data described in the station data section appears in Table IV. Since runoff was a function of precipitation, it was apparent that the stations with higher precipitation would, in general, have higher runoffs. Slight deviations from this might occur as a result of storm intensity variations. Also, as expected, there was a larger variation in runoff than in precipitation. The ratio of maximum to minimum runoff varied from 3.1 at Winfield to 8.9 at Hays. The ratio of maximum to minimum precipitation varied from 2.4 at Winfield to 5.0 at Hays.

Normal runoff totals varied from 5.00 inches at St. Francis to 14.55 inches at Columbus. Eighty per cent chance occurrence runoff varied from 7.60 inches at St. Francis to 16.92 inches at Columbus. Normal precipitation varied from 17.46 inches at Elkhart to 39.38 inches at Columbus.

Bark (11) states that "One of the interesting features of Kansas precipitation, ---, is the decrease of rain during the latter part of July." This decrease was very obvious in the eighty per cent chance occurrence temporal distribution

TABLE IV

SUMMARY OF STATION RESULTS
(All units are in inches)

Station	Precipitation Range	Normal Precipitation	Runoff Range	Normal Runoff	80% Chance Occurrence Runoff	Maximum 4-Week Increase	Dates of Maximum Increase	Mean Weighted Value P.W.R.*	80% Chance Occurrence P.W.R.*
Burr Oak	12.11-41.52	25.14	2.01-15.81	8.06	9.45	2.50	May 24 June 20	1.98	2.47
Columbus	21.91-56.44	39.38	5.47-25.11	14.55	16.92	3.00	June 21 July 18	2.83	3.30
Elkhart	7.46-29.47	17.46	1.93-11.76	5.48	7.68	1.50	July 19 Aug. 15	1.63	2.17
Hays	8.28-41.58	22.82	1.88-16.77	7.34	8.87	3.00	May 24 June 20	1.88	2.60
Healy	8.28-30.34	18.51	1.56-10.83	5.39	8.06	1.50	April 26 July 18	1.37	1.76
Horton	20.03-61.65	34.44	5.55-25.49	12.20	15.32	3.00	May 24 June 20	2.52	3.03
Manhattan	19.15-58.93	31.93	4.39-24.35	11.54	14.18	3.00	Jun.21-Jul.18 Aug.16-Sept.12	2.68	3.46
McPherson	14.84-48.03	27.31	3.67-18.50	8.98	12.34	2.50	April 26 May 23	1.82	2.45
Medicine Lodge	12.54-41.36	25.02	3.09-16.78	8.85	12.44	2.00	April 26 July 18	2.07	2.90
Minneapolis	15.19-54.22	27.06	3.42-22.94	9.45	10.83	2.50	May 24 June 20	2.21	3.02
St. Francis	10.86-30.07	18.55	1.92 - 9.95	5.00	7.60	1.50	May 24-Jun.20 Aug.16-Sept.12	1.27	2.09
Winfield	19.85-46.95	31.81	6.25-19.16	11.98	16.09	4.00	Sept. 13 Oct. 10	2.78	3.96

*Peak Weekly Runoff

of cumulative runoff curves for Manhattan and Columbus. The only station that had a peak accumulation during the period which included the latter part of July was Elkhart. For all stations, the normal readings for the 4-week periods preceding, including and succeeding late July were 1.80 inches, 1.13 inches and 1.33 inches respectively.

The maximum 4-week runoff accumulations ranged from 1.50 inches to 4.00 inches. For ten of the twelve stations, all or a part of the maximum accumulation occurred within the period of April 26 to July 18. The exceptions were Elkhart and Winfield where the peak periods were July 19 through August 15 and September 13 through October 10 respectively.

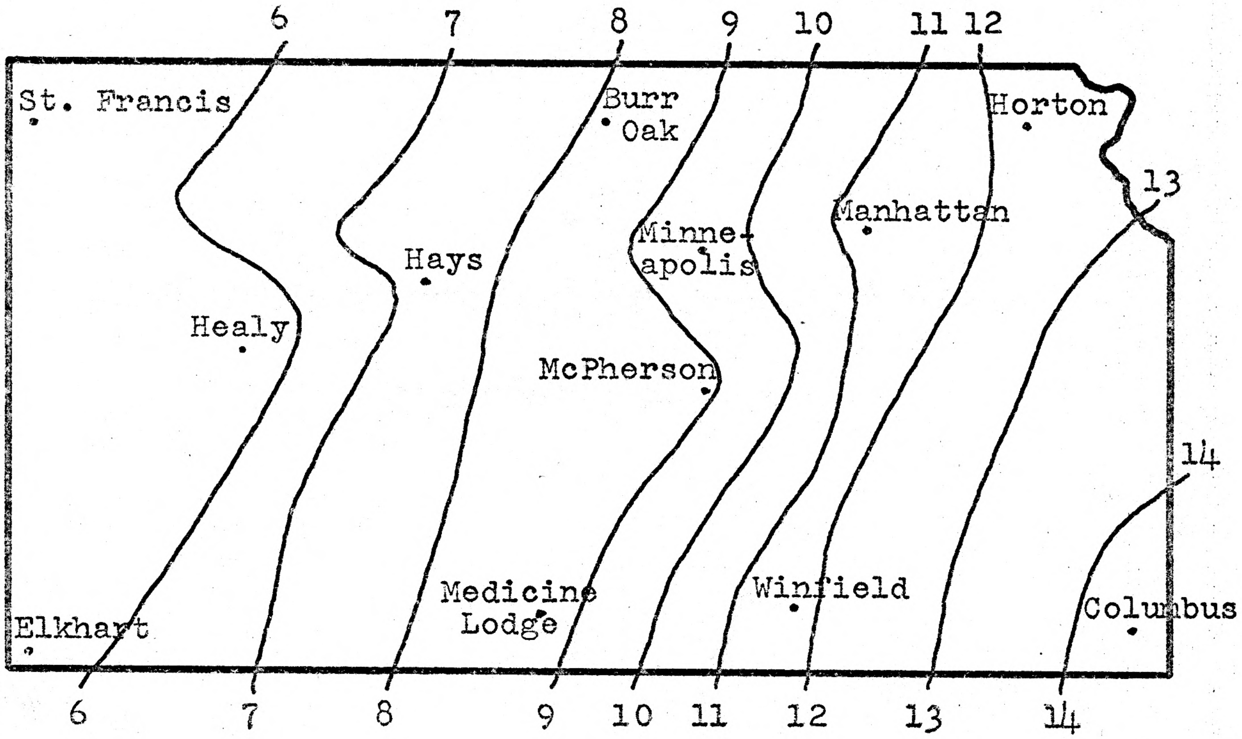
The mean weighted value of peak weekly runoff varied from 1.27 inches at St. Francis to 2.83 inches at Columbus. Eighty per cent chance occurrence of peak weekly runoff was under two inches at Healy, between two and three inches for six stations and over three inches for the remaining five stations.

Plates 40 and 41 show normal annual runoff and eighty per cent chance occurrence annual runoff. These plates were prepared by interpolating from the station results of this study.

EXPLANATION OF PLATE 40

Normal annual runoff in inches interpolated from station data.

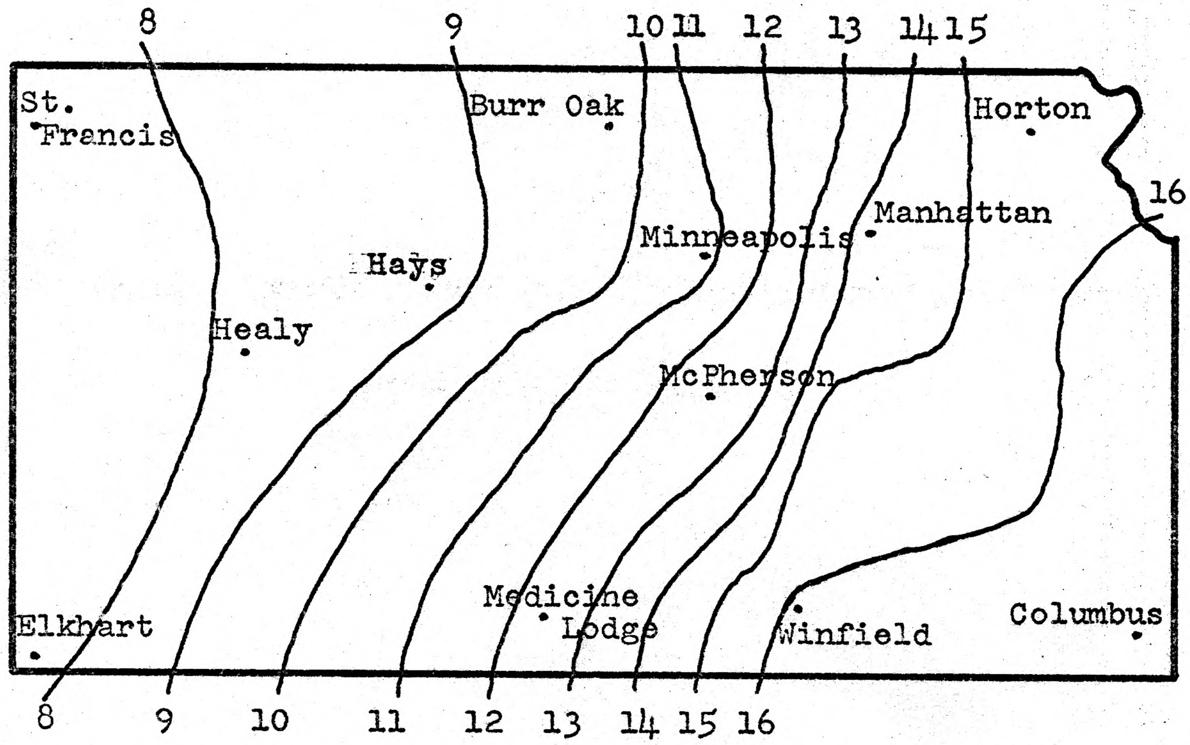
PLATE 40


St. Francis
Burr Oak
Horton
Manhattan
Minneapolis
Hays
Healy
McPherson
Medicine Lodge
Winfield
Elkhart
Columbus
6
7
8
9
10
11
12
13
14

EXPLANATION OF PLATE 41

Eighty per cent chance occurrence runoff in inches interpolated from station data.

PLATE 41


8
9
10
11
12
13
14
15
16
St. Francis
Burr Oak
Horton
Manhattan
Minneapolis
Hays
Healy
McPherson
Medicine Lodge
Elkhart
Winfield
Columbus

CONCLUSIONS

Following are the conclusions of this study.

1. The IBM 360 computer can be used successfully in conjunction with the weather tapes to determine total amounts of runoff and runoff characteristics.

2. Based on an average soil cover complex number of 91, uncorrected for antecedent moisture conditions, the normal annual runoff from unsurfaced feedlots in Kansas will vary from approximately 5.00 inches to approximately 15.00 inches.

3. This type of information would be beneficial in the design of runoff retention or storage structures.

SUGGESTIONS FOR FURTHER RESEARCH

1. This study was based on an empirical selection of a soil cover complex number. The number so selected has been supported in one field model study. Additional full scale feedlot studies should be initiated in this area.

2. In order to maximize the benefits of this type of information in design, it is necessary to also know the transport and storage losses. Studies in the areas of seepage and its variation with time; and, of evaporation rates and their fluctuations with water quality, surface scums, etc. should be initiated.

3. Another area of possible study is the area of management of the runoff storage. Some of the questions raised are: how frequently is it practical to empty the storage structure; what methods of emptying are available and feasible; and, where may the liquid and/or solids from the structure be deposited.

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Acknowledgment is given to Professors Harry Manges and Carl Anderson of the Agricultural Engineering Department for their review of the data and discussion of hydrologic aspects of the study.

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Special acknowledgment is given to Ralph Samuelson and Allen Crawford, program consultants for the physical sciences computer center. Mr. Crawford, a user programmer, gave unselfishly of his time to assist in solving some of the problems that developed.

Finally, acknowledgment is given to my wife, Joanne, for her encouragement and understanding.

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APPENDIX

```
           DIMENSION A(30),B(30,52)
           DIMENSION PLOT(6,52,50)
           DIMENSION YPREC(30)
           DIMENSION RWKLY(30,52)
           DIMENSION IYEARS(52),KDATE(30),IDATE(30)
           DIMENSION CUMRUN(30),CUMPRE(30)
           DIMENSION                MONTH(52),IDAYS(52)
      1000 FORMAT(' ')
       999 FORMAT(' ',18X,I2,4X,'WEEK BEGINNING ',I2,'-',I2,'-',I2,17X,F5.2
          .0X,F5.2)
       998 FORMAT('1',50X,'YEAR BEGINNING MARCH 1, 19',I2//)
       997 FORMAT(15X,'WEEK NUMBER',36X,'WEEKLY TOTALS',21X,'CUMULATIVE TOT
          .S'///)
       996 FORMAT('+',6X,F5.2,'--I',104X,'I- ')
       971 FORMAT('+',13X,104('-'))
       970 FORMAT('+',14X,52('I '))
       969 FORMAT(' ',14X,'1 2 3 4 5 6 7 8 9 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2
          .2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4 4 4 4 4 4 4 5 5 5')
       968 FORMAT(' ',32X,'0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
          .5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 ')
       995 FORMAT('+',14X,52(A1,1X))
      7273 FORMAT('0',41X,'TOTAL RUNOFF: ',F5.2,5X,'TOTAL PRECIPITATION: ',
          ..2)
       993 FORMAT(51X,'GRAPH NUMBER ',I1,' FOR STATION ',I4)
       992 FORMAT('1')
       991 FORMAT(14X,106('-'))
       990 FORMAT('+',122X,'TOTALS:')
       989 FORMAT('+',121X,A1,'=19',I2)
       988 FORMAT('+',2X,'I',118X,'PRECIP:')
       987 FORMAT('+',2X,'N')
       986 FORMAT('+',2X,'C',118X,'A=',F5.2)
       967 FORMAT('+',2X,'F')
       985 FORMAT('+',2X,'H')
       984 FORMAT('+',2X,'E',118X,'B=',F5.2)
       983 FORMAT('+',2X,'S')
       982 FORMAT('+',121X,'C=',F5.2)
       981 FORMAT('+',2X,'C')
       980 FORMAT('+',2X,'F',118X,'D=',F5.2)
       979 FORMAT('+',2X,'R',118X,'E=',F5.2)
       978 FORMAT('+',2X,'U')
       977 FORMAT('+',2X,'N',118X,'F=',F5.2)
       976 FORMAT('+',2X,'C')
       975 FORMAT('+',121X,'RUNOFF:')
       974 FORMAT('+',121X,A1,'=',F5.2)
       973 FORMAT(1H )
           INTEGER YEAR,WEEK,DAILY,SET
           REAL IRANK
           DATA BLANK/' '/
           DATA A1/'A'/
           DATA A2/'B'/
           DATA A3/'C'/
           DATA A4/'D'/
           DATA A5/'E'/
           DATA A6/'F'/
           IYEAR=31
           WRITE(3,998)IYEAR
           WRITE(3,997)
      8887 CALL RECORD(I1,I2,IYEAR,IMO,IDAY,I6,I7,IPREC,I9,I10,I11,I12,I13,
```

```
      14,I15,I16,I17)
        IF(IYEAR.LT.31)GO TO 8887
        IF(IMO.EQ.2.AND.IDAY.EQ.28)GO TO 888
        GO TO 8887
    888 DO 30 YEAR=1,30
        CUMRUN(YEAR)=0
        CUMPRE(YEAR)=0
        DO 52 WEEK=1,52
        V=0
        DO 7 DAILY=1,7
   7777 CALL RECORD(I1,I2,IYEAR,IMO,IDAY,I6,I7,IPREC,I9,I10,I11,I12,I13,
      14,I15,I16,I17)
        IF(IMO.EQ.2.AND.IDAY.EQ.28)GO TO 7777
        JYEAR=IYEAR
        IF(IPREC.EQ.5555)IPREC=000
        APREC=IPREC
        PREC=APREC/100.
        IF(DAILY.NE.1)GOTO 1
        MONTH(WEEK)=IMO
        IDAYS(WEEK)=IDAY
        IYEARS(WEEK)=JYEAR
      1 CALL RUNOF(PREC,RUNOFF)
        CUMPRE(YEAR)=CUMPRE(YEAR)+PREC
        V=V+RUNOFF
      7 CONTINUE
        CUMRUN(YEAR)=CUMRUN(YEAR)+V
        RWKLY(YEAR,WEEK)=CUMRUN(YEAR)
        WRITE(3,999)WEEK,MONTH(WEEK),IDAYS(WEEK),IYEARS(WEEK),V,CUMRUN(Y
      .R)
     52 CONTINUE
        WRITE(3,7273)CUMRUN(YEAR),CUMPRE(YEAR)
        KDATE(YEAR)=IYEAR-1
        IF(YEAR.EQ.30)GO TO 30
        WRITE(3,998)JYEAR
        WRITE(3,997)
     30 CONTINUE
        CALL SORT(A,CUMRUN,IDATE,KDATE,B,RWKLY,CUMPRE,YPREC)
        WRITE(3,992)
        DO 20 KGRAPH=1,5
        WRITE(3,993)KGRAPH,I2
        WRITE(3,991)
        DO 5 YEAR=1,6
        DO 4 WEEK=1,52
        C=B(YEAR,WEEK)
        K1=C*2+.5
        K=50-K1
        DO 3 INCH=1,50
        IF(INCH.EQ.K)GOTO 2
        PLOT(YEAR,WEEK,INCH)=BLANK
        GO TO 3
     11 PLOT(YEAR,WEEK,INCH)=A5
        GO TO 3
      2 IF(YEAR.LE.4) GO TO 10
        IF(YEAR.EQ.5) GO TO 11
        PLOT(YEAR,WEEK,INCH)=A6
        GO TO 3
     10 IF(YEAR.LE.2)GO TO 12
        IF(YEAR.EQ.3)GO TO 13
```

```
      PLOT(YEAR,WEEK,INCH)=A4
      GO TO 3
   13 PLOT(YEAR,WEEK,INCH)=A3
      GO TO 3
   12 IF(YEAR.EQ.1) GO TO 14
      PLOT(YEAR,WEEK,INCH)=A2
      GO TO 3
   14 PLOT(YEAR,WEEK,INCH)=A1
    3 CONTINUE
    4 CONTINUE
    5 CONTINUE
      DO 15 INCH=1,50
      T=INCH
      F=(50.-T)/2.
      WRITE(3,996)F
      GO TO(55,104,55,105,55,106,55,107,55,108,55,109,55,55,55,110,55,
     11,112,113,114,115,117,118,119,120,121,122,123,124,125,98,98,126,
     2,127,55,128,55,129,55,130,55,131,55,132,55,55,55,55),INCH
  104 J=IDATE(1)
      WRITE(3,989)A1,J
      GO TO 55
  105 J=IDATE(2)
      WRITE(3,989)A2,J
      GO TO 55
  106 J=IDATE(3)
      WRITE(3,989)A3,J
      GO TO 55
  107 J=IDATE(4)
      WRITE(3,989)A4,J
      GO TO 55
  108 J=IDATE(5)
      WRITE(3,989)A5,J
      GO TO 55
  109 J=IDATE(6)
      WRITE(3,989)A6,J
      GOTO 55
  110 WRITE(3,990)
      GOTO 55
  111 WRITE(3,988)
      GO TO 55
  112 WRITE(3,987)
      GO TO 55
  113 WRITE(3,986)YPREC(1)
      GO TO 55
  114 WRITE(3,985)
      GO TO 55
  115 WRITE(3,984)YPREC(2)
      GO TO 55
  117 WRITE(3,983)
      GO TO 55
  118 WRITE(3,982)YPREC(3)
      GO TO 55
  119 WRITE(3,981)
      GO TO 55
  120 WRITE(3,980)YPREC(4)
  121 GOTO 55
  122 WRITE(3,979)YPREC(5)
      GO TO 55
```

```
          SUBROUTINE SORT(A,CUMRUN,IDATE,KDATE,B,RWKLY,CUMPRE,YPREC)
          DIMENSION YPREC(30)
          DIMENSION A(30),CUMRUN(30),IDATE(30),KDATE(30)
          DIMENSION B(30,52),RWKLY(30,52),CUMPRE(30)
      996 FORMAT('1',40X,'RANK',5X,'YEAR',10X,'RUNOFF',10X,'PRECIPITATION'
         .)
      999 FORMAT(42X,I2,6X,'19',I2,10X,F5.2,15X,F5.2)
          WRITE(3,996)
          KNOCK=30
          DO30I=1,30
          JOT=1
          YPREC(I)=CUMPRE(1)
          A(I)=CUMRUN(1)
          IDATE(I)=KDATE(1)
          DO5L=1,52
          B(I,L)=RWKLY(1,L)
        5 CONTINUE
          DO20J=1,KNOCK
          IF(CUMRUN(J).GT.A(I))GO TO 19
          GO TO 20
       19 A(I)=CUMRUN(J)
          JOT=J
          YPREC(I)=CUMPRE(J)
          IDATE(I)=KDATE(J)
          DO6L=1,52
          B(I,L)=RWKLY(J,L)
        6 CONTINUE
       20 CONTINUE
          KNOCK=KNOCK-1
          IF(JOT.EQ.KNOCK+1)GO TO 21
          DO7L=JOT,KNOCK
          CUMRUN(L)=CUMRUN(L+1)
          CUMPRE(L)=CUMPRE(L+1)
          KDATE(L)=KDATE(L+1)
          DO11M=1,52
          RWKLY(L,M)=RWKLY(L+1,M)
       11 CONTINUE
        7 CONTINUE
       21 J=IDATE(I)
          WRITE(3,999)I,J,A(I),YPREC(I)
       30 CONTINUE
          RETURN
          END
```

```
      SUBROUTINE RUNOF(PREC,RUNOFF)
      A=PREC
      IF(A.LE.3.05)GO TO 10
      IF(A.LE.4.25)GO TO 11
      IF(A.LE.5.15)GO TO 12
      IF(A.LE.5.65)GO TO 13
      IF(A.LE.5.85)GO TO 14
      IF(A.LE.5.95)GO TO 15
      IF(A.LE.6.)GO TO 16
      B=4.92+A-6.
      GO TO 1
   16 B=4.92
      GO TO 1
   15 B=4.82
      GO TO 1
   14 IF(A.LE.5.75)GO TO 17
      B=4.73
      GO TO 1
   17 B=4.63
      GO TO 1
   13 IF(A.LE.5.35)GO TO 18
      IF(A.LE.5.55)GO TO 19
      IF(A.LE.5.45)GO TO 20
      B=4.44
      GO TO 1
   20 B=4.35
      GO TO 1
   19 B=4.54
      GO TO 1
   18 IF(A.LE.5.25)GO TO 21
      B=4.25
      GO TO 1
   21 B=4.16
      GO TO 1
   12 IF(A.LE.4.85)GO TO 22
      IF(A.LE.5.05)GO TO 23
      B=4.06
      GO TO 1
   23 IF(A.LE.4.95)GO TO 24
      B=3.97
      GO TO 1
   24 B=3.87
      GO TO 1
   22 IF(A.LE.4.64)GO TO 25
      IF(A.LE.4.75)GO TO 26
      B=3.78
      GO TO 1
   26 B=3.68
      GO TO 1
   25 IF(A.LE.4.55)GO TO 27
      B=3.59
      GO TO 1
   27 IF(A.LE.4.45)GO TO 28
      B=3.49
      GO TO 1
   28 IF(A.LE.4.35)GO TO 29
      B=3.40
      GO TO 1
```

```
 29 B=3.3
    GO TO 1
 11 IF(A.LE.3.65)GO TO 30
    IF(A.LE.3.95)GO TO 31
    IF(A.LE.4.15)GO TO 32
    B=3.21
    GO TO 1
 32 IF(A.LE.4.05)GO TO 33
    B=3.11
    GO TO 1
 33 B=3.02
    GO TO 1
 31 IF(A.LE.3.85)GO TO 34
    B=2.92
    GO TO 1
 34 IF(A.LE.3.75)GO TO 35
    B=2.83
    GO TO 1
 35 B=2.73
    GO TO 1
 30 IF(A.LE.3.35)GO TO 36
    IF(A.LE.3.55)GO TO 37
    B=2.64
    GO TO 1
 37 IF(A.LE.3.45)GO TO 38
    B=2.54
    GO TO 1
 38 B=2.45
    GO TO 1
 36 IF(A.LE.3.25)GO TO 39
    B=2.35
    GO TO 1
 39 IF(A.LE.3.15)GO TO 40
    B=2.26
    GO TO 1
 40 B=2.17
    GO TO 1
 10 IF(A.LE.1.65)GO TO 41
    IF(A.LE.2.35)GO TO 42
    IF(A.LE.2.75)GO TO 43
    IF(A.LE.2.95)GO TO 44
    B=2.07
    GO TO 1
 44 IF(A.LE.2.85)GO TO 45
    B=1.98
    GO TO 1
 45 B=1.89
    GO TO 1
 43 IF(A.LE.2.55)GO TO 46
    IF(A.LE.2.65)GO TO 47
    B=1.8
    GO TO 1
 47 B=1.71
    GO TO 1
 46 IF(A.LE.2.45)GO TO 48
    B=1.62
    GO TO 1
 48 B=1.53
```

```
      GO TO 1
   42 IF(A.LE.2.05)GO TO 49
      IF(A.LE.2.25)GO TO 50
      B=1.44
      GO TO 1
   50 IF(A.LE.2.15)GO TO 51
      B=1.35
      GO TO 1
   51 B=1.26
      GO TO 1
   49 IF(A.LE.1.85)GO TO 67
      IF(A.LE.1.95)GO TO 68
      B=1.17
      GO TO 1
   68 B=1.09
      GO TO1
   67 IF(A.LE.1.75)GO TO 69
      B=1.01
      GO TO 1
   69 B=.92
      GO TO 1
   41 IF(A.LE..95)GO TO 52
      IF(A.LE.1.25)GO TO 53
      IF(A.LE.1.45)GO TO 54
      IF(A.LE.1.35)GO TO 55
      B=.84
      GO TO 1
   55 B=.76
      GO TO 1
   54 IF(A.LE.1.35)GO TO 56
      B=.67
      GO TO 1
   56 B=.59
      GO TO 1
   53 IF(A.LE.1.15)GO TO 57
      B=.51
      GO TO 1
   57 IF(A.LE.1.05)GO TO 58
      B=.43
      GO TO 1
   58 B=.35
      GO TO 1
   52 IF(A.LE..55)GO TO 59
      IF(A.LE..75)GO TO 60
      IF(A.LE..85)GO TO 61
      B=.3
      GO TO 1
   61 B=.25
      GO TO 1
   60 IF(A.LE..65)GO TO 62
      B=.21
      GO TO 1
   62 B=.17
      GO TO 1
   59 IF(A.LE..35)GO TO 63
      IF(A.LE..45)GO TO 64
      B=.12
      GO TO 1
```

```
       64 B=.09
          GO TO 1
       63 IF(A.LE..25)GO TO 65
          B=.05
          GO TO 1
       65 IF(A.LE..18)GO TO 66
          B=.01
          GO TO 1
       66 B=0.
        1 RUNOFF=B
          RETURN
          END
```

```
   64 B=.09
      GO TO 1
   63 IF(A.LE..25)GO TO 65
      B=.05
      GO TO 1
   65 IF(A.LE..18)GO TO 66
      B=.01
      GO TO 1
   66 B=0.
    1 RUNOFF=B
      RETURN
      END
```

ANNUAL TOTALS AND TEMPORAL DISTRIBUTION OF CATTLE FEEDLOT RUNOFF IN KANSAS

by

FREDERICK GORDON BERGSRUD

B. Ag. E., University of Minnesota, 1960

AN ABSTRACT OF A MASTER'S REPORT

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1968

The objectives of this study were: to establish a system for determining the total annual runoff, the inflow rates, and the temporal distribution of runoff from cattle feedlots; to analyze data using this system; and, to examine the data to determine the range and distribution of occurrences using the system.

The factors affecting runoff were found to be in two categories, precipitation factors and watershed factors. The smallest increment in which precipitation factors were readily available was a 24 hour or daily basis. Watershed factors were expressed in terms of a hydrologic soil cover complex number which was developed by the Soil Conservation Service.

Because of the large volume of calculations necessary and the fact that daily precipitation records were available on IBM magnetic tape an IBM 360 computer was used. A computer program was developed to read daily precipitations from the tape and convert them to runoff based on a given Soil Cover Complex Number. The soil cover complex number used in this study was 91. This was based on an average antecedent moisture condition.

Data from twelve stations were analyzed for a period of thirty years beginning on March 1, 1931, and ending on February 27, 1960. The stations used gave good areal distribution and represented the full range of annual precipitation totals in Kansas which is from about 16 inches to about 40 inches.

The twelve stations used in the study were:

1.	Burr Oak	7.	Manhattan
2.	Columbus	8.	McPherson
3.	Elkhart	9.	Medicine Lodge
4.	Hays	10.	Minneapolis
5.	Healy	11.	St. Francis
6.	Horton	12.	Winfield

Normal precipitation in the period studied varied from 17.46 inches at Elkhart to 39.38 inches at Columbus. Normal runoff varied from 5.00 inches at St. Francis to 14.55 inches at Columbus. Eighty per cent chance occurrence runoff varied from 7.60 inches at St. Francis to 16.92 inches at Columbus. The mean weighted value of peak weekly runoff varied from 1.27 inches at St. Francis to 2.83 inches at Columbus.

The results of this study indicate that a computer can be successfully used with weather tapes to obtain runoff data from feedlots. The analyses of this data may prove beneficial in the design of runoff retention or storage structures.

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LIST OF PLATES

LIST OF TABLES