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PRELIMINARY REPORT ON THE STUDY OF THE PRECIPITATION ON THE PAWNEE NATIONAL GRASSLANDS

G. Bertolin and J. Rasmussen

GRASSLANDS BIOME

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Investigators[1]:

J. Rasmussen - Project leader
William Marlatt - Project leader
G. Bertolin - Investigator

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ABSTRACT

Preliminary results of a study of the precipitation of the Pawnee National Grasslands are presented. The spatial and time distributions and variations of precipitation are presented. A Markov Chain Probability Analysis is included in the discussion in addition to more classical statistical treatments. Some discussion of other meteorological parameters is included.

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[1] Present address of the above: Atmospheric Science Department, Colorado State University, Fort Collins, Colorado.

INTRODUCTION

The grassland, like the forest and the desert, possesses a unique ecology. The environment is largely governed by its climate. Therefore, in order to understand the ecology of the grassland one must know the climate. The objective of this report is to summarize the preliminary results of a study made to determine the climate of the Pawnee National Grasslands.

As one studies the climate on a smaller and smaller scale, one finds that the complexity of the problem increases. For example, the diurnal temperature variation at six feet above the earth's surface is a statistically well-behaved phenomenon; but, as one becomes interested in the diurnal temperature variation very near the earth's surface the complexity of the phenomenon increases dramatically. There is an open question with respect to what variables measured at what locations would most accurately describe the environment of the biological species in the grassland. We are limited in this study to describing the climate measured by the already existing meteorological stations as recorded in the data records. It therefore must be realized that the climate described is merely the summarization of that data. One must assume that this data encompasses or at least parameterizes the important aspects of the climate that are determinants of the environment of the biological species.

Considerable climatic variation could be expected to occur across the grassland area. The degree of resolution of this spatial variation is dictated by the density of observing stations. Further, one might expect to observe long-term changes in the climate. The degree of resolution of this long-term time variation of climate is dictated by the length and quality of meteorological record. Our data source for this study has a maximum record length of no more than 30 years, so no long-term trends can be determined.

This preliminary report summarizes the study of the climate completed to date. We have concentrated on the precipitation data, the variable for which data are most plentiful. In addition, some preliminary analyses of temperature, wind, and dew point temperature will be described.

PRECIPITATION ANALYSIS

The accurate determination of the precipitation at any location is not a simple task. One normally is limited to data from precipitation gauges; such data systematically are biased, due to wind effects on the collection of precipitation particles (Weiss and Wilson, 1957). This bias is also a function of precipitation type, being extreme for wind-blown snowfall. One may correct for this data deficiency by shielding the gauge. The data from the grasslands, however, are from unshielded gauges, so we must be aware of possible systematic errors, particularly during winter. Another source of bias in precipitation data arises from an attempt to estimate areal precipitation from a gauge network. Studies of this problem have shown that, on the average, as one increases the density of stations the areal precipitation increases (e.g., LaRue and Younkin, 1963; U. S. Weather Bureau, 1947) one intuitively would anticipate such a result since a sparse network would at times completely miss even large thunderstorm rainfall occurrences. For the Pawnee Grassland area, each gauge of approximately 50 sq inches is assumed to sample about 500 sq miles (2×10^{12} sq inches). Thus, the errors due to both instrument deficiencies and sampling deficiencies act, over a long record, to bias the data toward the low side. We proceed then to discuss the summarization of the precipitation data, realizing these sampling problems exist. The extent to which the data is biased should be studied; however, it is out of the scope of this project to carry out that program.

Data

Table 1 shows the details of the length of record for the various stations to be used in this study. Emphasis will be placed on the stations with 30 years of record; shorter record stations will be used only for definition of spatial variation.

We divided our data sources into two separate networks. The grassland network encompasses only stations within the grasslands; namely Central Plains Experimental Range[2/], Kauffman, and Grover. In addition, certain larger-scale features of the precipitation regime are studied, using the more widely spread stations. Fig. 1 shows the location of the stations referred to in Table 1. The area covered by the grassland network is about 1600 sq miles.

The Annual Precipitation Regime

Table 2 shows the average and seasonal precipitation for each station used in the study. In addition the average annual and seasonal precipitation along with the standard deviation are given for the grassland network. Note the wide variability between seasons and the large deviation from year to year. The precipitation variability, apparent from this data, probably is the most outstanding characteristic of the grasslands climate.

The strong seasonal variation of precipitation in the grasslands is described further in Fig. 2. Here the mean monthly precipitation and standard

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[2/] The Central Plains Experimental Range hereafter will be referred to as CPER.

deviation for the grassland network are shown. Again the dominant characteristic of the analysis is the variation, both within the year (summer vs. winter) and the variation from year to year for each month. In the grasslands, the three wettest months of the year, May, June, and July, produce an average of 50% of the annual precipitation. Conversely, the four driest months, November, December, January, and February, produce an average of only 8% of the total annual precipitation. If April-September inclusive are defined as the six months representing the summer season, then an average of 80% of the precipitation comes during these months. It would appear from this analysis that a "wet" vs. "dry" year is distinguished by whether or not the April through September precipitation was above or below normal. More discussion with respect to this will follow in the section discussing storm precipitation.

Spatial Variations of Annual Precipitation. A wide variation between stations of precipitation was noted in Table 2. Fig. 5a-c portray this data on isohyetal maps.

The minimum annual rainfall appears to occur near Nunn, a station with only 15 years of record (see Table 2). Thus the 11-inch isohyetal line is uncertain. However, it is very likely that the minimum is located somewhere near the western edge of the Pawnee Grasslands. This conflicts somewhat with the isohyetal maps compiled by the U. S. Weather Bureau (1954) (Fig. 4). Their placement of the minimum was about 25 miles to the east of our minimum. Their analysis, however, did not include many of the records which this study has utilized.

In order to look at the distribution of rainfall on a spatial basis, yearly rainfall over the grasslands and the surrounding area was analyzed with respect to longitude and latitude. Fig. 5a-c show the average yearly precipitation with latitude and longitude. Unfortunately, it is difficult to find stations that lie in a direct north-south or east-west line. Fig. 5a depicts a north-south line from Fort Lupton to Cheyenne. If the doubtful station at Nunn is not included, it can be seen that the latitudinal variation between Fort Lupton and CPER is less than .25 inches.

Fig. 5b is another north-south line, about 40 miles east of the first. From Fort Morgan to Kauffman, less than one-inch rainfall variation is encountered. Beyond that, a rise of over one inch is encountered north to Pine Bluffs.

These figures bring out two points. First, the Pawnee Grasslands and the area south of there appears to have little or no latitudinal precipitation variation. Furthermore, there appears to be a climatic divide present, either in southern Wyoming or at the northern edge of the Pawnee Grasslands. This divide is difficult to pinpoint because of sparse data points. Examination of United States Geological maps does reveal that a series of buttes 600 to 800 ft high occur just north of the Pawnee Grasslands, and these may be related to the precipitation increase observed to the north.

On the other hand, a distinct pattern emerges in a longitudinal direction, as shown in Fig. 5c. Basically, it shows the "rain-shadow" effect that can be expected to occur on the lee side of any mountain range. The precipitation minimum occurs near the western border of the Pawnee Grasslands, which is located about 30 miles east of the foothills of the Rocky Mountains and 65 miles east of the Continental Divide. From this point where the rain-shadow effect is at a maximum, the annual precipitation gradually increases to the Mississippi River and beyond. Although the precipitation near the Mississippi is nearly four times that of the minimum in the Pawnee Grasslands, the precipitation regime is still similar, i.e., wet summers and relatively dry winters.

An interesting point is that this eastward increase can be seen within the boundaries of the Pawnee National Grasslands. The westernmost station (CPER) has an average annual rainfall of about 12 inches, while Kauffman, a station 40 miles east of CPER, has an average annual precipitation of 14 inches. By interpolation, the eastern boundary of the grasslands should have a precipitation of about 14.5 inches. This is an increase of 20% in 65 miles. This increase occurs over uniform terrain and a surface elevation change of only 200 ft. Several hypotheses can be put forward to explain this climatological feature. Toward this end, the precipitation minimum will be split into two categories: the eastward dip from the foothills to the edge of the grasslands, and the subsequent eastward increase from the minimum rainfall area.

Three stations will be used for comparison, with CPER functioning as the only station in the rain-shadow minimum region with a sufficient record:

STATION	FORT COLLINS	CPER	AKRON
Rainfall	14.22 inches	12.22 inches	17.26 inches

The year also will be subdivided into four quarters. The most important quarters are late winter (February-April), and early summer (May-July).

The heaviest snowfalls occur in Fort Collins when an easterly wind allows an orographic effect caused by the foothills to enhance precipitation. This effect is apparently diminished as one goes eastward toward the grasslands. Thus, heavy wet snowfalls are increased in the foothills area, relative to the plains. Since 1.6 inches of the 2.0 inch increase between CPER and Fort Collins occurs in late winter, the orographic effect is probably responsible for this increase.

Of the 5.0 inch increase eastward from CPER to Akron, 2.3 inches occur in early summer. The rest occurs uniformly throughout the year. Since the dominant precipitation producing mechanism during early summer is the cumulus cloud system, one may assume that the additional precipitation is caused by greater convective activity over Akron. This greater activity would be caused by the higher temperatures and moisture content that prevail in the atmosphere over Akron. Further evidence of this phenomenon is the fact that northeastern Colorado has the highest incidence of hail in the United States, a product of extremely large convective storms, over the eastern border of the grasslands (Visher, 1954).

Preliminary results, as will be reported later, do show that higher temperatures occur more often in Akron than near the foothills. Greater moisture content in the air also is expected, since CPER lies further from the Gulf of Mexico, which is the major moisture source for the region. Quite often a "dew point front" can be found in eastern Colorado on the summer surface weather maps. East of this front, there is a sharp increase in the dew point temperature, which is a direct measurement of the amount of moisture in the air. West of the front, the air is generally quite dry. Thus, often the air within 50 miles of the foothills is too dry to initiate strong thunderstorm activity whereas, east of the front, cumulus convection is easily obtained.

The higher moisture content can be shown from a study of dew point temperatures at Fort Collins and Akron. The dew point temperatures at Fort Collins had to be substituted for CPER, since this parameter is not taken at CPER. This is a reasonable approximation, since CPER is only 20 miles east of Fort Collins, but 80 miles west of Akron. Table 3 shows five-year averages for the 7 PM dew point temperature observations.

In summary, higher temperatures and moisture content may be responsible for the large proportion of the increase in precipitation from CPER to Akron during summer. The decrease in precipitation from Fort Collins to CPER primarily during winter seems to be due to the orographic upslope effect of the foothills on the winter air masses. These two effects, superimposed on the large scale effect of the Rocky Mountains on the general circulation, cause the sharp rain-shadow effect found in the Pawnee Grasslands.

Daily Precipitation Analysis

Probability Analysis. The following discussion of the daily precipitation analysis consists of the evaluation of the grassland network stations alone. The arithmetic average of the three daily values was assumed to be representative of the areal precipitation occurring each day. This procedure was assumed valid since the stations are rather evenly distributed across the topographically uniform area.

Fig. 6 is the plot of the likelihood of precipitation falling each day. The daily data were smoothed by taking the average of 10 consecutive daily probabilities and plotting the value on the central day. It is interesting to note that during the wettest time of the year, the empirical probability of rain falling is only 37%. During the driest time of the year, probability of precipitation is less than 5%. The chief value of this graph is in demonstrating the general daily precipitation pattern throughout the year. According to Fig. 6, maximum probability of having a rainy day occurs in late May. A curious but statistically significant dip in the graph takes place in late June, with a secondary peak in July.

A comparison with average monthly precipitation values does show that May is the wettest month (see Fig. 2). However, June is usually the second wettest month. Thus a dip in the number of rainy days late in June is unexpected.

The possibility arises that there are fewer days with rain on the average in June than in May, but that each rainy day in June has a higher precipitation intensity. A graph of average precipitation per day with precipitation throughout the year disproves this idea (Fig. 7). Both the number of days with rain and the intensity of rain reach a peak in late May and take a noticeable dip in late June. At the present time, no explanation for this phenomenon can be given.

Markov Chain Analysis. A more elegant method of determining probabilities of precipitation has been shown to be the use of Markov Chain Analysis (e.g., Heerman, 1966).

The idea behind the Markov Chain Analysis is an attempt to improve the purely empirical probability that would be achieved by analysis such as demonstrated in Fig. 6. Normally, it is observed that past weather has an influence on today's weather. The chances of rain today are enhanced if it rained yesterday and decreased if yesterday was dry. One question that arises is how many days of past weather must be included to give a high degree of accuracy? Analysis of the problem by Heerman (1966) and others has shown that inclusion of yesterday's weather alone will produce quite satisfactory results. Inclusion of days further in the past adds little to the accuracy of the probabilities and a great deal to the complexity of the problem. A two-state, first-order Markov Chain was used on the grasslands precipitation data. The first-order Markov Chain signifies that only one day in the past is included in determining probabilities for the present day. "Two-state" refers to two choices on a given day; i.e., the day will be wet or dry. Table 4 shows three sets of the probability for each week of the year. The three sets delineate the different thresholds defining a wet day. The threshold is defined as 0.01 inch, 0.05 inch, or 0.10 inch, respectively. Within each threshold, three probabilities are given: the first column is strictly an empirical probability of a dry day without using the Markov Chain Analysis. Note the probability of a wet day is $P_{wet} = 1 - P_{dry}$. The second column is calculated by assuming the previous day was dry, and the third column was calculated by assuming the previous day was wet. The reader is referred to any modern probability theory, for instance Parzen (1960), for the details of the Markov Chain Analysis.

One interesting point should be brought out here. It can be seen from the table that that curious June dry period shows up even in the Markov Chain Analysis. Occasionally a rather large jump in probability occurs. It is probable that this discontinuity is due simply to the short record length.

Storm Analysis

Precipitation events often last more than one day but less than one week, so that the analysis of daily precipitation data often dissects homogeneous periods. Further, the choice of arbitrary chronological summation periods, such as weeks or months, often glosses over the significant precipitation events. We wish to perform a "natural period" analysis in which the individual period of precipitation, whatever its length, is dealt with. The following storm analysis describes the initial attempts to perform this work for the grassland network. In some cases, particularly during summer, the precipitation occurs in only a few hours. In this analysis, such shower precipitations are included as daily values, since no finer resolution is available because of the sampling procedure.

One storm definition used in this study was that given by Marlatt and Riehl (1963) while working with data from the Colorado River Basin. They defined a storm as any number of consecutive days producing at least .10 inches of rain, with each day having a minimum of .06 inches. Thus any total

As expected, the summer precipitation has a higher correlation than the winter. But the difference here is quite surprising. Essentially, it is indicated that the variation in the winter precipitation has virtually no connection with the variability of yearly precipitation. On the other hand, there is almost a one-to-one relationship between the variability of summer rainfall and the variability of the annual precipitation. Thus, the amount of precipitation in a given year can be closely estimated by the amount of rainfall produced only by summer storms greater than one inch.

An interesting set of statistics is formed if the number of storms required to produce 50% and 75% of both the annual and each season's precipitation is determined. This was done for the grassland network and is shown in Table 7.

A skewed distribution results if the days with rain are ranked and the number of rainy days that are required to produce 50% and 75% of the annual precipitation are evaluated. Table 8 shows that one-sixth of the rainy days give one-half of all precipitation and about one-third of the rainy days give three-fourths of the annual precipitation. There is an average of 52 days per year with rain. Therefore, three-fourths of the annual rainfall comes on 19 days of the year. Thus, most of the rainfall comes on a very few days, a result that complements the high correlation found between summer storms greater than one inch and the annual rainfall.

Another method of analyzing storms was proposed by Finklin (1967) in his work on the Sacramento River Basin. He tried to find a "noise limit" or lower limit below which the storm rainfall was not important to the annual rainfall. Daily precipitation values were accumulated for 0.1-inch rainfall segments and totaled for each segment. By combining consecutive classes he then precipitation less than .10 inches is not considered sufficient to have produced a storm. As an example, if a series of days with heavy rain are separated by one day with .05 inches or less, then it is considered that two separate synoptic events occurred and the result was noted as two storms.

The storm analysis consisted of dividing the storm precipitation into five class intervals: .10 to .25 inches, .26 to .50, .51 to .75, .76 to 1.00, and greater than 1.00 inches of precipitation. Two seasonal divisions were made: winter (October-March) and summer (April-September). A correlation analysis for the grassland network was run for each of the two seasons, between the seasonal precipitation and the storm precipitation for that season above the thresholds denoted above. These results are shown in Table 5. The correlation between precipitation for all summer storms greater than one inch and the seasonal precipitation is .92. In the winter the similar situation has a correlation of .54. If one uses the coefficient of determination (r^2), a value of .83 is achieved for the summer. This may be interpreted as meaning that 83% of the summer season variability of precipitation over the grasslands may be explained by storms greater than one inch. In the winter season only 30% of the variability is explained by storms greater than one inch. In order to explain roughly 83% of the variability of winter rainfall, all storms greater than .25 inches must be considered.

In view of the data, the results above seem reasonable. Most years produce no storms of one inch or greater in the winter. Conversely, any summer season in which no storms of one inch or greater occur is a very dry year. This follows, since 80% of the rainfall over the area comes in the summer.

It was decided to test the significance of each season's precipitation by running a correlation analysis between each of the total seasonal precipitations and the annual precipitation. Results are listed below in Table 6.

had the total rainfall on days in which less than 0.1 inches fell; days in which less than 0.2 inches fell; etc. This was done for each of the two seasons. The accumulations then were correlated against the seasonal precipitation. A graph of correlation coefficient vs. upper rainfall limit produced an inflection point which he interpreted as a noise limit.

This method was tried in our case, using only the CPER data for the summer season. Unfortunately, no sharp inflection point was found (see Fig. 8).

According to the figure, the noise limit would probably be somewhere around one inch. This seems rather high. It implies that rainfall less than one inch can be largely considered as noise. However, this fits well with the previous observation that there is a very high correlation between seasonal precipitation and precipitation only from storms greater than one inch.

Monthly Analysis

It has been noted that the wettest months are May, June, and July. The coefficient of variation, which is the standard deviation divided by the mean, is a method for determining the variability of monthly precipitation. Both the monthly mean and the monthly standard deviation are depicted in Fig. 2. The coefficient of variation for the grassland network is lowest during the wettest months of the year. During the drier months, October through March, it has been found that the standard deviation often exceeds the mean. Extreme year to year variability, then, characterizes the precipitation regime during the winter season.

A definite trend can be seen if the average number of days with rain per month is calculated for the grasslands network. This data is presented in Table 9. It is interesting to note that the average number of days per month with less than 0.1 inch of precipitation remains relatively constant throughout the year. The large increase in rainfall during late spring appears to be due in large part to the increase in the average number of days with precipitation exceeding 0.1 inch.

Other Climatic Controls

At the present time, other climatic variables are being studied. In particular, these are wind and temperature. Only two Colorado weather stations in or near the Pawnee Grasslands have wind speed data: CPER and Akron. At Akron the average annual wind speed is 5.5 mph, with an annual total of 48,000 miles of wind movement. CPER has an average annual wind speed of 5.2 mph, with a maximum average monthly value of 8.2 mph. The maximum occurs during April.

Wind direction records are exceedingly scarce throughout Colorado. At the present time, only very limited data are available. Work with wind direction, therefore, necessarily will be restricted.

Temperature data are fairly abundant, and a detailed analysis is currently being carried out. Preliminary investigation of temperature has revealed an aspect of climate that is rather unexpected. Partly because of the sheltering effect of the foothills, it was expected that the temperature extremes and averages would be lower in the summer and higher in the winter near the foothills as compared with the plains.

If temperature thresholds are studied (>90°F, >95°F, <10°F, <0°F, etc.), higher temperatures are found to be more frequent during the summer over the plains, but apparently there is no difference in the winter temperature thresholds. An eastward movement of 100 miles from Fort Collins more than doubles the number of days with temperatures higher than 90°F, but has an insiginificant effect on the number of days less than 0°F or 10°F. One possible explanation for this eastward increase in temperatures lies in the diurnal cloudiness pattern in summer, and is being investigated.

Another aspect under investigation is concerned with interrelationships between temperature, wind, and precipitation. Some justification has been found for the statement that drought years are aggravated by higher wind speeds and temperatures. Distinct relationships supporting this have been discovered, and will be reported after further study.

Conclusion and Future Plans

It has been shown that precipitation is an extremely variable quantity in the Pawnee National Grasslands. A useful method of analysis was discovered through the study of storms. The year-to-year rainfall variability is related closely to the variability of summer storms greater than one inch. An important result of the daily precipitation analysis was a rainfall probability determination through a Markov Chain Analysis. For the future analyses, emphasis will shift from precipitation to other climatic variables.

Wind and temperature analysis as outlined above will be continued. Other work will include a temperature probability scheme, perhaps like that done on precipitation; and an annual soil moisture budget analysis, based on climatic parameters.

Finally, the overall picture of the climate will be considered. In particular, the climatic effects of the mountains and the continentality of the region will be explored.

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Table 1. Location and history of stations used in study.

Station	Record Type	Record Length (years)	Dates of Records	Latitude (N)	Longitude (W)	Elevation (ft)
Akron	Monthly	30	3/1/30-2/28/35, 3/1/37-2/28/62	40°10'	103°09'	4538
Briggsdale	Yearly	15	1/51-12/65	40°39'	104°20'	4855
Cheyenne	Monthly	30	1/38-12/67	41°19'	104°49'	6126
CPER	Daily	24	3/1/40-2/28/41, 3/1/44-2/28/67, except 11/44, 12/44,1/47,2/47, 3/47	40°51'	104°43'	5394
Estes Park	Monthly	30	1/37-12/66	40°23'	105°31'	7525
Fort Collins	Daily	30	3/1/31-2/28/61	40°35'	105°05'	5004
Greeley	Monthly	30	1/37-12/66	40°25'	104°41'	4648
Grover	Daily	30	3/1/37-2/28/67	40°51'	104°24'	5090
Kauffman	Daily	30	3/1/37-2/28/67	40°50'	102°56'	5250
Julesburg	Daily	30	3/1/31-2/28/47, 3/1/49-2/28/62	41°00'	102°51'	3469
New Raymer	Yearly	17	1/51-12/67	40°36'	103°50'	4783
Nunn	Yearly	15	1/52-12/52, 1/54-12/67	40°42'	104°47'	5185
Pine Bluffs	Monthly	30	1/38-12/67	41°11'	104°04'	5047

Table 2. Annual and seasonal precipitation.

Station	Annual (inches)	Summer (inches)	Winter (inches)
Akron	16.76	13.06	3.68
Briggsdale	11.90	-	-
Cheyenne	14.87	10.93	3.93
CPER	12.22	10.07	2.15
Estes Park	15.96	11.33	4.63
Fort Collins	14.15	10.36	3.79
Greeley	11.71	8.69	3.02
Grover	13.23	10.52	2.71
Kauffman	13.90	11.34	2.56
Julesburg	16.31	12.86	3.45
New Raymer	13.42	-	-
Nunn	10.55	-	-
Grassland Network	13.12	10.64	2.48

Table 3. Five-year averages for 7 PM dew point temperatures.

Month	Fort Collins (°F)	Akron (°F)
May	34.5	37.2
June	47.0	49.3
July	53.7	55.2
August	45.1	47.2

Table 4. Probabilities of occurrence of dry day by Markov Chain Analysis.

Grassland Stations - CPER, Grover, and Kauffman
Probability that a given day will be wet or dry.
P(wet) = 1 - P(dry)
P(wet/dry) = 1 - P(dry/dry)
P(wet/wet) = 1 - P(dry/wet)

Period	Wet $\geq$ 0.01 Inches			Wet $\geq$ 0.05 Inches			Wet $\geq$ 0.10 Inches		
Begins	Dry	Dry/Dry	Dry/Wet	Dry	Dry/Dry	Dry/Wet	Dry	Dry/Dry	Dry/Wet
Mar 01	85	88	75	88	89	81	92	92	86
Mar 08	89	91	75	90	92	78	93	94	76
Mar 15	89	89	81	90	90	82	93	93	93
Mar 22	86	89	68	89	90	71	91	92	68
Mar 29	88	91	71	90	92	63	93	94	64
Apr 05	81	83	71	83	85	79	87	87	85
Apr 12	86	89	65	88	90	69	91	92	78
Apr 19	87	90	69	89	91	72	92	93	76
Apr 26	80	84	64	83	85	75	87	88	83
May 03	82	87	56	85	89	63	88	90	73
May 10	75	80	58	78	83	61	82	86	64
May 17	69	77	53	72	78	58	78	80	70
May 24	70	75	58	73	76	65	78	79	74
May 31	71	75	63	74	77	64	79	81	72
Jun 07	75	81	59	78	83	61	81	85	68
Jun 14	75	78	66	77	79	68	81	82	72
Jun 21	82	86	67	84	87	66	87	90	70
Jun 28	80	83	66	82	85	67	85	87	72
Jul 05	80	83	69	84	86	71	86	87	78
Jul 12	76	79	69	80	82	73	84	85	80
Jul 19	78	81	67	80	83	66	83	85	73
Jul 26	77	78	73	80	82	77	84	85	83
Aug 02	79	81	67	82	83	74	84	85	80
Aug 09	85	86	80	88	88	87	92	92	92
Aug 16	81	83	70	83	84	77	87	88	78
Aug 23	81	84	65	84	86	70	86	88	71
Aug 30	86	89	66	89	91	72	91	93	74
Sep 06	87	90	66	90	92	71	93	94	73
Sep 13	89	92	67	91	92	74	92	94	76
Sep 20	83	86	67	86	88	67	87	89	70
Sep 27	91	93	66	92	94	65	93	95	71

Table 4. (Continued)

Period	Wet ≥ 0.01 Inches			Wet ≥ 0.05 Inches			Wet ≥ 0.10 Inches		
Begins	Dry	Dry/Dry	Dry/Wet	Dry	Dry/Dry	Dry/Wet	Dry	Dry/Dry	Dry/Wet
Oct 04	94	95	89	95	96	96	97	97	96
Oct 11	91	92	83	92	93	85	94	94	84
Oct 18	90	91	81	91	92	84	93	93	86
Oct 25	93	94	76	94	95	75	95	96	79
Nov 01	91	92	88	93	93	91	95	96	91
Nov 08	93	94	86	95	95	88	96	97	92
Nov 15	90	90	92	92	92	98	94	94	99+
Nov 22	96	96	97	97	97	97	98	98	99+
Nov 29	96	96	90	97	97	94	98	98	83
Dec 06	91	92	88	94	94	92	95	96	92
Dec 13	96	97	88	98	98	87	98	98	89
Dec 20	93	94	84	95	95	88	96	97	84
Dec 27	95	95	95	96	96	94	97	98	97
Jan 03	93	94	69	93	95	72	96	97	86
Jan 10	93	94	87	95	96	93	98	98	92
Jan 17	93	93	93	96	96	99+	98	98	99+
Jan 24	88	89	78	90	91	81	94	94	93
Jan 31	95	95	84	97	97	97	99	99	99+
Feb 07	92	94	75	94	95	76	97	97	88
Feb 14	91	93	78	93	94	79	96	97	69
Feb 21	92	93	85	94	95	87	97	97	89

Table 5. Correlation between storm precipitation greater than threshold and seasonal precipitation.

Season	Storm Ppt >1.0 inch	Storm Ppt >0.75 inch	Storm Ppt >0.50 inch	Storm Ppt >0.25 inch	Storm Ppt >0.10 inch
Summer	.92	.96	.96	.99	.99+
Winter	.54	.71	.77	.94	.97

Table 6. Correlations between seasonal and annual precipitation.

	Summer vs. Annual Ppt	Winter vs. Annual Ppt
Correlation Coefficient (r)	0.95	0.12

Table 7. Percent of storms producing precipitation thresholds.

	Winter	Summer
50% of Seasonal Precipitation in:	33%	22%
75% of Seasonal Precipitation in:	82%	46%

50% of Annual Precipitation in:	25%
75% of Annual Precipitation in:	62%

Table 8. Percent of days with precipitation required for annual precipitation thresholds.

	50% of Annual Precipitation	75% of Annual Precipitation
% of days with precipitation	17%	37%

Table 9. Average number of rainy days/month for grasslands.

	<0.10 Inches (days)	≥0.10 Inches (days)
January	1.37	1.05
February	1.35	0.81
March	1.64	2.11
April	1.58	3.19
May	2.38	5.47
June	1.99	5.56
July	1.93	5.02
August	1.90	3.48
September	1.37	2.92
October	0.77	1.61
November	0.96	1.29
December	0.73	0.93

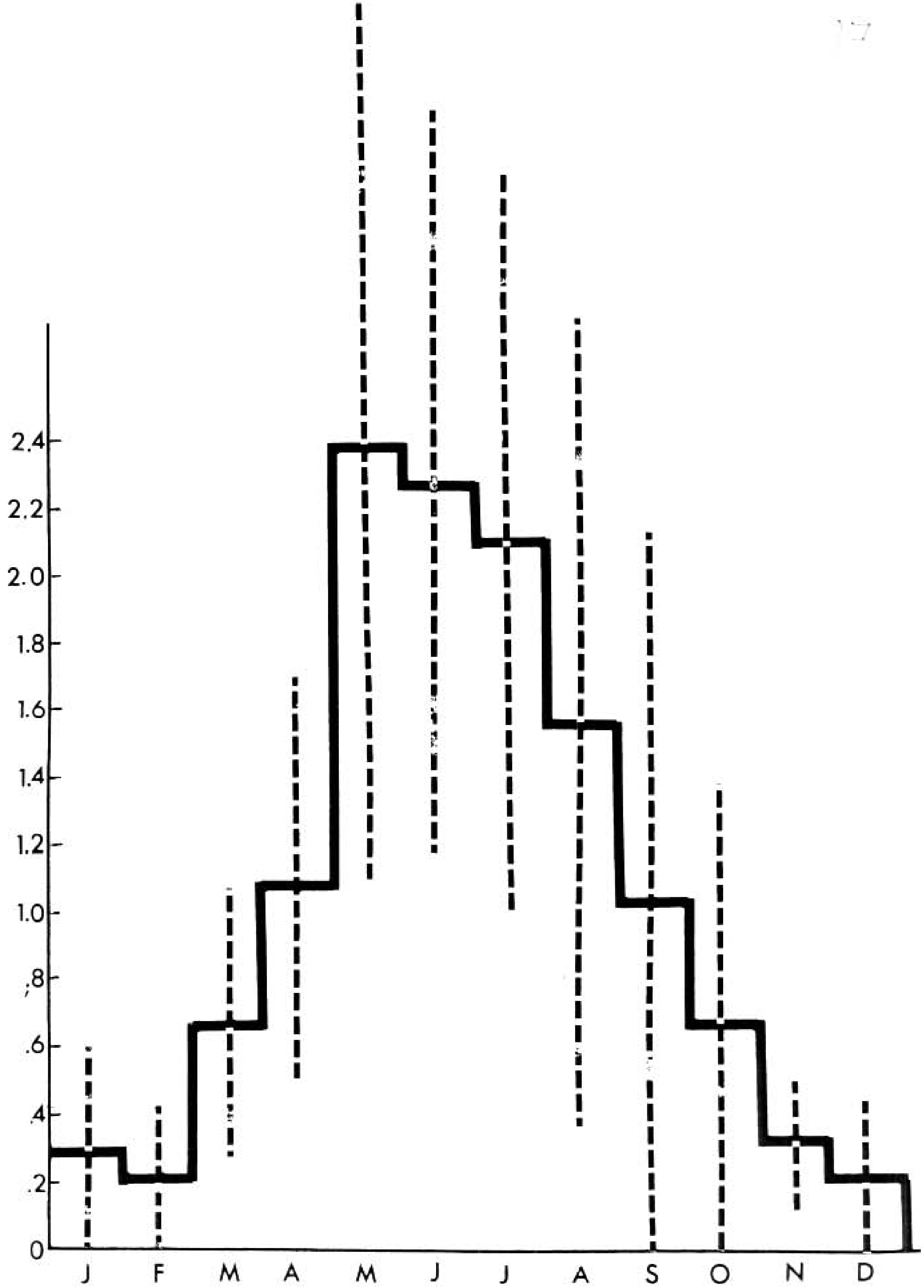

Figure 2. Average monthly precipitation for grassland network (solid line). Dashed line denotes ±1 standard deviation envelope around average monthly value for the CPER station.

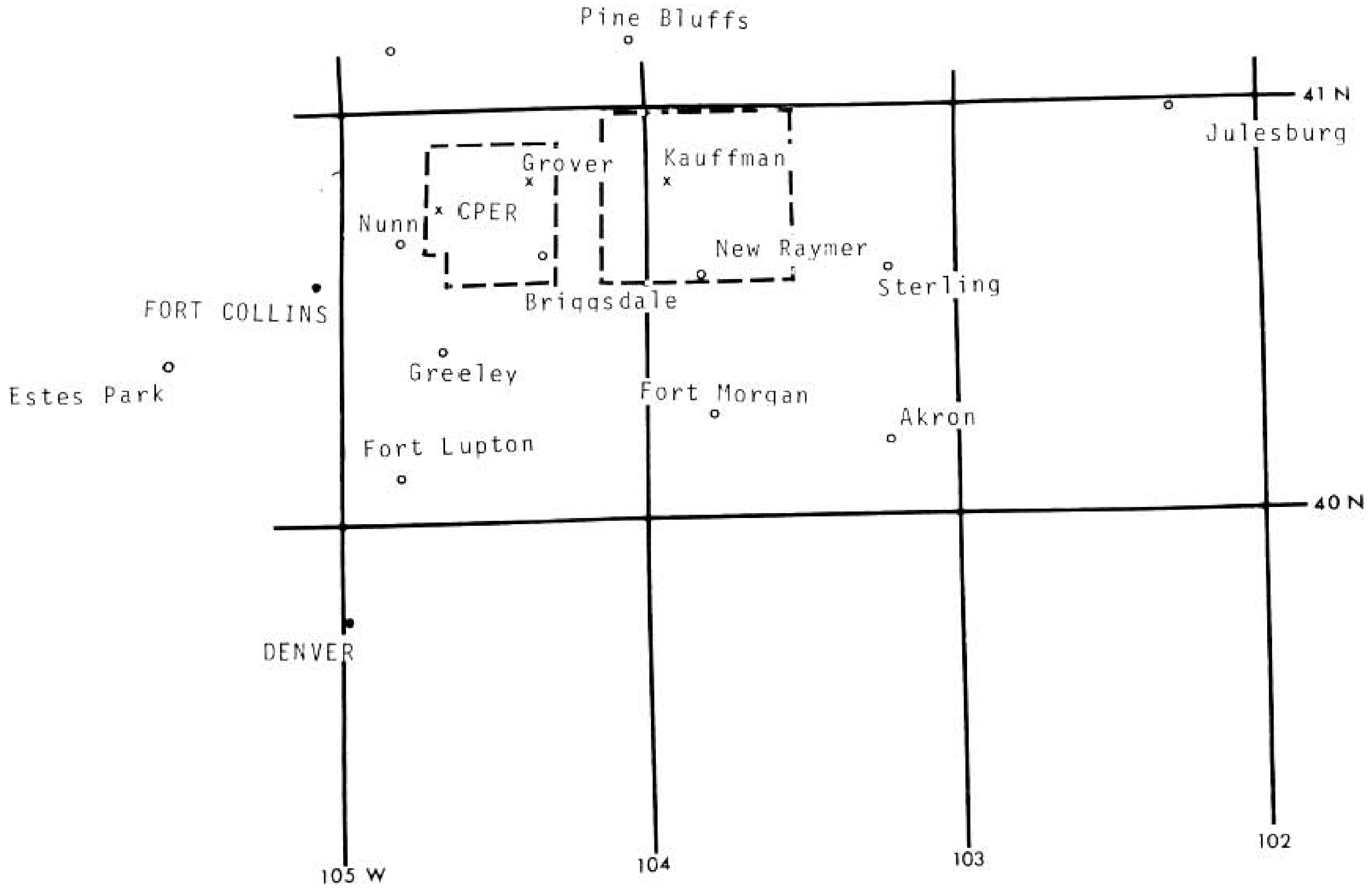

Figure 1. Station locations used in this study. Cross denotes grassland network stations. Area within dashed boundary defines Pawnee National Grassland.

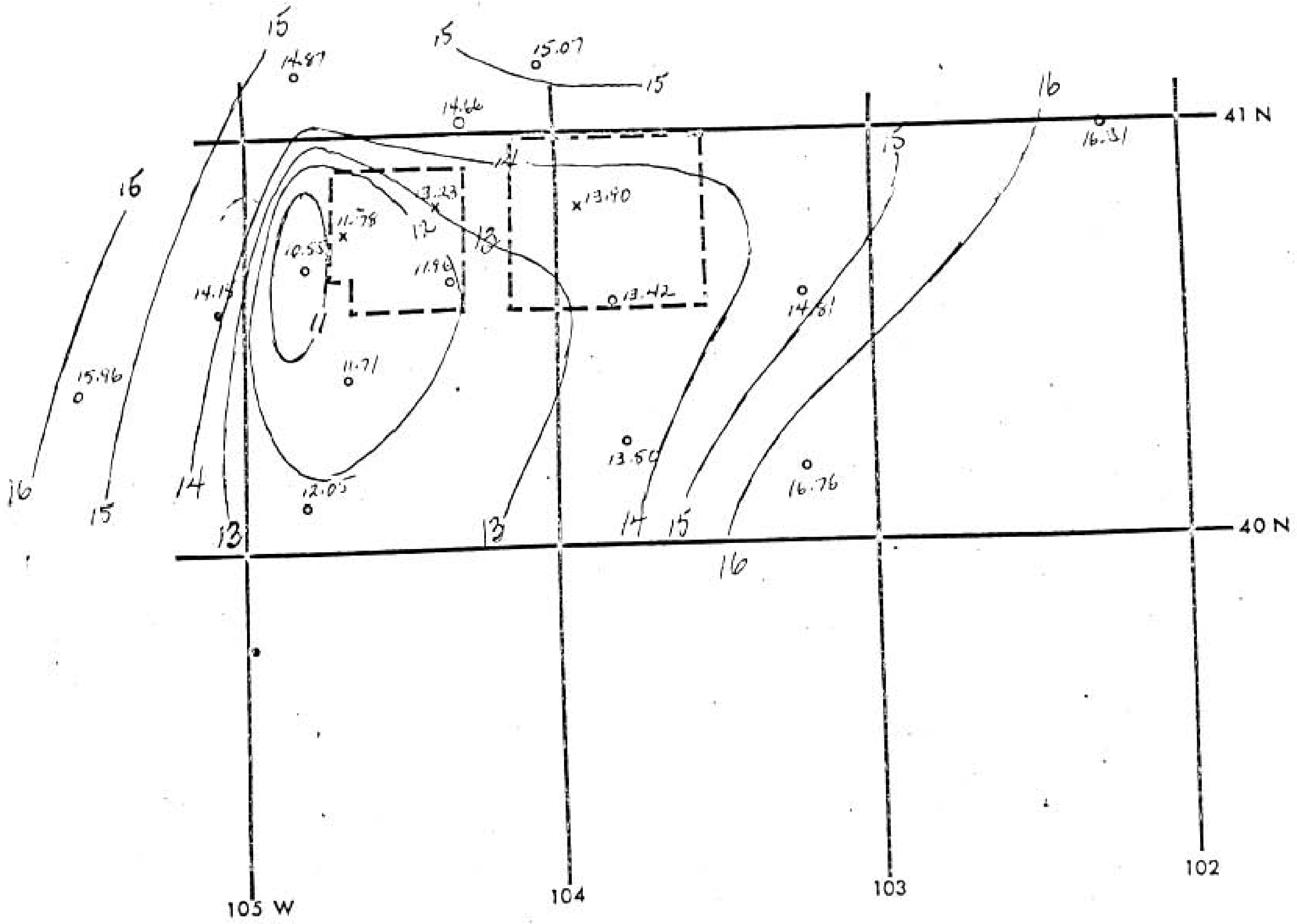

Figure 3a. Average annual precipitation (inches).

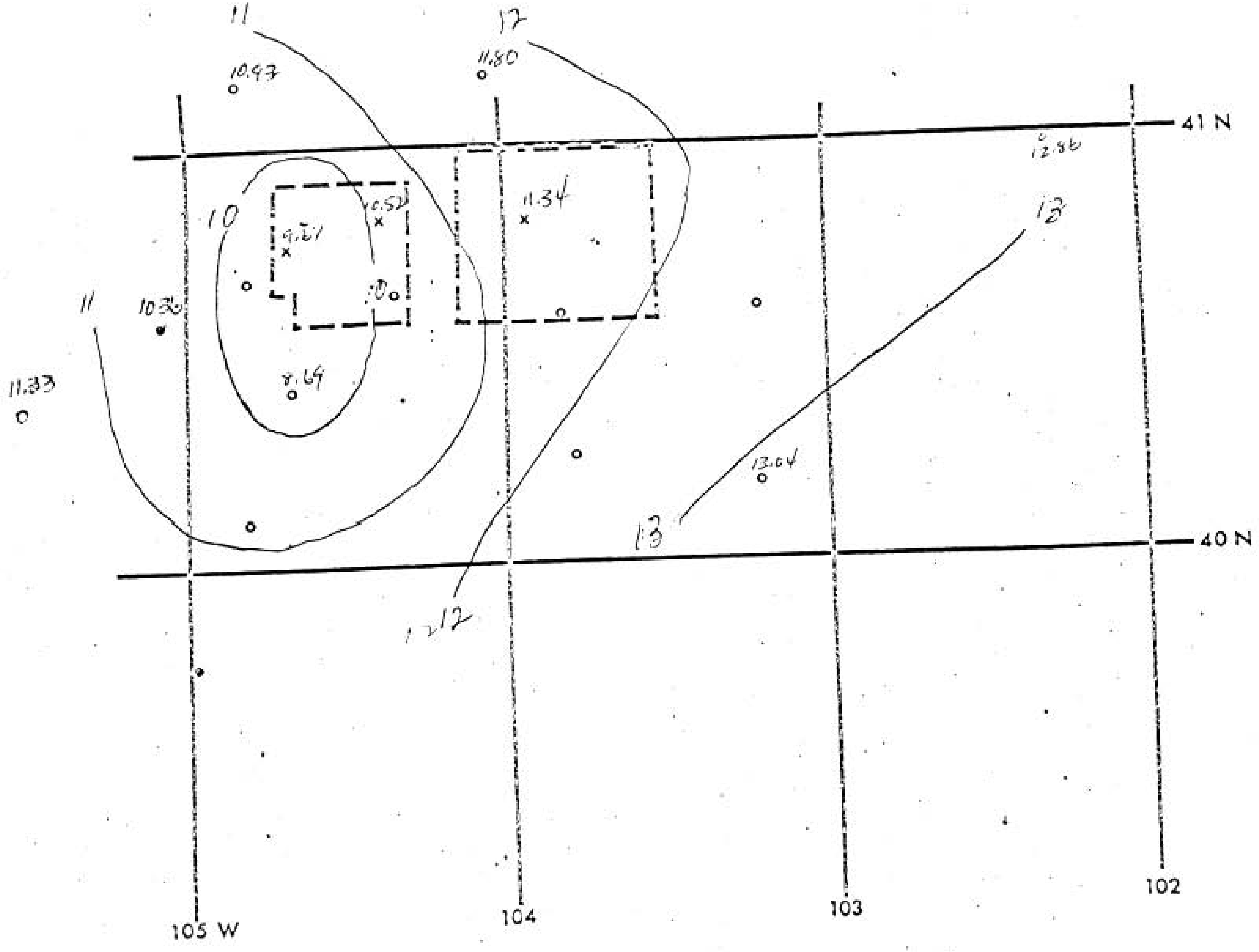

Figure 3b. Average summer (April-September) precipitation (inches).

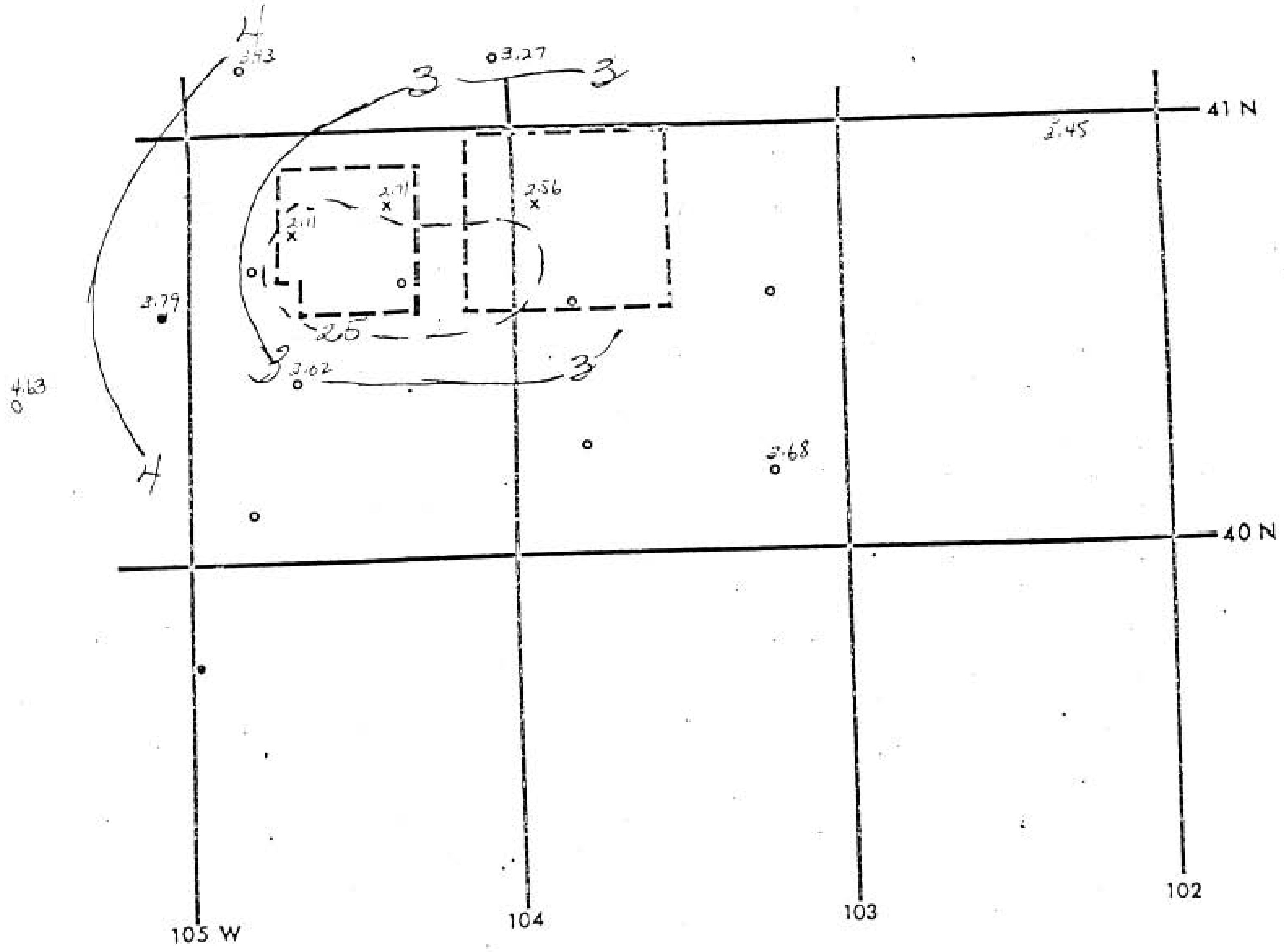

Figure 3c. Average winter (October-March) precipitation (inches).

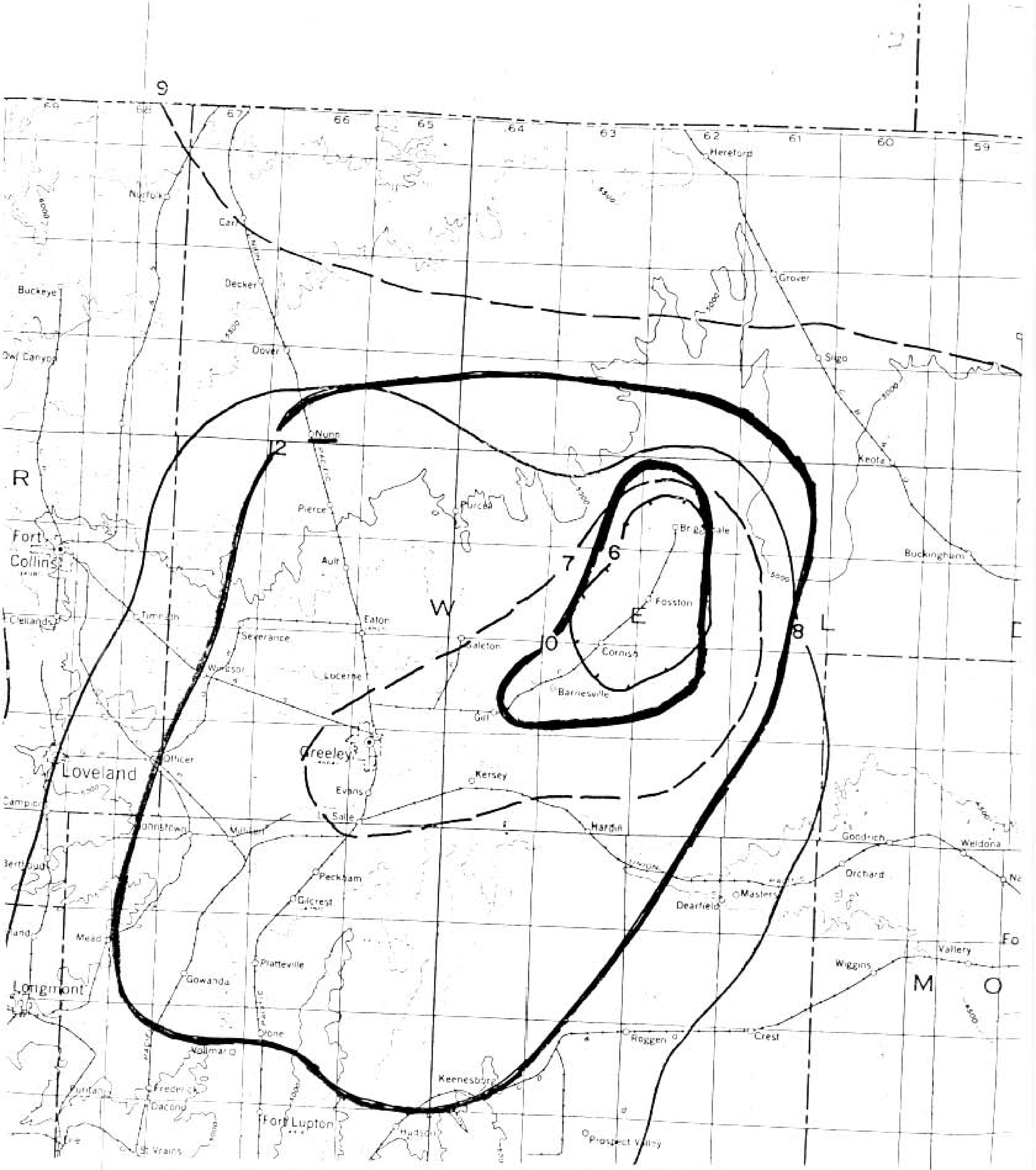

Figure 4. Average annual precipitation distribution (heavy line) taken from U.S. Weather Bureau, Department of Commerce (1954) map. Finer line is the May-September precipitation.

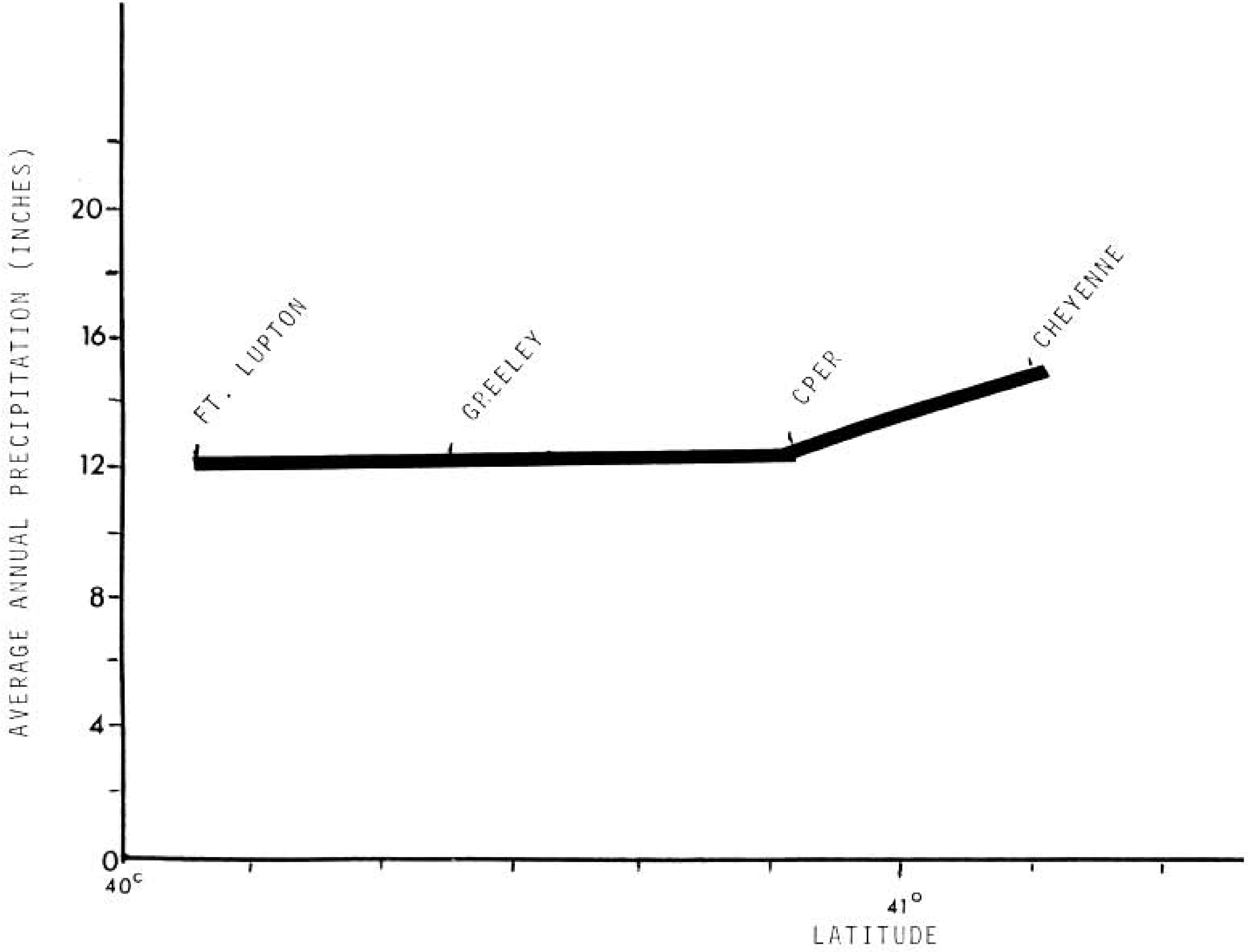

Figure 5a. Average annual precipitation profile vs. latitude. Section along latitude 104°45'-west end of grassland.

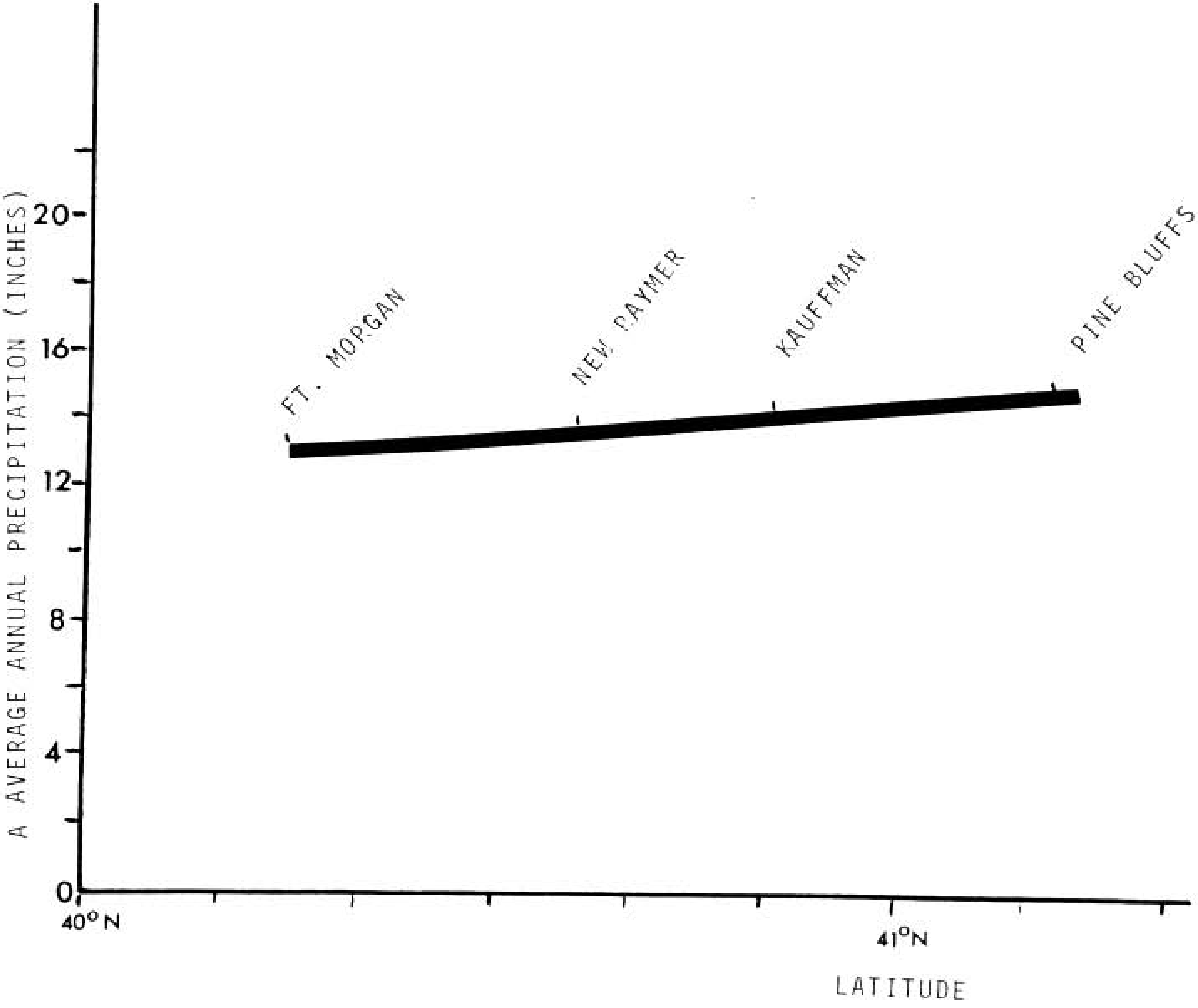

Figure 5b. Average annual precipitation profile vs. latitude. Section along latitude 104°-central portion of grasslands.

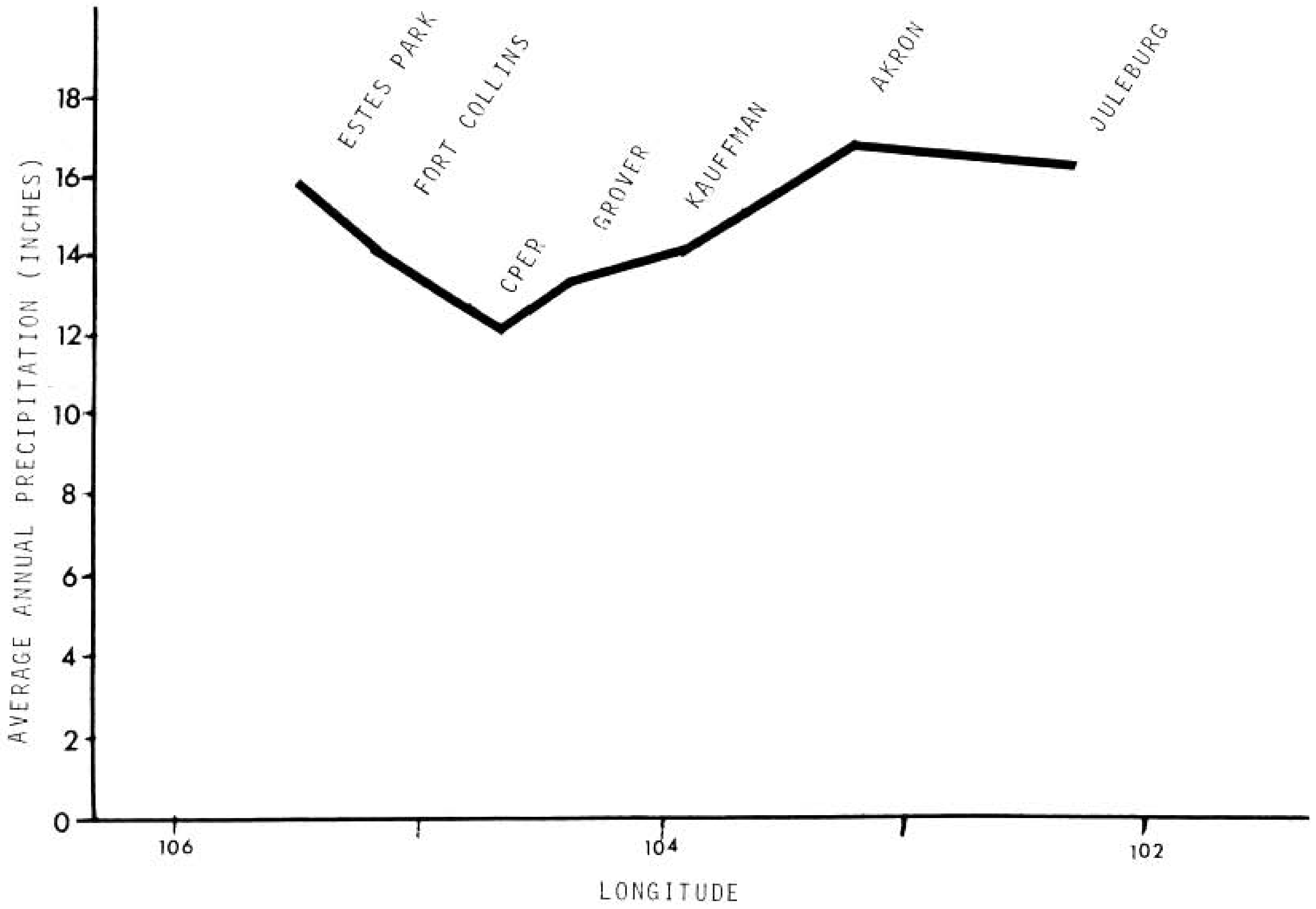

Figure 5c. Average annual precipitation profile vs. longitude.

Figure 6. Percent of days having precipitation over grassland network.

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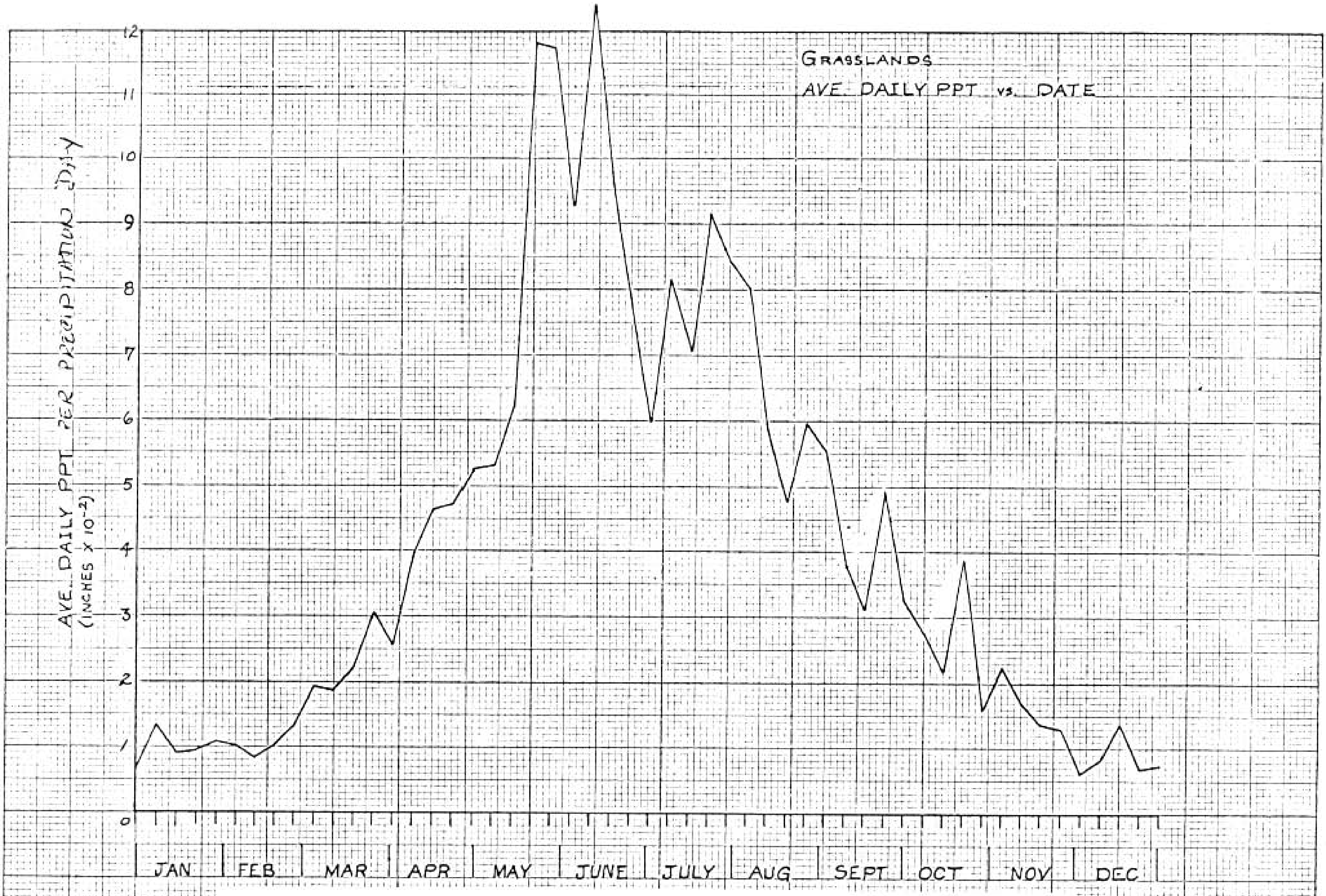

Figure 7. Average daily precipitation per percipitation day.

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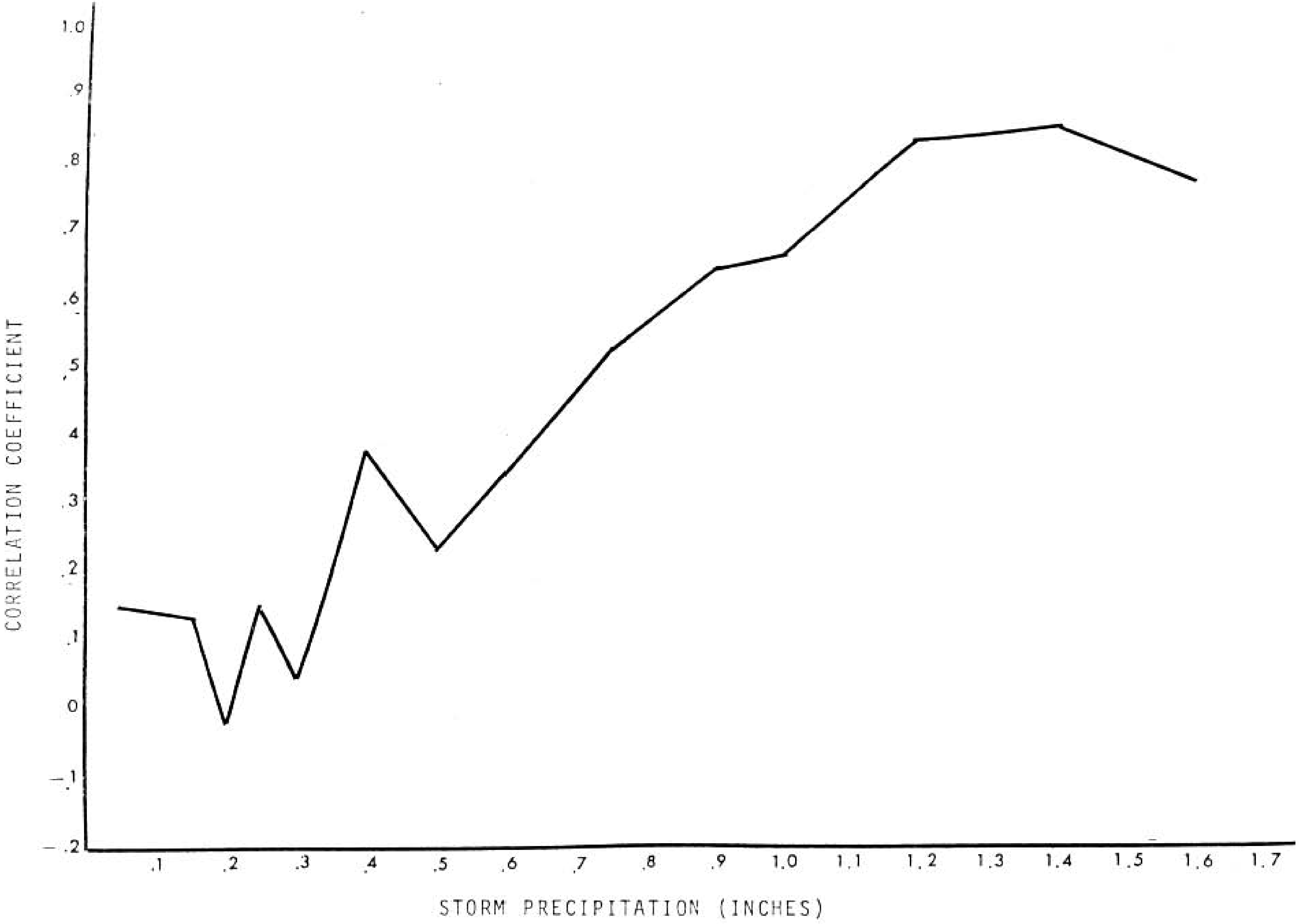

Figure 8. Correlation coefficient of summer and annual precipitation at CPER vs. total summer storm precipitation below specified level.