Kansas. From reading all the reports one is aware that the area was very dry with delayed wheat seeding, feed shortages, and poor prospects in general.

The streamflow data for September 1954 show very slightly more runoff than during September 1953, but apparently this was the result of fairly heavy rains between the eastern border of the area and the gaging station at Beloit. The basal cover data in table 14 give a specific bit of information which reinforces the idea that very serious drought conditions existed in September 1954.

In 1955 the spring rains again produced some temporary alleviation of the drought, but during July the situation became critical and the *Kansas Weekly Weather and Crop Reports* [63] of August 2 indicate that the crop, pasture, and hay prospects were fading rapidly, with supplemental livestock feeding on the increase. By the end of August (report of Aug. 30) it was apparent that many grain sorghum fields would not head, corn would not produce grain, and the pastures were supplying practically no feed at all. Further evidence of the extreme drought during August is the fact that the runoff for the month established a record low for August (see table 15).

The moisture situation was dismal all during 1956. The spring was dry and the summer and fall were drier. The total runoff for the year, computed by the method described in the next section, was the lowest of record. The following remarks [67] illustrate the extreme seriousness of the drought in western Kansas.

May 28, 1956	Pastures furnishing little or no grazing.
July 2, 1956	Dry soil delayed planting [of grain sorghums] and stands poor. Rain urgently needed. Supplemental feeding of livestock still necessary. Drought intensified.
July 30, 1956	Grain sorghums at a standstill; plants firing. Corn tassels turned white and stalks firing.
Aug. 27, 1956	Droughty conditions steadily increasing. Crops continue to deteriorate. Many sorghum fields beyond help. No available soil moisture to 4 ft. at Garden City.
Sept. 10, 1956	Supplemental feeding general and liquidation of herds increasing.
Sept. 17, 1956	Drought situation aggravated by 100° weather. A few plantings [of wheat] emerged to uneven stands, but plants beginning to die. Herds being liquidated.
Sept. 24, 1956	Seeding being delayed. Much damage to seedbeds [by severe dust-storms]. Wheat plants dying. Kansas River last three days lowest stage of record.
Oct. 8, 1956	All major streams at near-record low flows.
Oct. 22, 1956	Fields [for wheat] powder dry and seeding awaiting rains.
Oct. 29, 1956	Strong winds and dust severely damaged newly emerged [wheat] seedlings. Winter roughage supplies critically low.
Nov. 12, 1956	[Wheat] seeding continues in southwest and west central where soil powder dry.

When one compares the above remarks with the appropriate index values in table 13, it becomes apparent that the index values are relatively representative of the general agricultural situation. An index value of −4.00 seems to correspond reasonably well with "extreme" drought.

DROUGHT AND STREAMFLOW

Records of rates of streamflow can also be examined to determine whether or not such data show a useful relationship to drought severity. However, the available data pertinent to the western third of Kansas are far from satisfactory inasmuch as the stream-gaging stations are so located that the measured flow is not by any means dependent on only this area.

Four drainage basins are represented in the western third of Kansas [42]. An area in the northwestern corner, the equivalent of four or five counties, lies in the Upper Republican River basin and the drainage is toward the northeast. There are no long-record gaging stations which could be used to represent the runoff from this relatively small area. A similar situation exists in the southwestern part of the State where the Cimarron River carries the runoff from seven or eight counties. Here too no records are available for the period of concern in this study.

At Garden City, Kans., there is a long record of runoff on the Arkansas River [54]. This record is not particularly well suited for the purposes of this study because it represents too large an area, but it appears to be about the only one that can be used for this portion of the State.

With the exception of the previously mentioned counties in the northwest, the northern half of the western third of Kansas is drained by the Smoky Hill, the Saline, and the Solomon Rivers. Good runoff records exist for all three rivers [55]. The long-record stations are all a little too far east of our area, but the data may be at least partially indicative of the runoff from the area of concern.

The stations used were at Ellsworth, on the Smoky Hill River, Tescott on the Saline River, and Beloit on the Solomon River. The records of monthly runoff in thousands of acre feet were tabulated for these three stations and for Garden City for the period May 1929–August 1950 and the period October 1952–September 1957. No effort was expended in weighting or adjusting these records because even at best one could hardly expect to get more than a rough indication of the runoff from the study area. Therefore the runoff from the four stations was merely added to obtain a single value for each month. From these records table 15 was prepared. The three lowest index values for each month from table 13 have also been entered on table 15 for convenience.

From this table a number of things are apparent. First, the record low runoff for the 1–5-month period ending with April occurred in 1935. One can see also that the most serious April drought, as indicated by the index, also occurred in 1935.

The lowest 1-month and 2-month runoff values for the other months appear to coincide reasonably well with the lowest index values. For instance, the least April and May runoff (11,600 acre feet) occurred in 1937. The index, —4.48, also indicates the most serious May drought occurred that same year. Also, the least May and June runoff occurred in 1933 with 1956 not far behind (see footnote, table 15). The driest June according to the index was 1956 which was also the year with the least 3-month total runoff.

The remaining months in the table show much the same sort of thing. Considering the crude method of handling the only partially representative runoff information, the correspondence between years of very low index numbers and years of very small runoff is rather encouraging, but not unexpected. Both are a consequence of about the same climatic elements.

The reader will no doubt have noticed that the largest negative index value occurred in 1956 rather than in 1934 or 1936 as might have been expected. The runoff data for the periods ending with September seem to confirm that this dryness in 1956 was at least as extreme as that during the drought in 1934. As previously mentioned, some *effects* were worse in 1934 than in 1956 because of the wind and dust in 1934.

PASTURE FEED CONDITIONS

At the beginning of each month during the period April 1 to November 1 the United States Department of Agriculture receives numerous reports on pasture feed conditions in each State.

TABLE 15.—*Drought index values and the least amount of runoff (thousands of acre-feet) during periods of various lengths ending with the month and year shown, western Kansas*

	Length of period (months)										Year and amount of the 3 lowest index values for the month		
	1		2		3		4		5				
	Yr.	Amt.	Yr.	Amt.	Yr.	Amt.	Yr.	Amt.	Yr.	Amt.			
April	1935	2.9	1935	5.2	1935	8.0	1935	10.2	1935	12.5	−5.46 1935	−3.98 1936	−3.71 1937
May	1937	6.9	1937	11.6	1937	22.8	1934	[a] 38.9	1956	45.8	−4.48 1937	−4.40 1956	−4.07 1935
June	1933	5.3	1933	[b] 43.1	1956	56.4	1940	65.3	1940	68.2	−5.43 1956	−4.31 1937	−4.20 1934
July	1934	9.8	1933	25.6	1933	63.4	1933	88.4	1933	95.6	−5.47 1934	−5.31 1956	−4.90 [c] 1936
August	1955	5.0	1934	15.5	1940	88.9	1956	122.6	1956	128.7	−5.96 1934	−5.65 1956	−5.55 1936
September	1956	1.0	1956	18.4	1934	45.3	1956	110.5	1956	123.6	−6.20 1956	−5.34 1939	−5.31 1934
October	1939	1.5	1956	2.7	1956	20.1	1934	47.9	1956	112.2	−6.14 1956	−5.55 1939	−5.33 1934
November	1939	2.1	1939	3.6	1956	5.9	1956	23.3	1934	50.4	−5.78 1956	−5.44 1939	−5.96 1934

[a] 39.1 in 1956.
[b] 50.3 in 1956.
[c] also 1937.

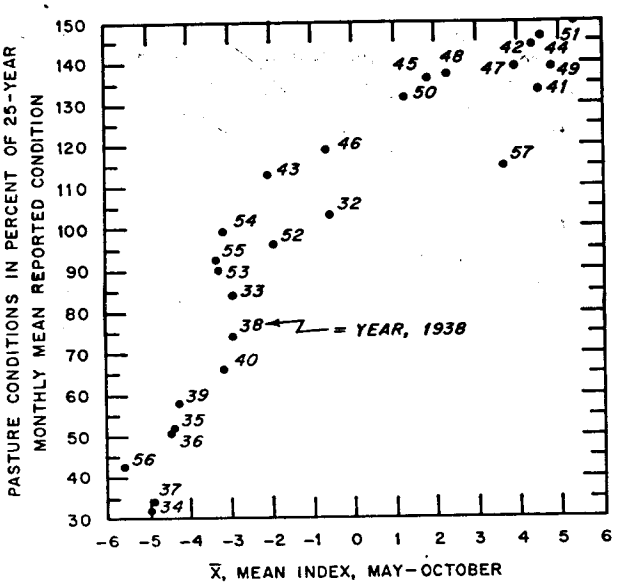

FIGURE 4.—Mean pasture condition, western Kansas June 1 to November 1, versus the average index $\bar{X}$ for the same growing season. (Data for period 1932–57.)

These subjective reports are expressed in terms of percent of normal condition, where "normal" indicates not the average but the expected condition under very favorable weather.

These monthly data for the western third of Kansas for 1932 through 1957 were obtained from the United States Department of Agriculture Crop Reporting Board by personal communication. Each monthly value represents approximately 200 individual reports. These data apparently contain some month-to-month and season-to-season fluctuations and trends which are in part dependent on the outlook and state of mind of the observers. It is suspected that the reports tend to show an exaggerated response to month-to-month weather changes. For example, from other accounts, such as table 14, there is evidence that pastures became gradually poorer and poorer during the drought in the 1930's. However, these condition reports show a very abrupt drop to a minimum of 11 percent of normal during 1934 followed by an improvement to 30 to 50 percent of normal during 1939.

In addition there are month-to-month trends in the data which indicate that a given percentage does not mean the same thing from month to month. For example, the average reported conditions for 25 years were as follows:

	Percent		*Percent*
Apr. 1	64	Aug. 1	62
May 1	64	Sept. 1	60
June 1	68	Oct. 1	59
July 1	69	Nov. 1	62

In order to remove this variability all the monthly values were recomputed in terms of mean reported condition. For example, a report of 34 percent of normal on June 1 becomes 50 percent of mean reported condition.

From these monthly values of mean reported condition it was possible to obtain a mean value for the period June 1 to November 1 for each year. Figure 4 shows the relation between this measure of pasture condition and the average April to October index (from table 13). The poorer condition in the 1930's as compared to the 1950's may be related to the amount of wind. The relatively poor condition in 1957 is the result of the poor condition (55 percent) that existed in the spring of this wet year. All in all, the index appears to be relatively representative of pasture conditions in western Kansas. No effort was made to investigate similar relationships in other areas.

12. DROUGHT CONDITIONS IN CENTRAL IOWA

The monthly index values for central Iowa for the period 1930–1962 [9] are shown in table 16. Only in 1931, 1934, 1936, 1956, and early 1957 does the index indicate really serious drought. Crops were rather poor in 1931, especially in the northern part of the area and average corn yield for the entire area was only 38.9 bushels per acre.

[9] 1930 and the years since 1957 were analyzed using the coefficients from the base period, 1931–57.

THE DROUGHT OF 1934

The severity of the drought in 1934 is evidenced by the following remarks [61] concerning the agricultural situation in central Iowa.

May 15, 1934..... Intense duststorms; meadows poor; hay and oats practically ruined; farm crop outlook poorest in memory; water scarce on great many farms.

TABLE 16.—*Drought (and wet spell) index, X, central Iowa*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1930	0.13	−0.21	−0.69	−0.55	−0.56	−0.47	−1.29	−1.98	−2.48	−2.31	−2.62	−3.02
1931	−3.26	−3.81	−3.94	−3.97	−4.12	−4.45	−4.14	−4.09	1.13	1.14	2.99	3.85
1932	4.10	3.67	3.13	2.40	2.21	2.04	1.85	2.89	2.76	2.48	2.76	2.87
1933	2.63	2.11	2.53	−.44	.54	−1.53	−1.64	−2.16	−2.25	−2.08	−2.81	−3.05
1934	−2.95	−3.19	−3.48	−4.09	−5.11	−5.98	−5.77	−5.86	.56	−.56	.82	.34
1935	.49	.76	.35	−.63	.30	1.65	1.97	1.28	1.37	1.98	2.44	2.55
1936	2.73	2.71	−.34	−.60	−1.12	−1.33	−2.88	−3.34	1.33	1.16	.70	.90
1937	1.34	1.41	1.33	1.68	1.74	−.33	−.71	−.71	−1.39	−1.30	−1.70	−1.95
1938	−1.95	−2.15	−2.15	.70	1.47	1.25	1.64	1.21	1.74	.93	1.26	1.11
1939	1.01	1.67	−.18	−.41	−1.29	−.92	−1.04	−.66	−1.43	−1.58	−2.20	−2.52
1940	−2.69	−2.45	−2.49	−1.91	−2.09	−2.61	.68	1.74	.94	.73	1.10	1.27
1941	1.68	−.11	−.47	−.93	−1.65	−.92	−1.19	−1.49	1.51	3.07	3.16	3.69
1942	3.43	3.31	2.98	1.95	2.06	2.24	2.98	3.07	3.32	3.20	3.13	3.16
1943	2.83	2.64	2.41	2.57	2.67	2.65	3.56	3.77	3.76	3.36	3.11	2.88
1944	2.88	2.75	2.92	3.59	4.76	4.52	4.82	5.32	4.75	3.85	3.32	3.27
1945	2.81	3.05	3.15	3.72	4.46	3.97	3.39	3.26	3.28	2.27	1.76	2.07
1946	2.58	2.04	2.57	1.55	1.72	2.35	2.28	1.98	2.49	3.10	2.95	2.56
1947	2.69	2.25	1.99	2.99	3.21	5.35	−.81	−1.78	−2.65	.76	−.08	−.02
1948	−.57	.59	1.02	−.11	−.68	−1.21	−.77	−1.15	−1.87	−1.88	.22	.45
1949	1.27	1.30	1.41	−.47	−1.20	−1.24	−1.53	−2.13	−1.88	−1.75	−2.41	−2.66
1950	−2.50	−1.97	−2.26	.12	.85	1.18	−.11	−.40	−.89	−1.35	−1.88	−2.26
1951	−2.58	.49	1.57	2.57	2.49	2.67	3.10	3.68	3.45	3.75	3.71	3.51
1952	3.41	3.00	3.75	3.02	2.78	2.60	2.69	2.76	−.72	−1.35	.25	.21
1953	.09	.49	.88	1.34	−.38	−.38	−.41	−1.14	−2.05	−2.95	−3.33	−3.47
1954	−3.91	−3.75	−3.59	.30	.59	1.05	.09	2.12	2.07	2.95	−.32	−.32
1955	−.31	.30	−.32	−.26	−.52	−1.28	−1.07	−1.76	−1.77	−2.14	−2.79	−3.25
1956	−3.61	−4.02	−4.49	−4.57	−4.73	−5.41	−5.14	−4.92	−5.01	−4.95	−4.92	−5.15
1957	−5.23	−5.48	−5.46	−5.30	−4.39	−3.91	−3.45	−2.97	−2.94	−2.28	−1.66	−1.45
1958	−1.41	−1.48	−1.83	−1.87	−2.33	.26	2.90	2.51	2.63	1.83	1.60	1.05
1959	.77	.88	1.76	1.88	2.54	1.82	1.40	1.03	1.07	1.15	1.42	1.48
1960	2.31	2.30	2.08	2.21	2.92	2.19	1.91	2.45	2.50	2.28	1.64	1.17
1961	.60	1.23	2.21	2.17	1.35	.78	2.14	1.82	3.45	3.69	3.94	4.00
1962	3.34	3.60	3.22	2.76	2.72	1.84	2.77	−.15	−.39	−.11	−.69	−1.15

June 5, 1934—— Pastures parched to tinder, feed situation acute; some corn dying; livestock being being sold for lack of pasture; one-half or more of the farmers [in Polk Co.] having to haul water.

June 19, 1934—— Pastures brown; corn fair; oats short and light.

July 3, 1934—— Corn rolled; small grain withered; more wells failing [in Hamilton Co.] and water being bought and hauled from long distances; pastures burned up; barley hardly tall enough to cut and very thin; wheat yield 5 to 20 bushels.

July 17, 1934—— Rain; pastures greening; corn now growing; oats and barley very poor.

July 31, 1934—— Oats yield 3 to 15 bushels per acre with quality very poor to fair; corn suffering; hauling water still in vogue [in Hamilton Co.]; cattle picking up since pastures improved; water situation [in Polk Co.] becoming more critical every day.

Aug. 14, 1934—— Corn badly hurt, some being cut for fodder; tomatoes and cucumbers not setting; potatoes not doing anything; forage not growing well; pastures very short and furnish practically no feed; practically every farmer [in Polk Co.] hauling water.

Aug. 28, 1934—— Corn will yield 10 to 40 bushels, only fair quality; ground too hard and dry for fall plowing; much of the corn crop going into silage or fodder.

When one compares the remarks above with those which applied to western Kansas, it may appear that 1934 did not produce extreme drought in central Iowa. However, the weather was *extreme for Iowa;* at no other period during the years studied was the moisture shortage in that area so disastrous. The drought index seems to be measuring this drought situation rather accurately.

Hydrologic Data.—It was not possible to locate any stream-gaging station or combination of stations that would reasonably represent the runoff from this relatively small area. The Des Moines River and the Iowa River both pass through the area but the gaging-station records probably reflect conditions outside the area at least as much as inside it. The Skunk River originates in and drains the central portion of the area, but the only long-record station is at Augusta about 75 or 80 miles to the southeast of the area of concern.

THE DROUGHT OF 1936

Fortunately, only July and August were extremely hot and dry, but they produced a very serious agricultural situation. By the third week in July there were reports [65] of moderate drought damage to corn. By late July it was estimated that the corn crop had been reduced by one-fourth and there were no good pastures. Rains in early September came too late for much of the corn, but produced a good supply of fodder and helped

pastures. Corn yields turned out to be better than expected. The index reached its largest value, −3.34, in August.

THE DROUGHT OF 1947

In September of 1947 there were complaints [62] of pastures dry and short, corn and soybean crops being injured by drought, and soil too dry for fall plowing and seeding. But the situation did not approach the seriousness of the extreme drought of 1934. The index, −2.65, at the close of September also indicates a much less serious drought than in 1934.

THE DROUGHT DURING THE 1950's

During most of the first half of the summer of 1953 growing conditions were ideal [62]. (Note that the index indicates this as a period of mostly near-normal weather.) The moisture shortage began to develop about the middle of the growing season, and ". . . by the end of the season it was quite dry over the entire State, with some areas in critical condition." In October "Reports of dry wells are common over the State." "The fire hazard has increased, . . . communities have banned all outdoor fires."

The really serious dryness occurred so late in the year that the agricultural reports are very meager, but from the quoted reports above one can estimate that the drought was quite serious. Apparently it lasted all winter because the first *Iowa Weekly Weather and Crop Bulletin* of the spring of 1954 (April 5) reported, "water is still being hauled for livestock."

Noteworthy dryness returned in late 1955, and 1956 brought the most serious drought since the 1930's. The following selected excerpts from the Crop Bulletins [67] are more or less indicative of the agricultural situation in central Iowa during the 1956 growing season. Most of the reports were worded in such general terms that one cannot tell what area of the State they apply to; only a few contain remarks specifically pertinent to the problem being considered here.

May 28, 1956..... Some late corn and soybeans not germinating because of a lack of moisture. Pastures and meadows need rain.

June 4, 1956..... Poor yields on first cutting of alfalfa; oats heading only 6 to 8 in. tall. Only 1.4 in. of available moisture in 5-ft. root zone of alta fescue at Ames.

June 11, 1956..... Corn and soybeans look good; pastures very dry and furnishing little forage.

June 18, 1956..... Oat crop light; pastures very dry; yields of first cutting of alfalfa generally poor; some stands of red clover did not survive the dry fall and winter; corn generally not showing drought damage yet.

June 25, 1956..... Oats being harvested as hay or pasture.

July 16, 1956..... Corn in excellent condition; second cutting of alfalfa short with poor yields.

July 23, 1956..... Corn and soybeans developing unevenly; excellent prospects where rains received, but prospects declining in drier spots.

July 30, 1956..... Hay fields damaged by lack of moisture, some too far gone to recover if rains came now. Soybeans hurting for rain. Many meadows too dry to furnish forage. Rains badly needed in most of State.

Aug. 6, 1956..... Corn prospects deteriorated in drier spots. Many clover seedlings destroyed by drought. Only 0.9 in. of available soil moisture in top 5 ft. at Ames.

Aug. 20, 1956..... Corn crop uneven with best prospect in years in some areas, while other areas need rain to avoid further deterioration. Fall plowing retarded by dry soil.

Aug. 27, 1956..... Crop prospects very uneven; some areas damaged beyond help by drought. Only 1.5 in. of available soil moisture (to 5 ft.) at Ames on August 31.

Sept. 24, 1956..... Fall plowing and wheat seeding at a standstill because of dry soil.

Oct. 8, 1956..... No available moisture to 5 ft. under alta fescue at Ames. Wheat only 50 percent planted, latest in 10 yr.

As they stand these remarks are not very informative; however, 1956 produced the least rainfall recorded for central Iowa during any year from 1930–60. It therefore seems likely that such remarks as "in the drier areas" included central Iowa. Insofar as the soil moisture measurements at Ames are representative, they certainly indicate an unusually dry condition at every sampling date.

As further evidence of the drought in central Iowa all rivers draining the area reached or almost reached record low stages during the latter half of 1956 [60]. As measured at Augusta the Skunk River equaled its 41-yr. record low in October, November, and December. The Iowa River at

Wapello was near its 42-yr. record low stage in both October and November. At Des Moines the Des Moines River equaled its 60-yr. record low in October and very nearly equaled it in July, September, and November.

The combined evidence indicates very unusual dryness in central Iowa during 1956. The index values show extreme drought from February 1956 through May 1957. This classification seems reasonable.

13. SUMMARY OF DROUGHT PERIODS AND FREQUENCY OF DROUGHT CLASSES

Tables 17 and 18 were prepared from tables 13 and 16. These tables show the month in which each of the various drought periods became established in western Kansas and central Iowa and the last dry month in each drought period. Also, the maximum value of the drought index has been tabulated for each period, as well as the number of months of mild, moderate, severe, and extreme drought as defined in table 11. The total duration of each drought period does not in every instance agree with the sum of the number of months in each class because on occasion a month or so in the incipient class occurred in the middle of a long drought period. July 1948 in central Iowa (see table 16) is an example of this.

WESTERN KANSAS

In western Kansas the median duration of drought is about 4 months, but the distribution is very skewed and the mean is about 12 months. A total of 339 months of drought occurred in the 76 years. This is 37 percent of the time. From table 13 one can also determine that a wet spell was underway in 37 percent of the months and that near-normal conditions existed in 12 percent of the months. It may at first seem unrealistic to have

TABLE 17.—*Drought periods, western Kansas, 1887–1962*

Start		End		Maximum severity	Number of months				
Year	Month	Year	Month		Mild	Moderate	Severe	Extreme	Total
1887	July	1887	July	−1.19	1				1
1888	February	1888	February	−1.02	1				1
1890	March	1890	March	−1.12	1				1
1890	June	1890	December	−3.22	1	2	3		6
1892	November	1895	May	−4.97	4	12	8	6	31
1899	May	1899	May	−1.28	1				1
1899	September	1899	October	−1.39	2				2
1900	December	1901	January	−1.19	2				2
1901	June	1902	April	−2.23	8	1			11
1904	January	1904	April	−2.11	2	2			4
1907	April	1907	May	−1.56	2				2
1908	April	1908	May	−1.94	2				2
1910	April	1911	November	−4.03	4	9	6	1	20
1913	May	1913	August	−4.12	2	1		1	4
1914	November	1914	December	−1.13	2				2
1916	July	1918	August	−3.16	12	13	1		26
1921	May	1921	May	−1.05	1				1
1921	October	1922	January	−1.41	4				4
1922	September	1923	April	−2.31	4	4			8
1925	March	1927	May	−3.22	12	11	3		27
1927	November	1928	January	−1.50	3				3
1930	March	1930	August	−1.53	5				6
1931	September	1931	October	−1.80	2				2
1932	August	1940	October	−5.96	8	22	30	39	99
1943	May	1943	November	−2.86	3	4			7
1946	April	1946	August	−2.62	3	2			5
1950	March	1950	June	−2.55	3	1			4
1952	June	1957	February	−6.20	6	17	23	11	57
Number of months					101	101	74	58	339
Percent of 912 months					11	11	8	6	37

Months of Beginning and Ending of Drought

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
First month	1	1	4	4	4	3	2	1	3	1	3	1
Last month	3	2	1	3	6	1	1	4	0	3	2	2

TABLE 18.—*Drought periods, central Iowa, 1930–1962*

Start		End		Maximum severity	Number of months				
Year	Month	Year	Month		Mild	Moderate	Severe	Extreme	Total
1930	July	1931	August	−4.45	2	3	5	4	14
1933	June	1934	August	−5.98	2	5	3	5	15
1936	May	1936	August	−3.34	2	1	1		4
1937	September	1938	March	−2.15	5	2			7
1939	May	1940	June	−2.69	5	7			14
1941	May	1941	August	−1.65	3				4
1947	August	1947	September	−2.65	1	1			2
1948	June	1948	October	−1.88	4				5
1949	May	1950	March	−2.66	6	5			11
1950	October	1951	January	−2.58	2	2			4
1952	October	1952	October	−1.35	1				1
1953	August	1954	March	−3.91	1	2	5		8
1955	June	1958	May	−5.48	10	6	4	16	36
1962	December				1				1
Number of months					45	34	18	25	126
Percent of 396 months					11	9	5	6	32

Months of Beginning and Ending of Drought

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
First month	0	0	0	0	4	3	1	2	1	2	0	1
Last month	1	0	3	0	1	1	0	4	1	2	0	0

three-fourths of the time devoted to either a drought or abnormally wet weather; but it is a well-known fact that normal or average weather does not occur very frequently, even on a monthly basis. This, coupled with the tendency for persistence, helps to explain the high percentage of abnormal conditions.

Table 17 also shows that western Kansas has mild drought during 11 percent of the months, moderate drought in 11 percent, severe drought in 8 percent, and extreme drought in 6 percent of the months.

At the bottom of table 17 is an auxiliary tabulation showing the number of times (out of the 28 drought periods) that each of the calendar months established a drought period. Spring and early summer account for about half of the drought beginnings, but apparently there is no really preferred time of beginning, so the information is neither startling nor particularly useful.

On the other hand it was a little surprising to find that almost one-third of the drought periods ended with April or May. This may be useful information in that it suggests that if a drought continues through May there is a good chance that June and July will also be drought months. There seems to be a slight tendency for the change to normal or wetter weather to occur during September, but the evidence is rather meager.

CENTRAL IOWA

The shorter record from central Iowa produced only the 14 drought periods shown in table 18. From this table and table 16 the following facts are evident.

Mild drought occurred 11 percent of the time, moderate drought 9 percent, severe drought 5 percent, and extreme drought 6 percent of the time. Drought was underway in 32 percent of the months, and a wet spell was underway in 50 percent of the months. In 11 percent of the months the weather was near-normal. (The remainder were "incipient.")

The average duration of drought was about 9.6 months, but the median was about 7 months. Half the droughts became established in May or June and all but three started between May and September. With the possible exceptions of March and August no month seems to have been a particularly preferred final drought month.

From these facts it is apparent that drought is almost as frequent in central Iowa as in western Kansas, but it is a little dangerous to make comparisons between the two areas because the analyses cover unequal periods of record.

MEANING OF THE DROUGHT CLASSES

On the basis of available evidence it appears

that the drought index values are reasonably comparable in their local significance both in space and time. It seems reasonable to postulate that a drought index of −4.0 spells economic disaster in any region in which the established economy is significantly dependent on the vagaries of weather for its moisture supply.

As a point of departure the following descriptions of the consequence of each of the four classes of drought are proposed. These descriptions are more or less ecological and are probably not as close to being universally applicable as is the drought index itself. However, they may be useful for certain purposes.

Mild drought: Some of the native vegetation almost ceases to grow.

Moderate drought: The least drought-resistant members of the native plant community begin to die and the more xerophytic varieties start to take their place.

Severe drought: Only the most xerophytic varieties of native vegetation continue to grow. And vegetal cover decreases.

Extreme drought: Drought-resistant varieties gradually give way to open cover. More and more bare soil is exposed.

14. PROGNOSTIC VALUE OF THE INDEX

This index apparently measures something that might be of value in forecasting. Inasmuch as it provides a single number which is a function of many aspects of the current and recent weather, it seems likely that the index could, under certain circumstances, be useful in predicting the precipitation for the following month.

Figure 5 shows that not only does precipitation average much less during drought periods than during wet periods, but also that the two regimes show some remarkable departures from the average precipitation climate of central Iowa. For example, the fact that February produces near normal precipitation, on the average, during wet periods warrants some investigation. Can one use the previous index value as an indicator that February precipitation is not likely to exceed the normal by any substantial amount?

Monthly precipitation forecasts are ordinarily issued in terms of "light," "near-normal" or "heavy." These classes are defined in such a way that each contains 1/3 of the total number of occurrences. For central Iowa the February limit for "light" for this 33-yr. period is about 0.58 in. and "heavy" includes all amounts in excess of about 1.25 in.

There were 13 years during this period when the index was $>+1.50$ at the end of January. These 13 cases were followed by 5 Februaries which had "light" precipitation, 6 with "near-normal" precipitation, and 2 with "heavy" precipitation. This suggests only a 15 percent probability of heavy February precipitation when the index is greater than +1.50 at the end of January.

Table 19 shows the relationship between May precipitation and the index value at the end of April. The class limits for May are shown in the table. Of particular interest is the fact that the index at the end of April was positive in 16 of the 33 years, and in only 2 of those 16 years did "light" precipitation occur during the following May. Even more surprising is the fact that in 13 of the 16 cases (81 percent) the May precipitation was greater than the long-term mean with 8 of the 16 falling into the "heavy" category. Equally surprising is the fact that in 12 of the 17 Mays which followed Aprils having a negative index value the precipitation was less than the long-term mean. "Light" precipitation was observed in about half of these cases and only 3 years produced "heavy."

This relationship seems too good to be true and very likely it is to some extent fortuitous, but the chance of its breaking down completely on subsequent data seems a bit remote.

This relationship suggests a number of things.

TABLE 19.—*Contingency table showing May precipitation in central Iowa as a function of the index value at the end of April, 1930–62*

Index value at end of April	May precipitation				
	Light <3.00 in.	Near normal		Heavy >4.80 in.	Total
		<Mean	>Mean		
X >0	2	1	5	8	16
X<0	9	3	2	3	17
Total	11	11		11	33

As far as drought is concerned there does not appear to be much chance of April being the last of a drought period. As a matter of fact one can determine from table 16 that 12 of the 15 Aprils having a negative index were followed by Mays which added to the droughtiness.

Of course, the factor that is being reflected in these relationship is persistence. It may be that this index is a more useful parameter for studying certain types of persistence relationships than is precipitation by itself.

Another subject for speculation arises here. Perhaps the persistence in the moisture aspect of this continental climate is related to the sources of the precipitation. It may well be that a good deal of the precipitation in continental climates represents moisture re-evaporated from land areas. This portion may be more substantial than some authorities have surmised. If it is, it would afford a partial explanation of the persistence of wet and dry periods. Begemann and Libby [2], from studies of the tritium content of rainfall, estimated that about one-third of the rain in the upper Mississippi Valley is ocean water and about two-thirds represents re-evaporated surface water.

As can be seen from figure 5, the July precipitation during drought periods in central Iowa does not average as much as it does during wet periods. Also, the difference between June and July is much less during drought periods than in the mean or during wet periods. This is an interesting difference which bears looking into.

The most striking thing that one finds on examination of the data is that there were 7 years when the *June* precipitation was less than the *July* normal with a drought underway at the end of June; and in all of these cases the July precipitation exceeded the June precipitation with the average difference being 1.98 in. Further, the July rainfall was normal or above in all but one of these 7 years.

Figure 5 also shows a large percentage difference in November precipitation between wet periods and drought periods. Apparently drought is rather persistent during the fall months because there were 12 years when drought was underway at the end of October and 9 of these were followed by Novembers in which the precipitation was below normal, the average departure being about 1 in.

Figure 6 shows a decrease in the average rainfall

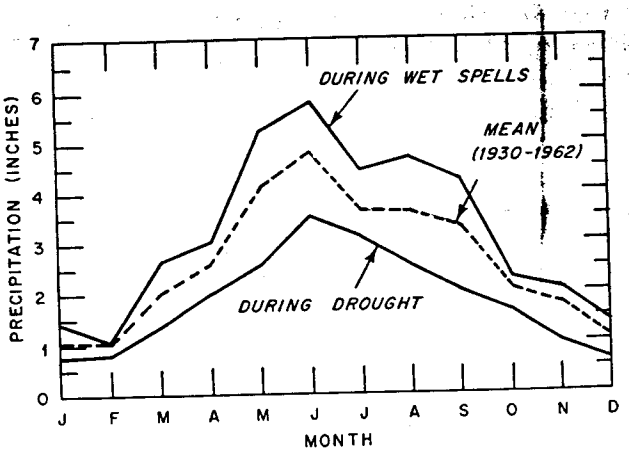

FIGURE 5.—Mean monthly precipitation in central Iowa.

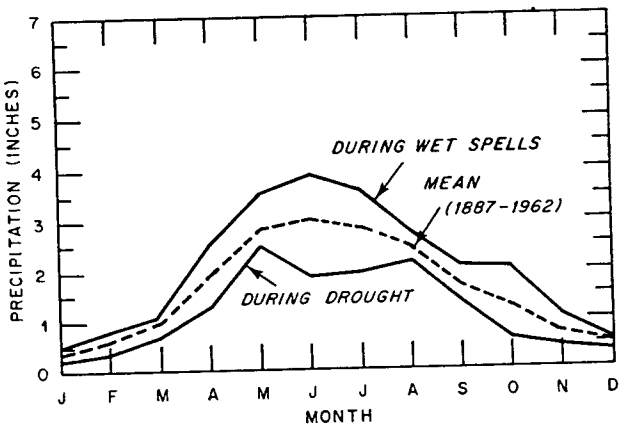

FIGURE 6.—Mean monthly precipitation in western Kansas.

from May to June in western Kansas during drought. This is in contrast to both the average change and the change during wet periods. On examination of the data it turns out that the drought index at the end of May was negative in 42 of the 76 years. In 30 of the 42 years the subsequent rainfall during June was less than the 76-yr. mean. There were 30 years when the May index was < -1.00 and 77 percent were followed by drier than average Junes.

The unusual dryness of October during drought periods in Kansas led to further examination of those years. There were 28 years when drought was underway at the end of September and 26 (93 percent) were followed by below average rainfall during October. In 24 of the years the Octo-

ber rainfall totaled less than 1 in. over the area. So, in Kansas too, we find some evidence that the index may be useful in forecasting.

These few examples demonstrate the need for further study of these and similar aspects of the usefulness of the index values.

15. THE METHOD APPLIED TO NORTHWESTERN NORTH DAKOTA

RESULTS AND VERIFICATION

In order to determine whether or not this method of analysis would provide reasonable final results in an area other than those on which it was primarily based, the data from the northwestern climatic division (six counties) of North Dakota were analyzed for the 30 years beginning with 1931. The derived means, coefficients, and constants are shown in table 20.

This Dakota area was chosen for analysis in 1961 because a drought was underway at the time, and it seemed timely to study an area in which drought was a problem of current concern. As it turned out this was not a particularly satisfactory region for a test because of the difficulty of locating auxiliary information for judging the reasonableness of the final index values.

Streamflow in this region (the Souris River) is almost completely regulated by controlled lakes and reservoirs. In addition, a number of new dams were built during the 1930's and there seems reason to believe that some of the low flows recorded at that time were a consequence of the flow being impounded behind newly constructed dams upstream.

The agricultural reports are at times a little misleading because the crops are so dependent on June precipitation. Ordinarily, almost one-fourth of the annual precipitation comes in June, and a hot dry June has a tremendous effect. As long as crops are deteriorating day by day, the agricultural reports stress the urgent need for moisture; but after the crops are harvested or dried up, published complaints of a moisture shortage diminish unless the shortage is so severe that even drinking water must be hauled in.

Table 21 summarizes the drought periods in northwestern North Dakota. The index reached its maximum negative value, −6.66, in August 1934 during the 20-month drought which began in August 1933. Note that this drought was in the extreme class 60 percent of the time. This drought was mostly in the mild class until April 1934 when the index, −2.41, showed it as moderate. By the end of the very dry May (rainfall 0.76 in.) the drought was in the extreme class with an index of −4.11. The next 11 months (except one) were all abnormally dry and the drought severity increased. The following index values were computed: June, −4.76; July, −6.24; August, −6.66; September, −6.04; October, −6.26; November, −6.13; December, −5.69. Drought severity continued to decrease in the following months, but moisture remained abnormally short until May 1935 when the drought ended. There is evidence that the drought in 1934 definitely reached an extreme severity.

TABLE 20.—*Means, coefficients and constants for northwestern North Dakota, 1931–1960*

AWC_s=1.00 in., AWC_u=5.00 in.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
T	6.3	10.5	21.4	40.5	53.2	61.3	69.2	66.9	56.1	44.4	26.0	13.6
ET	0	0	T	.86	2.40	3.52	3.46	2.32	1.25	.64	.02	0
PE	0	0	T	.91	2.95	4.26	5.52	4.69	2.68	1.13	.02	0
R	.41	.39	.59	.40	.13	.32	0	0	.21	.21	.54	.37
S	1.76	2.16	2.56	3.15	3.30	2.69	2.44	1.11	.64	.67	.81	1.35
PR	4.24	3.84	3.44	2.85	2.70	3.31	3.56	4.89	5.36	5.33	5.19	4.65
RO	.01	T	.01	.02	0	.15	0	0	0	0	0	0
L	0	0	0	.25	.91	.57	1.33	.48	.17	.07	T	0
PL	0	0	T	.80	1.64	1.83	2.08	.86	.28	.17	.01	0
P	.42	.40	.61	1.02	1.80	3.43	2.13	1.85	1.26	.77	.55	.37
α	1.00	1.00	1.00	.9410	.8142	.8272	.6272	.4953	.4647	.5672	.9492	1.00
β	.0970	.1029	.1727	.1400	.0467	.0976	0	0	.0392	.0385	.1040	.0800
γ	.0042	.0017	.0050	.0064	0	.0565	0	0	0	0	0	0
δ	0	0	0	.3180	.4450	.3141	.6396	.5546	.5967	.4368	.5172	0
K	3.43	3.30	2.95	2.33	1.94	1.62	2.10	2.35	2.25	2.57	2.84	3.47

TABLE 21.—*Drought periods, northwestern North Dakota, 1931–1962*

Start		End		Maximum severity	Number of months				
Year	Month	Year	Month		Mild	Moderate	Severe	Extreme	Total
1931	March	1932	September	−5.05	2	6	4	7	19
1933	August	1935	April	−6.66	6	2		12	21
1935	September	1935	October	−1.45	2				2
1936	June	1937	August	−4.14	1	1	12	1	15
1938	September	1938	September	−1.01	1				1
1939	September	1941	March	−2.18	13	2			19
1946	April	1946	September	−2.40	2	4			6
1949	April	1949	September	−2.00	4	1			6
1952	April	1953	February	−3.44	1	5	5		11
1955	October	1959	August	−5.30	17	5	8	4	47
1960	September	1962	April	−5.67	7	1	4	3	16
Number of months					56	27	33	27	163
Percent of 368 months					15	7	9	7	42

Months of Beginning and Ending of Drought

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
First month	0	0	1	3	0	1	0	1	4	1	0	0
Last month	0	1	1	2	0	0	0	2	4	1	0	0

Bavendick [1] leaves no doubt of this. He wrote:

> It was not until June [1934] that any semblance of normal precipitation occurred and even that month showed a deficiency [59 percent of 30-yr. mean]. To further aggravate the situation, duststorms of unprecedented severity occurred during April and May. Much of the livestock was shipped out of the State due to lack of feed. Drought was so severe that plans for the evacuation of farmers from western North Dakota were seriously discussed. . . . Many cattle died from lack of feed and water and from dust which accumulated in their lungs and stomach. Some persons died from "dust pneumonia" caused by an accumulation of dust in their lungs.

As was the case in Kansas the effects of the abnormal moisture deficiency were greatly increased by the windstorms and dust, but the driest spring and summer on record certainly seems a likely candidate for the classification of extreme drought.

Turning to the drought in 1961, we find serious complaints of drought as the hottest and driest June on record reduced the wheat crop to about one-fourth of average. There were a few local showers in July and those areas enjoyed some temporary relief, but this was followed by the driest and hottest August on record. The following selected comments from the *North Dakota Weekly Weather and Crop Report* of August 29, 1961 [64] illustrate the seriousness of the drought at this time.

"Stock water situation is serious with many hauling water to livestock [in Burke Co.]. [The same was true in Mountrail Co.] Wheat yields averaged 4 to 7 bushels with a variation of 1.5 to 17 bushels. [Much of this was summer-fallowed wheat.] Very little barley and oats was harvested. Wells and dugouts are being constructed. Majority of [Renville] County remains extremely dry. Fall tillage delayed because of dry weather. Everything is at a standstill."

By way of comparison, the computed drought index values during 1961 were as follows: May, −1.16; June, −3.11; July, −4.14; August, −5.67. The peak severity during this drought was the −5.67 at the end of August. Severity decreased during subsequent months until the drought ended with April 1962.

This drought does not appear to have been as devastating as the drought of 1934, and from a crop yield standpoint the drought of 1936 (X= −3.28 at the end of July) was apparently more serious [1] than this one in 1961. There are many reasons why the effects were not as serious in 1961. In the first place there is a good deal more know-how these days for coping with the problems of dryland agriculture. There is evidence here that the Great Plains Conservation Program [53] has already met with some success in its objective—"to assist farmers and ranchers to develop for themselves a land use program which will help them avert many of the hazards that come with the recurring droughts common to the region." In addition, the availability of livestock feed on soil-bank acreages greatly alleviated the stockmen's problems in 1961. This feed was made available for haying and grazing by an official

U.S. Department of Agriculture action in late June declaring this a drought disaster area.

This action—possibly necessitated by the wording of the soil-bank law—led to much confusion concerning the seriousness of the drought during June and July. Some noted this disaster designation and visualized conditions similar to those in the dustbowl days of the 1930's in the southern Plains.

Conditions in July 1961 were by no means as serious as those which prevailed at the peak of the droughts in the southern Plains in the 1930's and in the 1950's. Descriptions such as [56] bear this out. The index also reflects this fact. At the end of July 1961 the index showed −4.14 in northwestern North Dakota. This value compares with the western Kansas values of −5.96 in August 1934 and −6.20 in September 1956.

It is also interesting to note that in the Kansas cases the index was around −3.5 to −4.0 when disaster was declared, but in the case of northwestern North Dakota the index was only about −3.00. There seems to be some evidence that the index provides a better estimate of the severity of this drought than does the disaster declaration. However, one must always bear in mind that this index is a function of the anomalous weather rather than of the *effects* of the weather. Agriculturally, one might be justified in considering the June weather as a calamity, but from a meteorological standpoint the drought at the end of June could not reasonably be placed in the same category with the drought of 1934.

AN EXAMPLE OF CURRENT DROUGHT ANALYSIS

During the summer of 1961 there was a considerable amount of public interest in the drought in the northern Great Plains and the Prairie Provinces of Canada. A period of showery weather began early in July and immediately there were reports that the drought had ended. On the basis of this analysis an article was prepared [35] pointing out that the weather of June had already used nearly all the antecedent moisture so that above normal July rainfall was required if the evapotranspiration was to be normal. It was further demonstrated that July had increased rather than ended the water shortage in this area. Early in August another article was released [34] pointing out the strong climatological likelihood for the drought gradually becoming worse during August. This article was based, in large part, on equation (14) which estimates the amount of precipitation needed for "normal" weather. It turned out that August had provided this much rain only eight times during the last 30 years, with most of the eight occurring during years in which most months were wetter than normal. From this it was concluded that the drought was more likely to become worse than to end during August. Actually, this turned out to be the driest and hottest August in 30 years and the drought became more extreme by September 1.

During September it rained 2.79 in. over the area. This was, by equations (29) and (30), far from being enough moisture definitely to establish an end to the long period of drought, but it did produce a 27 percent probability that the drought had ended. At that time there was no way of being certain that September was not just an interruption in the long drought. In fact, October and November were among the driest of record and both reduced the probability that the drought had ended. By the first of December the probability had been reduced to 9 percent with no prospect of its reaching 100 percent before the following spring. The unhappy truth is that under the existing circumstances there was no way of making a reasonable estimate as to whether this very serious drought period had ended or if the area was destined to suffer through another hot dry summer. This is in marked contrast to the situation in July and early August when there existed relatively high probabilities that the drought would get worse before it got better.

Actually, the change from prevailingly dry weather to unusually wet weather did not take place until May of 1962. It turned out, therefore, that the wet weather of September 1961 was only a brief interruption in the dry weather. That this would be the case was suspected in early winter, but there was no certainty until the following spring. This demonstrates that the need for reliable seasonal weather forecasts remains. However, under certain circumstances this method does provide a useful substitute.

In general this method of analysis seems to have provided fairly good results in North Dakota. There seems no way of measuring exactly how well the index is describing the moisture variable. The best one can say is that the results seem reasonable both in time and in comparison with the results obtained in Kansas and Iowa.