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DROUGHT OF 1936

WITH DISCUSSION ON THE SIGNIFICANCE OF DROUGHT IN RELATION TO CLIMATE

BY
JOHN C. HOYT

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DROUGHT OF 1936

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By John C. Hoyt

INTRODUCTION

During each of the 5 years 1930–34, except 1932, one or more of the States except five—Maine, Vermont, Louisiana, Mississippi, and Arkansas—experienced a major drought. In 1935 water-supply conditions were in general normal throughout the country, but in 1936 droughts occurred in many localities.

A report on the droughts of 1930–34 has been published in Geological Survey Water-Supply Paper 680. The conditions during 1936 are presented in the present report, which is based on information collected under the direction of the 36 district engineers of the Geological Survey, supplemented by data made available through the United States Weather Bureau, Bureau of Agricultural Economics, and other agencies as indicated. Acknowledgment is hereby made to these various agencies. W. M. Littlefield has assisted in the arrangement and preparation of tables and graphs. W. G. Hoyt has supplied advice and material for the parts relative to water supply and the classification of climate, and W. B. Langbein has been of special assistance in the preparation of the sections treating of climate and its classification and drought aspects.

In some sections of this report, notably that entitled "Droughts as related to the semiarid States," there have been collected numerous pertinent quotations. This collection has the merit of making available in one place statements by several experts and thus serving as an exposition both of the subject and of the best thought upon it.

In this report, as in Water-Supply Paper 680, the following definition of a drought has been used. When in an area that is ordinarily classed as humid, natural vegetation becomes desiccated or defoliates unseasonably and crops fail to mature owing to lack of precipitation, or when precipitation is insufficient to meet the needs of established human activities, drought conditions may be said to prevail. Although water for irrigation or other uses in arid areas is always limited, special shortages in such areas are also regarded as droughts. Unsatisfactory distribution of precipitation throughout the year may be as effective in causing a drought as a shortage in the total amount. Temperature and wind may also play important parts, especially in relation to the damage done.

As interest in droughts may relate either to their physical characteristics as determined by the phenomena which cause them or to their economic effects as reflected by damage, they may be considered either as natural phenomena or as economic phenomena—usually both—and it is therefore essential in drought studies to take into account not only physical data but also information as to the extent and nature of human activities in the area affected.

Although deficiency in precipitation is the prime cause of drought, it is not possible to set for any region an exact limit of the total annual precipitation above which a drought does not exist and below which a drought may prevail. In general, however, in the humid and semiarid States there are no serious drought effects unless the annual precipitation is as low as 85 percent of the mean—that is, unless there is an annual deficiency of 15 percent or more. This limit is used in the present report as a measure of a drought year and may serve in many drought studies.

In considering droughts the division of the country into three sections with respect to precipitation—the humid East, the arid West, and the intermediate semiarid States—must be kept in mind. In the humid East precipitation is usually adequate to supply the needs of vegetation and of other activities. In the arid West precipitation is sufficient to supply only a certain amount of natural vegetation without irrigation, and other activities are limited by the water supplies that can be conserved. The semiarid States constitute a section that may be either humid or arid, depending on weather conditions in a particular year. Thus for a year or several years there may be adequate water for all needs, following which there may be a year or several years of deficiency, which creates an unstable condition as to agriculture and all other activities.

It has been found in drought studies that conditions are usually so variable as to both time and area that it is difficult to make comparisons or draw conclusions that can be considered more than general unless small areas are studied independently, and even then conclusions will generally apply only to the areas studied and for a given time and are not to be extended to apply to other areas or other times.

The average precipitation in each State for the 11 major drought years since 1881, expressed in percentage of the annual mean, is given in plate 1. Five of these drought years occurred during the period 1930–36. The figures indicate the percentage of the precipitation, and the shaded areas the States in which droughts occurred. Heavy-face figures indicate that the recorded precipitation is the minimum of record. During 1930–36 previously recorded minima were equaled or broken in 21 States, as indicated in table 1.

Drought conditions during 1936 were general over the humid and semiarid States. In the arid States water supplies were average or above, except for slight shortages in sections of Montana, Wyoming, and Colorado. In the humid section the principal drought areas were in the Ohio and upper Mississippi River basins and in Michigan. The areas affected were scattered, both as to time and place, and although droughts were severe in certain localities, they were not as severe as in 1930 and in general would not be classed as especially unusual. Damages in the humid areas were restricted to agriculture.

In the semiarid States, except Texas, the drought was especially severe, appreciably more so than in any previous years. The drought of 1936 was characterized by general crop failures, and there was much inconvenience due to lack of water supplies for various activities. As in most other droughts, excessive temperatures and hot winds contributed in large measure to the drought of 1936.

The drought of 1936 in the semiarid section again emphasizes the fact that radical adjustments must be made in activities if the area is to be self-sustaining. The conditions in this section became so serious that the President appointed the Great Plains Drought Area Committee, which reported in August 1936. After this report was made he appointed the Great Plains Committee, which summarized its studies and made its recommendations in a report entitled "The Future of the Great Plains", submitted in December 1936.

TABLE 1.—*States in which records of previous minimum precipitation were equaled or broken in 1930–36*

State	50-year mean 1881–1930 (inches)	Minimum, 1930–36			Minimum prior to 1930		
		Date	Inches	Percent of mean	Date	Inches	Percent of mean
Humid States:							
Rhode Island	44.07	1930	32.83	74	1918	36.57	83
Connecticut	44.96	1930	32.02	71	1924	34.84	77
New York	39.01	1930	32.18	82	1908	33.54	86
New Jersey	45.89	1930	35.28	77	1895	37.29	81
Pennsylvania	42.47	1930	28.82	68	1895	33.51	79
Maryland-Delaware	41.89	1930	23.78	57	1895	34.47	82
Virginia	42.18	1930	24.99	59	1925	32.53	77
Tennessee	50.30	1930	39.80	79	1925	40.50	81
Kentucky	45.81	1930	27.86	61	1894	34.81	76
West Virginia	43.83	1930	25.43	58	1895	32.82	75
Ohio	38.44	1934	26.60	69	1895	28.46	74
Michigan	31.29	1930	22.62	72	1925	25.51	82
Indiana	40.17	1934	29.70	74	1901	30.56	76
Arkansas	48.97	1936	31.78	65	1901	35.27	72
Georgia	50.48	1931	36.75	73	1904	37.17	74
Semiarid States:							
Kansas	27.48	1936	17.42	63	1917	19.60	71
South Dakota	20.77	1936	11.13	54	1894	15.30	74
North Dakota	17.70	1936	8.92	50	1917	10.92	62
Arid States:							
Colorado	16.79	1934	10.93	65	1890	11.97	71
Western Oregon	54.22	1930	37.11	68	1929	38.66	71

It is recognized that portions of Oregon are humid, though the State is here classed as arid.

CAUSES

The drought of 1936, like previous droughts, resulted from deficient and unsatisfactorily distributed precipitation, accompanied by high temperature and warm winds. The detrimental economic effects of the drought in the semiarid States were increased as a result of the previous droughts since 1930, from which recovery had not been made.

PRECIPITATION

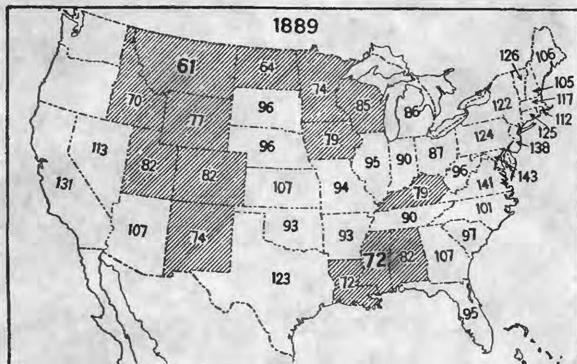
Records of mean annual precipitation give only a general indication of droughts. The distribution of the precipitation may cause severe drought in a year when the annual precipitation is normal or above, or on the other hand it may prevent a serious drought in a year of deficient precipitation. Therefore, precipitation as related to droughts should be studied on a seasonal basis in order to obtain a true picture.

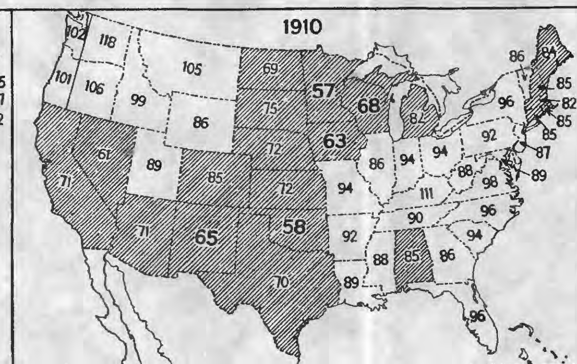
In a recent publication,[1] three seasons have been used as a basis for study, as follows: December through April, May through August, September through November. These three seasons correspond rather closely, over the United States as a whole, to the three seasons found by experience to be specially significant in water-supply studies—namely, the storage period, December through April, when losses are least; the growing period, May through August, when evaporation and transpiration are most active, with the resulting depletion of soil moisture and minimum ground-water recharge; and the replenishment period, September through November, when accretions to the soil moisture and ground water commonly occur. Under this arrangement precipitation records give a better basis for drought and other studies and show many conditions that are not disclosed by the annual figures. The studies in this report have been based on these three seasons.

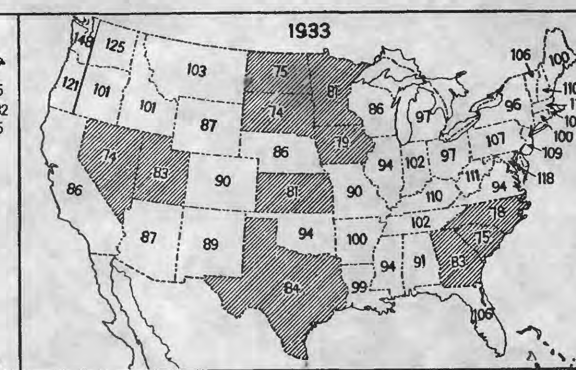
The average annual, seasonal, and monthly precipitation is shown in table 2. For the year ending November 30, 1936, these data are shown in table 3 and also graphically by States in figures 1 and 2. The following discussion for the various States in the three principal climatic sections of the country is based on these data.

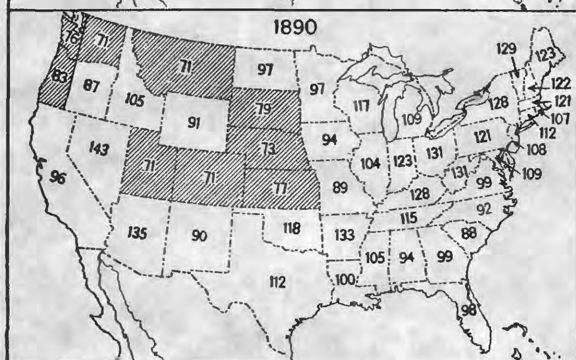
Humid States.—Precipitation did not exceed 85 percent of the normal in 54 percent of the area of the humid States. Twelve States were affected, comprising the greater portion of the Mississippi and Ohio River drainage basins and Michigan. The precipitation for these 12 States was 76 percent of the normal and ranged from 65 percent of the normal in Arkansas, which was the lowest on record, to 84 percent in Michigan and Tennessee. In the remainder of the humid States except Ohio (87 percent normal), the precipitation approached or exceeded normal.

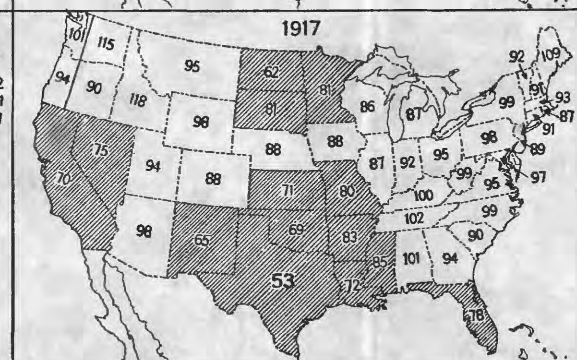
[1] Hoyt, W. G., and others, Studies of relations of rainfall and run-off in the United States: Geol. Survey Water-Supply Paper 772, 1936.

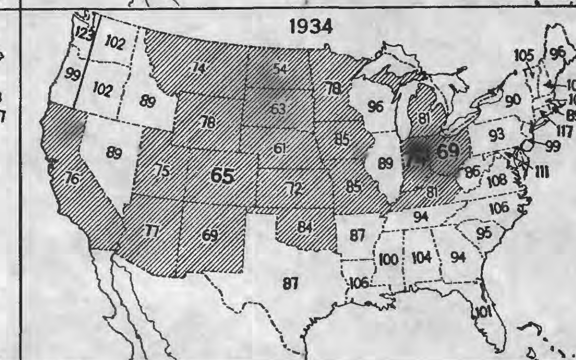


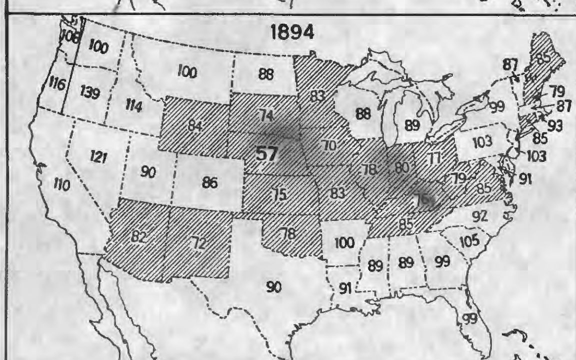


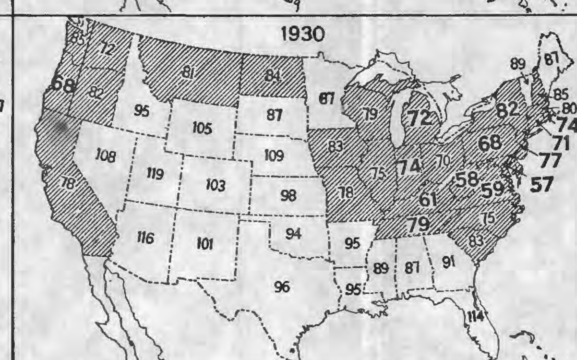


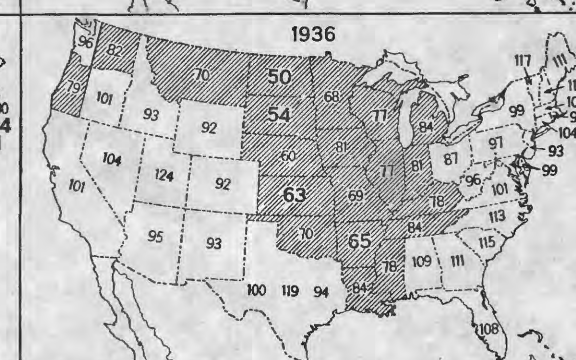


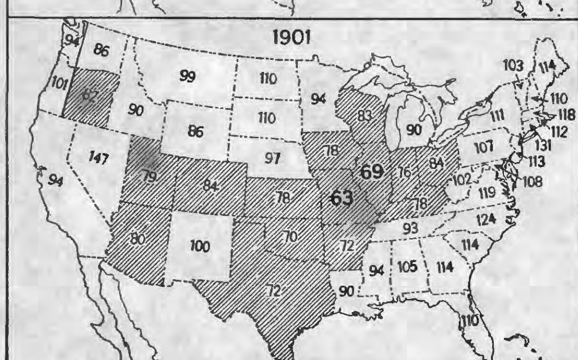


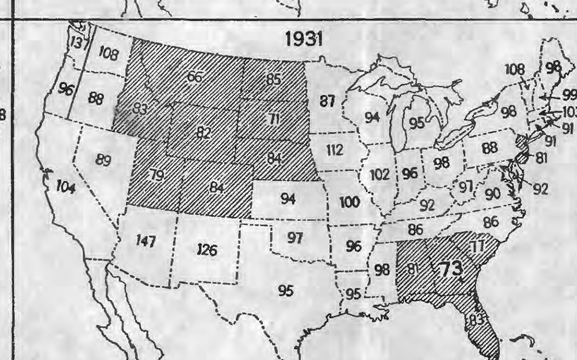












PRECIPITATION BY STATES IN PERCENT OF MEAN FOR ELEVEN MAJOR DROUGHT YEARS

All figures indicate percentage of mean. Large figures indicate minimum recorded. When annual precipitation falls to 85 percent of the mean, a deficiency of 15 percent, a drought may be said to exist. Shaded areas show the States having droughts under this definition. The percentages are for the calendar year except 1936, which is for December 1935 to November 1936 inclusive. In the arid States precipitation on a calendar year basis is not a true index of the water supply available for vegetation.

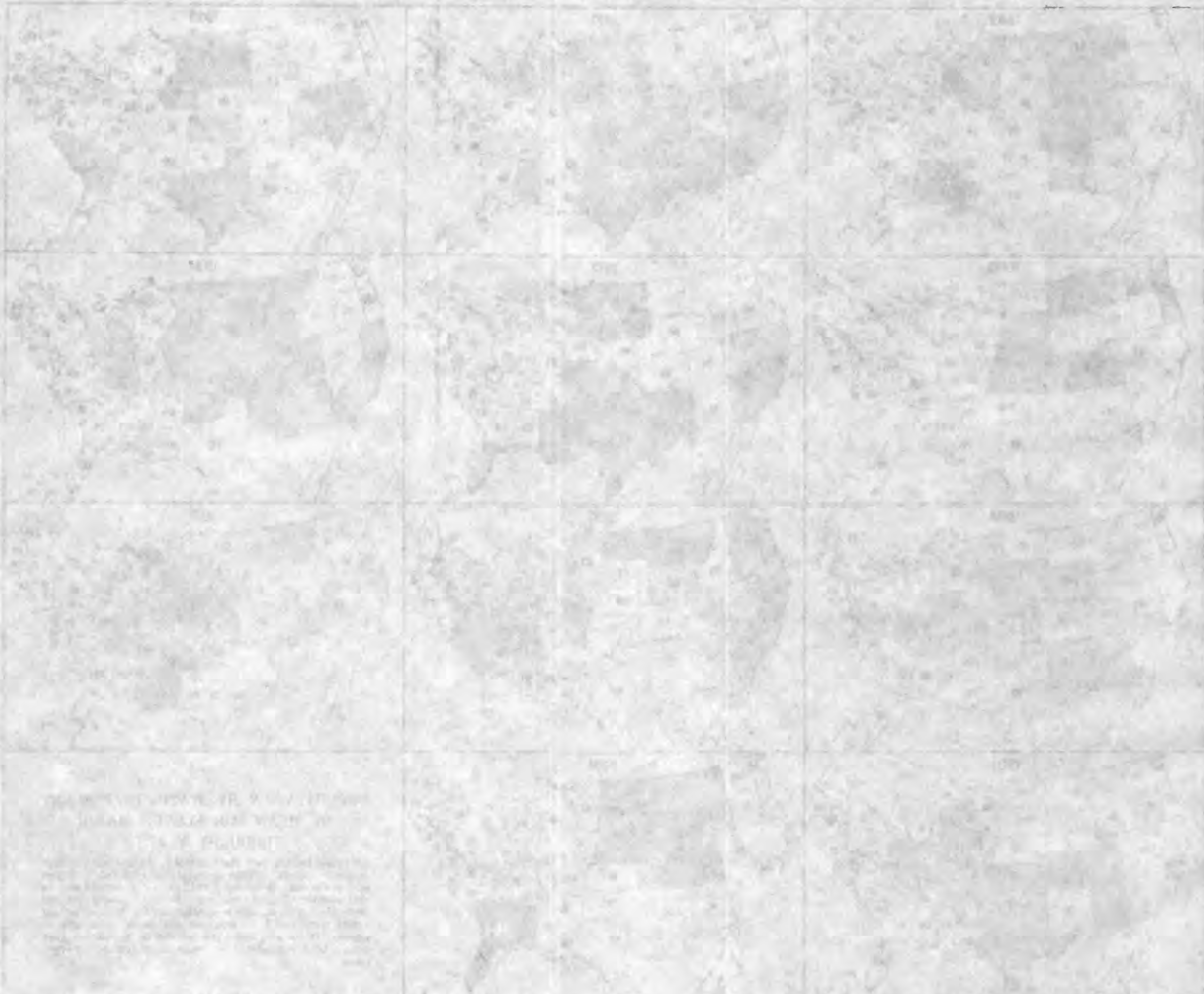


TABLE 2.—*Average annual, seasonal, and monthly precipitation*

State	50-year mean,[1] 1881–1930 (inches)	Total, 1936 [2]	Initial year for monthly means	Storage period						Growing period					Replenishment period			
				Dec.	Jan.	Feb.	Mar.	Apr.	Total	May	June	July	Aug.	Total	Sept.	Oct.	Nov.	Total
Humid States:																		
Maine	41.20	45.66	1888	3.24	3.53	2.99	3.58	3.09	16.43	3.16	3.42	3.35	3.35	13.28	3.63	3.60	3.34	10.57
New Hampshire	39.52	45.63	1888	2.95	3.01	2.67	3.31	3.03	14.97	3.07	3.52	3.61	3.60	13.80	3.70	3.16	3.12	9.98
Vermont	37.03	43.25	1888	2.63	2.78	2.46	2.93	2.84	13.64	3.10	3.61	3.70	3.59	14.00	3.67	3.24	3.05	9.96
Massachusetts	42.39	45.08	1888	3.53	3.72	3.48	3.96	3.55	18.24	3.27	3.40	3.44	3.73	13.84	3.76	3.51	3.43	10.70
Rhode Island	44.07	42.24	1888	3.81	4.05	3.68	4.16	3.84	19.54	3.40	2.98	3.08	3.67	13.13	3.55	3.57	3.42	10.54
Connecticut	44.96	46.65	1888	3.73	3.86	3.60	4.09	3.69	18.97	3.63	3.37	3.85	4.13	14.98	3.93	3.68	3.55	11.16
New York	39.01	38.56	1890	2.90	2.93	2.68	3.07	2.98	14.56	3.48	3.63	3.91	3.77	14.79	3.42	3.31	3.01	9.74
New Jersey	45.89	42.82	1885	3.65	3.57	3.61	3.78	3.61	18.22	3.73	3.71	4.79	4.75	16.98	3.56	3.41	3.18	10.15
Pennsylvania	42.47	41.00	1888	3.16	3.22	2.86	3.54	3.39	16.17	3.88	4.10	4.28	4.23	16.49	3.40	3.20	2.87	9.47
Maryland-Delaware	41.89	41.43	1895	3.15	3.30	2.95	3.57	3.45	16.42	3.41	4.04	4.22	4.59	16.26	3.17	3.02	2.46	8.65
Virginia	42.18	42.50	1891	3.08	3.24	3.12	3.77	3.30	16.51	3.74	4.13	4.49	4.33	16.69	3.14	2.94	2.39	8.47
North Carolina	50.44	56.96	1887	3.82	3.73	4.06	4.27	3.56	19.44	4.11	4.68	5.84	5.50	20.13	4.03	3.38	2.63	10.04
South Carolina	48.21	55.45	1887	3.63	3.60	4.27	3.91	3.17	18.58	3.57	4.71	5.81	5.69	19.78	4.12	3.06	2.33	9.51
Tennessee	50.30	42.39	1883	4.57	4.72	4.35	5.43	4.43	23.50	4.10	4.19	4.46	3.99	16.74	3.07	2.86	3.59	9.52
Kentucky	45.81	35.82	1889	3.95	4.33	3.38	4.73	3.97	20.36	3.99	4.12	4.13	3.70	15.94	2.98	2.73	3.47	9.18
West Virginia	43.83	41.86	1891	3.34	3.63	3.11	3.97	3.51	17.56	3.97	4.32	4.58	4.08	16.95	2.93	2.81	2.76	8.50
Ohio	38.44	33.25	1883	2.76	3.00	2.58	3.38	3.11	14.83	3.65	3.74	3.78	3.39	14.56	2.99	2.58	2.74	8.31
Michigan	31.29	26.27	1887	2.08	1.84	1.68	2.16	2.46	10.22	3.20	3.07	2.90	2.70	11.87	3.25	2.84	2.48	8.57
Indiana	40.17	32.46	1887	2.86	3.03	2.41	3.75	3.49	15.54	4.01	3.76	3.31	3.38	14.46	3.42	2.77	3.07	9.26
Illinois	37.26	28.54	1897	2.25	2.28	2.14	3.05	3.37	13.09	4.12	4.05	3.25	3.34	14.76	3.68	2.75	2.75	9.18
Arkansas	48.97	31.78	1891	4.26	4.22	3.29	4.74	4.84	21.35	5.02	4.02	3.80	3.58	16.42	3.40	3.17	3.69	10.26
Missouri	40.17	27.72	1888	2.05	2.31	2.06	3.26	3.91	13.59	4.77	4.61	3.68	3.84	16.90	4.18	2.92	2.66	9.76
Iowa	31.48	25.40	1873	1.19	1.08	1.09	1.72	2.71	7.79	4.07	4.62	3.68	3.54	15.91	3.86	2.37	1.61	7.84
Wisconsin	31.63	24.45	1891	1.31	1.20	1.17	1.77	2.51	7.96	3.58	4.01	3.55	3.23	14.37	3.65	2.47	1.85	7.97
Minnesota	25.91	17.55	1891	.79	.75	.74	1.19	2.04	5.51	3.15	4.02	3.30	3.17	13.64	2.87	1.93	1.16	5.96
Florida	52.94	57.37	1891	2.76	2.81	3.14	3.13	2.88	14.72	3.99	6.68	7.22	7.03	24.92	6.70	4.26	2.18	13.14
Georgia	50.48	56.09	1892	4.23	4.27	4.90	4.88	3.72	22.00	3.48	4.39	5.75	5.23	18.85	3.71	2.77	2.66	9.14
Alabama	53.11	57.80	1884	4.91	5.02	5.29	5.89	4.33	25.44	3.90	4.28	5.45	4.56	18.19	3.29	2.75	3.25	9.29
Mississippi	53.32	41.83	1888	5.31	5.04	4.90	5.76	4.85	25.86	4.39	4.14	5.05	4.24	17.82	3.07	2.61	3.62	9.30
Louisiana	55.64	46.62	1891	5.39	4.84	4.58	4.72	4.64	24.17	4.63	4.56	6.17	5.04	20.40	3.90	3.23	3.85	10.98

[1] Means for Oregon and Washington are for period of record through 1934. Means for western, middle, and eastern divisions of Texas cover period 1888 to 1936.
[2] Total precipitation for 1936 is for 12-month period December 1935 to November 1936.

TABLE 2.—*Average annual, seasonal, and monthly precipitation*—Continued

State	50-year mean, 1881–1930 (inches)	Total, 1936	Initial year for monthly means	Storage period						Growing period					Replenishment period			
				Dec.	Jan.	Feb.	Mar.	Apr.	Total	May	June	July	Aug.	Total	Sept.	Oct.	Nov.	Total
Semiarid States:																		
Oklahoma	32.63	22.73	1892	1.69	1.41	1.33	2.16	3.35	9.94	4.73	3.79	2.88	2.92	14.32	2.99	3.00	2.02	8.01
Kansas	27.48	17.42	1887	.85	.66	1.00	1.42	2.56	6.49	3.80	4.00	3.20	3.13	14.13	2.86	1.96	1.29	6.11
Nebraska	23.50	14.02	1876	.70	.51	.71	1.15	2.41	5.48	3.45	3.67	3.16	2.77	13.05	2.06	1.50	.78	4.34
South Dakota	20.77	11.13	1890	.57	.54	.56	1.11	2.06	4.84	2.88	3.37	2.45	2.13	10.83	1.51	1.20	.64	3.35
North Dakota	17.70	8.92	1892	.52	.48	.46	.78	1.42	3.66	2.32	3.39	2.41	2.02	10.14	1.55	1.03	.60	3.18
Texas:																		
Western division	16.62	16.57	1888	.61	.47	.57	.60	1.31	3.56	1.91	2.07	2.22	2.21	8.41	2.18	1.61	.87	4.66
Middle division	27.33	32.47	1888	1.70	1.41	1.44	1.70	2.81	9.06	3.67	2.85	2.25	2.08	10.85	3.08	2.48	1.85	7.41
Eastern division	41.67	39.08	1888	3.83	3.26	2.96	3.28	3.97	17.30	4.53	3.66	3.46	2.94	14.59	3.20	3.20	3.36	9.76
State	30.84	31.95	1888	2.26	1.91	1.84	2.07	3.05	11.13	3.76	3.08	2.65	2.40	11.89	3.01	2.62	2.26	7.89
Arid States:																		
New Mexico	14.49	13.41	1892	.69	.56	.71	.74	.88	3.58	1.15	1.23	2.55	2.48	7.41	1.64	1.13	.66	3.43
Colorado	16.79	15.50	1888	.90	.76	.98	1.29	1.77	5.70	1.91	1.40	2.22	1.97	7.50	1.32	1.17	.79	3.28
Wyoming	14.05	12.91	1892	.74	.79	.78	1.17	1.58	5.06	2.08	1.60	1.31	1.10	6.09	1.14	1.09	.70	2.93
Montana	15.21	10.71	1895	.88	.88	.69	.95	1.14	4.54	2.18	2.48	1.46	1.13	7.25	1.35	1.02	.96	3.33
Idaho	17.17	16.00	1893	1.97	2.21	1.71	1.78	1.40	9.07	1.68	1.29	.65	.66	4.28	1.05	1.47	2.05	4.57
Nevada	9.01	9.34	1889	.97	1.19	1.05	.97	.77	4.95	.88	.50	.37	.51	2.26	.41	.56	.64	1.61
Utah	12.67	15.69	1891	1.07	1.20	1.26	1.39	1.18	6.10	1.21	.57	.91	1.06	3.75	.99	1.09	.94	3.02
Arizona	13.10	12.51	1895	1.19	1.25	1.25	.96	.53	5.18	.30	.34	2.28	2.36	5.28	1.24	.83	1.02	3.09
California	23.53	23.65	1897	3.67	4.83	4.34	3.54	1.64	18.02	.98	.34	.07	.10	1.49	.45	1.23	2.41	4.09
Oregon:																		
Eastern	13.81	13.96	1890	1.69	1.82	1.51	1.31	1.14	7.47	1.25	.98	.37	.35	2.95	.74	.97	1.64	3.35
Western	54.22	42.78	1890	8.54	8.50	6.73	5.97	3.85	33.59	2.90	1.76	.50	.58	5.74	2.24	3.95	8.23	14.42
Washington:																		
Eastern	16.89	13.89	1890	2.50	2.41	1.75	1.44	1.02	9.12	1.17	1.03	.44	.45	3.09	.87	1.24	2.41	4.52
Western	56.98	54.93	1890	9.00	8.31	6.11	5.71	3.91	33.04	3.06	2.36	.95	1.14	7.51	3.00	5.00	8.38	16.38

It is recognized that portions of Texas, California, Oregon, and Washington are humid, though Texas is here classed as semiarid and the other States mentioned as arid.

TABLE 3.—*Annual, seasonal, and monthly precipitation, maximum temperature, and crop yields for year ending Nov. 30, 1936*

State	Precipitation																					Maximum annual temperature (° F.)		Number of days in June, July, and August with temperature of 100° or more	Crop yields (percent of 10-year average, 1921–30)
	50-year mean [1] 1881–1930 (inches)	1936		Storage period							Growing period						Replenishment period					Number of months below mean in 1936			
		Total	Percent of mean	Dec.	Jan.	Feb.	Mar.	Apr.	Total	Percent of mean	May	June	July	Aug.	Total	Percent of mean	Sept.	Oct.	Nov.	Total	Percent of mean		Of record to Nov. 30, 1936	1936		
Humid States:																										
Maine	41.20	45.66	111	1.91	6.40	2.75	7.66	4.39	23.11	141	3.66	3.25	2.63	2.59	12.13	91	3.12	5.09	2.21	10.42	99	7	106	96	0	103
New Hampshire	39.52	45.63	115	1.25	6.07	2.31	9.44	4.33	23.40	156	2.86	2.44	3.31	3.64	12.25	89	2.43	5.22	2.33	9.98	100	7	104	100	0	94
Vermont	37.03	43.25	117	1.20	4.83	2.05	7.24	4.32	19.64	144	2.93	2.12	3.89	4.68	13.62	97	2.31	5.06	2.62	9.99	100	6	104	97	0	94
Massachusetts	42.39	45.08	106	1.25	6.78	2.95	8.17	3.60	22.75	125	2.35	2.89	2.19	5.36	12.79	92	3.94	3.87	1.73	9.54	89	6	106	102	1	97
Rhode Island	44.07	42.24	96	1.16	6.96	4.06	7.13	3.36	22.67	116	1.65	3.31	2.06	2.87	9.89	75	5.88	2.56	1.24	9.68	92	7	101	94	0	102
Connecticut	44.96	46.65	104	1.05	7.01	2.70	7.88	3.85	22.49	119	2.91	4.89	2.22	4.31	14.33	96	3.96	4.49	1.38	9.83	88	5	105	103	2	106
New York	39.01	38.56	99	1.85	3.54	2.18	5.54	3.45	16.56	114	2.70	2.51	2.13	4.19	11.53	78	3.19	4.54	2.74	10.47	107	7	108	107	9	87
New Jersey	45.89	42.82	93	1.67	6.34	3.10	5.28	3.23	19.62	108	2.78	4.93	2.47	4.14	14.32	84	4.30	3.40	1.18	8.88	88	8	110	110	5	99
Pennsylvania	42.47	41.00	97	2.62	4.21	2.33	6.84	3.01	19.01	118	2.09	3.80	2.88	4.96	13.73	83	2.17	3.69	2.40	8.26	87	8	111	111	12	98
Maryland-Delaware	41.89	41.43	99	2.50	6.00	3.82	5.84	2.84	21.00	128	2.11	3.19	4.18	4.30	13.78	85	2.40	3.24	1.01	6.65	77	8	110	109	11	102
Virginia	42.18	42.50	101	2.31	6.44	3.86	5.83	3.43	21.87	132	1.35	3.36	4.20	3.65	12.56	75	3.30	3.66	1.11	8.07	95	6	109	109	16	92
North Carolina	50.44	56.96	113	3.00	7.79	4.72	6.22	5.59	27.32	141	.90	4.20	6.83	4.68	16.61	82	4.77	6.11	2.15	13.03	130	5	108	106	15	107
South Carolina	48.21	55.45	115	2.82	7.68	4.89	5.33	8.27	28.99	156	.48	3.66	5.06	4.84	14.04	71	4.51	6.14	1.77	12.42	131	6	111	105	25	130
Tennessee	50.30	42.39	84	1.69	5.02	3.10	6.77	4.32	20.90	89	1.31	1.04	6.75	2.21	11.31	68	3.10	4.01	3.07	10.18	107	7	113	110	46	100
Kentucky	45.81	35.82	78	2.39	2.99	1.95	4.85	4.79	16.97	83	1.50	.81	3.78	2.22	8.31	52	3.57	3.47	3.50	10.54	115	7	114	113	46	79
West Virginia	43.83	41.86	96	3.66	4.01	2.61	6.21	3.66	20.15	115	1.99	2.41	5.10	3.96	13.46	79	1.82	3.89	2.54	8.25	97	6	112	112	26	78
Ohio	38.44	33.25	87	2.47	1.65	2.55	3.65	2.02	13.24	89	1.78	1.74	3.06	3.59	10.17	70	3.18	4.00	2.66	9.84	118	8	113	111	23	96
Michigan	31.29	26.27	84	1.38	1.87	1.76	1.09	2.04	8.14	80	2.11	2.00	1.10	3.45	8.66	73	5.01	3.03	1.43	9.47	111	7	112	112	12	95
Indiana	40.17	32.46	81	1.61	1.47	2.59	2.74	3.17	11.58	75	2.02	1.37	1.59	3.04	8.02	55	4.84	4.44	8.58	12.86	139	8	116	116	47	85
Illinois	37.26	28.54	77	1.22	1.40	1.87	1.70	2.44	8.63	66	2.07	1.66	1.22	2.66	7.61	52	6.77	3.23	2.30	12.30	134	10	115	115	53	77
Arkansas	48.97	31.78	65	2.95	1.05	1.70	2.19	2.64	10.53	49	2.50	1.26	4.90	.44	9.10	55	4.15	5.00	3.00	12.15	118	9	120	120	77	119
Missouri	40.17	27.72	69	1.13	1.01	1.50	1.27	2.45	7.36	54	2.52	1.42	1.52	.84	6.30	37	8.62	3.55	1.89	14.06	144	10	118	118	69	60
Iowa	31.48	25.40	81	.95	1.68	1.33	1.02	1.10	6.08	78	2.91	2.85	.51	3.48	9.75	61	7.22	1.69	.66	9.57	122	9	118	117	50	64
Wisconsin	31.63	24.45	77	.91	1.31	1.57	1.58	1.28	6.65	84	2.70	2.29	1.01	5.15	11.15	78	3.48	2.26	.91	6.65	83	9	114	114	18	76
Minnesota	25.91	17.55	68	.78	.76	1.41	1.50	1.30	5.75	104	2.52	1.87	.73	2.93	8.05	59	2.07	.68	1.00	3.75	63	8	114	114	22	66
Florida	52.94	57.37	108	2.69	5.55	6.77	3.29	2.19	20.49	139	4.12	8.01	6.47	6.74	25.34	102	4.51	5.50	1.53	11.54	88	6	109	103	5	94
Georgia	50.48	56.09	111	2.75	9.21	6.50	4.32	7.92	30.70	140	1.22	3.00	5.04	6.41	15.67	83	4.50	3.87	1.35	9.72	106	6	111	106	34	123
Alabama	53.11	57.80	109	4.24	12.34	7.34	3.63	6.82	34.37	135	1.91	1.91	7.21	5.76	16.79	92	2.80	2.12	1.72	6.64	71	7	112	107	38	129
Mississippi	53.32	41.83	78	3.90	6.20	4.79	2.93	4.78	22.60	87	2.69	1.36	6.00	2.39	12.44	70	2.13	1.76	2.90	6.79	73	10	115	111	54	152
Louisiana	55.64	46.62	84	5.72	5.17	4.15	2.07	4.32	21.43	89	5.13	.53	6.42	4.42	16.50	81	2.73	2.22	3.74	8.69	79	8	114	114	42	131
Semiarid States:																										
Oklahoma	32.63	22.73	70	1.77	.39	.42	.51	.99	4.08	41	4.49	1.97	.71	.21	7.38	52	7.85	2.91	.51	11.27	141	10	120	120	78	52
Kansas	27.48	17.42	63	.27	.71	.23	.14	1.17	2.52	39	4.88	1.26	.86	1.06	8.06	57	4.84	1.82	.18	6.84	112	9	121	121	74	62
Nebraska	23.50	14.02	60	.29	.92	.81	.57	1.59	4.18	76	3.20	2.01	.57	1.62	7.40	57	1.78	.38	.28	2.44	56	10	118	118	66	45
South Dakota	20.77	11.13	54	.56	.65	.69	.78	1.28	3.96	82	1.67	1.32	.62	1.59	5.20	48	.74	.40	.83	1.97	59	9	120	120	60	37
North Dakota	17.70	8.92	50	.51	.56	.70	.82	.39	2.98	81	.80	1.34	.70	1.40	4.24	42	1.15	.21	.34	1.70	53	9	124	121	42	45
Texas:																										
Western division	16.62	16.57	100	.36	.66	.08	.32	.37	1.79	50	3.90	1.05	1.82	.55	7.32	87	5.98	.88	.60	7.46	160	9	----------	113	59	----------
Middle division	27.33	32.47	119	2.58	.53	.43	1.10	1.77	6.41	71	6.46	2.27	3.27	1.60	13.60	125	8.80	2.55	1.11	12.46	168	7	----------	120	78	----------
Eastern division	41.67	39.08	94	4.98	1.19	1.63	1.32	2.30	11.42	66	8.16	.76	7.02	1.73	17.67	121	4.64	3.11	2.24	9.99	102	8	----------	118	57	----------
State	30.84	31.95	104	3.18	.75	.73	1.02	1.69	7.37	66	6.52	1.59	4.15	1.47	13.73	115	7.04	2.44	1.37	10.85	138	8	120	120	80	89
Arid States:																										
New Mexico	14.49	13.41	93	.50	.86	.71	.32	.31	2.70	75	1.78	.94	2.07	2.07	6.86	93	2.78	.60	.47	3.85	112	8	116	111	53	104
Colorado	16.79	15.50	92	.36	.76	1.52	.99	.80	4.43	78	1.73	1.41	2.15	2.65	7.94	106	1.63	1.17	.33	3.13	95	6	115	112	45	95
Wyoming	14.05	12.91	92	.49	1.22	1.54	1.17	1.13	5.55	110	.52	1.82	1.55	1.27	5.16	85	.70	1.01	.49	2.20	75	6	114	110	36	77
Montana	15.21	10.71	70	.37	1.02	1.32	.72	.82	4.25	94	1.07	1.78	.73	.99	4.57	63	.95	.59	.35	1.89	57	10	113	113	36	52
Idaho	17.17	16.00	93	1.36	3.76	2.84	1.45	1.00	10.41	115	.94	2.05	.73	.82	4.54	106	.55	.33	.17	1.05	23	7	118	112	33	101
Nevada	9.01	9.34	104	.87	1.41	2.47	.59	.30	5.64	114	.45	.79	.79	.53	2.56	113	.29	.76	.09	1.14	71	6	122	117	82	106
Utah	12.67	15.69	124	.80	1.57	2.90	1.32	.65	7.24	119	.53	1.21	2.36	1.59	5.69	152	.54	1.64	.58	2.76	91	6	116	113	61	101
Arizona	13.10	12.51	95	.79	.78	1.81	.98	.14	4.50	87	.12	.19	2.32	2.24	4.87	92	1.46	.81	.87	3.14	102	8	127	123	86	117
California	23.53	23.65	101	2.46	5.00	9.51	1.86	1.59	20.42	113	.62	.81	.19	.13	1.75	117	.16	1.22	.10	1.48	36	7	134	126	84	102
Oregon:																										
Eastern division	13.81	13.96	101	1.64	3.92	2.18	1.03	1.22	9.99	134	1.02	1.58	.39	.20	3.19	108	.67	.03	.08	.78	23	7	119	111	14	102
Western division	54.22	42.78	79	6.45	13.26	6.91	4.10	2.20	32.92	98	4.50	2.53	.74	.08	7.85	137	1.18	.35	.48	2.01	14	7		103	1	
Washington:																										
Eastern division	16.89	13.89	82	1.95	3.53	1.82	1.25	.67	9.22	101	.82	2.44	.23	.15	3.64	118	.71	.18	.14	1.03	23	9	118	111	13	102
Western division	56.98	54.93	96	7.26	12.72	8.29	6.49	1.78	36.54	111	5.53	4.80	1.80	1.07	13.20	176	2.40	1.45	1.34	5.19	32	6		105	1	

[1] Means for Oregon and Washington are for period of record through 1930. Means for western, middle, and eastern divisions of Texas cover period 1888 to 1936.

It is recognized that portions of Texas, California, Oregon, and Washington are humid, though Texas is here classed as semiarid and the other States mentioned as arid.

Deficiencies in precipitation for the growing period in Kentucky, West Virginia, Illinois, Missouri, Iowa, Wisconsin, and Minnesota were sufficient to reduce materially the crop yields in these States, the reduced yields ranging from 60 to 79 percent of the normal.

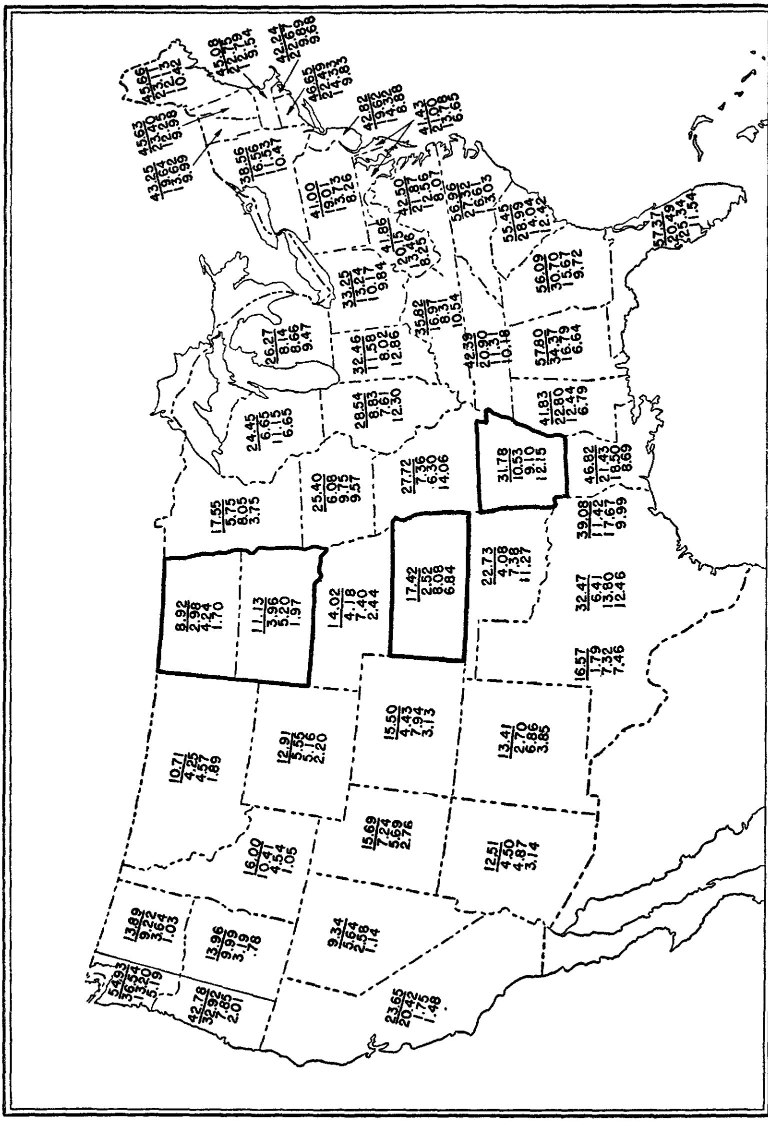


FIGURE 1.—Annual and seasonal precipitation, in inches, for 1936. Upper figure underscored, annual precipitation. Second figure, precipitation in December, January, February, March, and April. Third figure, precipitation in May, June, July, and August. Fourth figure, precipitation in September, October, and November. (In areas indicated by heavy outline the total precipitation in 1936 was lowest of record.)

Semiarid States.—Precipitation in the semiarid States except Texas ranged from 50 percent of the normal in North Dakota to 70 percent of the normal in Oklahoma, and all the States in the section except Texas were affected. Previous recorded lows were broken in North Dakota (50 percent of normal), South Dakota (54 percent of normal), and Kansas (63 percent of normal). In respect to both deficiency in precipitation and extent of area affected, 1936 was the worst drought year of record in the semiarid States.

During the growing season precipitation ranged from only 42 to

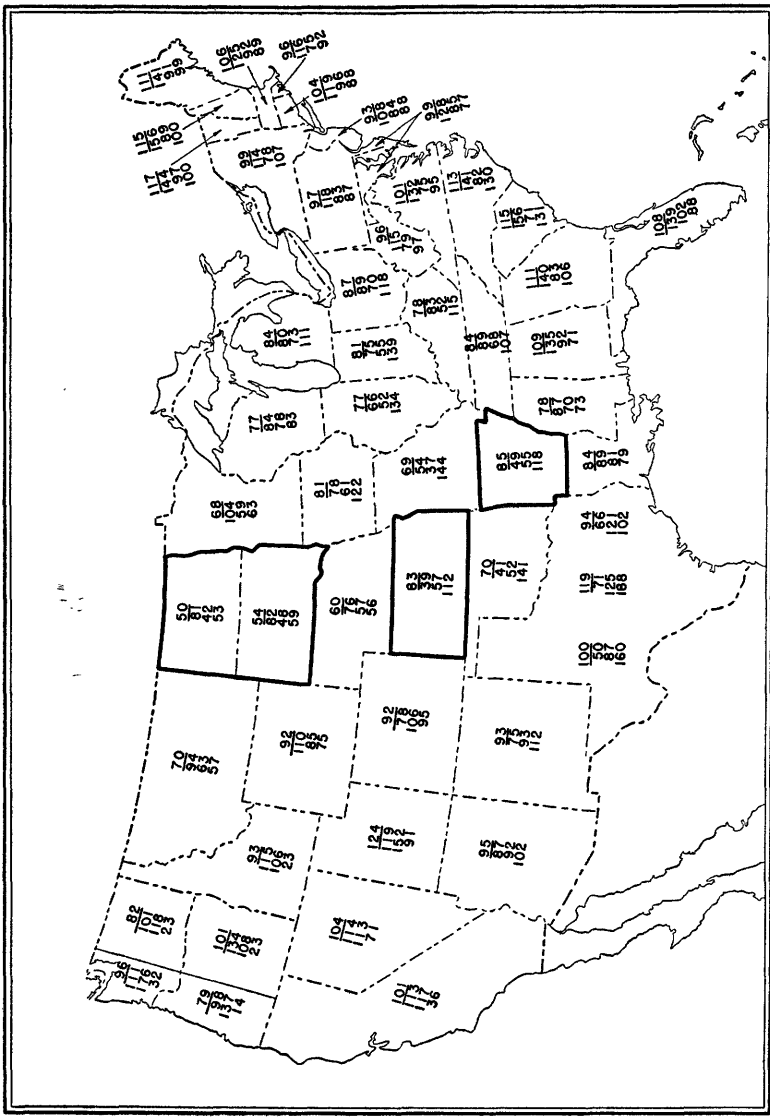


FIGURE 2.—Annual and seasonal precipitation, in percent of mean, for 1936. Upper figure underscored, annual precipitation. Second figure, precipitation in December, January, February, March, and April. Third figure, precipitation in May, June, July, and August. Fourth figure, precipitation in September, October, and November. (In areas indicated by heavy outline the total precipitation in 1936 was lowest of record.)

57 percent. It was the shortage during this period that made the drought so serious in this section. The crop yields in these States ranged from only 37 to 62 percent of normal.

Arid States.—The precipitation in the arid States approached or exceeded normal in all except Montana (70 percent of normal), western

Oregon (79 percent of normal), and eastern Washington (82 percent of normal). No previously recorded lows were broken. Although there was over 90 percent normal precipitation in Colorado, Wyoming, and New Mexico, deficiencies in the parts of these States bordering on the semiarid States was sufficient to produce severe drought.

The only pronounced deficiencies in precipitation in the arid States during the growing season were in Wyoming and Montana, and in these States crop yields were materially reduced.

TABLE 4.—*States in which 1935 or 1936 ranked as 1 of the 8 lowest years in precipitation for the period 1881 to 1936*

State	50-year mean, 1881–1930 [1] (inches)	Precipitation, 1935			Precipitation, 1936		
		Inches	Percent of mean	Drought rank [2]	Inches	Percent of mean	Drought rank [2]
Humid States:							
Rhode Island	44.07	37.74	86	7			
Connecticut	44.96	35.75	80	3			
Tennessee	50.30				42.39	84	4
Kentucky	45.81				35.82	78	5
Ohio	38.44				33.25	87	7
Michigan	31.29				26.27	84	5
Indiana	40.17				32.46	81	7
Illinois	37.26				28.54	77	3
Arkansas	48.97				31.78	65	1
Missouri	40.17				27.72	69	2
Iowa	31.48				25.40	81	7
Wisconsin	31.63				24.45	77	3
Minnesota	25.91				17.55	68	2
Mississippi	53.32				41.83	78	4
Louisiana	55.64				46.62	84	7
Semiarid States:							
Oklahoma	32.63				22.73	70	4
Kansas	27.48				17.42	63	1
Nebraska	23.50				14.02	60	2
South Dakota	20.77				11.13	54	1
North Dakota	17.70				8.92	50	1
Arid States:							
Montana	15.21	10.89	72	5	10.71	70	3
Idaho	17.17	12.40	72	3			
Western Oregon	54.22	40.63	75	3	42.78	79	4
Eastern Washington	16.89	12.01	71	3			

[1] Means for Oregon and Washington are for period of record through 1930.
[2] In order of intensity of droughts in State for the period 1881–1936, number 1 indicating most intense.

It is recognized that portions of Oregon and Washington are humid, though these States are here classed as arid.

As shown in table 3, under the 85 percent criterion there were droughts in 1936 in 18 States and also in eastern Washington and western Oregon. In 20 States 1936 ranked as 1 of the 8 years of lowest precipitation during the period 1881–1936, as indicated in table 4.

Previously recorded minima were broken in four States—Arkansas, Kansas, South Dakota, and North Dakota. Deficiencies during the growing season, May through August, were largely the cause of the severity of the drought. These deficiencies were especially great in the five northern semiarid States and in the bordering States to the east.

TEMPERATURE

During 1936 unusual temperatures were noticeable in most sections of the country. The winter was much colder than usual, especially in the Northeastern States. The spring and early summer were mild,

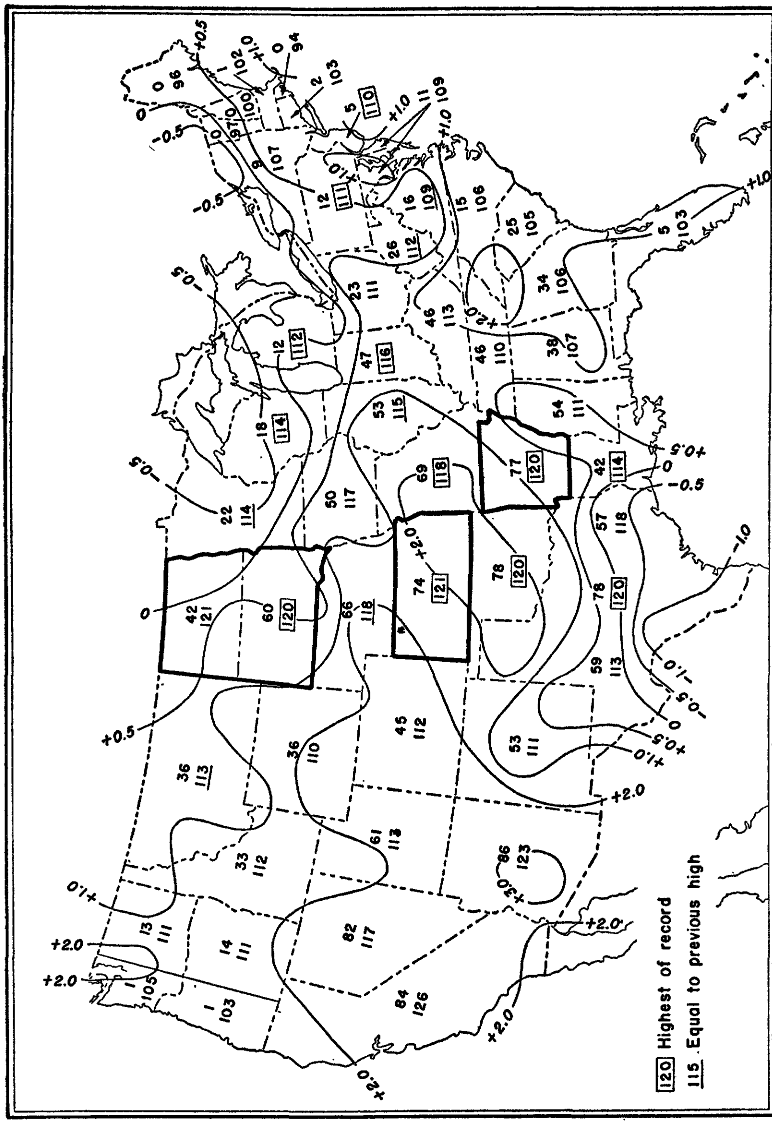


FIGURE 3.—Temperatures, 1936. Upper figure, number of days with maximum of 100° F. or more. Lower figure, maximum temperature during June, July, and August. In areas indicated by heavy outline the precipitation in 1936 was the lowest of record. Curves denote variation in average temperature from the normal.

but beginning with the middle of June excessive temperatures were recorded in most States, as indicated in table 3 and graphically in figure 3, which also gives the number of days during June, July, and August when temperatures of 100° or over were recorded in the various

States. Except in three of the New England States, maximum temperatures of over 100° were recorded in all the States, and in most States there were maxima of 110° or more. In all the semiarid States maxima of 120° or over were recorded, except in Nebraska, where the maximum was 118°. Previous maximum recorded temperatures were broken in 12 States and equaled in 6 others. Excessively hot days continued over long periods of time, as indicated in table 5.

TABLE 5.—*Number of days in June, July, and August, 1936, with maximum recorded temperature of 100° and 110° or above*

Place	100°	110°	Place	100°	110°
St. Louis, Mo	34	0	Ozark, Ark	62	5
Kansas City, Mo	51	4	Minneapolis, Kans	60	26
Des Moines, Iowa	27	1	Gannvalley, S. Dak	53	19
Alva, Okla	64	23	Clarendon, Tex	66	13

WIND

Severe wind disturbances were recorded during 1936 in South Carolina, Florida, Georgia, Mississippi, Iowa, Texas, and Utah. The worst storms were in Georgia and Mississippi. In April there were at least 7 major tornadoes in Georgia, causing 230 deaths and serious injury to 1,500 people. Property damages were estimated at $16,000,000 in what was said to be one of the worst tornado disasters ever known in the State. On April 5 a severe tornado demolished an appreciable part of Tupelo, Miss., killing 216 people and seriously injuring 700 others, with property damages estimated at over $3,000,000. The excessive heat that accompanied winds during the summer in the drought sections contributed largely toward the destruction of vegetation.

Reports in the Monthly Weather Review [2] indicate that dust storms during the first 7 months of the year, especially in the semiarid States, were more frequent and severe than usual but that during the last 5 months they were less frequent and severe.

EFFECTS ON GROUND AND SURFACE WATER SUPPLIES

Except in the semiarid States, there were no marked deficiencies in water supplies, either surface or ground, during 1936. Increased facilities for supplying water, which had been installed on account of shortages since 1930, produced adequate supplies to meet most needs.

In the absence of systematic observations extending over periods of considerable length, false impressions of the progressive depletion of ground water may be imparted by the deepening of wells or the adding of new wells in periods of drought. Surface water supplies generally fail first in a drought, and where insufficient storage has been developed recourse is frequently had to the sinking of new wells as the quickest and most direct means of obtaining potable water.

[2] A summary statement relative to dust storms in the Southwest is given in the issue for June 1936.

The ordinary well when first sunk does not penetrate very deeply below the water table; consequently it becomes necessary to deepen the well when the first drought lowers the water table. Furthermore, in some older wells the intakes clog, debris accumulates at the bottom, or the casings leak. Although such deterioration is continual, it becomes most noticeable and of greater effect in times of drought, when a general deepening or replacement of such wells becomes necessary.

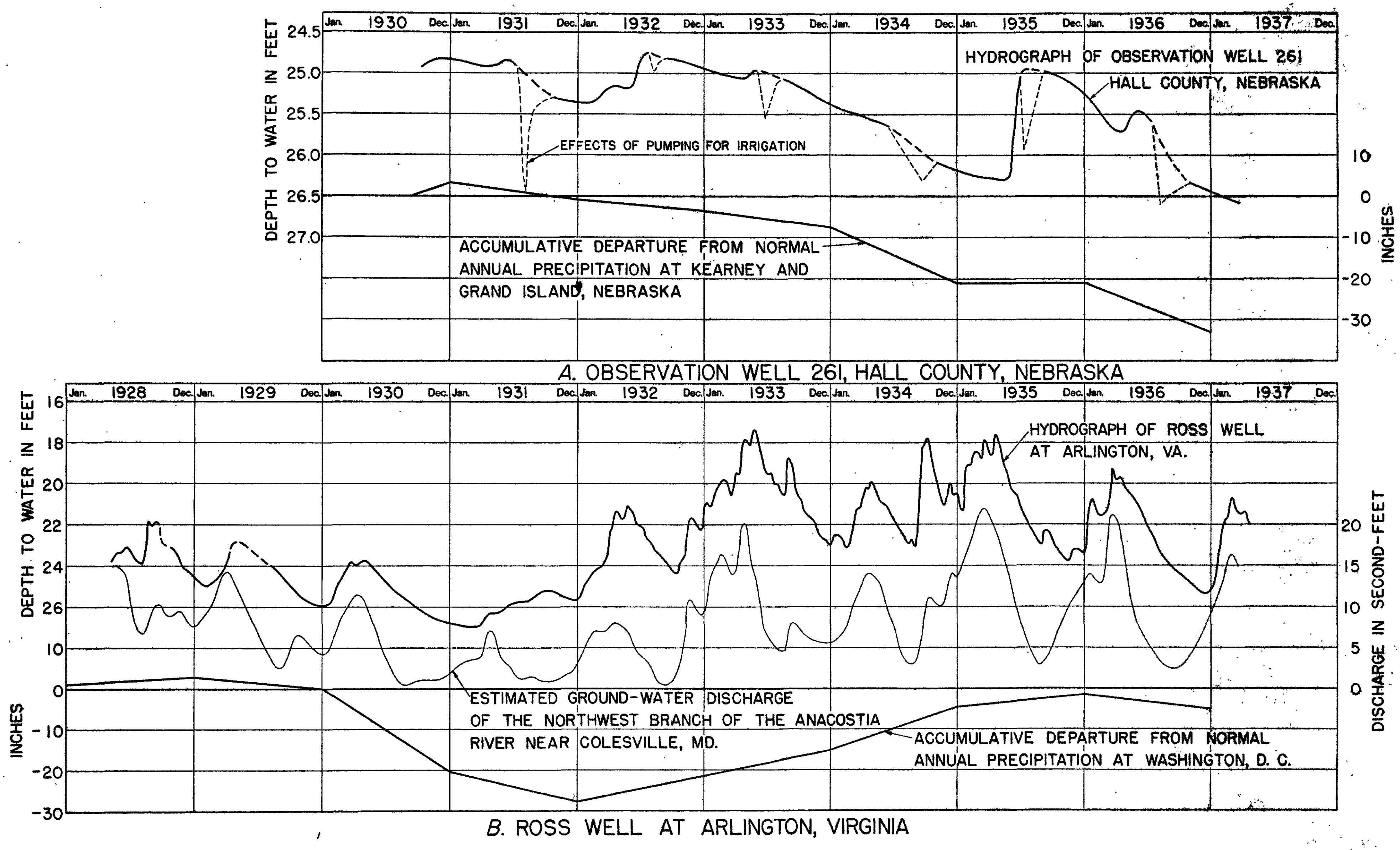
Such activities, although normal under the prevailing conditions, lead to the impression that there is a progressive lowering of the ground-water table. The fact that the ground water may later rise to former or higher levels as a result of subsequent precipitation is generally overlooked during a period of general well-being. Statistical studies [3] show that in many sections of the country precipitation and water-supply trends have been downward during the last few years. Similar downward trends in the past have been followed by upward trends, and there is nothing to indicate conclusively that the present downward trend may not soon be reversed.

GROUND WATER

Long-time records of fluctuation of the water table are not available, and studies relative thereto are based more on generalized impressions than on observed data. Precipitation in 1935 was adequate in most areas to replenish in a large measure the depletion in ground water which existed after the beginning of that year. As a result, few springs and wells dried up, and ground-water contributions to surface streams and lakes were fairly well sustained during 1936. Ground-water trends during 1935 and 1936 tend to refute the idea that there will not be a reversal in the downward trend of ground-water levels when precipitation returns to normal.

In the Midwest States ground-water levels in 1936 generally declined below the levels of 1935. In Wisconsin, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas a general lowering was indicated. Except in Oklahoma, where there was little recharge in 1935, the ground-water levels of 1936 in many of the areas that were affected by lack of rain in 1934 were appreciably higher than in 1934, although in most areas lower than in 1935. This condition was due to the rather general recharge of ground water in 1935, which was sufficient to create a hold-over that was ample in many areas to supply demands of 1936. These features are illustrated by the hydrograph of the fluctuation of the water surface of an observation well in the Platte River Valley in Nebraska, shown on plate 2, *A*, which also shows a graph of the accumulated departure from the mean annual precipitation. A comparison of these two graphs shows that

[3] Hoyt, W. G., and others, Studies of relations of rainfall and run-off in the United States: Geol. Survey Water-Supply Paper 772, pp. 20–57, 1936.



FLUCTUATION OF WATER SURFACE IN WELLS AND COMPARATIVE DATA.

the recent decline in ground-water levels corresponds with the deficiency in precipitation.

Heavy precipitation and floods in the Eastern States in the spring of 1936 caused water levels to rise in many wells higher than usual and in some to the highest levels in several years. However, there was less recharge during the summer than in most years, and therefore the ground-water levels generally declined by the fall of 1936 to levels as low as those in years with only moderate spring recharge. The ground-water levels, in most localities, however, stood above the low levels reached during the dry years of 1930–31.

The general behavior of ground water in the Eastern States is illustrated by the record of the Ross well at Arlington, Va., as shown on plate 2, *B*. With this record of well levels is a graph of the estimated ground-water discharge of the North Branch of the Anacostia River, at Colesville, Md., and a graph of the annual accumulated departure from the normal precipitation. Attention is directed to the trend of precipitation, which corresponds with that of the ground-water levels and the base stream flow.

SURFACE WATER

Few records of minimum stream flow were broken in 1936. Precipitation in the form of snow and rain in the headwater areas of the large tributaries of the Mississippi River from the west assisted materially in sustaining the low-water flow. In addition, the raising of the ground-water table in 1935 had an appreciable effect on most streams in the drought area. Examples of the effect of the drought of 1936 on stream flow in the principal drought areas are given in table 6. Conditions of low stream flow were most severe in the drainage basin of the Red River.

Water-supply conditions in the arid States are indicated by reports of the United States Bureau of Reclamation, which indicate shortages in only a few reservoirs, among which the most serious was in the Belle Fourche Reservoir, in South Dakota.

STABILITY OF WATER SUPPLY

Evaporation and transpiration have the first demand on precipitation. The amount which is used through these two means will vary and is principally dependent upon the amount and intensity of rainfall, temperature, and other climatic factors, the vegetable cover, and the physical characteristics of the area on which the precipitation falls. Ground-water recharge and stream flow are dependent upon the residual of precipitation that remains after the abstraction of water through the action of evaporation and transpiration. The drought-resistant qualities of an area depend upon the stability and amount of surface- and ground-water supplies. In general, the larger and more stable the residual the greater is the margin available for resisting drought.

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TABLE 6.—*New stream-flow minima in 1936*

Stream and station	Drainage area (square miles)	Years of record	Mean annual discharge for period of record (second-feet)	Discharge (second-feet) for year ending Sept. 30: Minimum, Day	Minimum, 7-day	Minimum, Calendar month	Annual	Minimum prior to 1936 (second-feet): 1-day	7-day
East Branch of Delaware River, Fishs Eddy, N. Y.	783	24	1,679	72	81.0	148	1,722	88 (September 1932)	92.4 (September 1932).
West Branch of Delaware River, Hale Eddy, N. Y.	593	24	1,074	33	36.4	51.8	1,215	39 (September 1913)	40.7 (September 1913).
Little Beaver Kill, Livingston Manor, N. Y.	19.8	12	47.1	1.2	1.3	3.11	55.8	2.1 (September 1935)	2.4 (August 1930).
Blue River, White Cloud, Ind.	467	5	547	14	16.6	33.5	268	14 (November 1934)	16.9 (November 1934).
West Fork of White River, Newberry, Ind.	4,670	8	4,050	251	255	323	2,333	355 (August 1934)	367 (August-September 1934).
Fall Creek, Millersville, Ind.	306	6	201	15	16.9	19.6	160	17 (August 1934)	17.9 (August 1934).
Wisconsin River, Muscoda, Wis.	10,300	22	8,607	2,100	2,501	2,611	7,417	[1] 2,000 (February 1918)	2,604 (August 1934).
Black River, Neillsville, Wis.	756	22	562	0.7	1.0	6.4	565	2 (August-September 1933).	2.1 (August-September 1933).
Milwaukee River, Milwaukee, Wis.	661	22	414	6	8.3	15	216	9 (August 1934)	13 (August 1931).
Red River, Grand Forks, N. Dak.	25,500	54	2,199	13	13.4	20.3	592	13 (October 1932)	16 (October 1934).
White River, Crawford, Nebr.	295	5	23.8	3.9	9.0	10.0	21.8	7 (July-August 1934)	7.3 (July-August 1934).
Niobrara River, Spencer, Nebr.	10,800	9	1,210	[2] 418	456	549	1,134	[2] 472 (July 1934)	550 (July 1934).
Niobrara River, Dunlap, Nebr.	1,550	5	43.4	0.6	1.5	3.4	36.3	1 (June-July 1934)	1.4 (June-July 1934).
Elkhorn River, Waterloo, Nebr.	6,390	8	736	78	87	210	517	121 (August 1934)	124 (August 1934).
Republican River, Bloomington, Nebr.	20,900	7	685	7	9.7	59.2	524	10 (August 1934)	12.1 (August 1934).
Gasconade River, Waynesville, Mo.	1,680	22	1,371	50	53.3	62.2	377	61 (August 1934)	62.1 (August 1934).
James River, Galena, Mo.	1,000	15	991	22	23	28.5	338	24 (August 1934)	26 (August 1934).
Current River, Van Buren, Mo.	1,640	24	1,809	490	511	551	950	542 (September 1925)	556 (August 1934).
Neosho River, Iola, Kans.	3,795	18	1,148	0	0	0	696	0.6 (September 1934)	0.9 (August 1934).
Walnut River, Winfield, Kans.	1,894	14	593	0	0	0	152	1 (August-September 1934).	1 (August-September 1934).
Buffalo River, Rush, Ark.	1,110	8	1,224	15	16	19.6	437	40 (August 1934)	40 (August 1934).
North Fork of White River, Henderson, Ark.	1,640	8	1,370	312	318	323	722	375 (August 1934)	384 (August 1934).
White River, Flippin, Ark.	6,170	8	5,662	105	112	152	2,206	134 (August 1934)	151 (August 1934).
White River, De Valls Bluff, Ark.	23,800	9	23,150	3,200	3,210	3,455	10,110	3,440 (August 1934)	3,500 (August 1934).
Mississippi River, Vicksburg, Miss.	1,144,500	5	514,500	101,000	102,400	125,400	401,600	127,000 (November 1931)	128,900 (November 1931).

[1] Estimated.
[2] Exclusive of winter minimum.

Figure 4 shows the normal amount of this residual in the United States as determined from a study of annual precipitation, temperature, and run-off over several comparatively large drainage basins. It was deduced from this study that in the humid East there passes

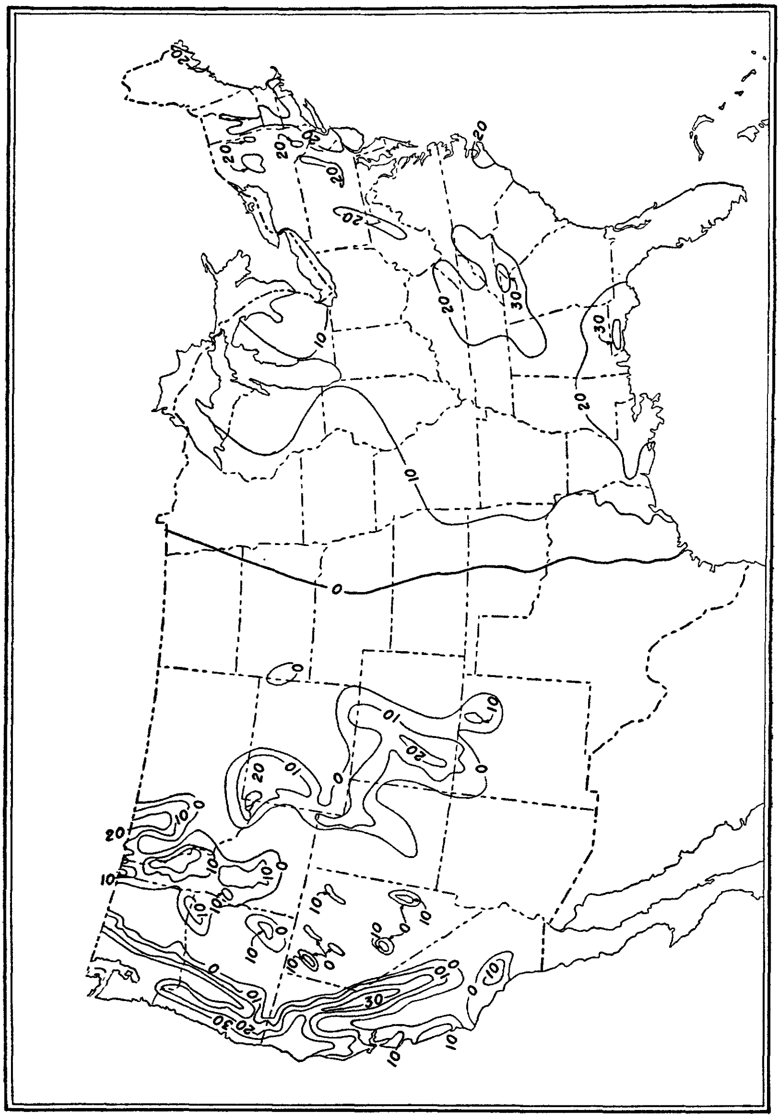

FIGURE 4.—Average annual excess of precipitation over requirements of consumption by evaporation and transpiration.

into the atmosphere through the processes of evaporation and transpiration an average annual amount equivalent to about 18 inches of water over the basin for a mean annual temperature of 39°, increasing to about 33 inches of water for a mean annual temperature of 64°.

This figure affords a basis for the study of the stability of water supplies and should be studied together with figure 18, discussed on pages 51–52 under variability of climate, showing geographically the frequency of occurrence of years in which rainfall has been insufficient to meet the requirements of normal consumption by evaporation and transpiration and further indicating the relative stability of the residual available for water supply.

In the eastern United States, essentially in that region east of the 10-inch residual line shown on figure 4, the margin of precipitation in excess of normal consumption by evaporation and transpiration and the relatively uniform seasonal distribution of rainfall are sufficient to assure perennial streams and relatively stable ground-water levels. Although years of drought seriously decrease the water supply, the streams in this region are never dry. In other words, the ground-water levels are maintained above the stream channels.

The region between the 10-inch residual line and the zero residual line (heavy line, fig. 4) lying to the west, in the Great Plains, generally coincides with the moist-subhumid climatic province as hereinafter described. In this region ground-water recharge occurs only during years of more than average precipitation of which the major part falls during the growing season, when the evaporation and transpiration demands are greatest. Although stream flow is sustained, it is not perennial, and frequent dry years occur, as indicated in figure 18.

In the area between the line of zero residual and the Rocky Mountains the precipitation is insufficient to meet the requirements of normal evaporation and transpiration more than 50 percent of the time, as shown in figure 18. Consequently annual ground-water recharge occurs only under the most favorable conditions of more than average and properly distributed precipitation. Stream flow that originates in this region is intermittent, and run-off occurs only because the precipitation which is concentrated in the growing season occurs in storms and falls at rates exceeding the capacity of the ground to absorb it. The only sustained streams are those which rise in the Rocky Mountains and higher plains and traverse this region, generally with a decreasing flow resulting from losses by evaporation, diversion, and seepage as they cross the plains.

In the Rocky Mountains and the Great Basin, with the exception of the mountainous areas, the precipitation is insufficient to meet requirements of normal evaporation and transpiration. However, certain portions of the higher northern areas have abundant precipitation, most of which falls as snow at times when evaporation losses are low, and consequently the resulting run-off is relatively large and well sustained. In the lower southern areas run-off follows the erratic rainfall, and the yield of streams is negligible. The floodwaters are discharged onto the valley floors, where they in part disappear by evaporation and seepage and in part are added to the ground-water storage and thus become available for water supply.

The precipitation of the Pacific coast region is concentrated in the winter, and that of the summer approaches zero. The average annual amount varies widely, from over 100 inches in a small area in northwestern Washington to less than 5 inches in southern California. As shown in figure 4, in the areas of high precipitation there is a wide margin of excess of precipitation over the losses, and stream flow is well sustained through the summer by flow from the melting snow and glaciers. The areas of low precipitation have intermittent streams similar to those of the Great Basin.

DECLINE OF LAKE LEVELS

Lake levels in the Great Plains area have shown decline in recent years. Although the primary cause for the decline is the decrease in precipitation over the tributary areas, the effects of the present upward trend in temperature and downward trend in relative humidity, with attendant high wind velocities, common in this region, have caused large increases in the rate of evaporation from lake surfaces, to an extent that the depth of the annual evaporation from water surfaces greatly exceeds the depth of annual rainfall.[4] Under these circumstances there is no contribution to run-off corresponding to the precipitation on the lake surfaces, but rather there is a continual loss of water from the lake which, where the tributary area is small relative to the water surface, is sufficient to cause a steady decline in level with consequent shrinkage in surface area.

Adolph F. Meyer, hydraulic engineer, has made a detailed study of the effects of the increase in temperature on evaporation and run-off.[5] Figure 5 shows the results of his analysis. The upper graph shows the annual precipitation since 1837 at Minneapolis and St. Paul, Minn. This graph shows that years of deficient precipitation have been grouped and have been preceded and followed by years of more than average precipitation, and that within the years of record there have been other periods of deficient precipitation that are comparable with that of 1930–36.

The lower left graph in figure 5 shows the results of the determination of the annual evaporation from lake surfaces for the period 1891–1936, obtained by the use of the Meyer formula,[6] an empirical expression for the rate of evaporation from water surfaces in terms of pertinent climatic elements as found in the published records of the Weather Bureau. In the absence of long-term records of observations of the evaporation, its use conveniently affords a logical basis

[4] See Geol. Survey Water-Supply Paper 772, pp. 49–110, for discussion of rainfall, temperature, and run-off trends.

[5] Meyer, A. F., unpublished manuscript.

[6] Meyer, A. F., Elements of hydrology, 2d ed., p. 238, John Wiley & Sons, 1928.

for the approximate evaluation of the rate of evaporation through a period as long as that of the available basic climatologic data. The climatologic data necessary to evaluate the Meyer formula for monthly evaporation are records of the monthly mean temperature, the mean relative humidity, and the mean wind velocity. Although there are other factors which influence the rate of evaporation, the Meyer formula includes those of major influence. The formula contains a coefficient whose selection is dependent upon the exercise of a certain degree of judgment but whose range has been fixed within fairly close limits. Comparison of determinations of the evaporation rates by

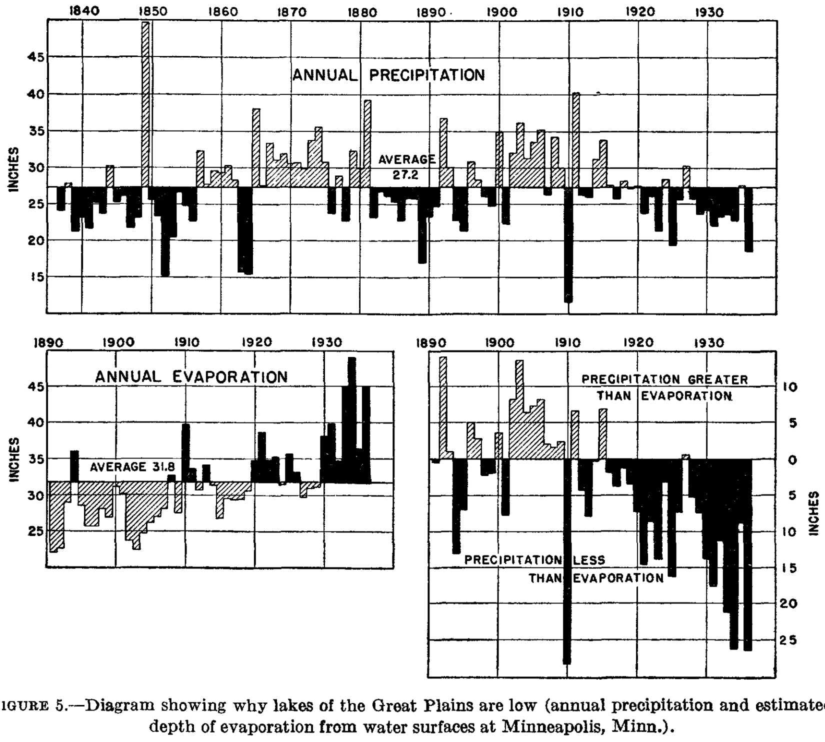

FIGURE 5.—Diagram showing why lakes of the Great Plains are low (annual precipitation and estimated depth of evaporation from water surfaces at Minneapolis, Minn.).

the Meyer formula and by actual observations shows good agreement. It appears from these computations that for the period 1891 to 1910 the annual evaporation from water surfaces has averaged about 29 inches, and since 1910 about 35 inches, an increase of approximately 6 inches.

The lower right graph in figure 5 shows the difference between the recorded annual precipitation and the computed annual evaporation from water surfaces since 1891. The recent deficient precipitation has combined with apparent large evaporation losses to produce such a condition that in only 3 years since 1910 has the precipitation exceeded the evaporation from water surfaces. According to these calculations, the precipitation before 1910 appears to have averaged about 2 or 3 inches greater than the evaporation from water surfaces, but since 1910 such annual evaporation losses appear to have been greater than the precipitation by about an average of 10 inches, and since 1930 by about 18 inches. During 1936 the precipitation has been less than the computed evaporation loss from water surfaces by 26.8 inches, making that year the worst of the period shown, except only the year 1910. It should be noted that although these determinations may be in error as to exact amount, they probably show departures from normal in appreciable amounts in recent evaporation.

The data and estimates shown in figure 5 relate to Minnesota. Further studies show that corresponding effects have extended over the Great Plains area, where generally the annual precipitation is never equal to the evaporation losses from free water surfaces.

In addition to its effects on lake levels, the evaporation rate is of significance in that it is to a large extent indicative of the natural and man-made water demands of an area, and consequently the magnitude of the rise in evaporation rate indicated for recent years is a measure of the real water deficiency and explains in part, at least, why the recent drought in the Great Plains area brought greater difficulties and suffering than were brought by droughts of previous periods of deficient precipitation.

The situation may be ameliorated to some extent by one or several years of greater precipitation, but a decline in evaporation rate would be of greater effect. Both may and probably will occur together. Figure 5 shows that years of more than average precipitation have frequently been years of less than average evaporation loss. The explanation of this may be that a period of greater rainfall may offer less opportunity for evaporation, as during this period the average relative humidity would be higher. However, according to Thornthwaite,[7] other factors remaining the same, a rise in precipitation from 2 inches a month to 4 inches a month would result in only 10 percent less monthly evaporation. It appears, therefore, that although a rise in precipitation would be of value in meeting the evaporation demands, the effects of deficient precipitation on the evaporation rate are probably not sufficient to account for the great rise in computed evaporation shown in figure 5, which is obviously out of proportion to the deficiencies in precipitation. The computed increase in evaporation is probably largely a reflection of the present upward trend in temperature and downward trend in relative humidity. Until there is a reversal in these trends, some such condition as that shown in figure 5 may be expected to continue.

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[7] Thornthwaite, C. W., Climates of North America: Geog. Rev., October 1931, pp. 633 et seq.

DAMAGE

The principal damage caused by the drought of 1936 related to agriculture. In most areas supplies of water for general use had been developed to provide for the ordinary drought year, but nevertheless there were shortages in certain areas in 1936.

VEGETATION

Except in the semiarid States, there was comparatively little damage to natural vegetation during the drought of 1936. Combined yields[8] of 33 important crops in 1936, expressed as percentages of the 10-year (1921–30) average yields, are given in table 3 and indicate that in the humid States there was material damage to cultivated crops in Kentucky, West Virginia, Illinois, Iowa, Wisconsin, Minnesota, and Missouri, and that in the semiarid States, except Texas, failures were general and yields were as low as 37 percent of normal. In the arid States yields approached or exceeded normal in all except Wyoming and Montana. A statement of the relation of droughts to crops is given on pages 39–44.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES

As already stated, most sections of the country now have extended their facilities for conserving and providing water for domestic and industrial supplies, so that serious shortages have generally been small. In 1936 no shortages except in certain small rural areas were reported in the humid States. Serious shortages, however, were reported in all the semiarid States except Texas.

E. P. Rothrock, State geologist of South Dakota, reports as follows:

In some areas west of the Missouri cattle were driven to artesian wells in areas where the drought would have been serious otherwise. In fact, I believe the artesian wells in our James River Basin have prevented much of the possible water famine.

The worst trouble has been with water supplies for our cities. Cities in the James Valley have had a rather serious time, though water supplies have been found to carry them over the drought. Rapid City, in the Black Hills, was forced to drill a series of wells for their water supply due to the reduced flow of Rapid Creek. The cities in the Big Sioux Valley seemed to have had little difficulty. For the most part their supplies came from gravel channels and shallow wells.

The water levels are evidently lowering, as is indicated by the falling of the lake levels which I have measured for the past 4 years. As yet, however, the water tables in southeastern South Dakota are, on the average, not more than 10 or 15 feet below the surface in wells that have been measured.

The supervisor of projects of North Dakota, Frederic W. Voedisch, reports serious shortages in that State as follows:

Because of the intermittent character of the rivers of North Dakota, the urban water supplies of this State are largely obtained from wells. A few of the larger

[8] Crops and Markets, vol. 13, no. 12, U. S. Dept. Agr., December 1936.

cities utilize surface water for their supplies; and, with the exception of those located on the Missouri River, all experience considerable difficulty in obtaining sufficient quantities of water during drought years.

Grand Forks and Fargo, on the Red River, have experienced considerable difficulty in the past 8 years in obtaining sufficient water for use during the winter months. According to W. P. Tarbell and J. H. Turner, city engineers of Fargo and Grand Forks respectively, no water has passed over either the dam on the Red River at Fargo or the dam on the Red Lake River at East Grand Forks for many months. After the spring flood waters have passed out of the basin the reservoirs above both of these dams are in reality sedimentation basins. In other words, Fargo consumes the entire flow of the Red River, and the only water in the channel below the dam is the effluent from the sewage-disposal plant and the seepage around the dam; and Grand Forks uses the entire flow of the Red Lake River, and the only water below the dam is the backwash from the Red River. The dam at Grand Forks was constructed not only for the purpose of impounding water, but also to keep the Red River from backing up into the Red Lake River above the intake of the waterworks.

Ottertail Lake was pulled down extensively to release water for Wahpeton, Breckenridge, and Fargo. At one time 102 miles of channel was dry in spite of this release of water, the losses being due to evaporation, seepage, and transpiration. Works Progress Administration and Drought Relief crews worked for 3 months clearing the channel between Wahpeton and Fargo, and for 2 months Breckenridge was paid to pump well water into the channel.

Red Lake, which is normally the source of the Red Lake River, has contributed little or no water to this river since the drought. Most of the water used from this river comes from Clearwater Lake, and there is considerable doubt as to whether this one small lake will continue to stand the burden in case of continued drought.

A unique method of overcoming an inadequacy of shallow ground-water supply has been developed by Valley City. Water from the Sheyenne River has been impounded, chlorinated, diverted as needed to an abandoned gravel pit, and then recovered in the shallow wells.

The condition of the shallow ground-water supplies is, of course, directly proportional to the amount of precipitation, but the deficiency of precipitation during 1936 alone could in no way account for the critical condition of these ground-water supplies at the end of that year. Each succeeding dry year finds the ground-water situation more acute.

A recent study of precipitation trends in the State, conducted by the State Geological Survey under allotment of funds from the Works Progress Administration, shows that many Weather Bureau stations in the State have had deficiencies in precipitation during the past 7 years of more than 45 inches, or the equivalent of practically 3 years' rainfall. Generally speaking, the rainfall in North Dakota has been below normal for the past 10 to 15 years. The Weather Bureau records at Bismarck, covering a period of 60 years, show that each succeeding 20-year period has an average of 1 inch less annual precipitation and a 1° increase in average annual temperature. The critical condition of the ground-water supplies of the State is therefore due in the main to an accumulation of deficiencies of precipitation.

A study of the municipal ground-water supplies of the State now being undertaken by the North Dakota Geological Survey, also under allotment of funds, shows that out of 281 incorporated towns in the State, which have been investigated to date, 102 reported problems in securing sufficient water supplies. Fifty-four of these towns were actually hauling water for domestic use during some portion or all of the year 1936.

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Most of the water supplies which are inadequate are obtained from impounded surface waters or shallow wells, the deep artesian wells being unaffected by the drought except in response to increased flow permitted and pumpage due to greater demand. It would seem, under these circumstances, that the solution to the problem of inadequate water supplies of North Dakota would be to drill deep wells. However, because of the high mineral content of these deep artesian waters and because of the harmful ingredients such as fluorine frequently found in them and their limited quantity in many localities, the water problem in the State as brought on by the drought is not simple of solution. Proper consideration must also be given to the chemical quality of the water. The picture as thus presented is rather dismal but not exaggerated.

HEALTH

No epidemics or unusual health conditions were reported which could be attributed to drought conditions in 1936. Health authorities are now so well organized that in general droughts are not permitted to affect health.

POWER

The Federal Power Commission reports that during the first 11 months of the year 37,296,000,000 kilowatt-hours of energy was generated at central hydroelectric stations, this being 36.2 percent of the total power output for public use for the period. The average percentage of the total output by central hydroelectric stations for the same 11 months for the last 16 years is about 37.1 percent—less than 1 percent more than that for the year 1936. This indicates that the output of hydroelectric power during 1936 was but little affected by the drought.

NAVIGATION

Because of low water in the upper Mississippi River it was necessary to suspend navigation during July and August, and navigation was also interfered with on the Missouri River. The Ohio and tributaries are in the main provided with slack-water navigation, and there were no interruptions on streams in that basin. No shortages affecting navigation were reported in the lower Mississippi or South Atlantic and eastern Gulf streams.

RECREATION AND WILDLIFE

Except in the semiarid States, where both natural and artificial lakes have in the main dried up or have been materially lowered, the drought had no effect on either recreational activities or wildlife.

RELIEF

Successive droughts since 1930 have necessitated the expenditure of large amounts of Federal money for relieving human distress. Although drought assistance has been extended to more than half the

United States, the major portion has been spent in a relatively small area comprised in the main within the Great Plains States. According to the report of the Great Plains Committee, the amount of obligations incurred for emergency relief and emergency works pro-

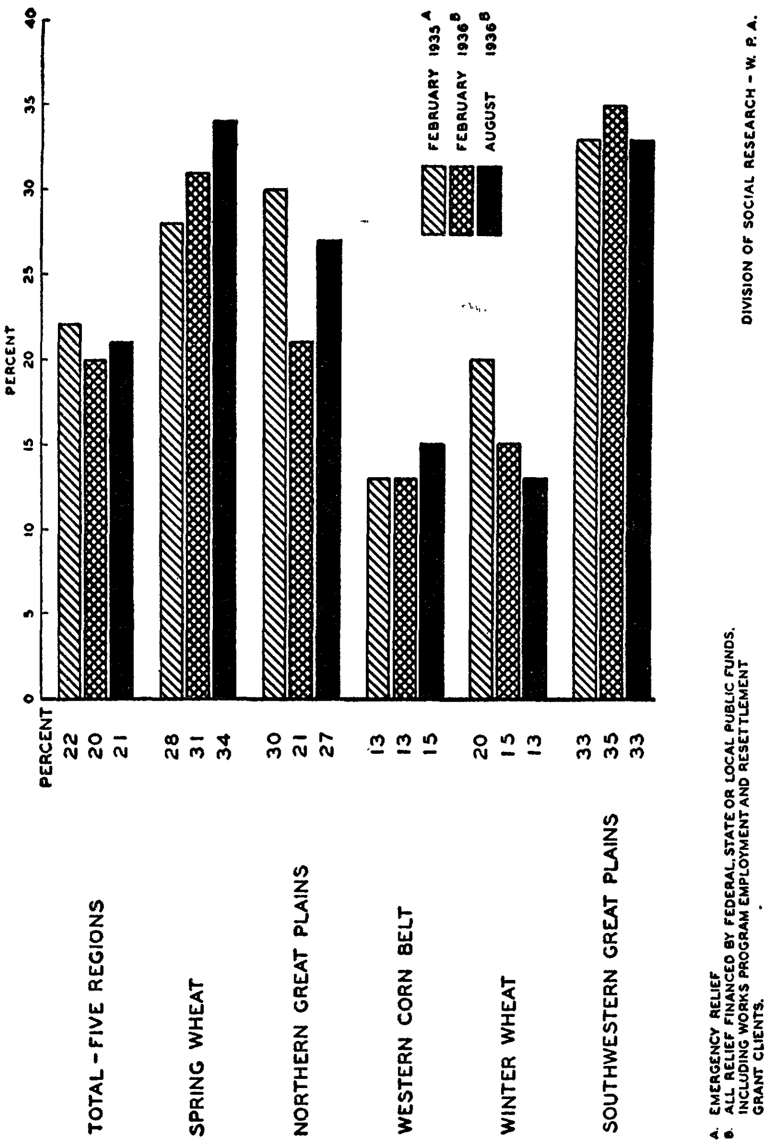

FIGURE 6.—Percentage of total rural families in typical agricultural regions of the Great Plains receiving public assistance in February 1935 and 1936 and August 1936.

grams from Federal funds in the Great Plains region through June 1936 amounted to $132,663,715. The accumulated Federal-aid expenditures in the area between April 1933 and June 1936 ran in some counties as high as $200 per capita of total population. Among the agencies that contributed were the Federal Emergency Relief Administration, Civil Works Administration, Works Progress Administration, Agricultural Adjustment Administration, and Resettlement Administration. (See fig. 6.)

MAJOR DROUGHT YEARS IN HUMID AND SEMIARID STATES

Under the 15 percent criterion there have been 39 droughts since 1880 in the humid States and 30 in the semiarid States, as indicated in figure 7, which also gives for the various years in both groups of

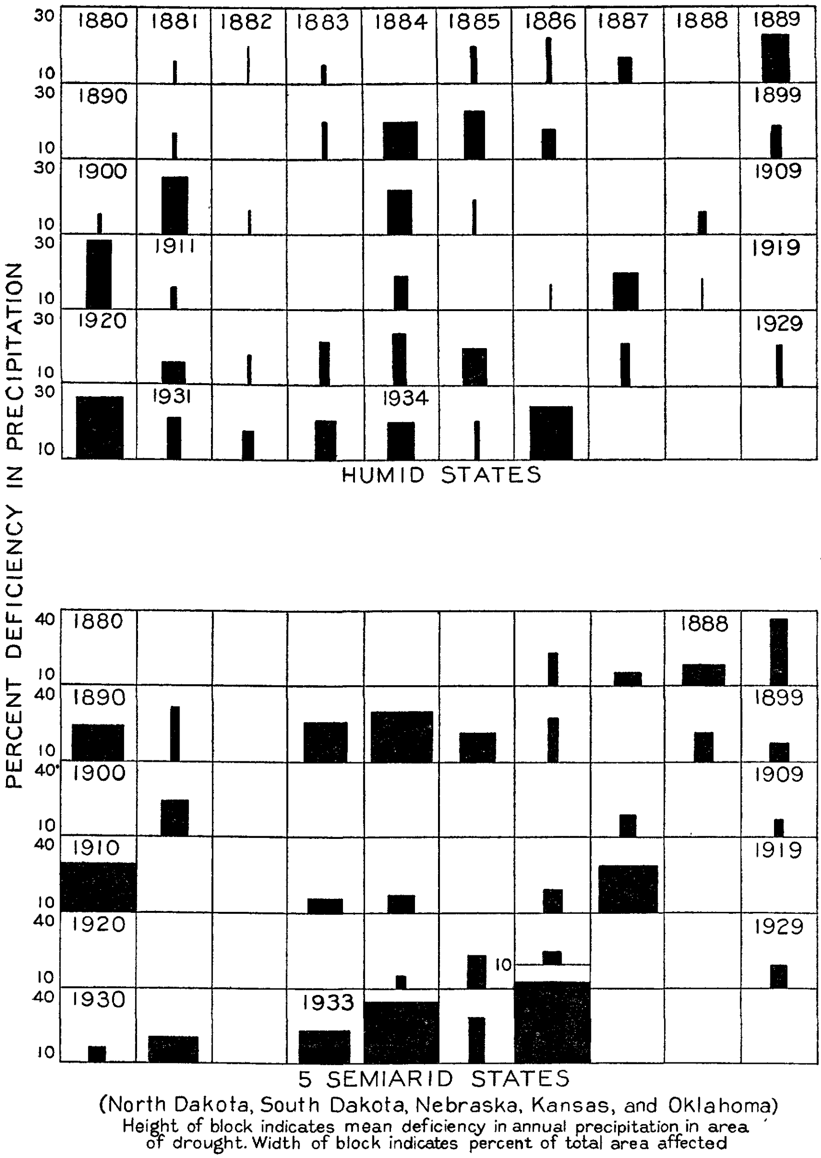

FIGURE 7.—Drought years, 1881-1936.

States the precipitation in percentage of normal and the percentage of the area in which the deficiency in precipitation was 15 percent or more. Both the extent of area affected and the deficiency in precipitation for any drought year are much less in the humid than in the semiarid States. Droughts in the humid States are rather uniformly distributed, whereas in the semiarid States droughts have recurred at intervals, and at each occurrence they have usually been prolonged for several years. The interval between specially noticeable droughts in the humid States is from 3 to 5 years. Moreover, in the humid States the precipitation is so much greater than the agricultural requirements that a high percentage of deficiency does not have as severe an effect as in the semiarid States, where the precipitation approaches the marginal requirements.

The precipitation and percent of area affected for the 15 worst drought years are given in tables 7 and 8 for both the humid and semiarid States. In the humid States the area of drought in these years has ranged from 17 to 63 percent, and in only 3 years has the area exceeded 35 percent. The minimum precipitation over the area affected by drought was 72 percent of normal, and in only 2 years was the precipitation less than 75 percent of normal. In the semiarid States the area affected in the 15 worst drought years ranged from 35 to 100 percent, and in 3 of these years—1910, 1934, and 1936—the entire semiarid region was in drought. The lowest precipitation over this region occurred in 1936 when it was 58 percent of normal. Both as to area affected and as to deficiency in precipitation the worst drought years in the humid States were, in the order named, 1930, 1936, and 1894, and in the semiarid States 1936, 1934, and 1910.

TABLE 7.—*Fifteen worst drought years in the humid States since 1880*

No.	In order of extent			In chronologic order			No.	In order of extent			In chronologic order		
	Year	Area affected (percent)	Precipitation in area of drought (percent of mean)	Year	Interval	Order of area affected		Year	Area affected (percent)	Precipitation in area of drought (percent of mean)	Year	Interval	Order of area affected
1	1930	63	74	1889	------	5	9	1925	30	80	1921	4	10
2	1936	54	76	1894	5	3	10	1921	30	84	1925	4	9
3	1894	45	80	1895	1	12	11	1904	29	78	1930	5	1
4	1901	34	75	1896	1	15	12	1895	27	77	1931	1	14
5	1889	32	77	1901	5	4	13	1933	24	80	1933	2	13
6	1934	32	80	1904	3	11	14	1896	18	79	1934	1	6
7	1910	30	72	1910	6	7	15	1931	17	82	1936	2	2
8	1917	30	80	1917	7	8							

TABLE 8.—*Fifteen worst drought years in the semiarid States since 1880*

[North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma]

No.	In order of extent			In chronologic order			No.	In order of extent			In chronologic order		
	Year	Area affected (percent)	Precipitation in area of deficiency (percent of mean)	Year	Interval	Order of area affected		Year	Area affected (percent)	Precipitation in area of deficiency (percent of mean)	Year	Interval	Order of area affected
1	1936	100	58	1887		15	9	1893	57	74	1913	3	12
2	1934	100	65	1888	1	10	10	1888	57	82	1914	1	14
3	1910	100	71	1890	2	6	11	1895	45	78	1917	3	5
4	1894	80	70	1893	3	9	12	1913	44	84	1931	14	8
5	1917	78	71	1894	1	4	13	1901	35	75	1933	2	7
6	1890	68	76	1895	1	11	14	1914	35	83	1934	1	2
7	1933	66	77	1901	6	13	15	1887	35	85	1936	2	1
8	1931	65	80	1910	9	3							

The 8 years with lowest precipitation in the period 1881 to 1936 are given for each State in table 9. Except in four of the humid States—Iowa (3 years), Wisconsin (1 year), Minnesota (2 years), and Louisiana (1 year)—all the years having a deficiency in precipitation of 15 percent or more are included among the eight lowest. However, in the semiarid States there were from 2 to 7 additional years when the deficiency in precipitation was 15 percent or more—in other words, there have been 10 to 15 years having a deficiency of 15 percent or more in the period 1881 to 1936. The table also shows the number of years when the precipitation did not exceed 70, 75, 80, and 85 percent of normal.

In general for the humid States it is true that although drought conditions may prevail in a portion of the area during any year, they have not usually been severe enough in respect to either area covered or deficiency in precipitation to interfere greatly with vegetation or human activities. Development in certain areas of the humid States, however, especially in the vicinity of the larger cities, has now progressed to a point where it is necessary to give more consideration to the relation between available water supplies and the demands made on them. With proper development it should be an especially exceptional drought when water supplies in the humid States will not be adequate to meet demands.

The conditions in the semiarid States are wholly different. Even in the better years the total precipitation is adequate to provide only for moderate demands of vegetation and evaporation, with a corresponding small residual for various human activities. Small deficiencies are therefore much more serious and involve great potential damage, because in general development in the semiarid States has progressed to a point where the needs for water exceed the supplies that can be depended upon.

TABLE 9.—*Number of years when precipitation did not exceed 85, 80, 75, or 70 percent of mean and the precipitation for the 8 years in which the precipitation was lowest, for the period 1881 to 1936, by States*

[Precipitation for 1936 is for 12-month period Dec. 1, 1935, to Nov. 30, 1936]

State	50-year mean [1] 1881–1930 (inches)	1			2			3			4			5			6			7			8			Number of drought years not included in 8 lowest	Number of years when precipitation did not exceed the following percentage of mean			
		Date	Precipitation		Date	Precipitation		Date	Precipitation		Date	Precipitation		Date	Precipitation		Date	Precipitation		Date	Precipitation		Date	Precipitation						
			Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		Inches	Percent of mean		85	80	75	70
Humid States:																														
Maine	41.20	1914	32.98	80	1905	33.23	81	1921	33.55	81	1924	34.37	83	1910	34.51	84	1908	34.73	84	1894	35.16	85	1911	35.63	87	0	7	1	0	0
New Hampshire	39.52	1908	30.76	78	1894	31.38	79	1899	31.66	80	1914	32.58	82	1910	33.41	85	1930	33.59	85	1909	34.36	87	1913	34.46	87	0	6	3	0	0
Vermont	37.03	1882	29.67	80	1914	30.16	81	1908	30.24	82	1911	30.54	82	1910	31.93	86	1894	32.14	87	1881	32.54	88	1930	32.88	89	0	4	1	0	0
Massachusetts	42.39	1930	33.84	80	1910	34.96	82	1883	35.77	84	1908	36.04	85	1924	36.08	85	1894	36.89	87	1914	36.92	87	1918	37.31	88	0	5	1	0	0
Rhode Island	44.07	1930	32.83	74	1918	36.57	83	1925	37.20	84	1924	37.46	85	1914	37.58	85	1910	37.66	85	1935	37.74	86	1892	38.17	87	0	6	1	0	0
Connecticut	44.96	1930	32.02	71	1924	34.84	77	1935	35.75	80	1894	38.01	85	1910	38.33	85	1914	38.44	86	1883	38.62	86	1892	38.77	86	0	5	3	1	0
New York	39.01	1930	32.18	82	1908	33.54	86	1895	33.89	87	1899	34.18	88	1934	34.97	90	1884	35.23	90	1883	35.33	91	1921	35.41	91	0	1	0	0	0
New Jersey	45.89	1930	35.28	77	1931	37.07	81	1895	37.29	81	1918	37.65	82	1885	37.87	83	1921	38.16	83	1916	38.17	83	1914	39.23	85	0	8	1	0	0
Pennsylvania	42.47	1930	28.82	68	1895	33.51	79	1922	34.88	82	1900	37.31	88	1931	37.36	88	1909	37.38	88	1925	37.86	89	1914	38.24	90	0	3	2	1	1
Maryland-Delaware	41.89	1930	23.78	57	1895	34.47	82	1925	34.91	83	1914	35.97	86	1904	36.49	87	1900	36.66	88	1896	37.11	89	1910	37.42	89	0	3	1	1	1
Virginia	42.18	1930	24.99	59	1925	32.53	77	1921	34.94	83	1881	35.40	84	1894	35.76	85	1904	36.11	86	1914	36.66	87	1931	38.00	90	0	5	2	1	1
North Carolina	50.44	1925	37.33	74	1930	38.04	75	1933	39.28	78	1911	42.65	85	1921	42.92	85	1904	43.27	86	1926	43.33	86	1931	43.57	86	0	5	3	2	0
South Carolina	48.21	1925	35.82	74	1933	35.95	75	1931	37.17	77	1911	39.80	82	1930	40.15	83	1904	40.98	85	1927	42.16	87	1890	42.29	88	0	6	3	2	0
Tennessee	50.30	1930	39.80	79	1925	40.50	81	1904	40.74	81	1936	42.39	84	1894	42.65	85	1895	43.10	86	1931	43.24	86	1914	43.97	87	0	5	1	0	0
Kentucky	45.81	1930	27.86	61	1894	34.81	76	1904	35.10	77	1901	35.65	78	1936	35.82	78	1889	35.97	79	1934	37.00	81	1895	38.47	84	0	8	6	1	1
West Virginia	43.83	1930	25.43	58	1895	32.82	75	1904	33.33	76	1894	34.52	79	1887	35.33	81	1885	37.23	85	1934	37.56	86	1900	37.62	86	0	6	4	2	1
Ohio	38.44	1934	26.60	69	1930	27.00	70	1895	28.46	74	1894	29.75	77	1901	32.36	84	1900	32.82	85	1936	33.25	87	1889	33.41	87	0	6	4	3	2
Michigan	31.29	1930	22.62	72	1934	25.46	81	1925	25.51	82	1910	25.69	82	1936	26.27	84	1889	26.86	86	1895	26.90	86	1917	27.21	87	0	5	1	1	0
Indiana	40.17	1934	29.70	74	1930	29.70	74	1901	30.56	76	1895	30.99	77	1914	31.54	79	1894	32.21	80	1936	32.46	81	1908	34.30	85	0	8	6	2	0
Illinois	37.26	1901	25.72	69	1930	27.89	75	1936	28.54	77	1894	28.89	78	1914	28.99	78	1895	31.89	86	1910	32.09	86	1887	32.38	87	0	5	5	2	1
Arkansas	48.97	1936	31.78	65	1901	35.27	72	1924	37.03	76	1885	37.55	77	1896	37.72	77	1917	40.72	83	1899	41.49	85	1887	41.89	86	0	7	5	2	1
Missouri	40.17	1901	25.28	63	1936	27.72	69	1930	31.27	78	1917	32.06	80	1887	32.77	82	1894	33.18	83	1934	34.19	85	1914	34.72	86	0	7	4	2	2
Iowa	31.48	1910	19.87	63	1894	21.94	70	1901	24.41	78	1886	24.71	78	1933	24.94	79	1889	24.95	79	1936	25.40	81	1930	26.10	83	3	11	6	2	2
Wisconsin	31.63	1910	21.41	68	1895	22.45	71	1936	24.45	77	1930	25.08	79	1932	25.37	80	1891	26.12	83	1901	26.34	83	1923	26.39	83	1	9	5	2	1
Minnesota	25.91	1910	14.73	57	1936	17.55	68	1889	19.08	74	1923	19.81	76	1934	20.30	78	1929	20.56	79	1933	20.97	81	1917	20.99	81	2	10	6	3	2
Florida	52.94	1927	40.71	77	1917	41.36	78	1931	43.97	83	1883	45.17	85	1921	45.24	85	1895	45.50	86	1916	47.10	89	1911	47.40	90	0	5	2	0	0
Georgia	50.48	1931	36.75	73	1904	37.17	74	1893	40.29	80	1927	40.65	81	1921	40.94	81	1925	41.00	81	1933	41.91	83	1916	43.50	86	0	7	3	2	0
Alabama	53.11	1904	39.21	74	1931	42.78	81	1889	43.30	82	1914	44.96	85	1925	45.20	85	1910	45.20	85	1896	45.25	85	1921	45.34	85	0	8	1	1	0
Mississippi	53.32	1889	38.31	72	1924	40.06	75	1904	41.48	78	1936	41.83	78	1896	43.13	81	1899	44.52	83	1887	44.57	84	1917	45.16	85	0	8	4	2	0
Louisiana	55.64	1924	38.34	69	1889	40.25	72	1917	40.27	72	1899	42.35	76	1904	43.83	79	1896	46.56	84	1936	46.62	84	1902	46.77	84	1	9	5	3	1
Semiarid States:																														
Oklahoma	32.63	1910	18.92	58	1891	22.31	68	1917	22.39	69	1936	22.73	70	1901	22.78	70	1888	23.40	72	1896	23.78	73	1886	[2] 25.00	77	7	15	11	7	5
Kansas	27.48	1936	17.42	63	1917	19.60	71	1910	19.67	72	1934	19.92	72	1893	20.25	74	1894	20.72	75	1890	21.16	77	1901	21.35	78	5	13	8	6	1
Nebraska	23.50	1894	13.30	57	1936	14.02	60	1934	14.40	61	1893	16.80	71	1910	17.03	72	1890	17.18	73	1895	18.75	80	1916	19.02	81	2	10	7	6	3
South Dakota	20.77	1936	11.13	54	1934	13.18	63	1931	14.66	71	1894	15.30	74	1933	15.31	74	1910	15.49	75	1925	15.90	77	1895	16.05	77	6	14	10	6	2
North Dakota	17.70	1936	8.92	50	1934	9.49	54	1917	10.92	62	1889	11.30	64	1910	12.19	69	1933	13.34	75	1929	14.32	81	1907	14.41	81	3	11	6	6	5
Texas	30.84	1917	16.21	53	1893	20.47	67	1910	21.46	70	1901	22.23	72	1909	23.45	76	1924	23.50	76	1916	24.59	80	1925	25.79	84	3	11	7	4	3
Arid States:																														
New Mexico	14.49	1910	9.46	65	1917	9.49	65	1892	9.51	66	1934	9.96	69	1902	9.97	69	1894	10.47	72	1924	10.65	73	1889	10.74	74	4	12	12	9	5
Colorado	16.79	1934	10.93	65	1890	11.97	71	1888	12.00	71	1893	12.89	77	1889	13.73	82	1924	13.75	82	1903	13.80	82	1902	13.88	83	4	12	4	3	1
Wyoming	14.05	1886	7.16	51	1887	8.80	62	1902	9.81	70	1919	10.46	74	1893	10.67	76	1889	10.81	77	1934	10.94	78	1900	10.95	78	5	13	8	4	3
Montana	15.21	1889	9.24	61	1931	10.09	66	1936	10.71	70	1890	10.78	71	1935	10.89	72	1904	11.04	73	1919	11.14	73	1934	11.25	74	4	12	9	8	3
Idaho	17.17	1888	10.08	59	1889	12.05	70	1935	12.40	72	1924	12.46	73	1929	13.06	76	1928	13.60	79	1895	13.63	79	1898	14.22	83	2	10	7	4	2
Nevada	9.01	1928	4.87	54	1887	5.18	57	1924	5.49	61	1910	5.53	61	1888	5.76	64	1929	5.83	65	1908	6.34	70	1926	6.39	71	8	16	16	11	7
Utah	12.67	1887	6.55	52	1883	7.72	61	1900	8.38	66	1890	9.00	71	1902	9.17	72	1934	9.49	75	1892	9.50	75	1881	9.57	76	11	19	11	7	3
Arizona	13.10	1885	7.12	54	1900	8.17	62	1903	8.43	64	1924	8.68	66	1899	8.70	66	1904	9.24	71	1910	9.36	71	1928	9.67	74	7	15	13	11	5
California	23.53	1898	10.35	44	1923	14.13	60	1887	14.63	62	1895	14.85	63	1929	15.00	64	1932	15.60	66	1917	16.48	70	1883	16.60	71	11	19	15	10	7
Oregon:																														
Eastern	13.81	1908	9.32	68	1898	9.72	70	1924	10.42	76	1918	10.53	76	1905	10.80	78	1928	11.21	81	1930	11.27	82	1901	11.29	82	3	11	5	2	2
Western	54.22	1930	37.11	68	1929	38.66	71	1935	40.63	75	1936	42.78	79	1918	43.28	80	1905	44.11	81	1892	44.25	82	1923	44.89	83	3	11	5	3	1
Washington:																														
Eastern	16.89	1929	10.19	60	1890	12.00	71	1935	12.01	71	1898	12.02	71	1930	12.12	72	1895	12.92	77	1922	13.37	79	1908	13.61	81	5	13	7	5	1
Western	56.98	1922	43.02	76	1890	43.17	76	1929	44.01	77	1905	46.18	81	1911	46.81	82	1923	47.25	83	1898	48.11	84	1925	48.13	84	1	9	3	0	0

[1] Means for Oregon and Washington are for period of record through 1934.

[2] Estimated.

It is recognized that portions of Texas, California, Oregon, and Washington are humid, though Texas is here classed as semiarid and the other States mentioned as arid.

DROUGHTS AS RELATED TO THE SEMIARID STATES

The climatic quality of an area—that is, humid, semiarid, or arid—is a major factor in determining the destructive effects of droughts. The one-hundredth meridian is frequently considered the approximate border line between the humid and arid sections of the United States. However, there is no well-defined line, as a wide belt extending on both sides of this meridian may be either humid or arid in any particular year, depending on the weather conditions. This belt is the principal semiarid climatic province of the country, and in general it coincides with the physiographic province of the Great Plains.

As indicated on figure 8, the Great Plains includes the greater parts of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and western Texas and small parts of the bordering States to the west, Montana, Colorado, Wyoming, and New Mexico. The area comprises about 561,000 square miles—18 percent of the area of the United States. Its population according to the 1930 census was 4,411,624—3 percent of the population of the United States. It is an area in which no great industrial development may be expected, and its future depends primarily upon the population that agriculture will sustain. Although the soils are among the richest on the continent, their production is limited by the unreliable water supply.

Since 1880 there have been 30 years when droughts of various severities have occurred in the Great Plains area, as indicated on figure 7; the five principal semiarid States (except Texas)—North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma—have had 15 years when 35 percent or more of the area was affected, and in 3 years, 1936, 1934, and 1910, 100 percent of the area was in drought. The precipitation over the drought area in these 3 years ranged from 58 to 71 percent of normal, as indicated in table 8.

As shown on figure 7 the years 1881 to 1885 were free from drought. During the next 4 years there were minor droughts. There was a severe drought in 1890, a lesser one in 1891, and none in 1892. Severe droughts again prevailed during 1893, 1894, and 1895, after which there were only minor droughts until 1910. During 1910 all of the Great Plains area was affected, the precipitation being only 71 percent of normal. Between 1911 and 1916 there were only minor droughts in 1913, 1914, and 1916. In 1917 there was a major drought, after which there were 6 years with no droughts. Minor droughts occurred in 1924, 1925, and 1926, but no droughts in 1927 and 1928. From 1929 to 1936 the worst drought period of record occurred, although in 1932 the area was not in drought. In 1934 the whole area was affected, with precipitation 65 percent of normal, the worst then on record, but in 1936 even this record was broken; all of the area again was in drought, with the precipitation 58 percent of normal.

The precipitation in the Great Plains is not only small in amount, but its variations from year to year are pronounced and frequently unfavorable for agriculture. As a saving feature, however, the normal distribution within the year is such that the greater portion of

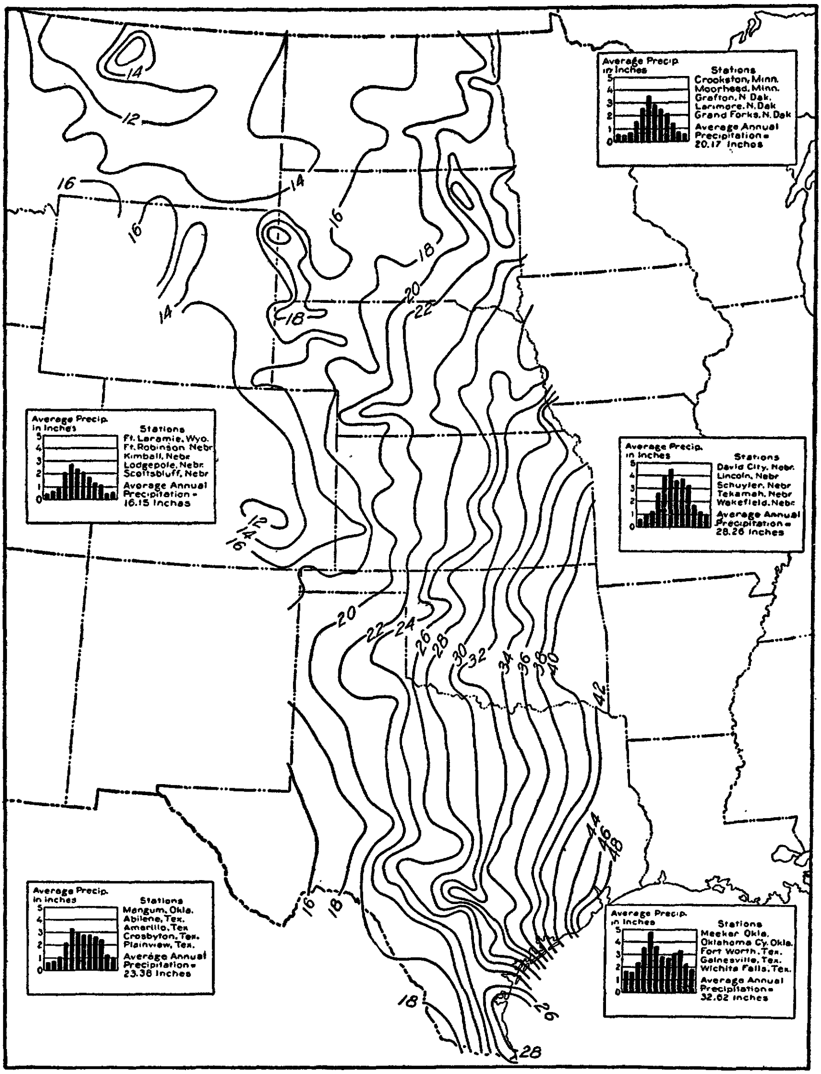

FIGURE 8.—Map of the Great Plains area showing average annual precipitation in inches for 40-year period 1895–1934, with typical monthly distribution. (Report of the Great Plains Committee.)

the precipitation occurs during the growing season, and most of it at the beginning of the season, when the crops most need it, tapering off from May to September. These characteristics are shown on figure 8. However, large annual deficiencies in the Great Plains area, when they occur, are usually at the expense of the precipitation of the summer, when their effects are made more serious by their combination with those of high temperatures. Studies of the trends of seasonal precipitation made by the Geological Survey and published in Water-Supply Paper 772 show that the recent deficiencies in precipitation of this region have been due almost entirely to decreases in the precipitation of the growing season, and that these decreases are more general and pronounced than the annual deficiencies. The following is a discussion by Thornthwaite [9] of the year to year precipitation characteristics of the Great Plains.

The rainfall record of Hays, Kans., one of the longest available, dates from 1868. A computation of the 10-year moving averages for the 67 years reveals three periods of scanty rainfall and two intermediate periods of more abundant precipitation. The heaviest average rainfall for any consecutive 10 years was 26.52 inches for the period 1896–1905, and the lowest was 20.60 inches for the period 1916–25. The highest 5-year average was 30.64 inches for the period 1874–78, and the lowest was 17.87 for 1891–95. The driest of the 5-year periods received only 58 percent as much rain as the more humid years.

Of the seven times since 1868 when the annual precipitation exceeded 30 inches, three were between 1875 and 1878. Only twice since 1903 has more than 30 inches of rain fallen in a single year. In 1894, the driest year, the rainfall was only 11.80 inches, whereas in 1874, the rainiest year, it amounted to 35.40 inches, exactly three times as much. The rainfall curves of all stations oscillate above and below the line of the normal but show no progressive change in either direction.

Apparently there is no cyclic recurrence of rainfall conditions which can be reduced to a simple mathematical expression that would permit forecast through extrapolation. Evidence derived from tree rings, lake levels, etc., indicates that in the Great Plains the period between 1825 and 1865 was a long drought with only occasional wet years. At that time the area may in truth have been the Great American Desert. On the basis of that experience we may assume that the present drought might be prolonged for 20 or more years. Since rainfall averages now stand far below the normal, it is safe to forecast an increase throughout the drought area, but we have no reason to expect it immediately nor to regard the occurrence of a single wet year as the conclusion of the drought. Until further advance is made in the field of accurate long-range weather forecasts, there is no way of anticipating climatic variations.

In a statement issued on February 1, 1937, by the Smithsonian Institution, Dr. Waldo R. Wedel, archeologist, says:

Tree-ring records in the Southwest decoded by Dr. A. E. Douglass, of the University of Arizona, show that in that region there were two major droughts perhaps comparable in intensity to and of much longer duration than those of the last 3 years. One was at the end of the thirteenth century, and one at the end of the sixteenth. There is some geological evidence of a severe drought in the northern Plains about 300 years ago, and it is reasonable to assume, although it has not been proved, that these droughts may have extended over the entire Plains area.

[9] Thornthwaite, C. W., The Great Plains, in Migration and economic opportunity, pp. 217-219, Univ. Pennsylvania, 1936.

Thornthwaite [10] indicates that the last 6 years have emphasized the important bearing which droughts have in the semiarid areas and states:

The history of the Great Plains has been marked by periods of overexpansion during years of heavier than average rainfall. Each was brought to a disastrous conclusion by one of the recurrent periods of drought. The forestalling of similar depressions in the future should be the major consideration in formulating a permanent plan for settlement of the Great Plains. This involves a detailed and long-range study of climate and conditions in the past.

In the development of the Great Plains too much optimism has been created by highly productive crop yields during humid years, which has blinded the settlers to the disastrous effects during years when weather conditions, over which man has no control, are unfavorable. This production has been capitalized by real-estate agents, bankers, implement agents, and others who have exploited the settlers, and has brought about a type and degree of development which was never intended by nature and which the factual information now available shows cannot be continued with success. The resulting conditions which are now apparent were foreseen by many early observers who gave ample warnings that were unheeded.

Among those who foresaw present conditions were John W. Powell and Willard D. Johnson, of the Geological Survey; Joseph Henry, of the Smithsonian Institution, and others. The warnings given by these men are outlined in an address by H. L. Walster, which appears on pages 53–60.

On August 5, 1889, Maj. J. W. Powell, then Director of the Geological Survey, addressed the North Dakota constitutional convention and restated the conclusion he had previously expressed as early as 1878, in part as follows: [11]

The State of North Dakota has a curious position geologically as related to agriculture. The eastern portion of the State has sufficient rainfall for agricultural purposes; the western part has insufficient rainfall, and the western portion is practically wholly dependent on irrigation. In the western portion all dependence on rains will ultimately bring disaster to the people. They are unwilling yet, a good many of them, to admit it, but the study of the physical conditions which prevail in this country and the application of the knowledge which has been given to mankind through the study of these same problems in Europe and Asia and Africa all prove this one fact—that in the western portion of this State they will have to forever depend on artificial irrigation for all agriculture. In the eastern portion they may depend upon the storms that come from the heavens, and there is a middle belt between the two regions which is of very great interest. They will soon learn in the western portion to depend upon irrigation and provide themselves with agencies for the artificial fructifying of the soil with water. In the eastern part they will depend on the rainfall, and in the middle portion they will have abundant crops; then for 2 or 3 years they will have less rainfall, and there

[10] Thornthwaite, C. W., op. cit., p. 217.

[11] Reclamation Era, September 1936, p. 201.

will be failure of crops, and disaster will come on thousands of people, who will become discouraged and will leave. Up and down, the temperature of agriculture will rise and fall with the seasons in this manner, and the only practical thing to do is to look the thing squarely in the face and remember that in middle Dakota agriculture will always be liable to meet with failure unless you provide against it. That is the history of all those who live on the border between the humid and the arid lands. Years will come of abundance, and years will come of disaster, and between the two the people will be prosperous and unprosperous, and the thing to do is to look the question squarely in the face and provide for this and for all years.

You hug to yourselves the delusion that the climate is changing. This question is 4,000 years old. Nothing that man can do will change the climate. A long succession of years will give you the same amount of rainfall that any other succession of the same length will give you. The settlement of the country, the cultivation of trees, the building of railroads—all these matters will have no influence upon your climate. You may as well not hope for any improvement in this direction. There's almost enough rainfall for your purposes, but one year with another you need a little more than you get.

Two reports issued in 1936 relative to the Great Plains should be studied by those who are interested in the area—one by Carter Goodrich and others [12] and the other by the President's Great Plains Committee.[13] The basic facts and conclusions in these reports, many of which are referred to and quoted herein, are similar, and they represent in general the conclusions of many students of the Great Plains area.

The report of the Great Plains Committee, page 77, states, "It is reliably estimated that not less than 165,000 people, or approximately 40,000 families, have moved away from the Great Plains drought area since 1930. Many more would have been forced to leave but for the emergency credit and relief funds poured into the area."

Notwithstanding this exodus, Thornthwaite [14] estimated that there still remained in 1936 a surplus in the region of approximately 59,000 families.

The debt situation in the Great Plains presents an economic background that cannot be ignored. The greater portion of this debt is owed to the Farm Credit Administration and other Federal agencies. In North Dakota, South Dakota, Nebraska, and Kansas this Federal indebtedness ranges from about $900 to $2,000 per farm. Private loans are additional.

The aggregate of principal and overdue interest on both Government and private loans and overdue taxes is so great that there appears to be no immediate prospect that the average settler will be able to pay. The situation appears to be almost hopeless, and remedial measures to be effective should be of such a nature that the settler can avail himself of them without increasing his obligations.

[12] Migration and economic opportunity, especially chapter 5, by C. W. Thornthwaite, Univ. Pennsylvania, 1936.

[13] The future of the Great Plains, 1936.

[14] Migration and economic opportunity, p. 245, 1936.

Thornthwaite [15] states that—

The high relief rate in 1934 indicated that both potential and real assets of the farmers were reduced to a very low level, since relief was not ordinarily granted until their resources were either exhausted or mortgaged. More than four-fifths of the farmers receiving relief reported their farms mortgaged, and three-fourths reported chattel mortgages as well.

According to a local judge in Baca County, Colo.—

The farmers can never escape from such a load of debt and see no other solution than outright repudiation. It is evident that many of the farmers have been able to remain on their lands only through a succession of loans which are unlikely to be repaid in full. This situation applies widely throughout the Plains.[15]

The age of the average farmer in the Great Plains is well over 50. A man of that age or older who can do but little more than keep up his taxes and interest has but small chance of greatly reducing the principal of his debt. The extent to which the next generation will be willing to assume debts will be important with respect to the future of the country.

Irrigation has been suggested as one of the principal solutions of the Great Plains problem. Unfortunately, the irrigable areas are limited to about 3 percent of the area, and the cost of irrigation is in general higher than the returns will pay. Thornthwaite [15] states that according to the experience of the Federal Reclamation Service, it is almost impossible for a settler without capital to become successfully established on an irrigation project. Since practically all of the farms in the Great Plains requiring rehabilitation are without capital they would be unsuitable for settlement without extensive subsidy.

The report of the Great Plains Committee, page 76, discusses the possibilities of irrigation as follows:

Irrigation at best can cause only minor changes in the economic life of the Great Plains. The scarcity of surface run-off (only about 5 percent of the rainfall reaches the main river systems) and the lack of large supplies of underground water limit the total possible irrigation development at reasonable cost to less than 2 or 3 percent of the land area. Moreover, much of this land lies in the eastern portions of the area, where recurrent humid and subhumid years encourage farming without irrigation. Irrigation projects in the area have failed repeatedly because the ditches and appurtenant workings were abandoned in years of plentiful rainfall. Most new large-scale projects are of doubtful feasibility under present reclamation policy. Medium-size projects probably will yield more substantial benefits.

As has been stated, any great industrial development in the Great Plains is not to be expected. Therefore, the future of the region depends primarily upon the population which agriculture will sustain. This in turn is limited by the reliable water supply. The existing agricultural development in the area will not support the present

[15] Thornthwaite C. W., *op. cit.*, p. 246.

population. The commonly accepted remedy is that the population should be reduced, the size of the farm unit should be increased, much land should revert to Government administration, and the type of agriculture should be adjusted to the local conditions.

Thornthwaite [16] has suggested:

> The ideal situation in the Great Plains would be a practically complete return to grazing economy, where pasture on the range is supplemented by raising of feed and forage crops in those areas which can be irrigated and elsewhere on soils which are sufficiently resistant to deterioration by wind and water. This does not mean a reestablishment of great ranches and the restoration of the "cattle kings," but rather an increase in the size of farms to a point where cultivation and grazing can both be controlled.

In chapter 6 of the report of the Great Plains Committee attention is directed to topics that have an important bearing on the future of the Great Plains, divided under the following heads:

Lines of Federal action.
Lines of State action.
Importance of local action.
Readjustment of farm organization and practices.
Organization for readjustment and development.

Under "Lines of Federal action", attention is called to the following steps in procedure:

Investigations and service.
Federal acquisition of land in range area.
Control and use of lands acquired by Federal Government in range area.
Measures to increase the size of farms.
Development of water resources.
Resettlement.
Compensation to local governments on Federal land acquisition.
Control of destructive insect pests.
Development of other resources.

In reference to the relative importance of the Great Plains with respect to the country as a whole, the report of the Great Plains Committee, on page 94, points out:

> The region is a source of supply for foods and other materials. It is also a great market. Its economy has been interwoven with the economy of the Nation. These lines of economic relation must be maintained in full vigor. Outside capital has a self-interest as well as a public responsibility in maintaining them.

The present situation in the Great Plains might have been avoided if heed had been given to the warnings of early students of the area. In discussing marginal precipitation requirements in his report on the survey of the Rocky Mountain region, Powell [17] stated:

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[16] Thornthwaite, C. W., op. cit., p. 243.
[17] Powell, J. W., 45th Cong., 2d sess., Ex. doc. 73, p. 3, 1878.

The limit of successful agriculture without irrigation has been set at 20 inches, that the extent of the arid region should by no means be exaggerated; but at 20 inches agriculture will not be uniformly successful from season to season. Many droughts will occur; many seasons in a long series will be fruitless; and it may be doubted whether, on the whole, agriculture will prove remunerative. On this point it is impossible to speak with certainty. A larger experience than the history of agriculture in the western portion of the United States affords is necessary to a final determination of the question.

This statement refers to the broad belt that separates the arid regions of the West from the humid regions of the East, coincident with the Great Plains.

Later Hay [18] stated:

The almost boundless extent of tillable land, the ease with which large areas can be cultivated, and the wonderful fertility of the soil have attracted settlement farther and farther from the Mississippi Valley out upon the Great Plains, and even into and across the regions which from scantiness of rainfall are known as subhumid or semiarid. The tide of settlement rolling westward has been thrown back again and again by the almost insurmountable barrier interposed by the meagerness of rainfall. Individuals and communities have attempted to make homes, have invested all of their available means in enterprises dependent upon farming, and after perhaps a year or two of success, due to an unusual amount of precipitation or to a fortunate shower coming at the right time, have been compelled by prevailing droughts to abandon their possessions and scatter, almost penniless, to other localities. These men have been succeeded by others, perhaps more sanguine of success or ignorant of the fate of their predecessors, and they in turn have become disheartened by repeated crop failures. Here nature seems to have lavished her resources, withholding only one—that of an ample supply of water.

Notwithstanding these and many other statements, development in the Great Plains area has progressed to a point where drastic readjustments must be made. It is generally agreed that the final solution of the problem can be arrived at only after more complete studies, and then there must be the fullest cooperation of all interested groups. As Thornthwaite [19] says "Until it is possible to accomplish considerable retrenchment there are only two alternatives for the Great Plains—either permanent poverty and distress or permanent subsidy."

On pages 53–60, is presented an address, "Backgrounds of Economic Distress in the Great Plains," delivered by H. L. Walster, dean of the Division of Agriculture and director of Experiment Station and Extension Service, North Dakota Agricultural College, at the National Catholic Rural Life Conference at Fargo, N. Dak., October 12, 1936. In this address Dean Walster discusses frankly and clearly the problems of the Great Plains as he sees them. Of these problems, those related to recurrent drought are most significant.

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[18] Hay, Robert, Water resources of a portion of the Great Plains: Geol. Survey 16th Ann. Rept., pt. 2, p. 541, 1895.

[19] Thornthwaite, C. W., op. cit., p. 250.

THE SHELTER BELT

The Great Plains were treeless when the first white men arrived and labeled them a desert. After settlement had begun, their barrenness, monotony, and high winds suggested the possibility of improving the conditions of this semiarid region by planting trees. The possibility has attracted much attention and recently has taken the form of the proposed shelter belt.[20] The valuable attributes of trees in this region are pointed out as, first, to offer a barrier against the devastating winds; second, to effect the more economic use of the available water supply; and, third, to make the region more pleasant as a place in which to live, thereby improving the morale of the inhabitants.

Various attempts have been made to accomplish these objectives.

> In 1873 the Timber Culture Act was passed on the assumption that if the western farmers were induced to plant trees, rainfall would be increased to such an extent that climatic hazards to crop production would be removed. This act gave an additional quarter section of land to the homesteader who would plant and maintain 40 acres of it in timber. This idea has reappeared time and again on the Plains and was the basis of the much-publicized "shelter belt."' [21]

The original Timber Culture Act was amended in regard to certain details of tree acreage and density required for patent and was finally repealed in 1891. The act was not considered successful in encouraging the planting of large acreage in trees.

The desirability of trees has nevertheless provided a great urge to have them, even in a region where soil characteristics and scant moisture available normally discourage their growth. The shelter-belt project, however, constitutes a scientific effort to evaluate all possible factors, and it is assumed that with the competent direction available in the United States Forest Service the project is possible of achievement, and that locally and in a restricted sense some benefits may be obtained. The desire for trees has in the past caused the fallacy cited above by Thornthwaite as the basis of the Timber Culture Act of 1873, that trees will ultimately turn an arid region into a humid one. An upturn in the annual rainfall of the Plains about 1880 led many of that period to state that the upturn was caused by the cultivation of the sod land. The following quotation from Aughey [22] is typical of the reasoning of the period which has led to the present sad consequences to men and women who have practically staked their lives on its validity:

> It is the great increase in the absorptive power of the soil, wrought by cultivation, that has caused and continues to cause an increasing rainfall in the State.

[20] Shelter-belt planting in the Plains region, U. S. Forest Service, 1935.
[21] Thornthwaite, C. W., op. cit., p. 209.
[22] Aughey, Samuel, Sketches of the physical geography and geology of Nebraska, 1880.

In 1866 Joseph S. Wilson, then Commissioner of the General Land Office, petitioned the Congress as follows:

If one-third of the surface of the Great Plains were covered with forest, there is every reason to believe the climate would be greatly improved, the value of the whole area as a grazing country wonderfully enhanced, the greater portion of the soil would be susceptible of a high degree of cultivation.

This theory seeks its support on the assumption that, inasmuch as trees and vegetation, in general, transpire large quantities of water they serve well to increase the atmospheric moisture available for precipitation. It should now be realized that in a region in which the run-off represents 1 inch or less in depth on the basin, evaporation and transpiration losses are about equal to the rainfall. The prevention of the return to the sea of the small run-off would be valuable as a conservation measure, but at most it could have slight if any effect on local precipitation.

Although there is much evidence that a large portion of the precipitation in the Great Plains is water re-precipitated after evaporation from land areas, nevertheless the destination of water evaporated into the atmosphere is dependent upon the movements and other characteristics of the atmosphere, which in general are part of an ever-changing continental pattern. Atmospheric moisture is essential to rainfall, but it is also necessary that meteorologic events be such that condensation can occur. It is possible, and moreover it frequently happens, that the atmosphere contains moisture sufficient to produce substantial precipitation and yet no rain falls. J. B. Kincer, meteorologist of the United States Weather Bureau, in an address before the American Meteorological Society at Pittsburgh, Pa., in December 1934, outlined the factors requisite to condensation as follows:

The only effective method of producing rain is through the cooling of the air in volume and degree sufficient to extract from it a goodly portion of its valuable water treasure hidden in vapor form. Nature effects this cooling in a number of ways and usually on an immense scale, far greater than man could ever hope to emulate. Air moves from place to place over the earth's surface in mass formation. These masses are of two major sources, polar and tropical; those of polar origin are dense, heavy, and relatively cold, and those of tropical inception warmer and lighter. A mass of tropical origin moving northward may come in contact with a polar mass, and, being lighter, it naturally flows up over the opposing dense air just as it would flow up the side of a mountain that by chance may be disposed in its path. In its ascent, through expansion, the cooling necessary to produce rain is effected. This illustrates nature's method of producing rain in appreciable amounts; no other is effective. Under different circumstances the process varies, of course, often being decidedly local.

During the past droughty summer there was a persistent absence of the dense, cool polar air masses from the north until about the middle of August, when a more normal movement began, definitely breaking the heat wave and, in conjunction with more favorable cyclonic air circulation farther south, producing drought-relieving showers over the interior States. Just how these drought conditions definitely establish themselves and persist so long, as in 1934, has not yet been determined, but it is evident that any effort of man to effectively change the situation would be fruitless.

The United States Forest Service [23] makes the following statements:

The general effect of shelter belts is not the creation of more rainfall over the area covered by tree growth, but the more economic use and conservation of the available rainfall. Shelter-belt planting is not a cure-all of unfavorable climatic conditions in the Plains region.

Romantic expectations, such as raising the water table or increasing the rainfall, should not be entertained.

It is apparent, therefore, that most of the benefits that may be expected from a shelter belt in the Great Plains relate to the amelioration of the effects of the wind and to the esthetic aspects.

NATURAL VEGETATION AND SOILS IN THE GREAT PLAINS IN RELATION TO CLIMATE

The Great Plains occupy a unique location in the continent with respect to climate and vegetation. They form the transition zone between the humid East and the arid West, and across the Plains there is a characteristic decline in normal precipitation from east to west. At the eastern limit, as shown in figure 4, the normal annual precipitation is approximately sufficient to satisfy the normal consumptive requirements of evaporation and transpiration of a luxuriant type of grassland vegetation, but as one proceeds westward the vegetation shows the effect of marked and progressive decrease in annual precipitation. Figure 8 shows the geographic distribution of precipitation over the Great Plains and shows also that the greater part of the annual precipitation falls during the growing season. The mean annual temperature in the Great Plains increases from north to south, being 38° F. at the Canadian border and 65° in Texas, and is associated with a significant variation in the type of vegetation.

The Great Plains are frequently subdivided on the basis of the dominant natural vegetation into three main areas, designated, from east to west, the tall-grass (true) prairies, the central or mid-grass plains, and the short-grass plains.[24] The boundaries of these areas of plant distribution follow in general lines of equal precipitation but are modified, by the rise in temperature from north to south, to the extent that for the same vegetative type a greater precipitation is required in the southern portion than in the northern.

The differences in soil moisture available for plants are significant in the determination of plant distribution. The amount of such moisture depends upon the precipitation (minus that intercepted by plants and the surface run-off), the evaporation from the soil, and the nature of the soil. The evaporation is influenced primarily by temperature but also by relative humidity and air movements and

[23] Possibilities of shelter-belt planting in the Plains region, pp. 9, 35, 1935.

[24] Weaver, J. E., and Clements, F. E., Plant ecology, pp. 463-465, McGraw-Hill Book Co., 1929.

by the relative opportunity for evaporation. Soil characteristics that influence the soil moisture are its capacity to absorb precipitation through infiltration and its capacity to retain moisture.[25] These characteristics are exemplified by coarse sandy soil on the one hand and clayey soil on the other, which are in a sense complementary soils, the former having a high infiltration capacity and low retention capacity, and the latter a low infiltration capacity and high retention capacity. The grassland vegetation of the Great Plains largely depends upon the supply of moisture to the surface soil during the growing season, rather than upon the deeply stored water. Grasslands are characteristically regions of summer rainfall. The greatly lowered precipitation in the Great Plains during autumn and winter, which results in dryness of soil, is a factor that might bear on the occurrence and adaptation of some plants. The available moisture, however, is not the only factor, for temperature appears to have a direct bearing upon the favorable as well as the optimum growth of plants.

In the areas of scanty rainfall the soils are characterized by an upper leached zone, the soil proper, beneath which the leached-out calcareous material has accumulated as a hardened and impervious layer. In the short-grass plains the leached zone is comparatively shallow; farther east, with increasing rainfall, its depth increases; and in the eastern tall-grass prairies the rainfall is sufficient to percolate to a considerable depth without segregation of the leached material. Local variations in soil types may be found, and these local variations are more commonly related to parent rock or to manner of deposition rather than to climate.

Under changing natural conditions the plant life of a region progresses from youthful stages to maturity and climax. In the particular habitats of the Great Plains there has been survival through competition in which the diversified factors commonly understood to represent climate, such as precipitation, temperature, evaporation, and light relations, have different degrees of effect. The past successional floral history of the Great Plains, which has been interrelated with soil derivation, has resulted in plant climaxes that are directly adapted to the particular conditions existing on the Plains, including those of drought. Agriculture in the Great Plains is practically concerned with the relation between the natural soils and the details of rainfall and evaporation that under extremely unfavorable conditions lead to drought. The natural vegetation therefore constitutes a valuable indicator that may serve as a guide in the adoption of successful agricultural practices.

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[25] Horton, R. E., Hydrologic interrelations of water and soils: Soil Sci. Soc. America Proc., vol. 1, pp. 401-429, 1937.

DROUGHTS AND CROPS

In a recent article Thornthwaite[26] writes:

Although the influence of climate on the distribution of vegetation and agriculture has been recognized from early times, the precise nature of this influence was indeterminate prior to the development of meteorological instruments and the collection of records. The thermometer, barometer, and rain gage were products of the eighteenth century. Meteorological records have accumulated very slowly, and there are barely a dozen rainfall records in existence which are continuous over 150 years.

It is only within the last three or four decades that the influence of climate on soil formation has been recognized. This recognition followed the systematic study of soils and their descriptive classification initiated by the Russian school of pedologists in the early nineties. In summarizing the relation of soil to climate, Dr. Marbut, former Chief of the Soil Survey, said, "The coincidence of soil belts and climatic belts has caused soil students to conclude that climatic forces are the predominant soil-forming agencies of the world."

During the last two decades those sciences which are dependent on climatology, including plant ecology, soil science, and geomorphology, have developed rapidly. The climatic basis of the distribution of plants, soils, and land forms has been the subject of considerable research and has been reduced to a certain degree of order. Scientists working in these fields have recognized that their future development on a truly scientific basis requires a consideration of climate in quantitative terms.

From the standpoint of agriculture, probably the most significant climatic factor is the relation of precipitation to evaporation. Its effect on soil development is direct and positive. Where precipitation exceeds evaporation, a surplus of water flows into and through the soil and along its surface as run-off. Where the evaporation rate exceeds the precipitation, run-off is limited to periods of intensive rain, and accumulation in the soil is limited to a few inches or feet near the surface, with an area beneath which remains permanently dry. This climatic relation to soil formation is well known and accounts for the development of the two major soil groups—lime-accumulating soils, or pedocals, and aluminum- and iron-accumulating soils, or pedalfers. Where the evaporation rate exceeds the precipitation, the soluble materials are not leached out and carried away but are concentrated a short distance beneath the surface. Where the precipitation exceeds the evaporation, the more soluble materials are rapidly leached away, leaving only relatively insoluble materials such as iron and aluminum.

Although the precipitation-evaporation ratio is of obvious significance, its actual determination is extremely difficult. Present measures of both precipitation and evaporation are grossly inadequate. The expression of total precipitation in numerical form has little significance, since all precipitation is included, regardless of the conditions under which it fell. The rainfall of a crop season is a composite made up of a series of rains, each possessing an individual pattern of distribution. The rains may be gentle showers or downpours, long or short in duration, and some may occur during the day and others at night. Periods without rain may last for a few days or for several months.

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[26] Thornthwaite, C. W., The significance of climatic studies in agricultural research: Soil Sci. Soc. America Proc., vol. 1, p. 475. 1937.

In his chapter on the Great Plains [27] Thornthwaite writes:

The lack of uniformity of rainfall during a crop season may be illustrated by reference to the rainfall regimen in Abilene, Tex., in 1911. The total rainfall for the year was 25.88 inches. Of this amount 7 inches had fallen by May 1; during May and June only 0.14 inch fell, and by July 13 the total fall amounted to 7.49 inches. During the last 19 days of July 6.21 inches fell, of which 3.50 came in 1 hour. During 2 hours, one in July and the other in December, there was a total precipitation of nearly 6 inches, and during the two storms a total of 9.30 inches, 36 percent of the year's supply.

The numerical expression of total precipitation can mean little, since it includes all rainfall irrespective of the conditions under which it occurred. Some methods of evaluating the effectiveness of individual rains, even sections of rains, must be developed. The effective annual rainfall would differ from the total annual rainfall; there would be deductions for excessive or badly distributed rain and additions for possible carry-over from the preceding season. Until a method has been found for the satisfactory determination of rainfall efficiency, attempts to correlate rainfall and crop yields are necessarily premature.

In the paper first cited [28] Thornthwaite adds:

Measures of temperature are likewise far from adequate. Our only temperature index at present is derived from the position of a column of mercury in a small glass tube—obviously far removed from vegetation or soil. All measures of temperature efficiency must in one way or another be derived from recorded temperature values. Here, as well as in the consideration of precipitation and evaporation, the sciences of climatology, ecology, and pedology require the services of plant physiologists and microbiologists.

Cheapness of crop production, due to mechanization of agriculture, now makes possible the cropping of land which otherwise would not have been used. By including the yield of such lands the apparent production per acre has been reduced. Changes in systems of cropping and improvements of seed also influence yield. These and other factors increase the difficulty of correlating crop yields with climate.

Notwithstanding the inadequacy of crop statistics and the lack of correlation between vegetable growth and the factors upon which it depends, the crop statistics published monthly by the United States Department of Agriculture are of much value for general comparisons and give an indication of production from year to year on a reasonably comparable basis. In fact, they give the only systematic information that is available on production.

The 1936 crop yields [29] in percent of the 10-year average for 1921–30 are given in table 3 and figures 9 and 10. A study of the total precipitation for the growing period May, June, July, and August, 1936, in comparison with the crop yields, is indicated in figure 11 and shows that when the precipitation during the growing season is 8½ inches or more the crop yields in general amount to 90 percent or more of the

[27] Thornthwaite, C. W., in Goodrich, Carter, and others, Migration and economic opportunity, pp. 227–228, Univ. Pennsylvania, 1936.

[28] Thornthwaite, C. W., The significance of climatic studies in agricultural research: Soil Sci. Soc. America Proc., vol. 1, p. 276, 1937.

[29] Crops and Markets, vol. 13, no. 12, U. S. Dept. Agr., December 1936.

10-year mean. Apparent departure from this rule in New York, West Virginia, Wisconsin, Iowa, and Texas can be explained by an examination of the distribution of precipitation during the growing season, as indicated in table 3. For example, in Iowa the crop yield was only 64

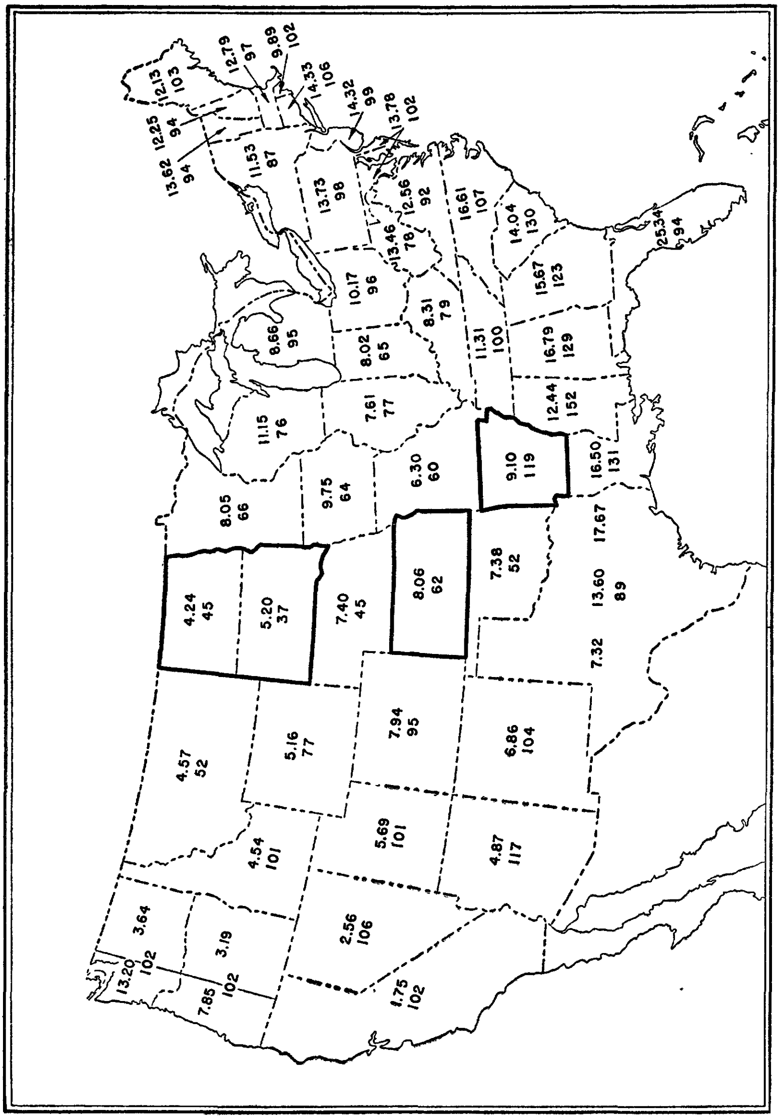

FIGURE 9.—Total precipitation for May, June, July, and August, 1936, in inches (upper figure), and composite yields of crops per acre expressed as percentage of average yield, 1936 (lower figure). In areas indicated by heavy outline the precipitation in 1936 was the lowest of record.

percent of the average with a rainfall of 9.75 inches. The May and June precipitation was approximately normal, but the July precipitation was only 0.51 inch. July is a month when the plant needs for water are great. Although the August precipitation was 3.48 inches, the period of maximum need had passed, and it was too late to save the crops.

As indicated in table 10 there were nine humid States in which crop yields in 1936 fell below 90 percent of normal; the lowest yield was in

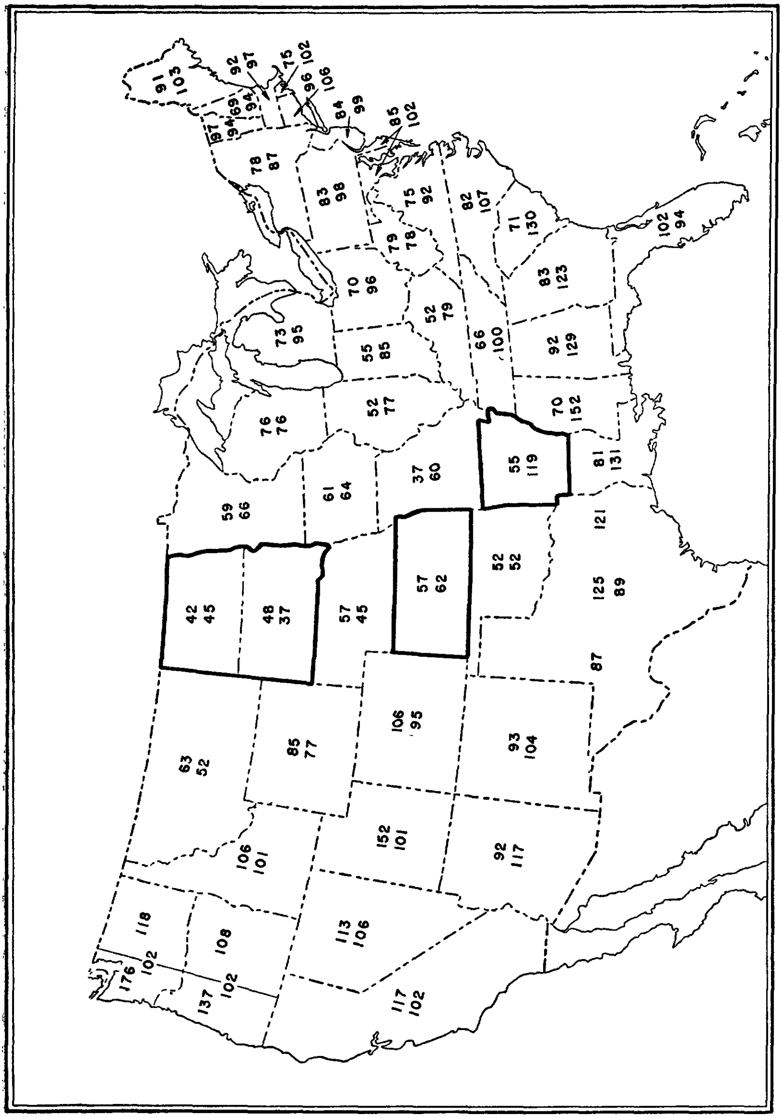

FIGURE 10.—Total precipitation for May, June, July, and August, 1936, in percentage of mean (upper figure), and composite yields of crops per acre expressed as percentage of mean, 1936 (lower figure). In areas indicated by heavy outline the precipitation in 1936 was the lowest of record.

Missouri, with 60 percent; in two other States, Minnesota (66 percent) and Iowa (64 percent), the yields were below 75 percent of normal. All the semiarid States had yields below 90 percent of normal, the lowest in South Dakota (37 percent) and the highest in Texas (89 percent). In all the arid States except two, Montana (52 percent) and Wyoming (77 percent), the yields exceeded 90 percent of normal. The yields in these States, however, except Montana and Wyoming, are largely dependent upon irrigation and are not a true index of drought conditions.

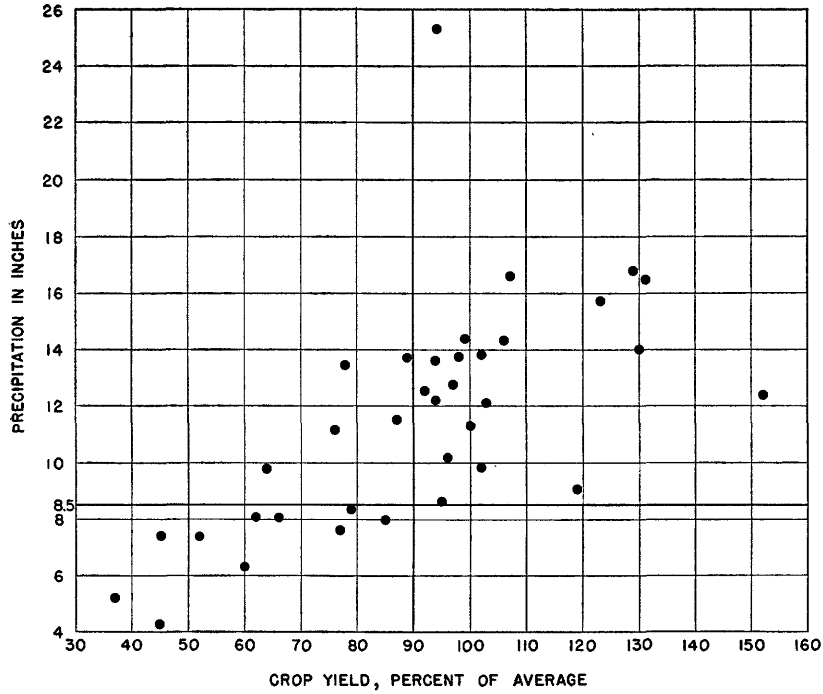

FIGURE 11.—Relation of composite yields of crops per acre in 1936 to total precipitation in May, June, July, and August, 1936, for humid and semiarid States.

TABLE 10.—*States in which precipitation in 1936 in the period May to August, inclusive, was less than 85 percent of normal or in which 1936 crop yields were less than 90 percent of normal*

State	Precipitation		Crop yields (percent of 10-year average 1921–30)	State	Precipitation		Crop yields (percent of 10-year average 1921–30)
	Total	Percent of mean			Total	Percent of mean	
Humid States:				Humid States—Contd.			
Missouri	6.30	37	60	West Virginia	13.46	79	78
Illinois	7.61	52	77	Louisiana	16.50	81	131
Kentucky	8.31	52	79	North Carolina	16.61	82	107
Indiana	8.02	55	85	Pennsylvania	13.73	83	98
Arkansas	9.10	55	119	Georgia	15.67	83	123
Minnesota	8.05	59	66	New Jersey	14.32	84	99
Iowa	9.75	61	64	Semiarid States:			
Tennessee	11.31	68	100	North Dakota	4.24	42	45
Ohio	10.17	70	96	South Dakota	5.20	48	37
Mississippi	12.44	70	152	Oklahoma	7.38	52	52
South Carolina	14.04	71	130	Nebraska	7.40	57	45
Michigan	8.66	73	95	Kansas	8.06	57	62
Rhode Island	9.89	75	102	Texas	13.73	115	89
Virginia	12.56	75	92	Arid States:			
Wisconsin	11.15	78	76	Montana	4.57	63	52
New York	11.53	78	87	Wyoming	5.16	85	77

The foregoing statistics indicate that much must be learned before a definite correlation can be made between climatic and other factors and crops. Although precipitation and temperature are the two basic factors involved, much difficulty is due to the lack of a method of quantitative estimation of their effects on vegetative processes and man's activities, or of the nature of the effects of the distribution or concentration of these factors, not only within a year but from year to year.

DROUGHTS AND THE CLASSIFICATION OF CLIMATE

In recent years much progress has been made in the theoretical classification of many of the climatic and other fundamental factors entering into the drought problem. In this connection the work of Köppen[30] is outstanding and gives a logical and scientific approach to the subject. Following the lines indicated by Köppen's work, Thornthwaite[31] and Russell[32] have made valuable contributions to the subject, with especial reference to the United States. Through these and other studies related to the classification of climatic factors a start at least has been made toward the development of a system of classification of regions with respect to water supply and other characteristics related to droughts.

In the initial concept droughts were regarded as related primarily to lack of water and the presence of other conditions that discourage plant growth. The lack of water for other than plant use has been a later consideration in the drought problem. Among the principal factors that affect plant growth are precipitation, temperature, and soil. In an arid or desert country a shrub survives on a meager amount of water and in an alkaline soil. In the semiarid or prairie country grasses thrive that would die in the desert. In the humid regions dense vegetation is commonly abundant. An intimate relation between native plant growth, climate, and soil may be observed. The plant association that evolves as a stable phase of plant succession resulting from processes of selection and survival under given climatic and edaphic conditions is termed the climax association. Consequently the climax association in arid or semiarid regions possesses great drought-resistant qualities, because it is but a reflection of its environment and is well acclimated to conditions as they exist. But when man introduces plants that require moisture in excess of demands of the climax vegetation and neglects to supply the additional amount of water necessary, he creates a situation in which more than the natural supply of water is needed and which to him

[30] Köppen, Wladimer, Versuch einer Klassifikation der Klimate: Geog. Rev., October 1931, p. 633.

[31] Thornthwaite, C. W., Climates of North America according to a new classification: Geog. Rev., October 1931, pp. 633-655.

[32] Russell, R. J., Dry climates of the United States: California Univ. Pub. in Geography, vol. 5, no. 5, pp. 245-274, 1932.

may therefore become a drought. A similar situation is created if in the development of a region demands are created for water for man's uses in excess of that which is normally available.

In connection with the present-day activities of a highly organized civilization, therefore, it is increasingly difficult to define droughts on the basis of a study of meteorologic conditions alone. Among the factors entering into the problem are the climatic conditions, principally precipitation and temperature, the physical condition of the earth's surface, and the activities of man in the region under consideration.

There is no simple way to classify ground areas with respect to droughts. Not only must the amount of precipitation and temperature be taken into account, but other conditions that have a bearing on the magnitude of the residual precipitation available for man's use must be considered.

Thornthwaite [33] made an attempt to determine critical climatic limits by evaluating the effectiveness of precipitation in terms of the temperature at which it fell. Temperature as a factor in the effectiveness of precipitation for plant activities has long been recognized, and Thornthwaite's classification offers a logical measure of this effectiveness.

Meyer [34] has pointed out that

> Other factors remaining constant, the rate of evaporation from shallow water is approximately doubled for every 18° increase in temperature. Van't Hoff and Arrhenius have enunciated the principle that most chemical reactions and physiological processes double in activity for every similar increase in temperature. This law has been found, by experiment, to apply to a number of phases of plant activity. It has, for example, been found to be substantially correct for the rate of fixation of carbon dioxide by plants in sunlight; and, inasmuch as transpiration occurs during the process of carbon dioxide assimilation, when the stomata open in the sunlight, it is reasonable to conclude that the rate of transpiration, insofar as it is dependent on temperature, substantially follows Van't Hoff's law.

Thornthwaite has assumed that the rate of evaporation from free water surfaces is a measure of the characteristics of a region with respect to the natural loss or consumption of water through evaporation from land and water areas and through the transpiration of vegetation. To evaluate the rate of evaporation, he has derived an empirical relationship for the monthly evaportation in terms of the mean monthly temperature, using the monthly precipitation as an indication of the atmospheric humidity. Thornthwaite has indicated that the effectiveness of precipitation is measured by its ability to supply

[33] Thornthwaite, C. W., Climates of North America according to a new classification: Geog. Rev., October 1931, pp. 633–655.

[34] Meyer, A. F., Elements of hydrology, 2d ed., p. 261, 1928. See also Barrows, H. K., A study of the effect of temperature upon different reactions and processes: Boston Soc. Civil Eng. Jour., April 1937.

the consumptive demands of the local vegetation. On the theory that these demands are proportional to the evaporation, as discussed above, he has used the ratio of monthly precipitation to monthly evaporation to indicate the effectiveness. A statistical index of the precipitation effectiveness of the year is computed by adding together the sum of the 12 monthly ratios. The sum is multiplied by 10 for convenience.

Five major moisture provinces are recognized, and their boundaries are defined in terms of the annual index of precipitation effectiveness—namely, (A) wet, (B) humid, (C) subhumid, (D) semiarid, and (E) arid. The normal positions of these provinces of the United States

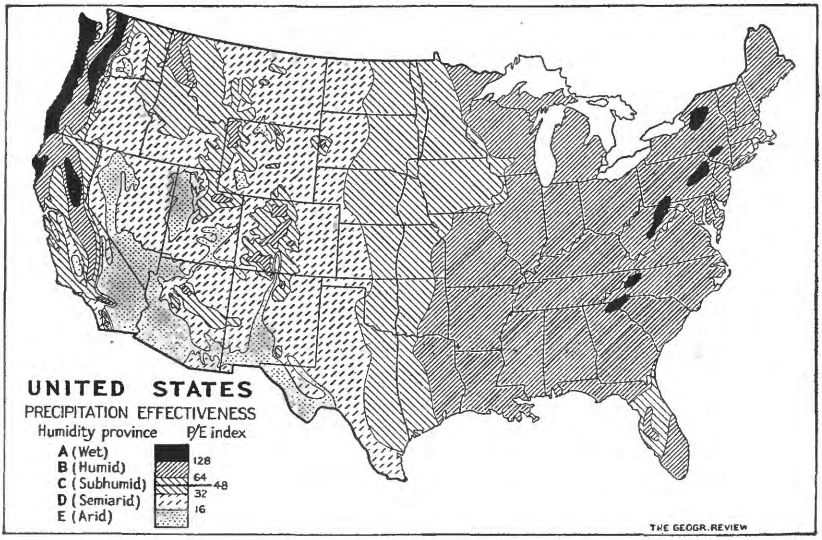

FIGURE 12.—Normal climatic regimen of the United States.

are shown on figure 12 and their position during 1936 on figure 13. In addition three moisture subprovinces, defined on the basis of seasonal distribution of precipitation effectiveness, are recognized in the United States—(*r*) moisture abundant in all seasons, (*s*) moisture deficient in summer, and (*d*) moisture deficient in all seasons. These subprovinces are defined by the proportion that the precipitation effectiveness of 3 summer or winter months, whichever is the greater, bears to the total annual effectiveness.

Thornthwaite also recognized climatic division in accordance with thermal efficiency, which is assumed as being directly proportional to the difference between the monthly mean temperature and the freezing point, on the assumption of a linear relation between the evaporation rate and the temperature. On this basis an annual index of thermal efficiency is computed in a manner similar to the computation of the precipitation efficiency as described above. In addition five thermal subprovinces are defined on the basis of the summer concentration of thermal efficiency. These climatic divisions are shown on figures 14 and 15.

This system of classification offers a unique method of defining the climate of a region, on the basis of observed meteorologic data. Mathematical definiteness may be given to the boundaries of these climatic provinces and subprovinces, whose migrations can be traced annually. This constitutes a distinct advance in climatology.

In the United States the thermal efficiency is generally adequate, and variations in the precipitation effectiveness are the ruling factors

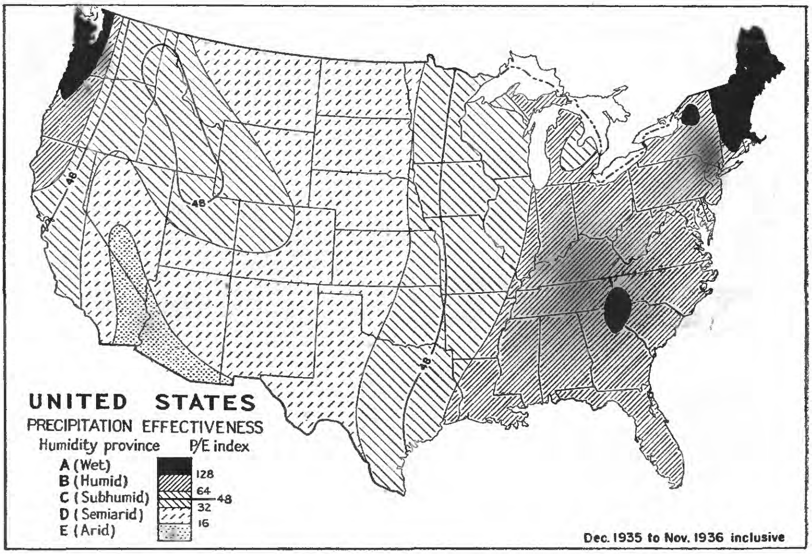

FIGURE 13.—Climatic regimen of the United States during 1936.

and determine the climatic boundaries. Consequently, the precipitation effectiveness is of basic interest, particularly in a study of droughts.

A condition that exists when a drier climate has temporarily displaced a normal wetter climate is an indication of drought. Although in this report a year having 85 percent or less of mean annual precipitation has been adopted as indicative of drought conditions, objection may be raised to an arithmetical measure as such. First, it does not consider the effects of temperature and the distribution of the precipitation with respect thereto; and, more important, it does not consider that in some areas large variations in precipitation may occur without seriously influencing normal activities, whereas in other areas, particularly those near the marginal boundaries of the humid and arid provinces, small percentage variations have great and controlling effects on many activities. The variations of precipitation and of temperature that are of interest with respect to droughts in a particular region are those that result in a decrease in moisture available below the critical climatic limit for that region. Thornthwaite's climatic boundaries afford definite measures of these limits.

Figure 13 shows the location of the major humidity provinces in the United States during 1936, based on the precipitation effectiveness of the 12-month period December 1935 to November 1936. Comparison of this figure with figure 12 shows a general eastward movement during 1936 of the subhumid province, with consequent

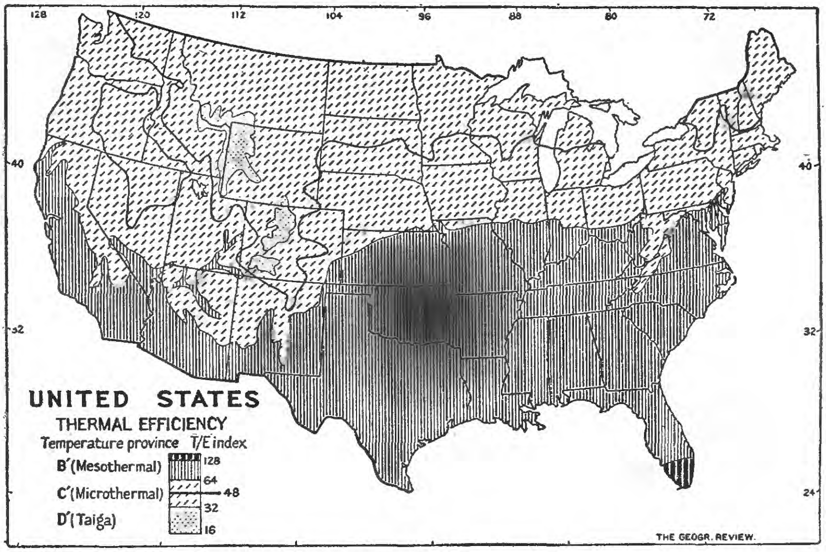

FIGURE 14.—Normal distribution of thermal efficiency in the United States.

contraction of the eastern humid province and enlargement of the semiarid province. Texas remained nearly normal, acting as a hinge point for the northward increase of the general eastern movement of the subhumid province. In North Dakota and South Dakota the semiarid province completely displaced the subhumid. However, the normally arid States showed in general little change in 1936, with some exception in Utah and Nevada, where the normally arid areas were somewhat contracted. New England is indicated as wet, because of the large rainfall during a period of low temperature, which caused the floods of March 1936 in that area.

An analysis of the growing-season records is of greater interest, however, because important variations that may be obscured in the annual record are thereby exposed for study. In the arid West water supply and irrigation are largely dependent upon storage of the previous winter's rainfall and snowfall, rather than upon the precipitation of the growing season, and consequently a study of the deficiencies in that area should center in the winter season. The availability of this water for the growing season is largely dependent upon the adequacy of the development works, and to that extent the influence of climate is obscured. Furthermore, a study of the precipitation in the arid States during the storage period of 1935–36, recorded in table 3, shows that the precipitation was about normal or better. Aside from the effects of the chinook winds in the northern arid areas, the temperature of the storage period is of little influence, provided it is below the freezing point, as it matters little whether

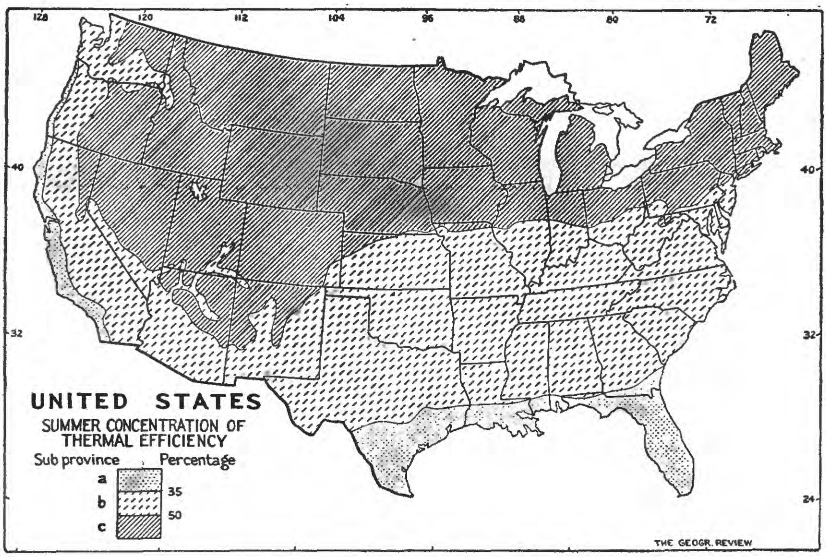

FIGURE 15.—Normal summer concentration of thermal efficiency in the United States.

snow falls at say 25° or 10° F. For these reasons no special study of the precipitation of the nongrowing season is indicated.

The moisture available during the growing season, May to August, as indicated by the precipitation effectiveness, is shown for a normal year in figure 16 and for 1936 in figure 17. The outstanding feature of 1936 is the large expansion and eastward movement of the belt of moisture deficiency, with consequent large contraction of the area of summer-moisture sufficiency to the eastern Coastal States. The eastern boundary of the belt of moisture deficiency, although remaining in an approximately normal position in Texas, moved eastward from its normal position in North Dakota and South Dakota, as far east as western New York, intersecting eastern Kentucky and Tennessee. Areas normally in the belt of moisture deficiency as shown on figure 16 became semiarid, notably Montana, Wyoming, North

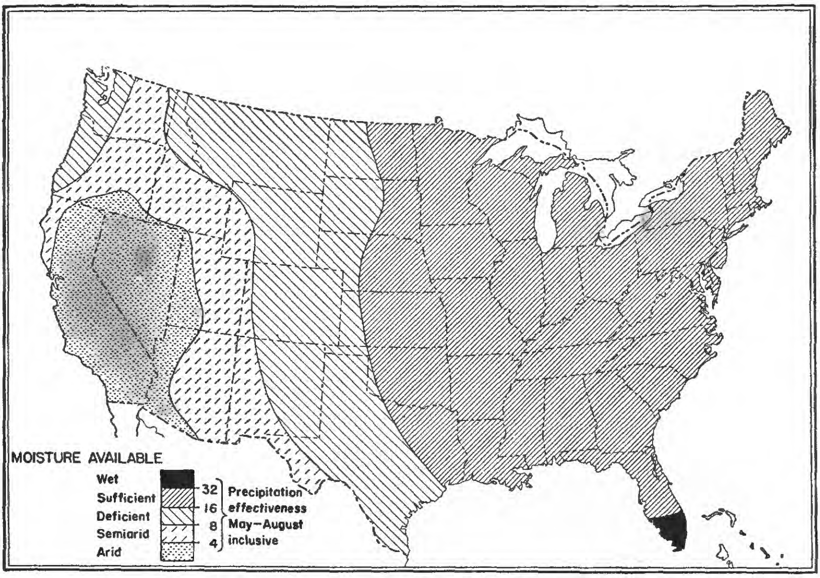

FIGURE 16.—Moisture available during the normal growing season.

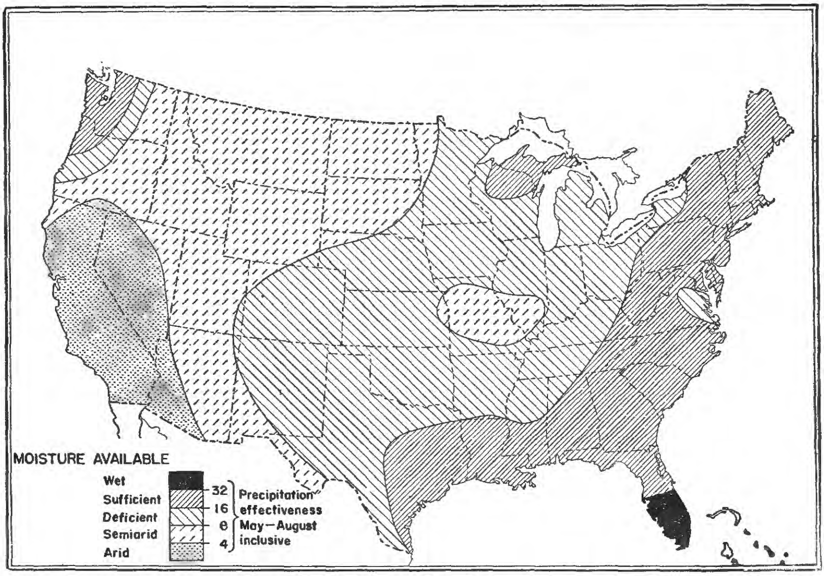

FIGURE 17.—Moisture available during the growing season of 1936.

Dakota, and South Dakota. The arid region showed some contraction in 1936.

In the humid and semiarid provinces drought conditions may be said to be indicated whenever the moisture available has decreased to an extent equivalent to that of the next lower humidity province, and severe drought to be indicated when it has decreased to that of the second lower humidity province. Accordingly in 1936 summer drought conditions were indicated over a wide area in the Central States, with severe drought conditions in Missouri, North Dakota, South Dakota, and part of Minnesota.

VARIABILITY OF CLIMATE

The preparation and study of maps of normal climatic regimen is often futile without a study of the variability of the climate of the region. An economy is adapted most easily to a climatic regimen that remains fairly uniform from year to year. But in areas of great climatic variability the adjustment is made difficult, and consequently, in such areas, economic and physical distress commonly occur during unfavorable years, and it is to the solution of the problem offered by these areas that much political and economic thought has recently been directed.[35]

An attempt has been made to set up a measure of climatic variability in terms of the frequency of the occurrence of years in which the precipitation has been less than sufficient to meet the normal demands of evaporation and transpiration.

With other factors, such as wind, remaining the same, evaporation and transpiration will vary directly with temperature within the limits of available water. A study of annual precipitation, temperature, and run-off over several large drainage basins indicates that the normal annual consumption by evaporation and transpiration varies from about 18 inches at a temperature of 39° to about 33 inches at 64°. On this basis, the frequency with which the annual precipitation has been less than the requirements of normal consumption by evaporation and transpiration is shown on figure 18. When the requirements of normal consumption are not met vegetation tends to suffer owing to a lack of moisture, and there is little or no residual water available for stream flow or to recharge ground water.

In the preparation of figure 18 stations having long-term records were favored, and the selection of stations was so made that each State had at least four stations uniformly distributed over its area.

The critical area and the area of greatest variability lies between the lines representing 80 and 20 percent frequency and is generally coincident with the Great Plains. In this area there may be a year of sufficient precipitation followed by a year or years in which the rainfall does not meet the demands of evaporation and transpiration. The 50 percent line that runs through the Great Plains is of special interest, as it separates the humid East from the arid West. The area west of the 80 percent line never has enough rainfall for successful

[35] This subject is treated at length by Isaiah Bowman in Geog. Rev., January 1935, pp. 43–61, and in Headwaters, control and use: Upstream Engineering Conference, 1935, pp. 76–105.

production of crops without irrigation, except along the northwest coast and in some of the intermountain area shown on figure 12 as either wet or humid. The area east of the 20 percent line is the area of least variability and in general has adequate precipitation for normal crops. East of the Mississippi River years of insufficient rainfall to meet the demands of transpiration and evaporation occur less than 5 percent of the time.

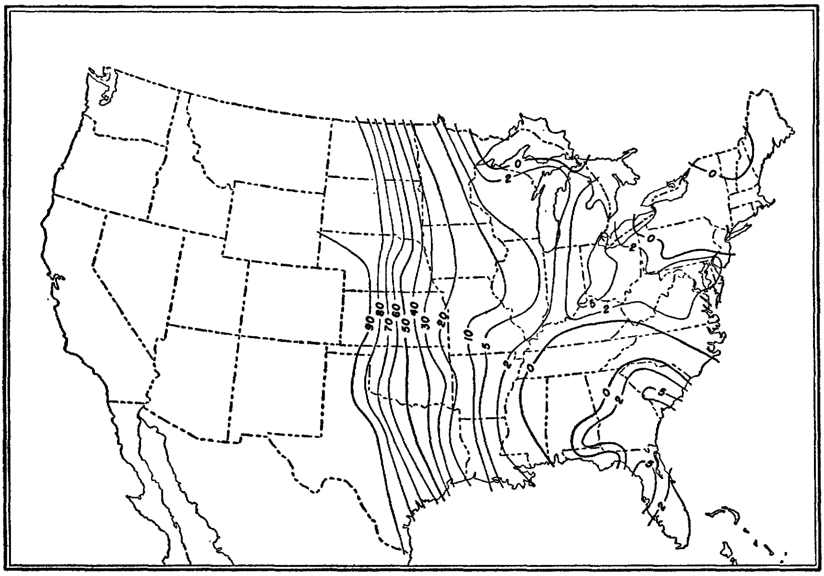

FIGURE 18.—Percentage of time during the period of record in which annual precipitation has been less than consumptive requirements of evaporation and transpiration.

CLIMATIC RISKS

It is now generally recognized that droughts are natural phenomena which may occur in any locality and at any time and that nothing can be done to prevent them. In general, however, the damages incident to droughts are frequently the result of man's activities, and these can be alleviated if proper consideration is given to the water-supply characteristics of the area in which development is made. The data now available for most areas are sufficient, if properly used, to indicate the water supplies that may be reasonably expected in any region.

In the humid regions there is usually enough rainfall to supply the needs of vegetation and most human activities. As shown in tables 7 and 9, there are years when water is short, but in general droughts are not especially prolonged or serious. However, increased demands for water, due to intensive development in urban sections that formerly had adequate supply, now frequently result in shortages during brief periods. In the arid regions development is definitely limited and largely depends on the water that can be conserved, stored, and made available for agriculture through irrigation and for other uses. The semiarid region is one of special risk, and here the problem is not simple. Periods of sufficient water are enjoyed, and then without warning shortages occur which virtually reduce the area to aridity.

The extent to which climatic risks and part-time use may be compensated by actual productiveness in competition with sections where nature has been more lavish with her bounties is largely an economic problem. Although physical geography and the scientific study of climate offer a basis upon which to determine where economic effort of certain types may be applied and where it should be withheld, the question of climatic risks remains as much economic as physical. Consequently, the problems of droughts and climatic variability are complex.

Whether our climate is changing is a question that has remained unanswerable. It would be scientific quackery, indeed, to venture a forecast upon the basis of our very short climatologic records. It is certain, however, that Quaternary climates have changed since the glacial epoch, but historical records are so infinitesimal in relation to geologic time that they provide no backsight upon which to base a statement of climatic trends. It will only be through the keeping of long continuous records of the behavior of natural phenomena that it may be possible for our posterity, through our recorded experiences, to plan profitably and intelligently for the best use of their resources.

BACKGROUNDS OF ECONOMIC DISTRESS IN THE GREAT PLAINS

By H. L. Walster [36]

The Great Plains—what and where are they, and why are they so frequently in a state of economic distress? From the point of view of the Nation the Great Plains might well be defined as an area of stress and strain: they have been and probably always will be the stage upon which the American people will try their great social and economic experiments. They will also continue to be the stage upon which Mother Nature will reveal herself in the greatest variety of moods, ranging from sumptuous plenty in the bountiful years to niggardly scarcity in the years of drought, hot winds, grasshoppers, rust, or other disaster.

E. C. Chilcott, long a native of South Dakota and for many years senior agriculturist, in charge of the Office of Dry Land Agriculture, Bureau of Plant Industry, United States Department of Agriculture,

[36] Dean, Division of Agriculture, and director of Experiment Station and Extension Service, North Dakota Agricultural College. Presented at the National Catholic Rural Life Conference, Fargo, N. Dak., October 12, 1936.

defined the Great Plains as an area of about 450,000 square miles west of the 98th meridian and limited in its western boundary by the 5,000-foot contour. It includes most of North Dakota, South Dakota, eastern Montana, eastern Wyoming, most of Nebraska, eastern Colorado, the western half of Kansas, western Oklahoma, the panhandle of Texas, and eastern New Mexico. Such is the prosaic geographic delineation.

But the Great Plains are something more than mere geography: They are the land of romance—the land of Buffalo Bill and of Billy the Kid; the land of the cowboy, of the lariat, and the 6-shooter; the domain of the cattle kings, the scene of the lonely vigil of the sheep herder. They are the broad acres from whence are filled the granaries, the oil casks, and the larders of the Nation.

The Spanish legacy to the history of the Great Plains extends back more than 4 centuries to 1530, when Álvar Núñez Cabeza de Vaca first saw a buffalo near the southern margin of the Great Plains. The Spaniard, first white invader of the Great Plains, found a congenial environment. Webb [37] has pointed out that these adventurers came from the semiarid part of western Europe, from a treeless land where they had long built homes from adobe, brick, and stone, and that they were superb horsemen. When the 4-H Club boy of western North Dakota rides his spotted pony to school today, he little realizes that it owes its spots to the Moorish invasion of Spain and the Spanish dispersal of horses in North America. The story of the Great Plains is the story of the rise and fall of the horse.[38] The horse provided a means of transport to both white man and Indian in a great open country traversed by but few navigable rivers. The next time you see an alleged cattleman trying to herd a bunch of cows with a model T Ford or any other mechanical contraption, just register the fact that you have witnessed the passing of an era; that era was at its zenith when the first herd of Texas longhorns trailed their way to the northern Great Plains.

Those first herds arrived in the late seventies of the nineteenth century. What is now North Dakota had only 2,000 cattle in 1870; by 1880 it had 70,000, and that number had risen to 189,000 by 1886.[39]

The Great Plains have always suffered from two kinds of wrong publicity—that spread by the misleading optimist and that spread by the misleading pessimist. The Great Plains have always been a happy hunting ground for the boomer and the booster, and they have quite invariably left behind them a sorry trail marked "busted." Beef bonanzas were floated in England and Scotland, and every possible effort was made to exploit the range. The Badlands Cowboy,

[37] Webb, W. P., The Great Plains, pp. 94–98, Ginn & Co., 1931.
[38] Idem, pp. 52–68.
[39] The western range, 74th Cong., 2d sess., S. Doc. 199, table 25, p. 119, 1936.

of Medora, N. Dak., short-lived but vivid newspaper of the North Dakota cow country, records the following incident in one of its 1886 issues:

Marquis de Mores returned last Thursday evening from his eastern trip and started down the river Sunday with his wife on a hunting expedition. He has completed contracts with the French Government to supply its soldiers with a newly invented soup. He intends to visit Europe soon to make contracts with western-range cattle companies who have their headquarters there for the slaughtering of their cattle.

Then came the severe winter of 1885–86, followed by the equally severe drought in the summer of 1886. George Stewart says:

Financial confidence, which started to wane in 1885, was almost completely lost, and the winter of 1886–87 gave a body blow to the beef bonanza. When the depression caused loans to be called, credit liquidation brought forced sales and bankruptcy.

The farmer had begun to occupy the western North Dakota range country in the early eighties; these first sod-busters refused to listen to the advice of Major Powell [40]—namely, that "Crop agriculture would not yield a dependable family living in most of this area except under irrigation."

A disastrous rainless season afflicted the early farmer in western Dakota Territory at a very early date. The issue of the Bismarck Daily Tribune for October 15, 1886, contains the following illuminating editorial:

The Northern Pacific Co. will act upon the advice of its general emigration agent, Col. P. B. Groat, and all farmers along the line of the road whose crops were a total failure this year will be furnished with good seed wheat for next season. This encouragement to farmers at this time will do an immense amount of good, as many who decided to do but little fall plowing for next spring's seeding will now prepare all the ground possible and make up next season for what has been lost this year.

Your particular attention is called to one phrase in the above editorial—namely, "will now prepare all the ground possible."

Officialdom in the person of one Lauren Dunlap also broke into the editorial columns of the Bismarck Tribune on October 1, 1886, with a summary in the Monthly Weather Review. (Mr. Dunlap was attached to the Immigration Office of Dakota Territory.) Immigration commissioners are, of course, traditional optimists and, like the rest of us, are not endowed with prevision, although they frequently claim that particular ability. So we find Mr. Dunlap saying anent the drought of 1886:

Dakota has suffered the same and no more than her sister States in the West from a dry, hot period of weather this summer, the like of which has not been experienced before in years. Never since the settlement of Dakota began in

[40] Quoted from L. F. Kneipp, assistant chief, Forest Service. See The western range, p. 394; also Major Powell's address at the dedication of the first North Dakota capitol building.

earnest has the drought been so general, and it is reasonable to suppose that such an experience as the Territory has now passed through safely, after all, may not be repeated again in the lifetime of the youngest Dakotan.

Subsequent history must adjudge Mr. Dunlap overoptimistic, for his youngest Dakotan was destined to suffer the droughts of 1893, of 1897, of 1900, of 1910, of 1917, of 1934, and of 1936, but it is true that the major droughts have not been confined to the Great Plains.

Opinions with respect to the suitability of the Great Plains to crop farming, into which destiny has now thrust millions of its occupiers, have varied from the days of the first explorers. Maj. Stephen H. Long's 1819–20 expedition across the plains is probably responsible for the label "Great American Desert." His map published in London in 1823 carries the phrase "Great Desert" but does not delineate its boundaries. The early geographies extended the boundaries with little regard to the facts. In 1859 Joseph Henry, the famous physicist of the Smithsonian Institution, wrote in the columns of the American Agriculturist that a "vast extent of country, almost one-half of the width of the American continent, was quite unfit for tillage." Henry [41] called the territory from the 98th meridian to the Pacific coast valleys "a wilderness unfitted for the uses of the husbandman." Owen Wister, whose "Virginian" was "wild and wooly and full of fleas, and hard to curry above the knees" characterized Henry's ideas as "rancid with philanthropy and ignorance." [41a] Even Horace Greeley, of "Go West, young man" fame, thought that the desert was growing.

* * * * * * *

The soils of the Great Plains are fertile soils—that is, they contain a great store of available and potentially available plant food; the average lower rainfall of the Great Plains has prevented the excessive leaching of these soils. Such depletion of fertility as has occurred has been largely through the removal of crops and the loss of nitrogen through wastage by fire. The Great Plains exemplify the dictum laid down by Sir John Russell, the world's greatest student of soils: "It is not the crops that exhaust the land, but the cultivation." But although Great Plains soils have not had their fertility exhausted, we must remember that they are wind-swept. Wind-swept soils are always subject to wind-erosion damage. Wind erosion has taken a heavy toll throughout the length and breadth of the Great Plains; water erosion, too, has levied a heavy toll, particularly in the warmer longer season in the southern part of the Plains.

In a short address which the present speaker [Mr. Walster] made to an informal session of experiment-station directors in November 1935 he said:

Conservation is not congenial to the American temperament. Coronado ventured into the unknown Great Plains to find gold in order that he and his

[41] Quoted by Hulbert, A. B., Soil, its influence on the history of the United States, 1930.
[41a] Idem, p. 205.

Spanish adventurers might spend it. The cattlemen trailed their herds over the same trails eternally seeking new and distant pastures. The sheepmen followed with their still more efficient grass consumers. Both cattlemen and sheepmen increased their herds and flocks to the capacity of a particular range, then left it for greener pastures.

Then came the farmer—the Plains settler with his plow and his harrow, pulverizing the ancient soil structures and destroying the equally ancient soil cover. Not satisfied with the toll taken by beast and mold-board plow, we invented that most efficient of all methods for destroying soil structure and soil cover—dry farming. And how we praised it! What congresses and conferences we held to extol the praises of all that it implies! The prospectus for the Seventh International Dry-Farming Congress held at Lethbridge, Alberta, Canada, in 1912 stated, "Dry-farming methods can be used with profit upon every acre in every district of the world." The American West and the Canadian took this enthusiastic advice, and they have become "brothers in adversity."

Will a mere rearrangement of fields into alternate strips of crop and summer fallow now so prominently advocated by the Soil Conservation Service ultimately accomplish anything but a mere postponement of that exhaustion by cultivation which Sir John Russell so aptly epitomizes? "Were I to succumb to the lure of alliteration, I should be inclined to characterize strip farming as 'planners' palliative.' It is the type of recommendation being greeted with the same cocksure enthusiasm as greeted original apostles of dry farming."

The Office of Dry Land Agriculture of the Bureau of Plant Industry, United States Department of Agriculture, has maintained a series of 23 experiment stations up and down the Great Plains for the last 25 years or more. E. C. Chilcott summarized all the crop work of these stations in United States Department of Agriculture Miscellaneous Circulars 81 and 81, supplement 1, published respectively in 1927 and 1931. * * * Chilcott sums up as follows:

> The Great Plains area has been and should continue to be chiefly devoted to stock raising, and all agencies interested in the agricultural, social, and economic development of this vast region of more than 450,000 square miles should unite in bringing about conditions that will make possible the fullest development of its natural resources for stock production. Crop production should be aimed to supplement livestock production rather than to compete with it.

Back of the whole story of such degrees of economic distress as the Great Plains have experienced lies the wrong use of the land. To place the sole blame for that wrong use upon the operator or even the owner is to ignore the facts of history. Let us look at some of these facts:

First and foremost lies the fact that land prices and local taxes have in general been too high for the revenue-producing capacity of the land.[42] Men have not been able to afford land ownership; this has meant a growing land tenancy. In eight of the Great Plains States 15 percent of the farmers were tenants in 1880; by 1910, 30

[42] See Chilcott, E. C., U. S. Dept. Agr. Misc. Circ. 81, p. 94, 1927.

percent of them were tenants, and by 1935, 40 percent. A rising tide of tenancy has not been conducive to livestock farming; the non-resident landlord and too many of the resident landlords still seek revenue from the outturn of the threshing machine.

The farm-debt situation in the Great Plains presents a background to the economic situation which cannot be ignored. The greater proportion of this debt is owed to one or another of the several arms of the Farm Credit Administration. * * *

American agriculture is young; the agriculture of the Great Plains is still younger, and the agriculture of the northern Great Plains is even younger. The agriculture of that part of the United States east of the Great Plains—by and large, the humid agriculture of this country—is relatively old and evolved from a simple subsistence agriculture to its present diversified form. The diversified agriculture of New England, the Atlantic seaboard, and the great dairy and corn belt has evolved from a simple cash grain farming with few livestock into a system wherein feed and forage crops provide grain and pasture for the herds and flocks which dominate the landscape.

The agriculture of the Great Plains has had an entirely different history: except in a few rare instances or special locations the Great Plains never had a subsistence phase. Most of our pioneers were surplus producers from the start. The tragedy of the Great Plains lies in the obstinate fact that at fairly regular intervals great portions of the Plains people are forced by the whims of nature to a subsistence level or to charity. The closer historical connection between the initiation of Great Plains agriculture, especially northern Great Plains agriculture, and modern developments in farm machinery and mechanical power foreordained this difference.

The cowboy once dominated the Great Plains; now the cowboy is largely confined to such portions of badlands, sandhills, butte-dominated terrane, and stony, rocky, or gravelly hills as the plowboy has not yet wholly invaded.

The Great Plains was once a cow country: herein its history differs sharply from the history of the land to the east of the Plains The plowboy has always been rather proud of his conquest of the prairie plains, of his successful drive against the cowman.

The plowed range lands must be rehabilitated; the agricultural lands within the range territory must be made to serve the livestock enterprise. All this requires much planning and more action. Society is not yet wholly ready to help the Great Plains farmer and his neighbors out of a bad situation. Every time government moves to the aid of the economically distressed, the cry of governmental interference is raised. Dudley Stamp says that "Planning the land for the future is essentially the work of securing the optimum use for the benefit of all." Heroic remedial measures will be required to return the Great Plains to their best use, and let me assure you that the so-called best people will not always approve. Plans for best land use must be subject to change. Sir Josiah Stamp, in his 1936 presidential address before the British Association for the Adanvcement of Science, emphasized what the planner is always up against—to wit, "Unknown demand schedules, the unceasing, baffling principle of substitution, the inertia of institutions, the crusts of tradition, and the queer incalculability of mass mind." Sir Josiah Stamp is dealing with imponderables not reducible to maps, charts, or models, the favorite static devices of the planners. We shall have to inject into the best provision we can map for the Great Plains and for agriculture and ranching generally more imponderables than our planning fancies have yet devised. These imponderables will deal with such age-old ideas as hate and love, selfishness and unselfishness, greed and generosity. These imponderables will deal with the spirit of man.

Are we willing to have social control over the land, the greatest of all instruments of production? Then we must have a strong national government, for as [B. H.] Hibbard, in his great history of public-land policies, has pointed out, social control of the land is not possible under a weak government. Social control does not mean abolition of private ownership; properly administered it can mean more lands in private ownership and greater security on the land. Will you agree with Hibbard when he says that "The types of agriculture least suited to a laissez-faire land policy are forestry and grazing"? Laissez-faire implies that the county, the State, and the Nation keep "hands off." When Hibbard published his book, just 11 years ago, he said, "Precedents for giving seed wheat to certain settlers are well established; but precedents for helping them out of a bad bargain altogether, rather than to put up with it, have yet to be established."

But we have had an unprecedented series of drought years and an unprecedented depression since Hibbard reached that conclusion. Drought and depression have written precedents all over this country. We are helping farmers out of bad bargains, and we are protecting ranch lands. Whether or not this era of land reforms upon which we are fairly entered gives us an enduring and worthy land policy and program of conservation of lands and land users will depend upon the intelligence and honesty used in developing the program and the public understanding and appreciation of the need for action.

Our approach to some of the fundamental problems in production in the Great Plains has been, from the beginning of settlement, that of a rather blind faith in machines, and with little or no faith in biological science. This is well illustrated by the early adherence to the fallacious notion that "rain follows the plow" and the continuing fallacious notion that we can be saved by some new tillage implement. Improved tillage implements are helpful but they are not the complete answer. The answer to the problems of the Great Plains lies in a more complete ecological approach. More people must come to understand human ecology, plant ecology, and animal ecology. When we understand the Great Plains "ekos," the environment about its people, its plants, its animals, we shall be able to deal with the Great Plains intelligently.

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