RESERVOIR DESIGN CRITERIA

by

VERNON HART ROSEBRAUGH

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

CIVIL ENGINEER

June 1956

APPROVED:

Redacted for Privacy

Professor of Civil Engineering

In Charge of Major

Redacted for Privacy

Head of Department of Civil Engineering

Redacted for Privacy

Chairman of Engineering School Graduate Committee

Redacted for Privacy

Dean of Graduate School

Date thesis is presented May, 1956.

Typed by V. H. Rosebraugh.

ACKNOWLEDGEMENTS

The author wishes to acknowledge assistance and encouragement from Professors R. F. Morse and W. F. Robohn of the Civil Engineering Department of Kansas State College.

Appreciation is extended also to Professors L. S. Hobson and D. A. Nesmith of the Engineering Experiment Station for assistance and advice in pursuing the research and in obtaining necessary data.

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RESERVOIR DESIGN CRITERIA

CHAPTER I

INTRODUCTION

The purpose of this study was to devise an empirical method of determining design criteria for small surface water supply reservoirs. The Engineering Experiment Station of Kansas State College sponsored a project that was aimed at this important problem. The project had as its aims the determination of the apparent inadequacies of reservoir water supplies for municipalities of Kansas during drought periods and the development of criteria to guide future design.

A prolonged drought has existed in Kansas since the extremely heavy rainfall of 1951. During this time many of the water supplies for cities in the State have been inadequate to provide for normal demands. The water history has shown a record of restricted use, increased rates to reduce use, and even the hauling of water by truck and rail to supplement the limited available supply. The inconvenience, loss of revenue, and adverse publicity have been of great importance to the cities in the eastern part of the State that have depended upon storage of surface runoff for their water supplies.

A search of published material on hydraulics, hydrology, and water supply yielded a great deal of data on the solution of specific problems. However, only fragmentary clues were discovered which could suggest a method of approach to the establishment of general design criteria. Inquiries addressed to Governmental agencies, and College and University Experiment Stations in the area west of the Mississippi River showed no record of similar studies. Since no precedent was available to guide the research along this line, a new approach had to be devised.

CHAPTER II

FACTORS AFFECTING STORAGE

The drought that has extended from October of 1951 until the present has been one of the most severe the State of Kansas has known. The precipitation record for the State has shown a steadily-increasing rainfall deficiency from that month until the present time. With only a few exceptions the monthly precipitation has been below normal since then, with few "wet" months to provide recharge of surface storage and underground reserves. This shortage of rainfall has, of course, been the primary reason for the trouble with water reservoirs. The duration and severity of drought period over which many of the reservoirs were designed to provide storage were probably underestimated.

Another factor contributing to the water shortage in many cities has been the rapid increase in urban population in the years since 1930. Although the state-wide population of Kansas increased only three percent from 1930 to 1950, a migration from farm to city has resulted in an increased rate of growth of cities, especially in the eastern third of the State. Wichita, for example, has seen its own population double in the last two decades. Many other cities have had less spectacular but still large increases in population.

An unexpectedly large increase in water consumption has occurred. The American city dweller has been using 160 gallons per day in recent years, an increase of 60% in the last 20 years. The recent municipal use of water in Kansas has been 155 gallons per day per capita (4, p. 65), slightly less than the National average, but still six times as much as the rural citizen used. Washing machines, air conditioners, lawn watering, and all the conveniences associated with city living have contributed to the rise in water consumption. There has been no recent development to indicate that the rate of use of this important commodity will not continue to rise.

The silting of reservoirs has resulted in a decrease in the effective volume of storage. The deposition of silt in reservoirs has increased materially in recent years due to increased cultivation of land in reservoir watersheds. As a result of siltation studies, cities have reported reductions of storage volume up to 50% of the original capacity.

The effect of evaporation has probably been underestimated. It has not been unusual to have six or seven feet of evaporation loss during a dry year. This loss has been equal to half of the average reservoir depth in many cases. Since dry spells have usually been accompanied by hot weather and sunshine, the effect of evaporation has tended to increase the shortage problem materially.

Seepage losses have been very difficult to evaluate, and have been appreciable in many installations. Many of the reservoirs were built about 20 years ago in the days of W. P. A. The designs often were less than the best and engineering data for dams in the area were not available at that time. Evidence has been found to indicate that excessive seepage losses have resulted, some to the point of having caused partial structural failure. It has been necessary to include seepage losses with evaporation losses in analyses of installations in most cases.

There has been a complete absence of data on runoff from watersheds of the size that normally are used to charge water supply reservoirs. The stream gauging that has been done in the area has measured the larger streams. Since most of the drainage areas used for water supplies feed small streams, no data have been made available for use in computing runoff for the smaller reservoirs.

CHAPTER III

SUMMARY OF EXISTING CONDITIONS

The cities in Kansas which have depended upon surface water supplies were situated in the eastern third of the State. The locations of these cities have been plotted in Figure I. The dependence of populations in this area upon surface runoff has been dictated by rainfall pattern and subsurface geology.

The average monthly rainfall for the eastern division of the State has been plotted in Figure II (8, p. 23). The major portion of precipitation has normally occurred as rainfall during the spring and summer months. Since the water-equivalent of the snow fall has been small in normal years, most of the moisture received by the land has run off as it has fallen.

A large portion of the rain in the State has fallen during thunder showers. Consequently, runoff has frequently been large in proportion to the total fall during the rains of high intensity. However, during a drought when the heavy rains have failed to materialize and the winter snows have been light, the runoff from drainage areas has been very small. Winters have often been the time of the most acute water shortages.

The average annual precipitation in the State has

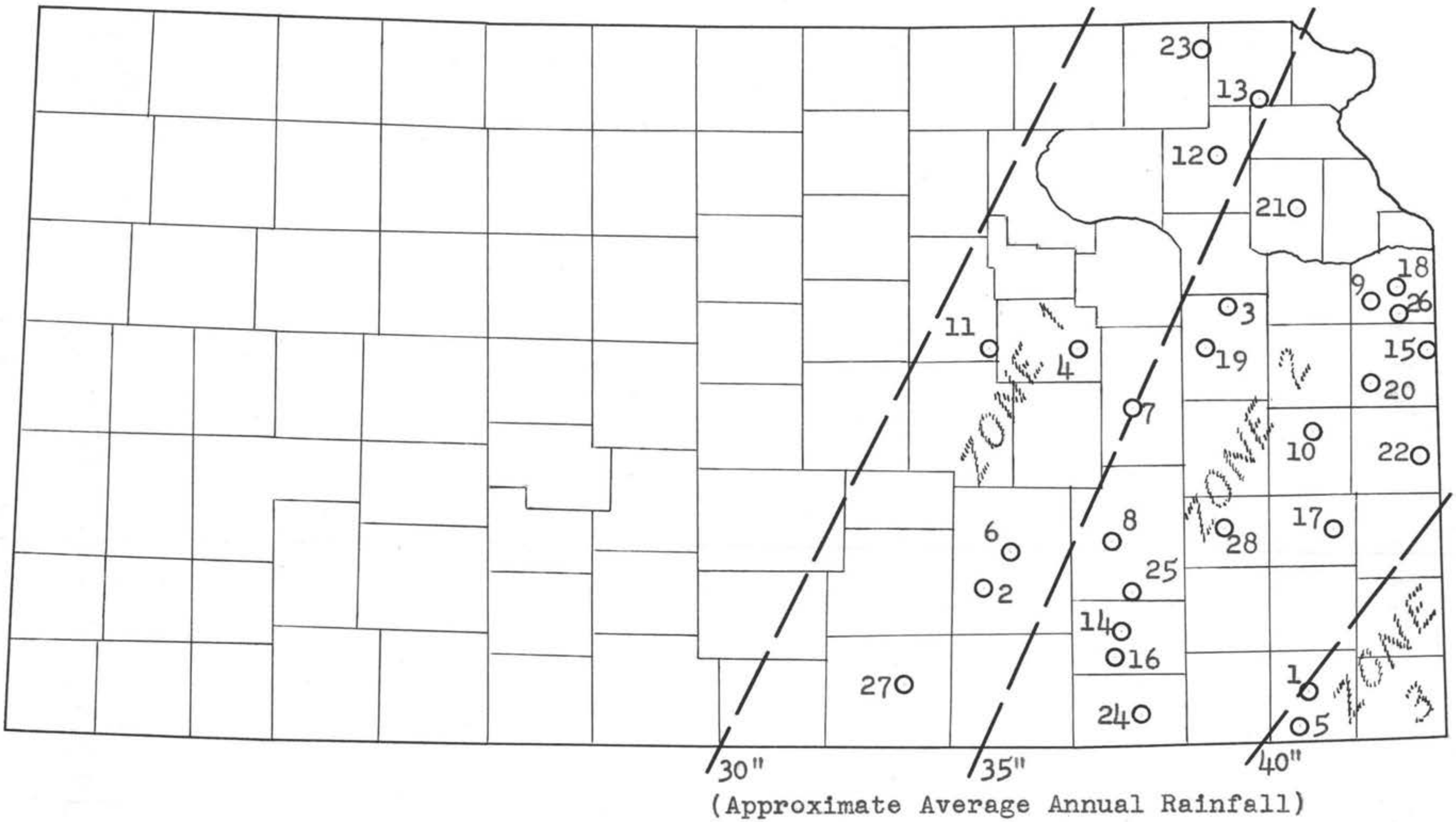

FIG. I. LOCATION OF SURFACE STORAGE RESERVOIRS

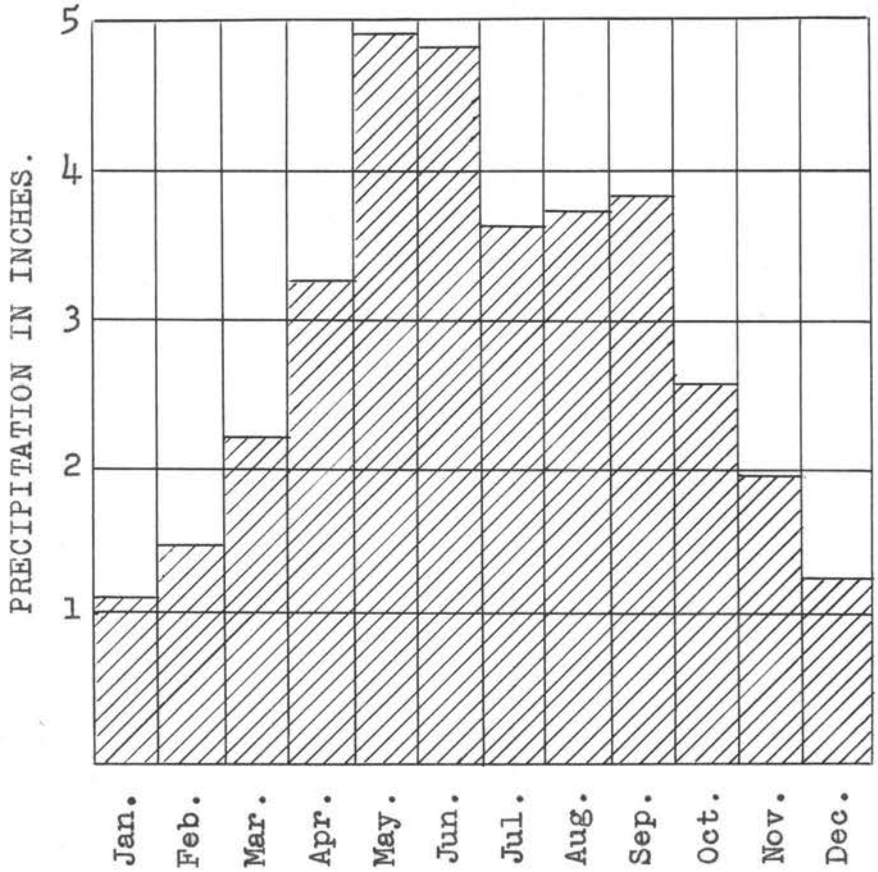

FIG. II. AVERAGE MONTHLY PRECIPITATION FOR THE EASTERN DIVISION.

varied quite uniformly from about 15 inches in the west to over 40 inches in the southeast. All of the surface storage reservoirs have been located in the area having an average annual precipitation in excess of 30 inches as indicated in Figure I. During years of normal or near normal rainfall the surface supplies have been adequate. However, when droughts of long duration have occurred, the problem of water supply has become critical.

The topography of the area in which surface water supplies have been required has prevented the construction of ideally-shaped reservoirs for water storage. The flat, rolling country has forced the construction of wide, shallow storage areas that have been particularly susceptible to serious losses through seepage and evaporation.

The underlying layer of impervious limestone has assisted the runoff in the area but has prevented the digging of successful wells in nearly all cases. In the larger river valleys there has been deposited layers of pervious material. These deposits have enabled some of the larger cities to make use of shallow wells and infiltration galleries for their sources of water. However, the smaller cities have had to depend upon surface runoff since they have not had access to water from the larger streams. One city dug 17 wells in its search for an adequate water supply during the current drought. The best well of the group yielded 10 gallons per minute!

All of the factors influencing the construction of storage reservoirs have tended to make them very expensive. In addition to the cost of the structures involved, the pools themselves covered many acres which resulted in a loss of tillable land in the reservoir areas. Since many of the reservoirs were constructed during a time in which funds were difficult to obtain, many cities probably built the biggest dam they could afford and hoped for the best.

Of the cities in Kansas which have depended entirely upon storage of surface runoff for their water supplies, 70% have had to curtail water use during the three years immediately preceding June, 1955. This curtailment of water use generally took the form of restriction of lawn watering and car washing. However, in the case of two cities in eastern Kansas, it became necessary to haul water to supplement the city supply. This hauling of water entailed a great deal of expense and inconvenience.

In order to increase the available supply of water, three cities have constructed additional reservoirs and one has increased the storage volume by deepening the reservoir area by excavation. Additional storage has been secured in three cases by raising the existing dams, and other cities have supplemented their surface supplies by use of river water and springs, usually at considerable expense.

The cities served by surface water reservoirs had small population-equivalent demand for industries. It was not included in the totals of population served in this study since it was roughly proportional to the amount for other cities of equivalent size in eastern Kansas. Where there were large industries such as oil refineries they had private supplies for their industrial use.

The installation of check dams and farm ponds in watersheds has reduced runoff from drainage areas. The use of terraces and contour plowing in erosion control have also served to reduce the effectiveness of watersheds. Check dams, ponds, terraces, and improved farming methods have helped to reduce siltation of reservoirs as partial compensation for their effect in reducing runoff. All events have pointed toward the increased use of these devices which have served to complicate the problem of obtaining adequate quantities of surface water for municipal use.

CHAPTER IV

RECORD OF PRECIPITATION

Curves of cumulative excess precipitation were plotted for several precipitation-recording stations in eastern Kansas. They indicated a definite cycle of alternating wet and dry periods from about 1840, the time at which the earliest precipitation records for the area started. The last four years have been on the downhill side of the curve, indicating that possibly another dry cycle has arrived. If the curve repeats its performance of the past 15 or 20 years, a relatively dry period for the next several years may be expected.

In the past, continued dry spells have been broken every two or three years by relatively wet years such as 1935 and 1951 which served to fill reservoirs and at least partially to recharge ground water supplies.

The eastern portion of the State was arbitrarily divided into three precipitation zones for this study as shown in Figure I. The pattern of rainfall record was plotted for the three zones in Figures III, IV, and V. The curves for these three illustrations were plotted from precipitation data taken at rainfall recording stations within the respective zones. The ordinates for the curves were referred to the average rainfall for the station at which the record was made.

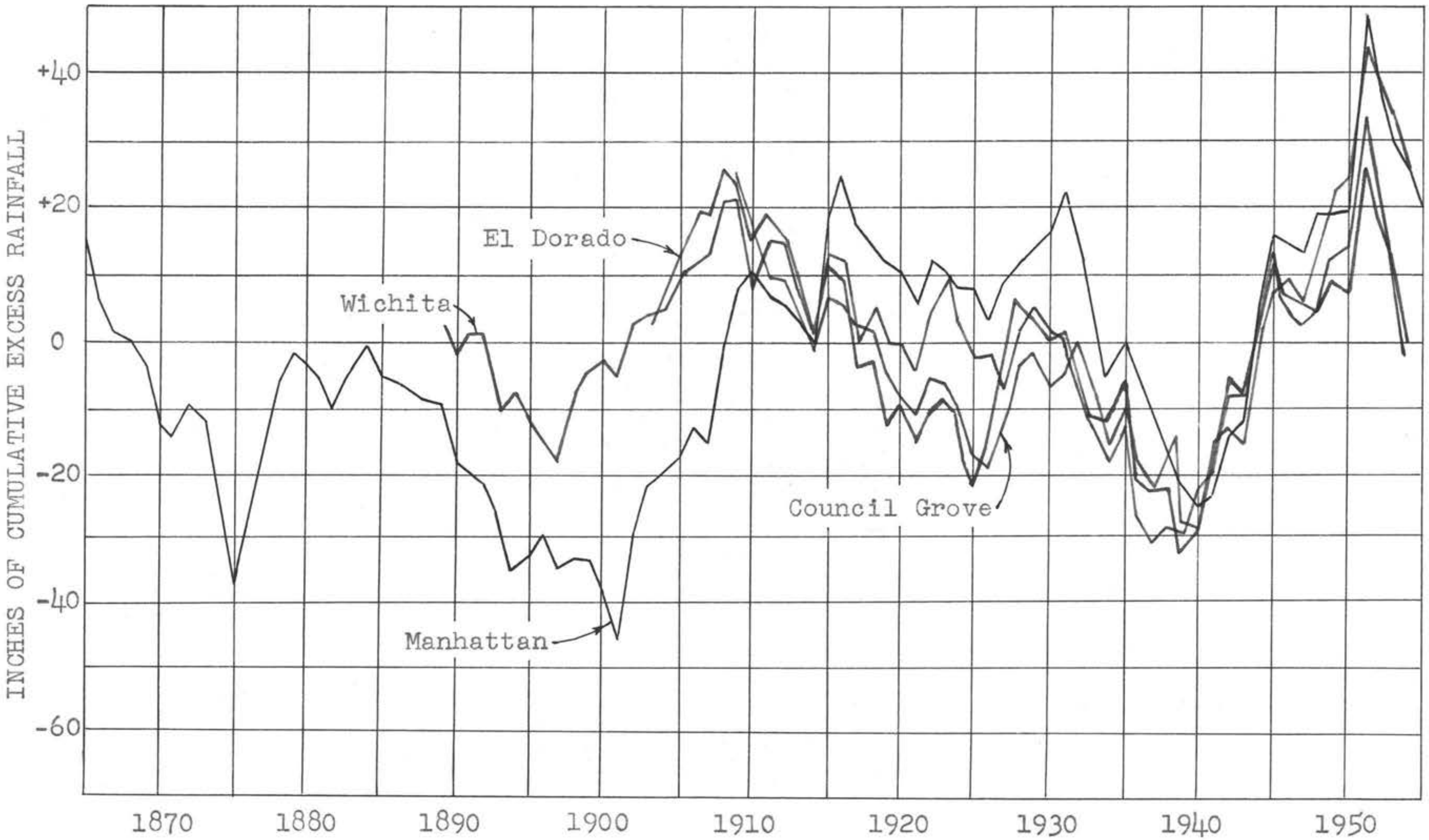

FIG. III. CUMULATIVE EXCESS PRECIPITATION, ZONE 1.

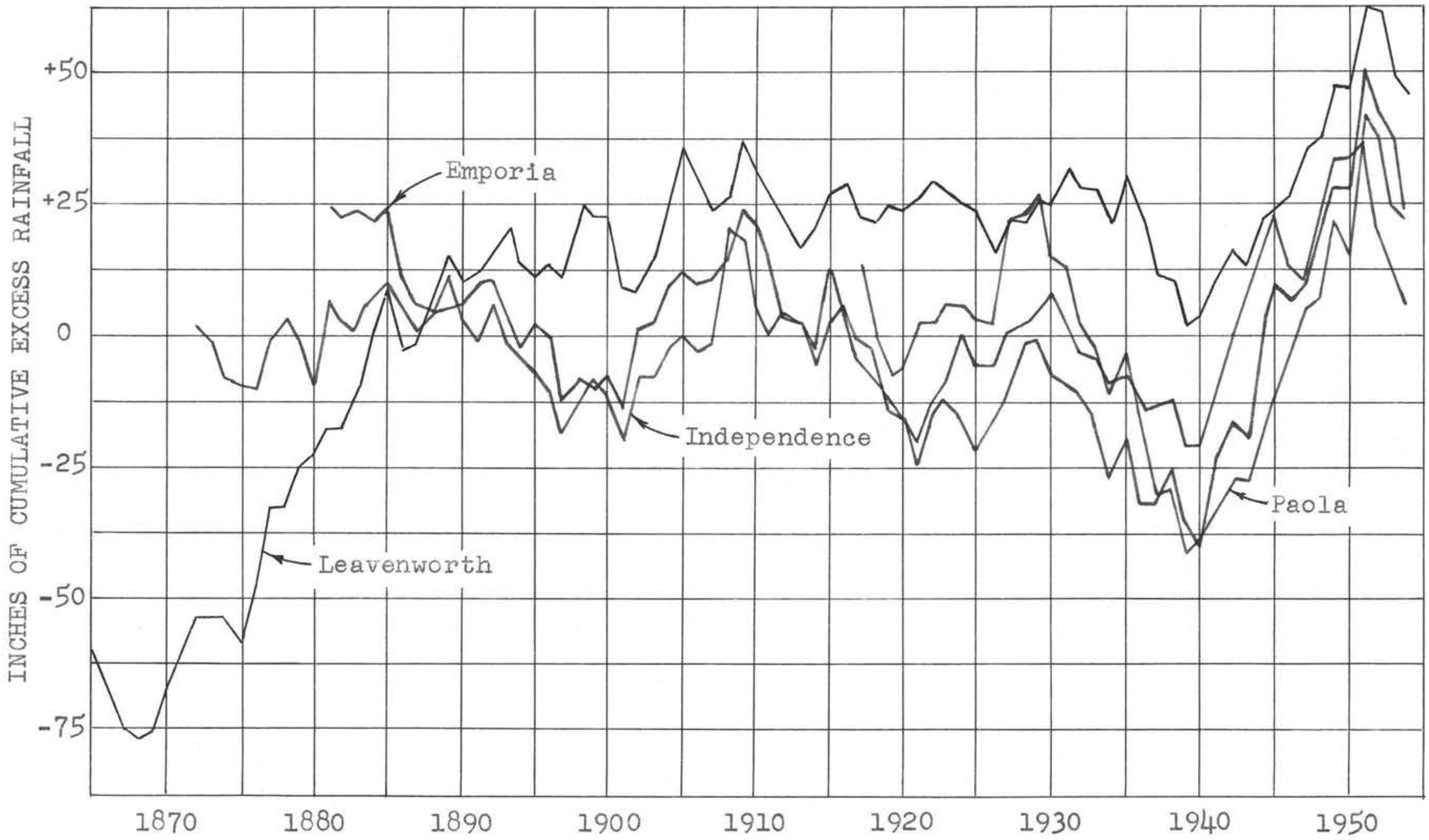

FIG. IV. CUMULATIVE EXCESS PRECIPITATION, ZONE 2.

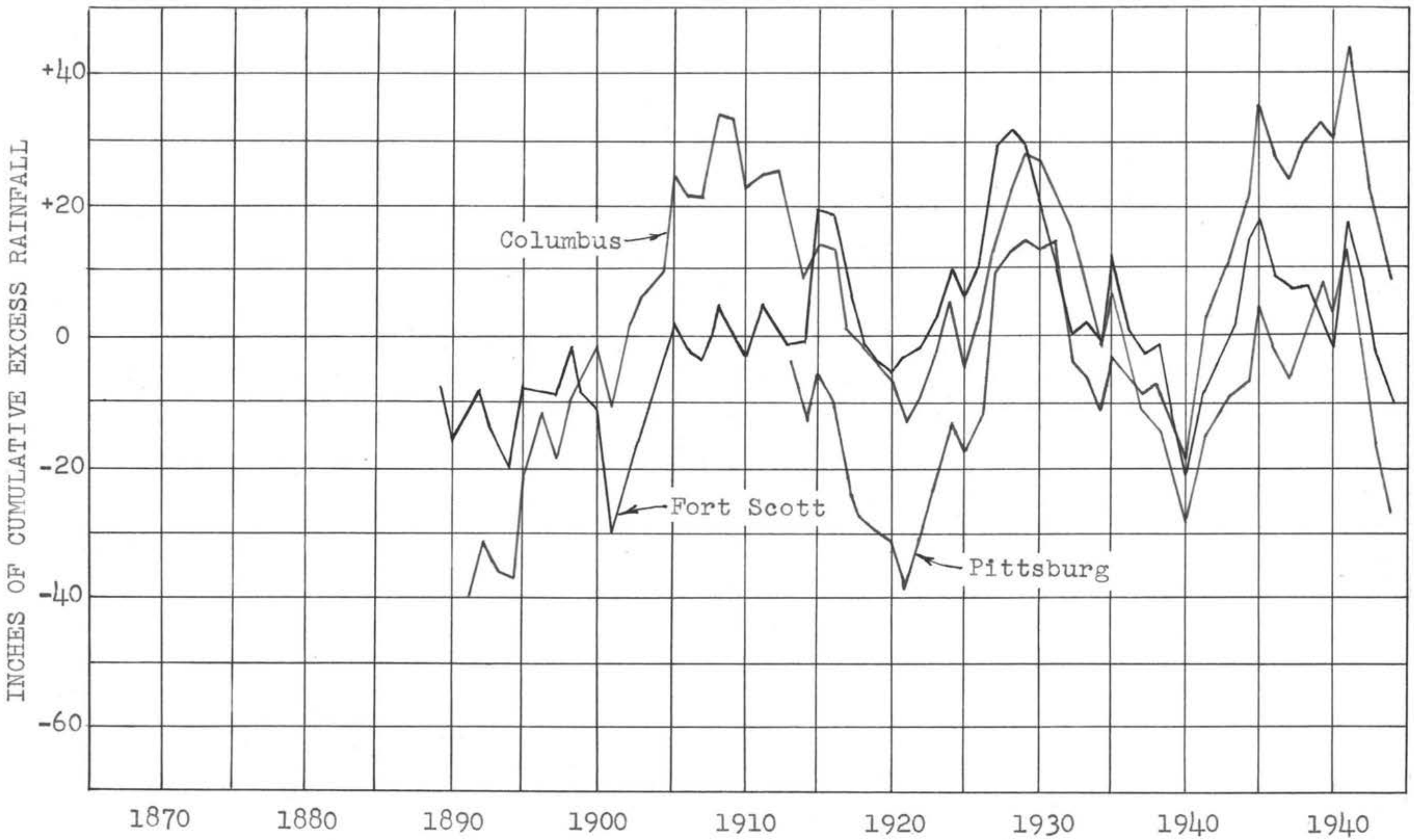

FIG. V. CUMULATIVE EXCESS PRECIPITATION, ZONE 3.

In order to determine the span of years over which a reservoir might have to supply storage, curves of monthly cumulative excesses and deficiencies of rainfall were plotted. These cumulative curves were plotted for the longest of the dry periods of record and provided a graphical representation of the continuing droughts. From these graphs, duration and severity of dry spells were compared. These curves were plotted in Figures VI, VII, VIII, IX, and X from data drawn from records taken at selected gaging stations within the three rainfall zones.

In his paper on reservoir design, T. B. Robinson used curves of cumulative monthly rainfall deficiency to compare drought severities for the State of Kansas (10, p. 27). He plotted curves from data for the average rainfall for the State to compare the drought of 1932 - 1935 with the current dry spell (1952 through 1955). He found that the current drought has been more severe up to the time of his writing (early Spring of 1955) than the drought of 1932 - 1935.

The monthly excess precipitation curves plotted in this study indicated that the droughts that have occurred during the lives of the reservoirs being studied have been as severe as any of record. The drought that has extended from 1952 through 1955 has been as great in deficiency of rainfall and as prolonged as any except the drought of 1936-1941.

This information on relative severity would provide criteria for reservoir design with respect to probable severity and duration of future droughts. If the current drought (1952-1955) should continue, it could become the most severe of record and should serve as the basis for future reservoir design.

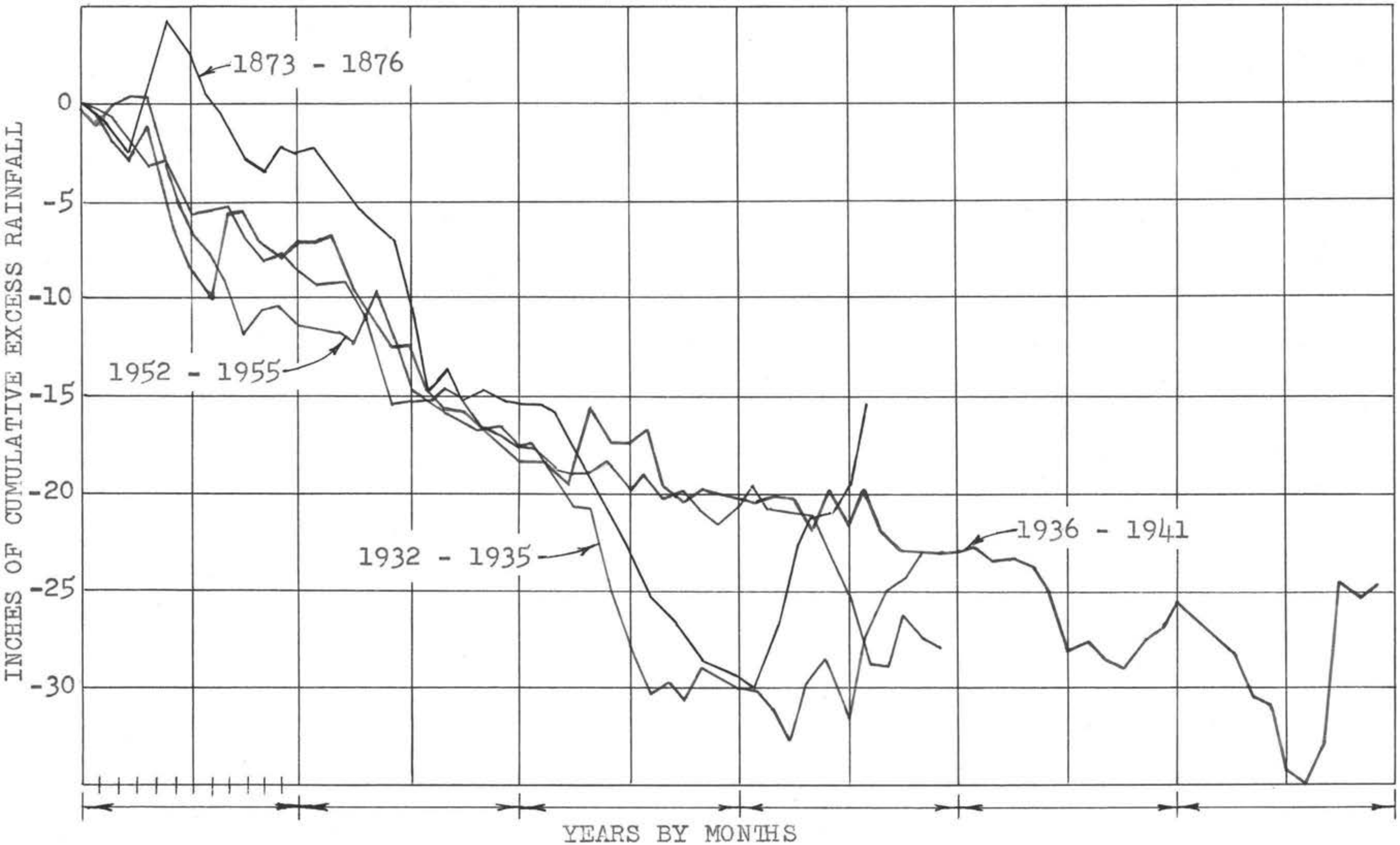

FIG. VI. CUMULATIVE MONTHLY EXCESS PRECIPITATION
MANHATTAN, KANSAS, ZONE 1.

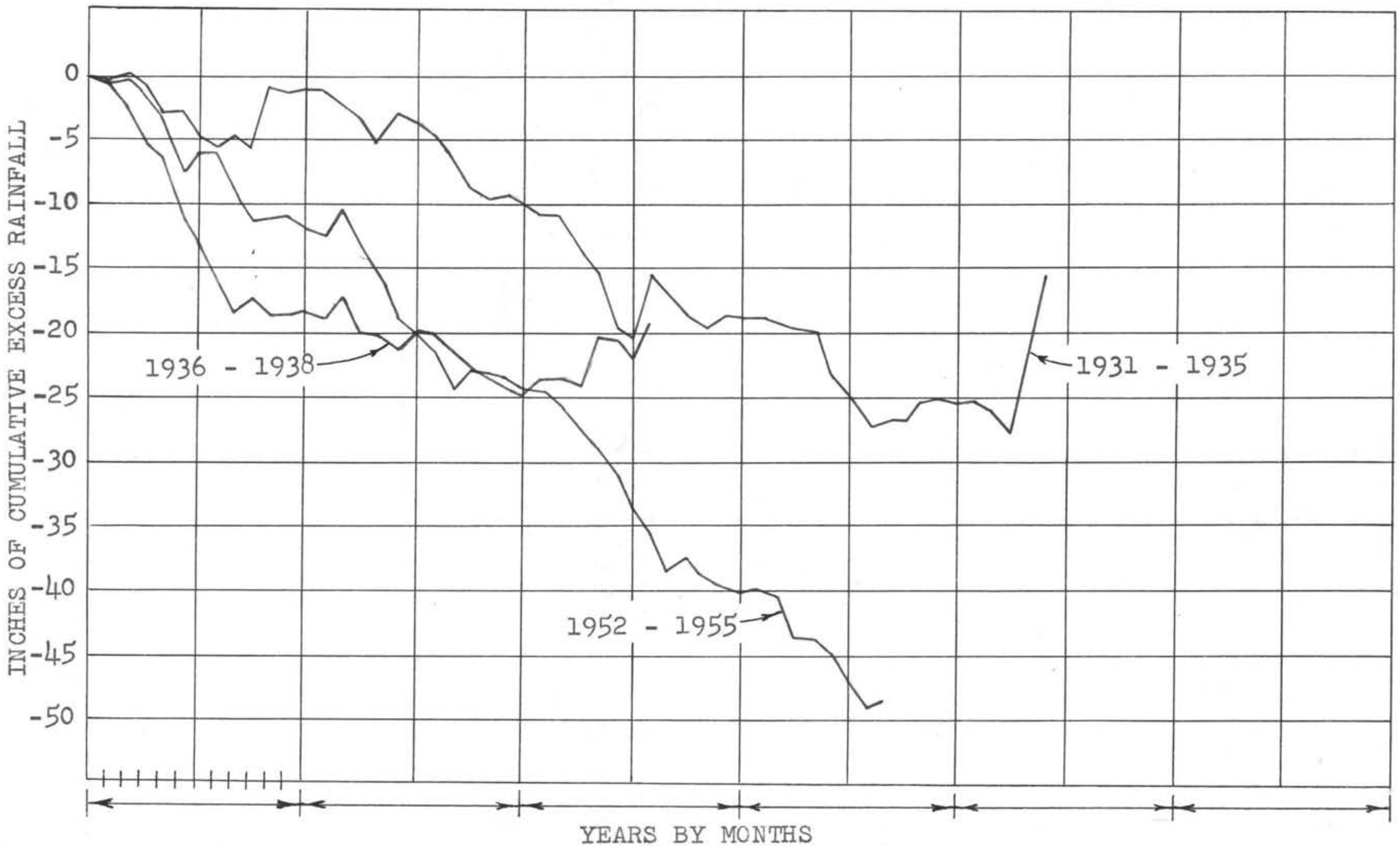

FIG. VII. CUMULATIVE MONTHLY EXCESS PRECIPITATION
WICHITA, KANSAS, ZONE 1.

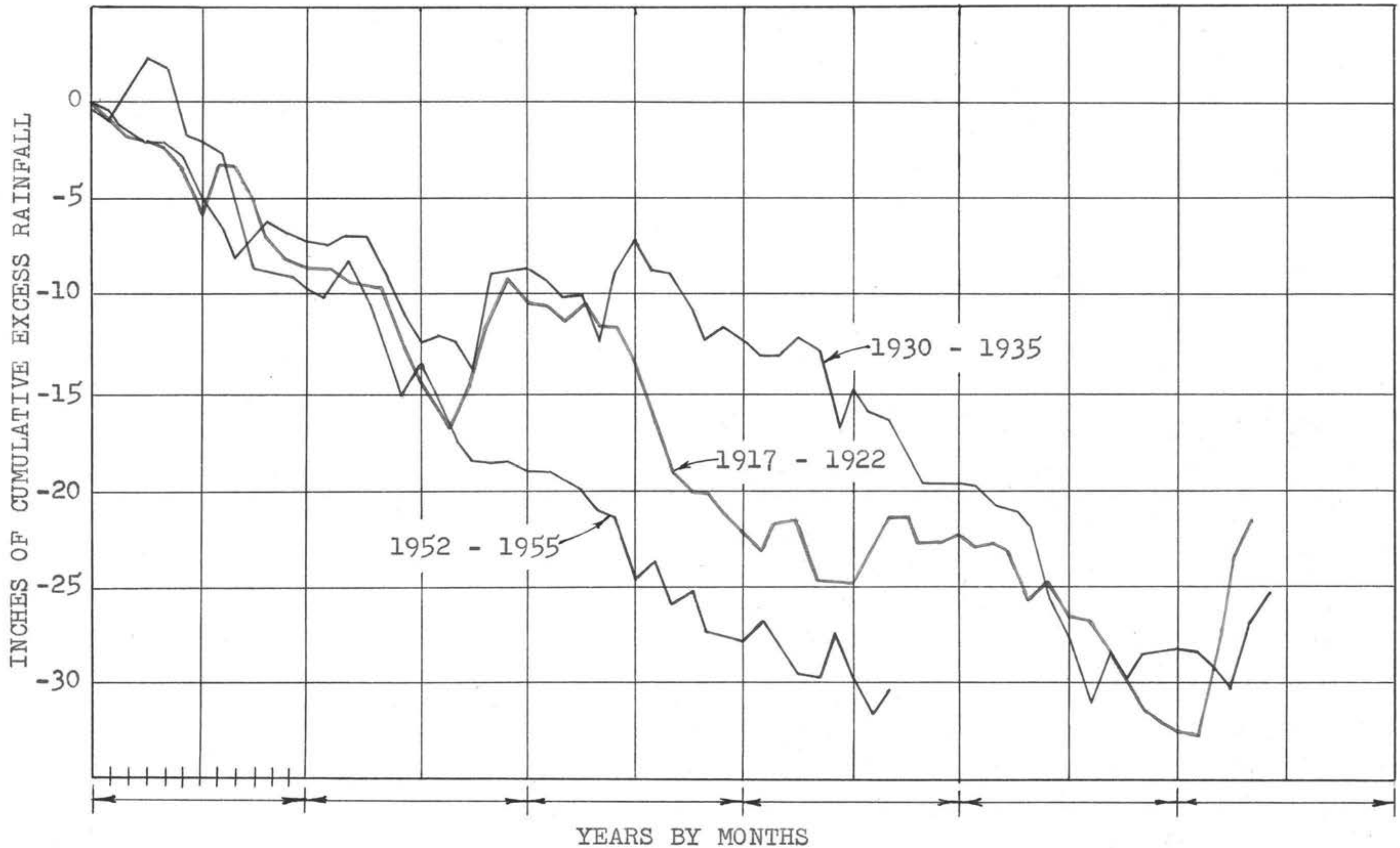

FIG. VIII. CUMULATIVE MONTHLY EXCESS PRECIPITATION
EMPORIA, KANSAS, ZONE 2.

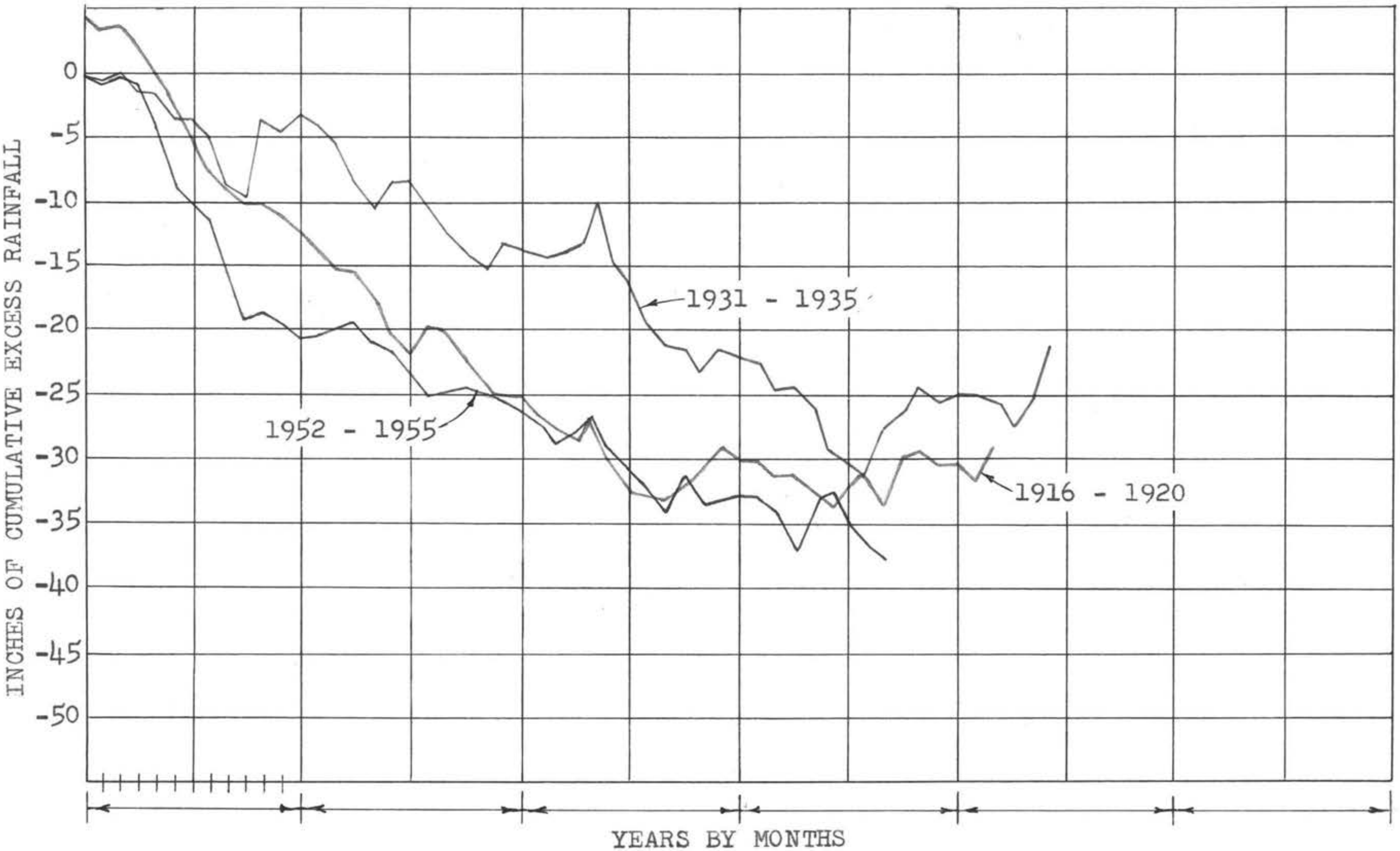

FIG. IX. CUMULATIVE MONTHLY EXCESS PRECIPITATION
INDEPENDENCE, KANSAS, ZONE 2.

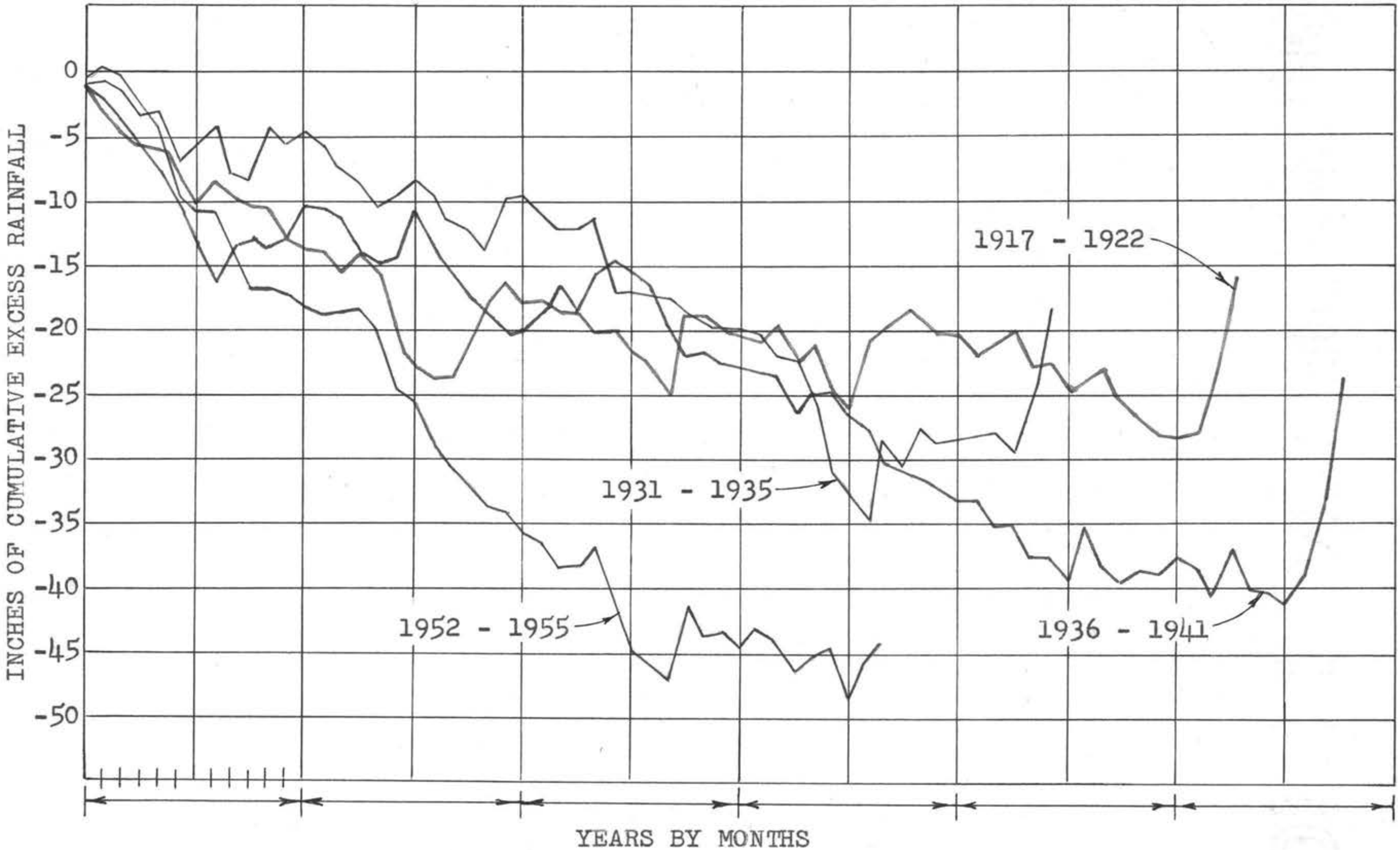

FIG. X. CUMULATIVE MONTHLY EXCESS PRECIPITATION
COLUMBUS, KANSAS, ZONE 3.

CHAPTER V

SOURCES OF DATA

Data on water supply installations for use in this study were obtained by interviewing city officials, consulting engineers, various agencies, and by directly observing the sites of the reservoirs.

During the month of June of 1955, the writer visited each city in Kansas that depended upon surface storage for its water supply. City engineers, water superintendents, and other city officials were very cooperative in supplying data and showing the cities' water supply facilities. Where information was unavailable from the city officials, the consulting engineers hired by the city were contacted and much additional data was thus obtained. Many State agencies and the U. S. Department of Agriculture have also been very helpful.

Unfortunately, much data was unavailable. Some of the reservoirs were constructed many years ago and no plans were drawn, or were so sketchy that information on volume, pool area, and watershed area were unobtainable. In a few cases, plans had been misplaced or had just disappeared. Where responsible firms of consulting engineers had been hired, complete information needed for this study was generally available.

One item of desirable information that was unavailable in almost all cases was a stage-volume curve. Cities interested in having complete data on record should insist that this curve be included in a set of plans for a water reservoir.

Photographs of each installation were taken from angles that showed the characteristics of the watersheds feeding the storage reservoirs. Where intakes were visible, they were included in at least one of the views.

Data for plotting curves of cumulative excess precipitation (Figures III to X, inclusive) were taken from rainfall records published by the Weather Bureau of the U. S. Department of Commerce.

FIG. XI. MANY KANSAS RESERVOIRS WERE NEARLY DRY

FIG. XII. A FEW SPILLWAYS HAVE BEEN RAISED

CHAPTER VI

OBSERVED RESERVOIR DATA

Numerical data deemed necessary for computations used in this study were values for population served, drainage area of watershed, reservoir volume, reservoir pool area, and average rainfall. These data were tabulated in Tables I and II. Where numerical values for required items were considered unreliable, they were omitted from the tabulations.

Population served was determined by inquiry of the city official, such as city manager or water superintendent, who had knowledge of the number of people using water. In many cities the figure obtained was an estimate. Most cities supplied water to all residents and, in some cases, to a small rural population.

The drainage area of watersheds was taken from plans on file, aerial photographs, and, in a few cases, from an estimate by a city official. The areas, in acres, of the watersheds were believed to be quite accurate as recorded in Table I.

The figures for reservoir volume, like the drainage areas, were obtained from a variety of sources. In many cases the original plans were available, and in others, measurements had been made recently in sedimentation srudies. A few of the volumes recorded in Table I were estimates by city officials. The volumes, in millions of gallons, as used in the computations were probably sufficiently accurate.

The areas of the reservoir pool when full were recorded in Table II. The areas in acres were, in most instances, educated guesses. They were used to provide a comparison of proportions between reservoir characteristics and to indicate a measure of the evaporation losses.

Average annual rainfall for each reservoir installation was obtained by scaling from a map of average annual rainfall for Kansas (8, p. 24). The values were determined by interpolation between plotted lines of equal precipitation (isohyetal lines). Units used in computation were inches of rainfall per year and were tabulated in Table II.

General topographic features of drainage areas were observed for subjective comparison between the several watersheds. An estimate of percentage of cultivated land in each watershed was made to provide comparison of drainage area characteristics.

TABLE I. OBSERVED RESERVOIR DATA

	City	People Served	Drainage Area (acres)	Reservoir Volume (M.G.)
1	Altamont	1,300	1,100	26
2	Augusta	6,000	4,992	750
3	Carbondale	450	--	--
4	Council Grove	3,000	8,000	3,000
5	Edna	450	150	45
6	El Dorado	12,500	43,520	4,500
6_o	Old reservoir	12,500	21,120	1,000
6_n	New reservoir	12,500	22,400	3,500
7	Emporia	12,000	10,240	2,020
8	Eureka	4,000	9,600	600
9	Gardner & N.A.S.	3,200	3,300	760
10	Garnett	2,700	1,600	302
11	Herington	4,500	11,500	554
12	Holton	2,300	954	220
13	Horton	2,700	7,040	380
14	Howard	1,300	6,500	250
15	Louisburg	700	500	94
16	Moline	900	--	--
17	Moran	550	--	--
18_n	Olathe (new res.)	5,000	10,300	1,250
18_o	Olathe (old res.)	5,000	--	140
19	Osage City	1,900	3,100	150
20	Osawatomie	4,000	600	95
21	Oskaloosa	500	350	67
22	Pleasanton	1,200	755	--
23_n	Sabetha (new res.)	2,000	5,882	409
23_o	Sabetha (old res.)	2,000	5,882	205
24	Sedan	2,000	2,880	175
25	Severy	500	1,200	23
26	Spring Hill	600	742	26
27	Wellington	9,000	11,520	1,100
28	Yates Center	2,250	2,880	240

TABLE II. OBSERVED RESERVOIR DATA

	City	People Served	Full Pool Area (acres)	Average Rainfall (inches)
1	Altamont	1,300	13	40
2	Augusta	6,000	250	34
3	Carbondale	450	--	36
4	Council Grove	3,000	434	33
5	Edna	450	12	40
6	El Dorado	12,500	1235	34
6_o	Old reservoir	12,500	365	34
6_n	New reservoir	12,500	870	34
7	Emporia	12,000	404	35
8	Eureka	4,000	--	36
9	Gardner & N.A.S.	3,200	100	38
10	Garnett	2,700	63	38
11	Herington	4,500	--	32
12	Holton	2,300	59	35
13	Horton	2,700	200	35
14	Howard	1,300	60	36
15	Louisburg	700	--	38
16	Moline	900	--	36
17	Moran	550	--	38
18_n	Olathe (new res.)	5,000	148	38
18_o	Olathe (old res.)	5,000	--	38
19	Osage City	1,900	49	36
20	Osawatomie	4,000	22	38
21	Oskaloosa	500	23	36
22	Pleasanton	1,200	26	39
23_n	Sabetha (new res.)	2,000	--	33
23_o	Sabetha (old res.)	2,000	120	33
24	Sedan	2,000	65	37
25	Severy	500	10	36
26	Spring Hill	600	15	38
27	Wellington	9,000	340	33
28	Yates Center	2,250	120	37

CHAPTER VII

COMPUTATIONS

The analysis of the characteristics of water supply and storage reservoirs for small cities posed a difficult problem. There were so many variables involved that each problem seemed to be unique. The difficulties were complicated by the fact that the reservoirs were located on watersheds of small creeks for which there were no available flow records.

It was anticipated that any theoretical approach would involve so many variables that it would be unwieldy. Another difficulty would have been lack of reliable data on such items as seepage, siltation, evaporation, runoff, use, and other factors that would have been difficult to evaluate. For these and other reasons it was decided to attempt an empirical approach.

Upon close study, it became obvious that any guide to future design must be in analysis of existing installations expressed in general terms. Moreover, closer inspection of the watersheds indicated a general similarity of topography of the drainage areas of the reservoirs studied. Gently rolling hills with approximately 50% cultivation was the general rule, with minor variations from this figure. The shapes of the reservoir storage areas generally were quite similar and the positions and types of retaining works, while of many different forms, were of no importance in this study.

A decision was made to attempt to correlate the important characteristics of the reservoirs and drainage areas, making use of the general similarities of the several sites. From such correlation, values might be derived which could serve as guides for future design. Such guides would have to be used with caution and a full understanding of the bases for their derivation.

It was felt that four variable features were of primary importance in reservoir performance. These were population served, area of watershed, volume of storage, and average rainfall. Such factors as seepage, siltation, variation in consumer use and evaporation had to be considered to be minor or common to all the reservoirs in some fixed proportion. Where some of these secondary factors might be expected to be important in a reservoir design, compensation for them would have to be made for the individual installation.

It appeared from an investigation of the successful reservoirs that a deficiency in drainage area could be at least partially compensated for by an increased volume of storage. The reverse also appeared to be true, and both seemed to be reasonable. These compensating effects suggested combining both area and volume with population served in a factor adjusted for average rainfall.

In adjusting for average rainfall, the effectiveness of watershed area and storage volume were adjusted proportionately to 40 inches of annual precipitation. In other words, an acre of drainage area or a million gallons of potential storage volume in an area in which the average rainfall was 38 inches were assumed to be 38/40 as effective as similar quantities in a 40-inch rainfall area.

The figure of 40 inches was used in the computations to express the ratio in terms of the maximum average rainfall zone for the area of the State in which the investigated reservoirs were located. This procedure provided a common base for comparison of the effectiveness of the reservoirs with their attendant drainage areas in the three rainfall zones.

After areas and volumes were adjusted for average rainfall, preliminary plottings of the adjusted values against population served were made. These graphs seemed to indicate that approximately two (2) adjusted drainage acres and 100,000 gallons of adjusted storage volume were required minimum values for each person served. Further examination of the plots showed that the drainage areas and storage volumes did tend to compensate for each other's deficiencies.

The expression finally decided upon to show the relationship between the selected primary factors was written as

$$K' = \frac{0.5\ A}{2P} + \frac{10\ V}{2P}$$

where K' = the derived factor

A = the adjusted drainage area in acres

V = the adjusted reservoir volume in millions of gallons

P = the population served

This expression for K' obviously was not a true algebraic equation and was not intended to be one. It was dimensionally incorrect since ratios of acres per person and millions of gallons per person can not be properly added. The K' factor was intended to be used as a basis for comparison between proposed and existing reservoirs. The expression was set up so that the minimum values of two adjusted drainage acres and 100,000 gallons of adjusted storage volume per person served would give a K' value of 1.00.

Computations of ratios of adjusted drainage area per person served and adjusted volume of storage per person served were made. These data were required in the computation of the K' factor. They also served to provide a comparison of individual installations and to determine the measure of compensation between runoff area and storage volume.

The ratios of reservoir volumes to drainage areas for the various surface storage reservoirs were computed and tabulated. These ratios were supplied for the use of designers wishing to compare design ratios with ratios for existing installations.

The computation of ratios of reservoir volumes to pool areas was made to provide a measure of the efficiency of a reservoir with respect to evaporation and seepage losses.

Some publications have listed suggested values for the ratio of pool area to drainage area. To provide a basis of comparison with other installations, these ratios for the reservoirs investigated were computed and tabulated.

It was deemed desirable to provide as many ratios of pertinent characteristics as seemed useful for comparisons of reservoirs. In the investigation of a proposed design on an empirical basis, as many facets of a design should be compared as possible. In view of the history of reservoir operation in the eastern part of Kansas, no basis for comparison between existing and proposed reservoirs should be ignored. It was hoped that this study would provide readily useful information for such comparisons.

FIG. XIII. SILTATION HAS REDUCED VOLUME OF LAKES

FIG. XIV. WATER RESERVOIRS SERVE MANY PURPOSES

CHAPTER VIII

COMPUTED DATA AND GRAPHS

Computed values of drainage area and reservoir volume adjusted for average rainfall were tabulated in Table III. Values of K' factor calculated from the adjusted areas and volumes were also listed in Table III.

Tables IV, V, and VI contained ratios that were thought to be useful for checking against similar ratios for proposed reservoir designs. In making up the ratios the same units were used that appeared in Tables I, II, and III.

Values of adjusted drainage area were plotted against number of persons served in Figures XV and XVI. Figure XVI was constructed to show the values for the smaller cities in more detail than appeared in Figure XV. A line indicating a drainage area of two acres per person was shown in both Figures for comparison of drainage areas.

Figures XVII and XVIII were constructed to show the storage volume of reservoir installations with the corresponding values of persons served. Figure XVIII was drawn to such a scale that values of storage volume for the smaller reservoirs would be more plainly shown. A line showing a capacity of 100,000 gallons per person was drawn to indicate a possible minimum value for storage capacity.

Values of computed K' factors were plotted in Figure XIX for each city studied for which sufficient data were available for such computations. Lines indicating values of 1.0 and 1.2 for K' were drawn to provide bases for comparison of possible recommended minimum values.

In the plotting of Figures XV to XIX, inclusive, distinction was made between reservoirs with records of unsuccessful operation, adequate reservoirs, and reservoir installations that were too new to have been tried. The key numbers by the points plotted on these graphs referred to the reservoir index numbers indicated in the first column of Tables I and II.

TABLE III. COMPUTED RESERVOIR DATA

	City	Adjusted Drainage Area	Adjusted Reservoir Volume	K' Factor
1	Altamont	1,100	26	0.31
2	Augusta	4,240	640	0.71
3	Carbondale	--	--	--
4	Council Grove	6,600	2,475	4.68
5	Edna	150	45	0.58
6	El Dorado	36,990	3,825	2.27
6_o	Old reservoir	17,950	850	0.78
6_n	Nes reservoir	19,040	2,975	1.57
7	Emporia	8,960	1,770	0.92
8	Eureka	8,640	540	1.22
9	Gardner & N.A.S.	3,135	720	1.37
10	Garnett	1,520	287	0.67
11	Herington	9,200	443	1.00
12	Holton	834	193	0.51
13	Horton	6,160	330	1.18
14	Howard	5,850	225	1.99
15	Louisburg	475	89	0.81
16	Moline	--	--	--
17	Moran	--	--	--
18_n	Olathe (new res.)	9,785	1,188	1.68
18_o	Olathe (old res.)	--	133	--
19	Osage City	2,790	135	0.72
20	Osawatomie	570	90	0.15
21	Oskaloosa	315	60	0.76
22	Pleasanton	736	--	--
23_n	Sabetha (new res.)	4,853	337	1.61
23_o	Sabetha (old res.)	4,853	168	1.02
24	Sedan	2,664	162	0.74
25	Severy	1,080	21	0.75
26	Spring Hill	705	25	1.00
27	Wellington	9,500	900	0.76
28	Yates Center	2,664	222	0.79

TABLE IV. COMPUTED RESERVOIR DATA

	City	(Adjusted Drainage Area)/ (Persons Served)	(Adjusted Reservoir Volume)/ (Persons Served)	(Adjusted Reservoir Volume)/ (Adjusted Drainage Area)
1	Altamont	0.85	0.02	0.02
2	Augusta	0.71	0.11	0.15
3	Carbondale	--	--	--
4	Council Grove	2.20	0.82	0.38
5	Edna	0.33	0.10	0.30
6	El Dorado	2.96	0.31	0.10
6_o	Old Reservoir	1.44	0.07	0.05
6_n	New Reservoir	1.52	0.24	0.15
7	Emporia	0.75	0.15	0.20
8	Eureka	2.16	0.14	0.06
9	Gardner & N.A.S.	0.98	0.22	0.23
10	Garnett	0.56	0.11	0.19
11	Herington	2.04	0.10	0.05
12	Holton	0.36	0.08	0.23
13	Horton	2.28	0.12	0.05
14	Howard	4.50	0.17	0.04
15	Louisburg	0.68	0.13	0.19
16	Moline	--	--	--
17	Moran	--	--	--
18_n	Olathe (new res.)	1.95	0.24	0.12
18_o	Olathe (old res.)	--	0.03	--
19	Osage City	1.47	0.07	0.05
20	Osawatomie	0.14	0.02	0.16
21	Oskaloosa	0.63	0.12	0.19
22	Pleasanton	0.61	--	--
23_n	Sabetha (new res.)	2.43	0.17	0.07
23_o	Sabetha (old res.)	2.43	0.08	0.03
24	Sedan	1.33	0.08	0.06
25	Severy	2.16	0.04	0.02
26	Spring Hill	1.17	0.04	0.04
27	Wellington	1.06	0.10	0.09
28	Yates Center	1.18	0.10	0.08

TABLE V. COMPUTED RESERVOIR DATA

	City	(Drainage Area)/ (Persons Served)	(Reservoir Volume)/ (Persons Served)	(Reservoir Volume)/ (Drainage Area)
1	Altamont	0.85	0.02	0.02
2	Augusta	0.83	0.12	0.15
3	Carbondale	--	--	--
4	Council Grove	2.67	1.00	0.38
5	Edna	0.33	0.10	0.30
6	El Dorado	3.48	0.36	0.10
6_o	Old reservoir	1.69	0.08	0.05
6_n	New reservoir	1.79	0.28	0.16
7	Emporia	0.85	0.17	0.20
8	Eureka	2.40	0.15	0.06
9	Gardner & N.A.S.	1.03	0.24	0.23
10	Garnett	0.59	0.11	0.19
11	Herington	2.56	0.12	0.05
12	Holton	0.41	0.10	0.23
13	Horton	2.61	0.14	0.05
14	Howard	5.00	0.19	0.04
15	Louisburg	0.71	0.13	0.19
16	Moline	--	--	--
17	Moran	--	--	--
18_n	Olathe (new res.)	2.06	0.25	0.12
18_o	Olathe (old res.)	--	0.03	--
19	Osage City	1.63	0.08	0.05
20	Osawatomie	0.15	0.02	0.16
21	Oskaloosa	0.64	0.13	0.19
22	Pleasanton	0.63	--	--
23_n	Sabetha (new res.)	2.94	0.20	0.07
23_o	Sabetha (old res.)	2.94	0.10	0.03
24	Sedan	1.44	0.09	0.06
25	Severy	2.40	0.05	0.02
26	Spring Hill	1.24	0.04	0.04
27	Wellington	1.28	0.12	0.10
28	Yates Center	1.28	0.11	0.08

TABLE VI. COMPUTED RESERVOIR DATA

	City	(Reservoir Volume)/ (Pool Area)	(Pool Area)/ (Drainage Area)
1	Altamont	2.00	0.012
2	Augusta	3.00	0.050
3	Carbondale	--	--
4	Council Grove	6.91	0.054
5	Edna	3.75	0.080
6	El Dorado	3.64	0.028
6_o	Old Reservoir	2.74	0.017
6_n	New Reservoir	4.02	0.039
7	Emporia	5.00	0.039
8	Eureka	--	--
9	Gardner & N.A.S.	7.60	0.030
10	Garnett	4.79	0.039
11	Herington	--	--
12	Holton	3.73	0.062
13	Horton	1.90	0.028
14	Howard	4.17	0.009
15	Louisburg	--	--
16	Moline	--	--
17	Moran	--	--
18_n	Olathe (new res.)	8.44	0.014
18_o	Olathe (old res.)	--	--
19	Osage City	3.06	0.016
20	Osawatomie	4.32	0.037
21	Oskaloosa	2.91	0.066
22	Pleasanton	--	0.034
23_n	Sabetha (new res.)	--	--
23_o	Sabetha (old res.)	1.71	0.034
24	Sedan	2.69	0.020
25	Severy	2.30	0.008
26	Spring Hill	1.73	0.020
27	Wellington	3.24	0.030
28	Yates Center	2.00	0.042

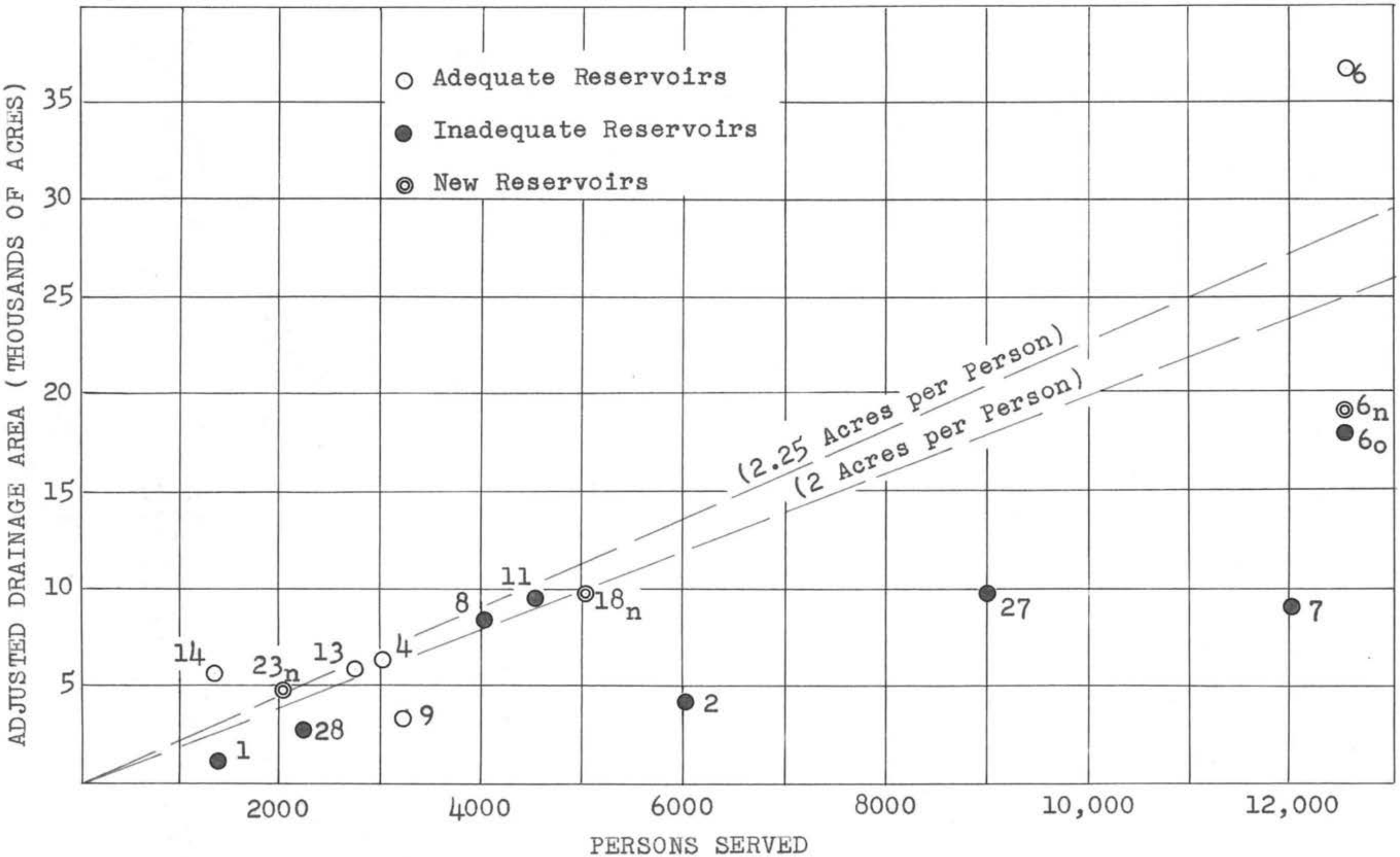

FIG. XV. ADJUSTED DRAINAGE AREAS

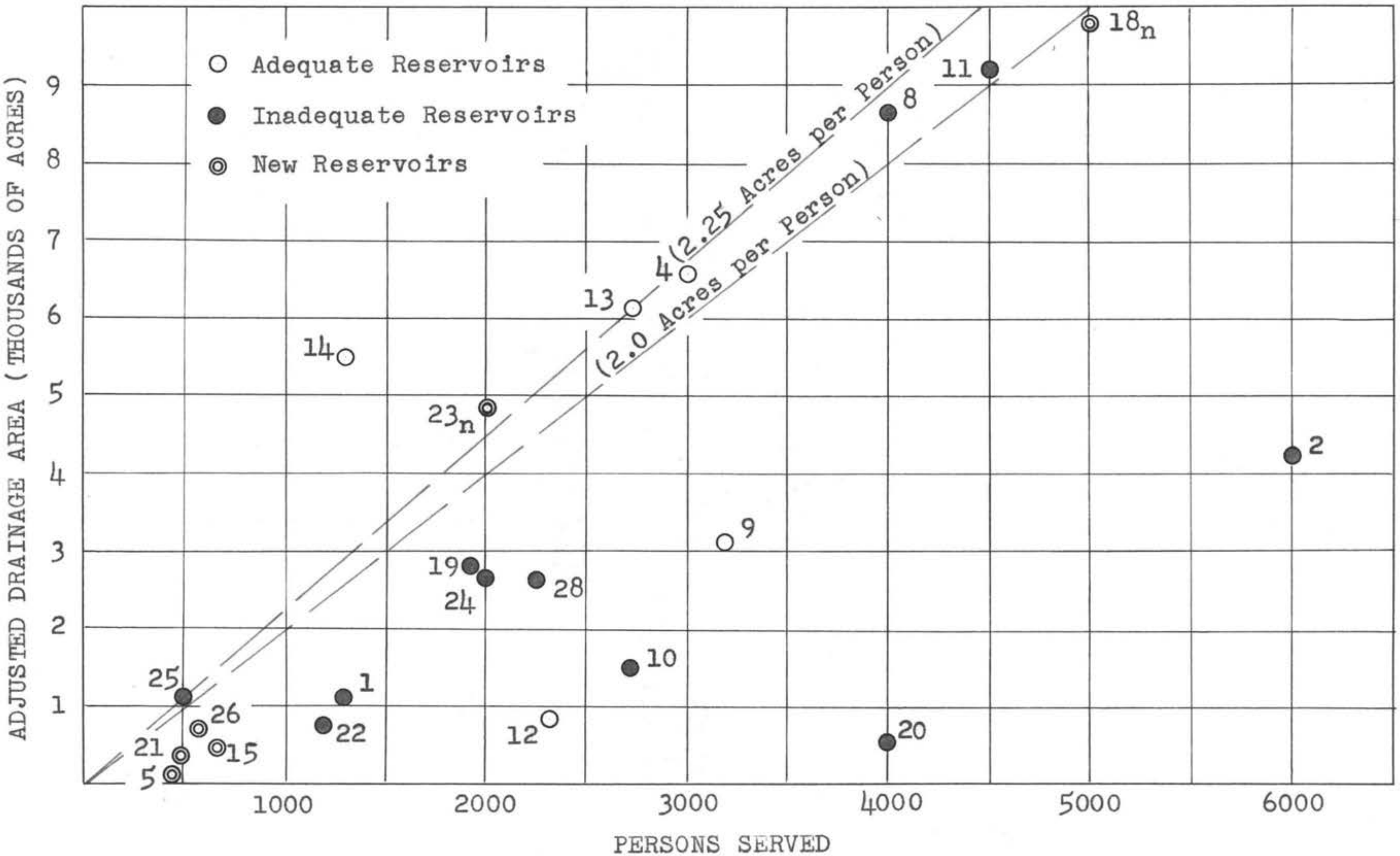

FIG. XVI. ADJUSTED DRAINAGE AREAS

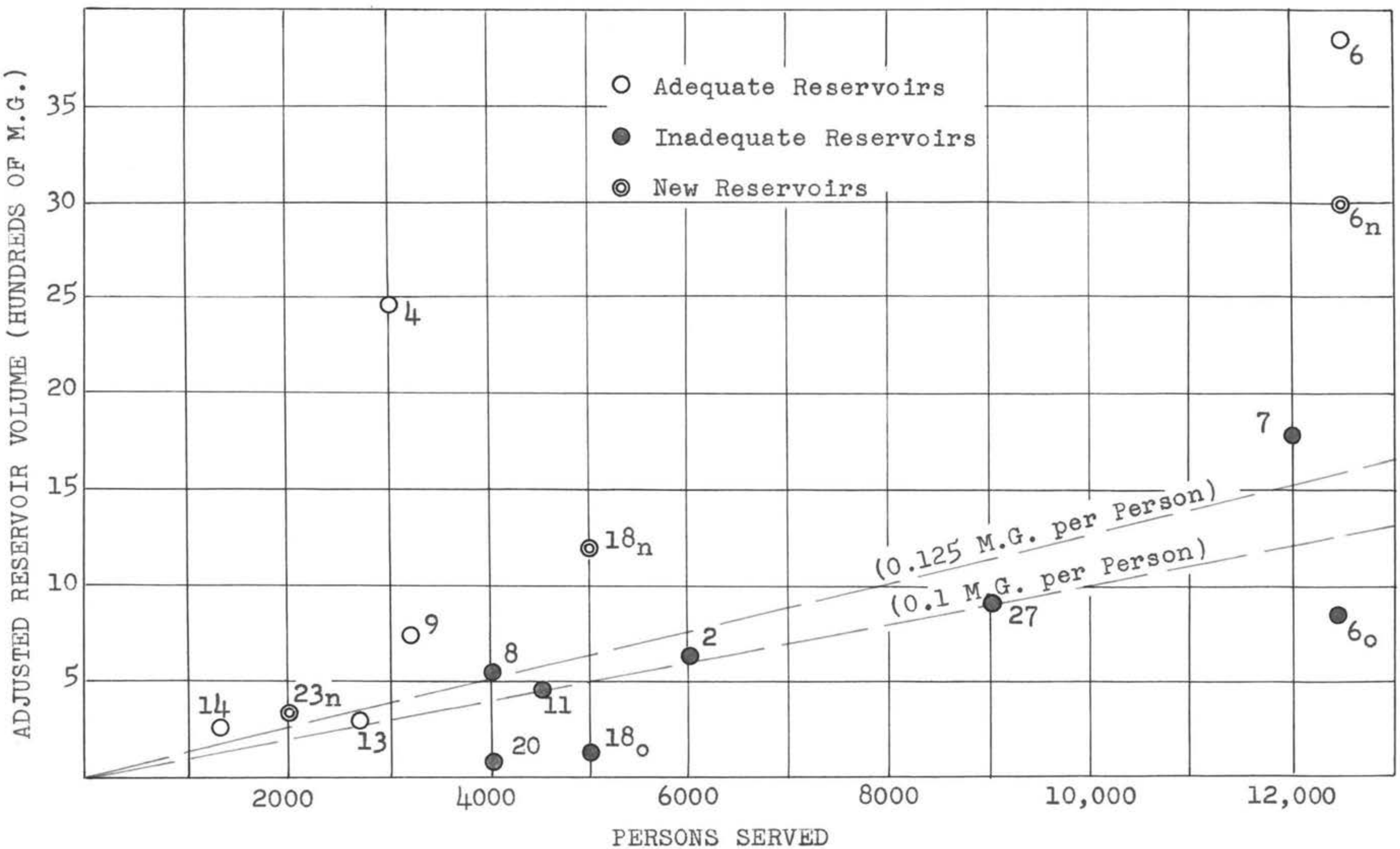

FIG. XVII. ADJUSTED RESERVOIR VOLUMES

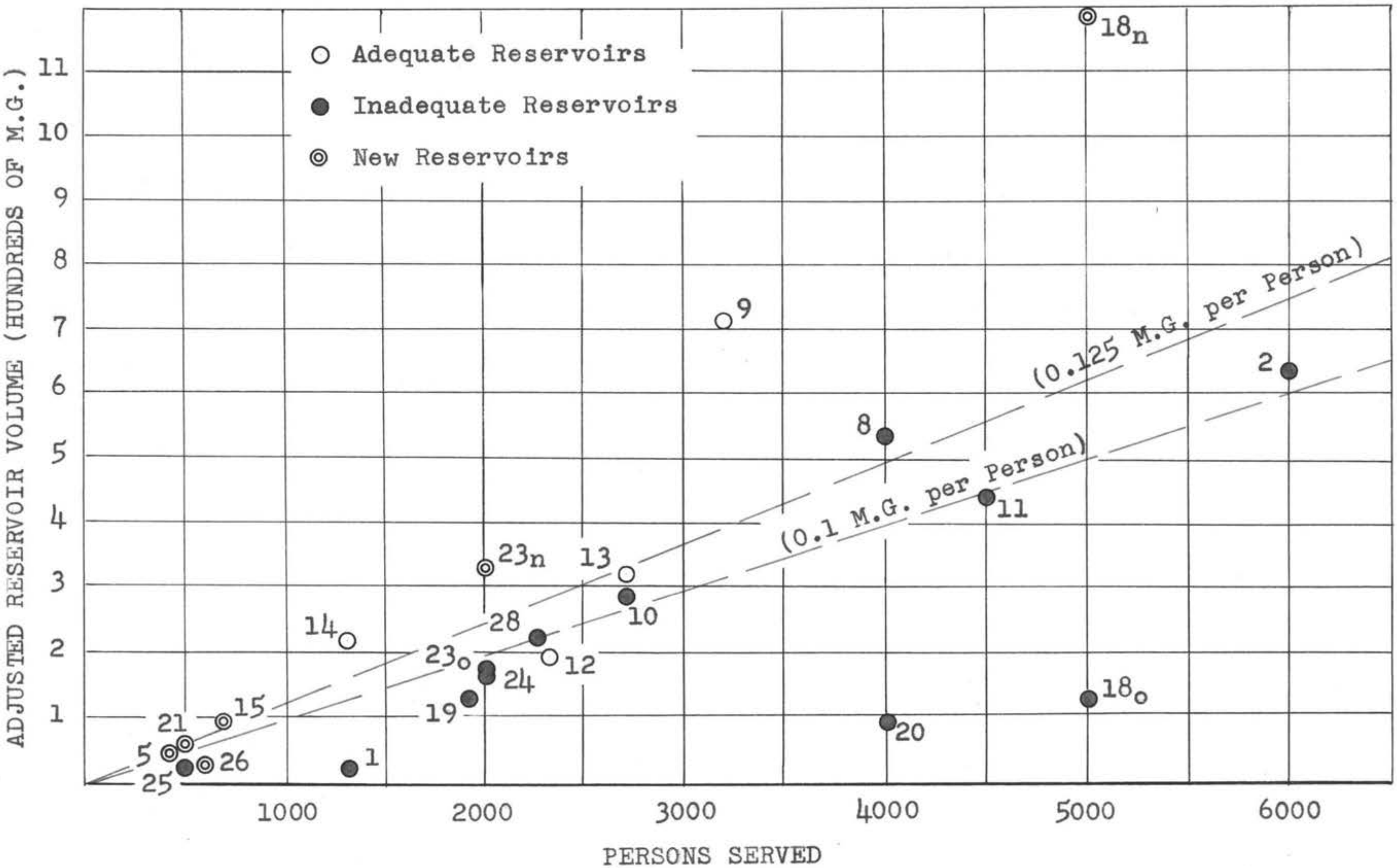

FIG. XVIII. ADJUSTED RESERVOIR VOLUMES

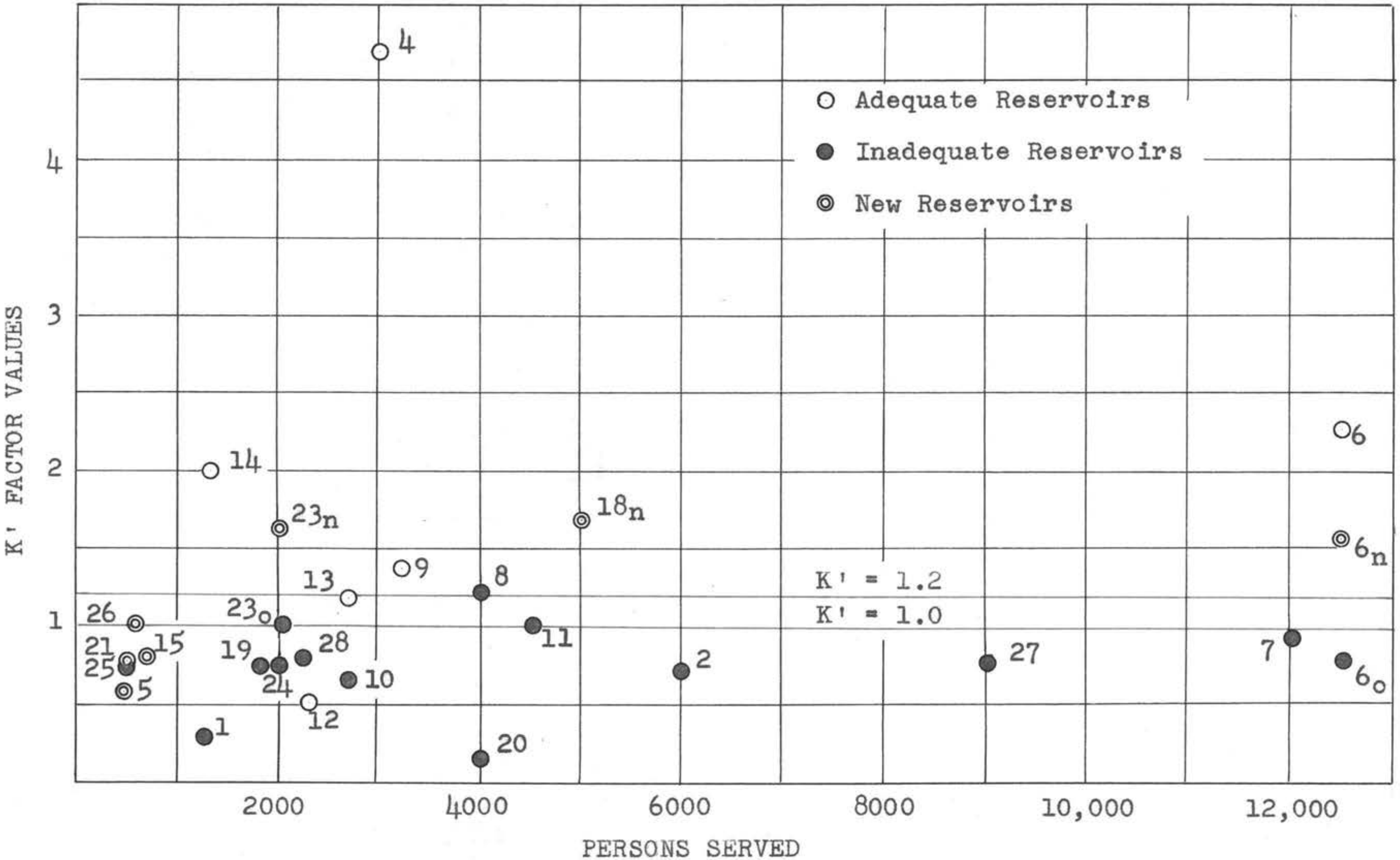

FIG. XIX. VALUES OF K' FACTORS

CHAPTER IX

SUMMARY AND CONCLUSIONS

It was noted that Figures XV and XVI indicated that most of the reservoirs having records of inadequacy or being too new to have dependable records fell below the line indicating a drainage area of two adjusted acres per person. The figure of two adjusted acres per person for funoff area was used as absolute minimum in computations of the K' factor.

Examination of Figures XVII and XVIII resulted in the selection of 100,000 adjusted gallons of storage per person served as the minimum value of reservoir storage. In these graphs most of the points plotted for inadequate reservoir storage fell below the line indicating 100,000 adjusted gallons per person.

The compensation between volume of storage and drainage area was well illustrated by reservoirs numbers (7) and (9). Reservoir (7) for the city of Emporia had adequate volume as indicated in Figure XVII, but fell far short of the required drainage area as shown in Figure XV. Reservoir (9) for the city of Gardner and the Olathe Naval Air Station was deficient in drainage area (Figure XVI) but had sufficient excess volume of storage (Figure XVIII) that the reservoir has given adequate service.

The most consistent guides to adequacy of reservoir

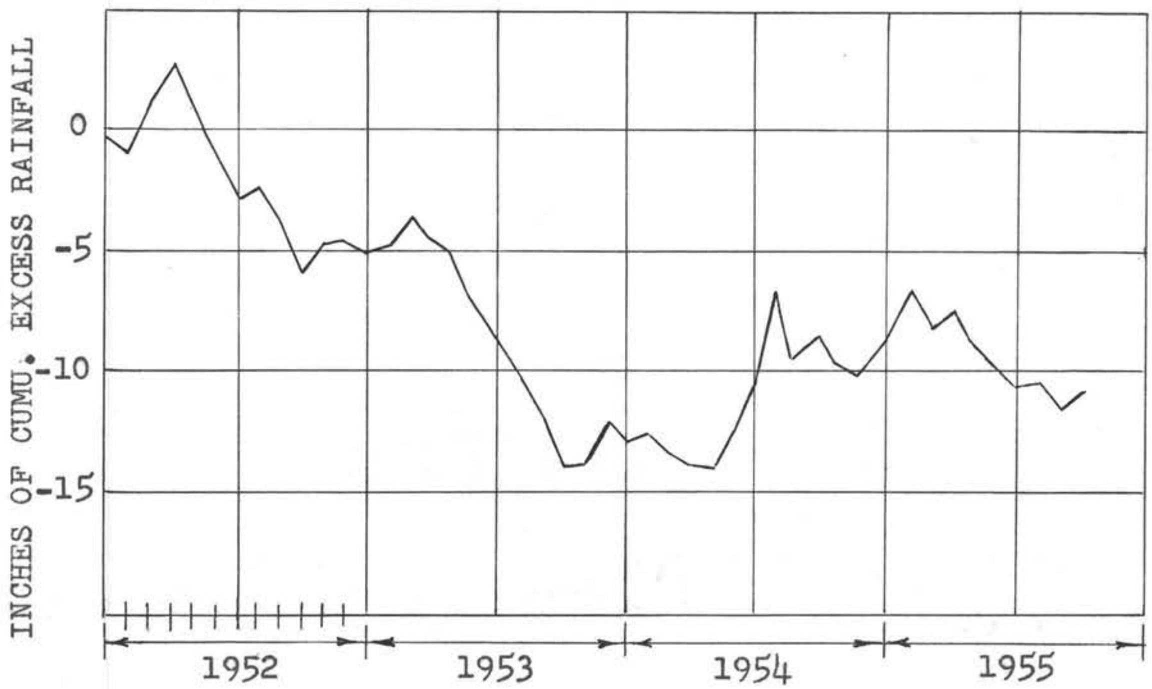

FIG. XX. CUMULATIVE MONTHLY EXCESS PRECIPITATION HOLTON, KANSAS

installations were the values of K' factors as plotted in Figure XIX. It was noted that nearly all of the K' values of new and inadequate reservoir installations fell below 1.0, and all were 1.2 or less.

It was recommended, then, that adjusted areas of 2.25 acres per person and adjusted volumes of 125,000 gallons per person be taken as desirable minimum design values. These figures gave a computed value of 1.2 for the K' factor. Minor variations from the values of 2.25 and 125,000 were felt to be permissible if the value of the K' factor did not fall below the recommended minimum design value of 1.2.

Ratio	Average for All Reservoirs
1. Drainage area (acres)/person	1.66
2. Volume (M.G.)/person	0.16
3. Adjusted area (acres)/person	1.46
4. Adjusted volume (M.G.)/person	0.14
5. Volume (M.G.)/drainage area (acres)	0.12
6. Volume (M.G.)/pool area (acres)	3.72
7. Pool area (acres)/drainage area (acres)	0.034
8. K' factor	1.13

TABLE VII. SUMMARY OF AVERAGES OF RATIOS

It was noted in Figure XIX that all but one of the values of K' less than 1.0 represented either inadequate or new reservoirs. The one exception was number 12, Holton's installation. Investigation revealed that the Holton reservoir was located in the glaciated area of Kansas and possibly has had the benefit of subsurface storage in the layer of highly pervious material deposited in this area.

Further investigation of Holton's record showed that the city has been fortunate during the 1952 - 1955 drought. As indicated in Figure XX, the Holton area has had a cumulative deficiency of about 14 inches of precipitation during this period. This deficiency has been less than half the shortage of moisture suffered by the rest of the State as shown by Figures VI to X, inclusive.

An example for persons interested in computing minimum design values for a proposed surface water supply reservoir was made as follows. A reservoir for a city of 3500 people in an area having an average rainfall of 35 inches per year required a minimum storage capacity of 125,000 x 3500 x 40/35 = 500,000,000 gallons. The same reservoir required a drainage area of at least 2.25 x 3500 x 40/35 = 9000 acres. These volume and area values gave a K' factor of 1.19 for the installation.

Average values of observed and computed data and computed ratios were summarized in Table VII. These figures represented the averages of available data on the reservoirs investigated in this study. They were tabulated for use in comparing proposed design features with similar characteristics of existing reservoirs.

The computed minimum and average figures and ratios in this study were intended to provide criteria to guide engineering judgement in reservoir design. They indicated values of pertinent factors for successful and unsuccessful existing reservoirs and attempted to supply numerical values which would show a line of demarcation between them. In common with all calculations, such computed values were intended only to provide comparative data, leaving the decision on final figures to experienced engineering judgement.

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