IMPACTS OF PHYSICAL AND BIOLOGICAL FACTORS AFFECTING THE ECONOMIC DEVELOPMENT OF IRRIGATION RESOURCES

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CHAPTER I

INTRODUCTION

The Problem

Irrigation is one of the most important ancient agricultural practices used by man. Oriental farmers have practiced the flooding of rice paddies for thousands of years. Irrigation systems are known to have been in use in Southwestern United States long before Columbus discovered America. Yet, in spite of the antiquity of this practice, very little is actually known of the influence physical factors have on irrigation farming, to say nothing of economic factors.

Irrigation is known to have been practiced in Oklahoma before statehood. How widespread this practice was is not known, but the earlier studies of the U. S. Geological Survey indicate that there was some irrigation as early as 1890.

Table I

Comparison of Total Land Surface, All Land in Farms, Total Acres Irrigated and the Percentage of Irrigated Land to All Farm Land.[1]

Years	Total Land Surface	All Land In Farms (acres)	Total Land Acres Irrigated	% Irrigated Land To All Farm Land
1953	44,341,120	(36,000,000)	92,500[2]	(.2569)
1950		36,006,603	44,209	.1227
1945		36,161,822		
1940		34,803,317	4,160	.0120
1935		35,334,870		
1930		33,790,817	1,573	.0046
1920		31,951,934	2,969	.0093
1910		28,859,353	4,388	.0152

[1] U. S. Census of Agriculture, 1950, V. III, pt. 2, p. 2-34.

[2] The Problem of Municipal and Industrial Water Supplies, Report to the Governor of Oklahoma, Conservation of Natural Resources Committee, Oklahoma Society of Professional Engineers, 1953, p. 19.

In recent years irrigation has become increasingly important to Oklahoma Agriculture. This is evident from the census data. (Table I).

The number of acres irrigated in Oklahoma has increased greatly whereas the total acreage farmed has remained relatively stable. More recent estimates of the number of acres irrigated are not available, but the increasing interest farmers have shown in irrigation leads to the belief that acreage under irrigation has greatly increased since 1953. (Fig. 1). A comparison between ground and surface water rights applications shows a greatly increased demand for ground water. While a number of these applications undoubtedly were from municipalities and industries, a large percentage of the ground water in Oklahoma is used for irrigation.

Estimates of the Oklahoma Society of Professional Engineers report that there are 2,012,000 acres of land in Oklahoma physically suited to irrigation development. Of this total acreage, however, they estimate that only 372,000 acres can actually be considered as potentially capable of development.[3]

There are several factors which limit the potential development areas to only about 18.5 percent of all the land physically capable. For example, in Western Oklahoma the quantity and quality of the available water is often inadequate for irrigation. In the East, limitations include the unsuitability of lands for irrigation, flooding hazards, and inadequate drainage. Economic feasibility, the most important limitation, exerts an influence upon irrigation in the entire state.[4]

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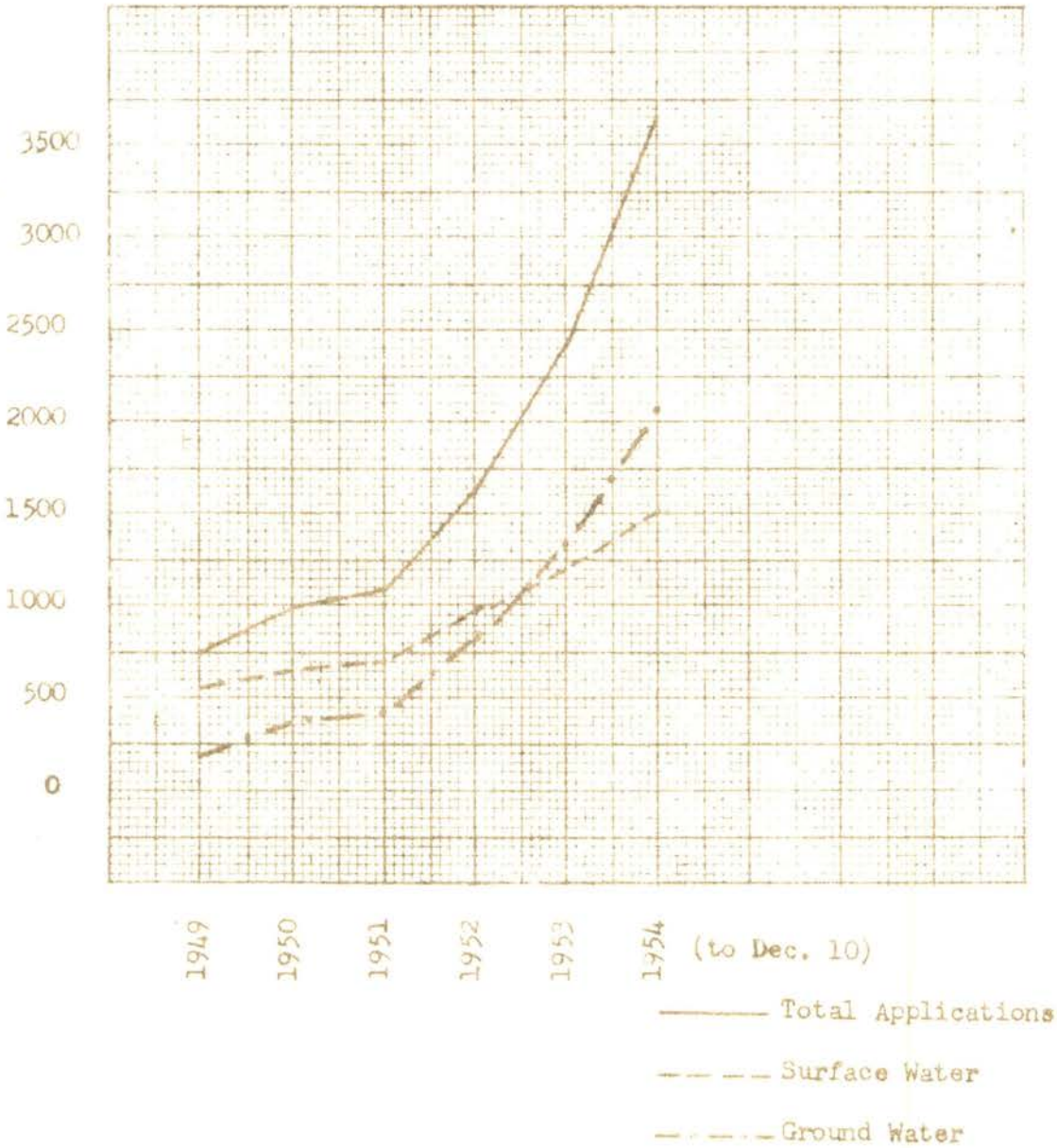
[3]*Ibid.*, p. 19.

[4]*Ibid.*, p. 18.

FIG. I WATER RIGHTS APPLICATIONS *



*Source: Unpublished data, Oklahoma Planning and Resources Board, Oklahoma City, Oklahoma.

While the above factors apply to major areas, it is known that within these areas combinations of resources are such that the above restrictions do not preclude irrigation. These are the areas for which this study was made.

Purpose of the Study

The primary purpose of this study has been to integrate physical and hydrological factors which influence irrigation farming. This has been done so that farm operators may have a better understanding of the factors which impose limitations and restrictions upon irrigation farming. These factors have been defined and explained in order to relate the more important aspects of each factor to the overall scheme of irrigation.

A corollary to the primary objective has been to assemble the basic data available from prior research pertaining to Oklahoma in order that future researchers will be able to review quickly, work done in the field. This will help to eliminate the "retread" research which has been characteristic of many areas of study. A second corollary is that of presenting the areas of deficiency in basic information on the overall problem of related irrigation research.

This study was undertaken in order to prepare the groundwork for an economic analysis of irrigation in Oklahoma. This type of research was beyond the scope of the present study since further empirical research must be done before economic evaluations can be made. This study hopes to show gaps which must be closed before economic studies can be made of irrigation in Oklahoma.

Farm operators who wish to adapt irrigation practices to their farms must consider first, the physical limitations of their land, second, the

adaptability of plants which can and would be irrigated, third, climate as a factor in irrigation, and fourth, the available water resources. These factors impose limitations and restrictions upon irrigation development.

Irrigation has been known to double, triple and even quadruple crop yields. These increases in yields are subject, in part, to the limiting factors outlined above, as well as the others governing the feasibility of irrigation.

Increases in production usually are responsible for increased income to farmers since the demand for agricultural products at the farm level is considered to be almost perfectly elastic. Thus with a horizontal demand curve, the increase in production results in an increase of total returns to the farmer.

Increased income from additional production however, may be offset by increasing costs. These increased costs due to irrigation are seen as economic limitations to justification of irrigation development. If the added costs can be more than offset by the additions to income from increased production, irrigation development is justified. The added net income resulting from greater marginal return in relation to marginal costs, will tend to increase the level of income the farm operator receives.

A higher level of income can be maintained if the operators are able to control the level of production. Production can be controlled so as to maintain a relatively higher level of output during such periods as the recent drouth from 1952-1955. By this means of control the farmer may be able to increase or at least stabilize his income level, one of the long-range goals in agricultural research.

CHAPTER II

REVIEW OF PREVIOUS RELATED STUDIES

General Comments

Specific knowledge of ground water resources in Oklahoma is inadequate because of lack of basic research. Early studies by the U. S. Geological Survey mentioned ground water resources briefly when they recognized the value of ground water as a potential source for industrial or municipal uses. A few studies of irrigation were made, but they were incomplete.

Studies made by government agencies, colleges, and other research groups in the areas of technology, soil, crops, and climate are rather plentiful. However, few have had more than an indirect applicability to irrigation and use of ground water resources.

It follows, therefore, that there are many blank spaces dealing with ground water resources in determining economic feasibility of irrigation systems from ground water basins. Certain physical data also are lacking. For instance, the percentage of an inch of rainfall which enters the soil that eventually reaches an aquifer remains unknown. Also, the rate at which water enters the soil, with the exception of the surface layer has not been determined.

The following presents, in a historical outline, the sequence of irrigation studies and the new areas of research.

Before 1900

Practically all research into the subject of water resources prior to 1900 was by the United States Geological Survey - Water Supply

Branch.[1]

In the earlier survey reports Oklahoma was included as a portion of a larger area. "Irrigation Practices on the Great Plains"[2] and "The High Plains and Their Utilization"[3], are typical titles of the earlier reports.

During this period ground water resources were treated as inconsequential or as non-existent. Ground water was accepted as being present, but probably was assumed to be of little economic value except for stock watering and household uses. This is shown by the indecision of the following quotation.

> "It is the purpose of this paper to show that the High Plains, except for an insignificant degree, are nonirrigable, either from streams, flowing or stored, or from underground sources, and that therefore, for general agriculture, they are irreclaimable; but that; on the other hand, water from underground is obtainable in sufficient amount for the reclamation of the entire area to other uses; that such reclamation has already begun, and is in process of gradual but sure development; and that it will be universally profitable."[4]

This quotation is a statement of the purpose of one of the reports of this period. The language is highly confusing and the data included in the paper fails to substantiate the ideas presented.

Other projects concerned in part with ground water resources, including those in the Oklahoma Indian Territory, were in process before 1900. The results and conclusions of the research were equally

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[1] U. S. Geological Survey, Water Supply Papers, No. 1-1181, 1897 to present.

[2] "Irrigation Practice on the High Plains," U. S. G. S., W. S. P., No. 5.

[3] Johnson, W. D., "The High Plains and Their Utilization," U. S. G. S., Annual Reports Part IV, pp. 600-741.

[4] Ibid.

as vague and irrelevant.

1901-1950

Early phases of research into the field of water resource development were hampered by two limitations. Gould, in 1905, presents these as being "considerable public resentment" and "no cheap method of elevating water from the depths required."[5]

The period from 1901-1950 was one of expanding knowledge. Separate studies in the fields of hydrology, crops, soils, irrigation, climate, and others were being developed. Also a considerable amount of study of subsurface geology was undertaken. Many of the studies contained data on the moisture content of the soil along with the analysis of well waters. Gould's paper includes a separate section on "well-water analysis."[6]

The first major development in studying ground waters for irrigation purposes came in 1914 when a report was published on hydrology research in the United States. The report contained two articles on irrigating from ground waters. The first article combined some of the earlier unrelated studies of wells, geology, soil, and climate which were placed in order and compared. This was the beginning of integrated studies of source and use of water. The second article was similar to the first, giving such information as occurrence and quantity of water, quality of water, and irrigation developments. Data were included in this article which helped substantiate and qualify the

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[5]C. N. Gould, "Geology and Water Resources of Oklahoma," U. S. G. S., W. S. P., No. 148, 1905.

[6]Ibid., p. 146.

statements made.[7]

Thompson presented a paper in 1921 on the subject of ground water irrigation. This paper was prepared following a very severe drouth in 1915-1918. The drouth had prompted the use of climatological, geographical, geological, and water analysis studies.[8]

In 1925, Renick made a survey of the "Additional Ground Water Supplies for the City of Enid, Oklahoma." This study gave recognition to the relationships of ground water to topography, soil, and vegetation. These factors are now recognized as being part of any study dealing with irrigation.[9]

As progress was made in the study of water resources, the legislature became aware of the need for more information on the subject in the state. Therefore, the Oklahoma Geological Survey was established by a legislative act in 1908. The work done by this organization was and is general, but is very well organized. Much basic information can be obtained from studies of these geological survey reports.

The first publication by the Oklahoma Geological Survey on ground water which was of any importance was prepared by Gould and Longsdale in 1926. This bulletin gives a detailed report on the geology of Texas

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[7]"Contributions to the Hydrology of the United States," U. S. G. S., W. S. P., No. 345, 1914.
a. A. T. Schwennesen, "Ground Water for Irrigation in the Vicinity of Enid, Oklahoma," pp. 11-23.
b. A. T. Schwennesen, "Ground Water for Irrigation in the North Fork of Canadian River near Oklahoma City, Oklahoma," pp. 41-51.

[8]D. G. Thompson, "Ground Water for Irrigation Near Gage, Ellis County, Oklahoma," U. S. G. S., W. S. P., No. 520, p. 33-53.

[9]B. Coleman Renick, "Additional Ground Water Supplies for the City of Enid, Oklahoma," U. S. G. S., W. S. P., No. 520 B, 1925.

County. A chapter on agriculture and another on water resources is included. Both are combined with many physical phases of geology as well as other natural conditions. A geological map of the county is included which shows the formations underlying the area.[10]

Another bulletin, "Geology and Ground Water Resources of Texas County, Oklahoma," contains a detailed report on geology and ground water in Texas County. Several comments on recharge of ground waters are noted in this bulletin. This is one of the first notices of any estimated amount of recharge other than mere mention of the process. Previous information was added to new information with greater emphasis being placed upon an overall study of the problem.[11]

"Ground Water Irrigation in the Duke Area, Jackson and Greer Counties, Oklahoma," "Ground Water in Kingfisher County, Oklahoma," and "Ground Water Supplies in the Oklahoma City Area, Oklahoma" are typical titles of the Oklahoma Geological Survey--Mineral Reports. These are condensed reports on production of irrigation wells or wells tapping the aquifers peculiar to the area. Some comments are included on recharges, yields, movements, discharge, and underflow.[12]

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[10]Charles N. Gould and John T. Longsdale, "Geology of Texas County, Oklahoma," Oklahoma Geological Survey, No. 37, 1926.

[11]Stuart L. Schoff, "Geology and Ground Water Resources of Texas County, Oklahoma," Oklahoma Geological Survey, No. 59, 1939.

[12]Oklahoma Geological Survey, Mineral Reports.

a. Stuart L. Schoff, "Ground Water Irrigation in the Duke Area, Jackson and Greer Counties, Oklahoma," No. 18, 1948.
b. Stuart L. Schoff, "Ground Water in Kingfisher County, Oklahoma," No. 19, 1948.
c. C. L. Jacobsen and E. W. Reed, "Ground Water Supplies in the Oklahoma City Area, Oklahoma," No. 20, 1949.

Many such bulletins and reports have been published by the Oklahoma Geological Survey. Most of these present detailed reports on ground water resources, but many of them have little value in an economic study of ground water.

A few studies related to irrigation have been made by the Oklahoma Agricultural Experiment Station in Stillwater. Most of the bulletins and circulars published by the college deal more specifically with the techniques of irrigation, although some mention is made of ground water used for irrigation.

Two reasons for the slow adaption of irrigation systems in Oklahoma are shown by Experiment Station reports as late as 1946. The first was the higher costs of production under irrigation, and the second was the deficiency of ground water studies. These limitations on background materials increase the difficulties of research in the economics of irrigation.[13]

A circular by the Experiment Station, "Irrigation for Oklahoma," includes points to consider in planning an irrigation system. Some yield data and other general information is presented, along with additional sources of information in the bibliography.[14]

Panhandle Oklahoma A. & M. Bulletins No. 64 and 65 present the general aspects of irrigation in the Oklahoma Panhandle. Along with these reports are the results from irrigating vegetables at the High

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[13]"Looking Forward in Oklahoma Agriculture," Oklahoma Agricultural Experiment Station, No. B-299, June, 1946, p. 48.

[14]"Irrigation for Oklahoma," Oklahoma Agricultural Experiment Station, No. C-131.

Plains Experiment Station in Goodwell, Oklahoma.[15]

Another phase of study during this period is presented in "A Chemical Analysis of Oklahoma Waters," a bulletin prepared by the Oklahoma A. & M. Engineering Experiment Station in Stillwater. This bulletin presents the hardness of water as a factor limiting irrigation in Oklahoma. (Hardness in this instance refers to the content of soluable salts.) A section in this bulletin, "Geology of Oklahoma Ground Water Supplies," gives a very good description and average hardness of water for each principal aquifer in Oklahoma.[16]

The census of irrigation in 1950 shows that during the period of 1901-1950, irrigation farming was not practiced to any great extent in Oklahoma. The census reports only 44,209 acres as the total land under irrigation from either surface or ground water. Therefore, irrigation was of only minor importance in relation to the total 36,000,000 acres of land farmed in the state.[17]

However, 1901-1950 was a time of horizontal expansion for Oklahoma in relation to studies of ground water resources. During this time the separate areas of resources were investigated and reported, and the major deficiencies found. The following deficiencies are clearly evident: (1) a lack of summary research reports, (2) a lack of combined

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[15]W. N. McMillen, "Deep Well Irrigation in Oklahoma," Panhandle Agricultural Experiment Station, No. 64, and "Irrigated Vegetables in the High Plain," Panhandle Agricultural Experiment Station, No. 65.

[16]Smith, Dott, and Workentin, "A Chemical Analysis of Oklahoma Waters," Oklahoma Engineering Experiment Station, No. 52, 1942, pp. 16-18.

[17]Irrigation of Agricultural Lands, U. S. Census of Agriculture, Arkansas and Oklahoma, Vol. III, part 2, pp. 2-34.

studies, (3) too much individual research, and (4) a lack of coordination between research agencies.

1950-1955

The period of horizontal expansion of research in ground water resources in Oklahoma has necessarily overlapped into this period. Recently, more of the research has been conducted in the basic physical problems of water resources use. Much of this research has been due to a greater realization by the public of the importance of ground water.

Several agencies have combined their efforts in order to place the problem of irrigation under the supervision of competent men. Agencies cooperating in this type of research are (1) The Oklahoma Planning and Resources Board, (2) The United States Geological Survey, (3) the Oklahoma Geological Survey, (4) The Oklahoma Research Foundation, (5) Oklahoma A. & M. College, (6) The Extension Service, (7) The Soil Conservation Service, (8) The Bureau of Reclamation, and (9) Several independent research foundations. Eventually data from these agencies may be coordinated as a source of fundamental information on the economic feasibility of irrigation from ground water.

At present, one of the greatest problems found in the water resources study is the fact that no single agency is responsible for dissemination of information. Many of the reports are made by one or two cooperating agencies who publish limited information. These reports are usually filled with descriptive information but fail to extend the area of factual knowledge. This "retread" process of reporting information is slow and not conducive to progress. There are, however, a number of helpful articles concerning ground water resources.

The Planning and Resources Board in cooperation with the U. S. and Oklahoma Geological Surveys has recently published one of the most complete reports on ground water, "Ground Water Resources of the Cimmaron Terrace." It covers all conditions and uses of ground water in parts of Kingfisher, Garfield, Major, and Alfalfa Counties. The bulletin contains general information such as topography, drainage, climate, agriculture, population, industry, formations, ground water, irrigation and industrial development. It also gives specific information relating to such things as hardness of water, local conditions, well reports, performance reports, detailed well logs with descriptions of formations, and expectable yields.[18]

The study of nine other areas in various stages of completion is being carried on at the present time. The difficulties of obtaining funds and competent research personnel for these projects have delayed completion of this series of reports.

The Soil Conservation Service has recently completed an "Irrigation Guide." This manual describes conditions affecting infiltration of water into the root zone, requirements of plants and other information.[19]

The Bureau of Reclamation has introduced recommendations for studies of ground water possibilities on the Arkansas River between Keystone, Oklahoma and Fort Smith, Arkansas. This was done in lieu of adequate surface water storage dams for irrigation, drainage, and

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[18]"Ground Water Resources of the Cimmaron Terrace," Division of Water Resources, Oklahoma Planning and Resources Board, No. 9, 1952.

[19]"Irrigation Guide," U. S. D. A., Soil Conservation Service, Oklahoma City, Oklahoma.

municipal uses.

All of the previous agency reports are roughly summarized in two publications: (1) "A Report to the Governor of Oklahoma"[20] and (2) "Oklahoma's Water Resources."[21] These publications are itemized estimates of future water needs for Oklahoma as based upon present knowledge. They include discussions on irrigation, municipal, and industrial uses of water, along with maps showing the approximate location of the ground water aquifers in the State.

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[20]"Report to the Governor of Oklahoma on the Problem of Municipal and Industrial Water Supplies for Oklahoma," The Conservation of Natural Resources Committee, Oklahoma Society of Professional Engineers, Jan. 9, 1953.

[21]"Oklahoma's Water Resources," Division of Water Resources, Oklahoma Planning and Resources Board, 1953.

CHAPTER III

THE RELATIONSHIP OF SOILS TO IRRIGATION

In order to determine whether or not a soil is capable of producing crops profitably under irrigation, it must be examined from the standpoint of the following:

1. Classification of the soils
2. Moisture holding capacity
3. Intake rate of soil
4. Effective depth of the soil
5. Percolation

Classification of Soils

For a soil to be adapted to irrigation, the surface layer must be medium or fairly fine textured and have a deep, mellow, open structure which allows easy penetration of roots, air, and water. It must have free drainage yet have good water holding capacity. This physical combination occurs most often in the recently deposited alluvial soils of the flood plain of streams or on alluvial fans. Another requirement which ordinarily is essential if a soil is to be irrigated is that it be relatively free of harmful salt or alkiline deposits. However, on alluvial soils, because of the stratified or layered construction of that type soil, such deposits are not always so important since it often has adequate drainage.[1]

Some of the upland areas were developed from older alluvial, lake-laid, wind-laid, or loessial deposits or from underlying bedrock. Loess soils are generally desirable for irrigation. Upland soils generally

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[1]"Soil, Water Supply, and Soil Solution," Yearbook of Agriculture, 1938, p. 706.

have a much more definite profile, greater uniformity of texture, and less variable stratification than alluvial soils. They are also more likely to have better surface drainage and to be freer of soluble salts. Many upland soils are coarse textured, sandy, gravelly or stony and have less waterholding capacity, lower content of organic matter, less nitrogen, and less available phosphorous than alluvial soils. Upland soils are less productive than the alluvial soils, but are less subject to damage by water logging.[2]

Generally, neither very sandy soils nor heavy clays are desirable for irrigation development. Sandy soils do not hold sufficient water, are relatively infertile, and are less productive under average farming practices than medium textured soils. The soils of medium texture--fine sandy loams, clay loams, and silty clay loams--are commonly more productive and more desirable for irrigation.[3]

Another characteristic to be considered in discovering whether a soil can feasibly be irrigated, is its profile. The soil profile refers to the layered construction of the soils and which regulates the degree of infiltration. Soils may range from highly permeable to very slowly permeable according to the texture of the soil profile. (Fig. 2) In addition, root development, an important factor in decision making for irrigation farming is affected by the soil profile.

Moisture Holding Capacity

The capacity of soils to retain moisture in the zone where it will be available to plants is known as the moisture holding capa-

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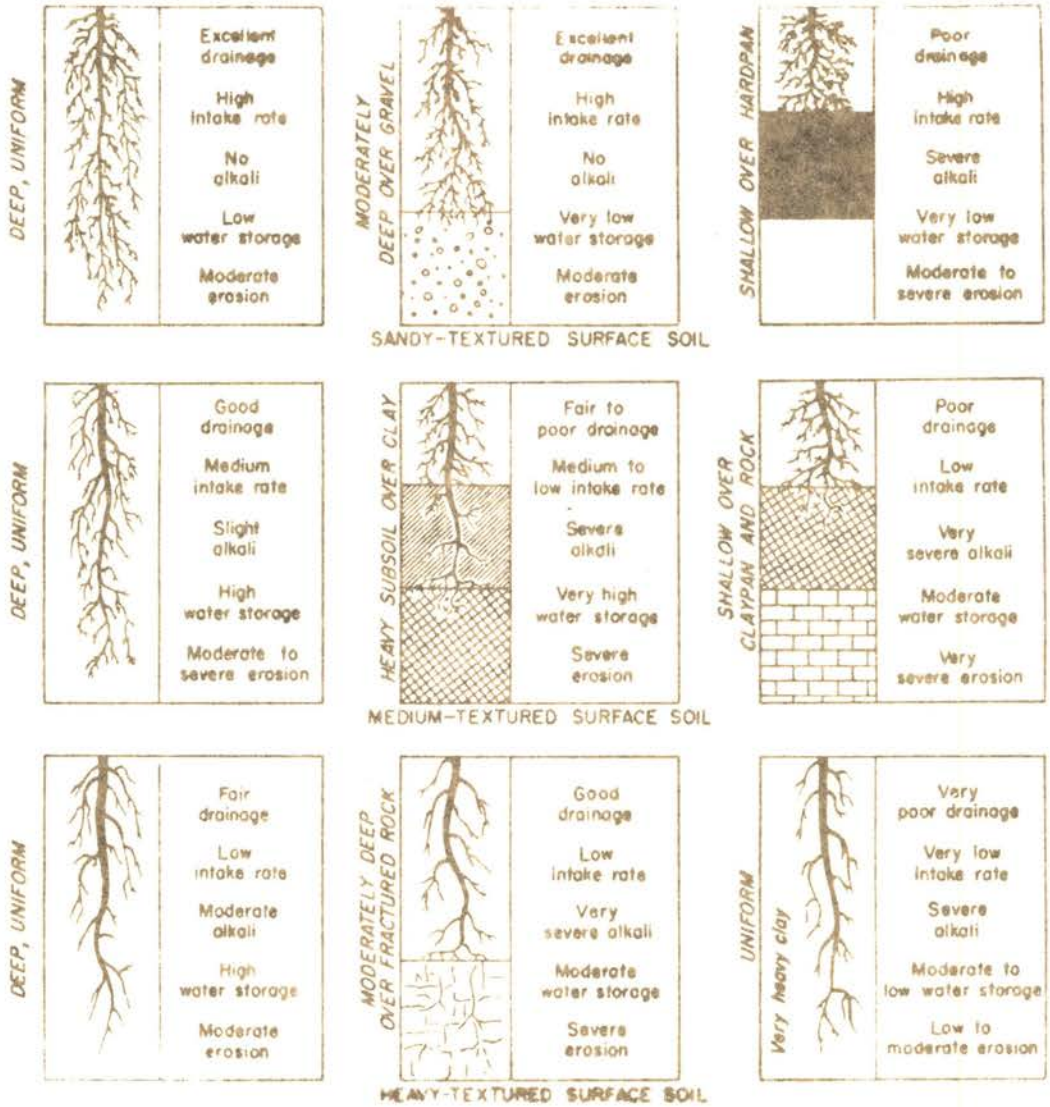
[2]Ibid., p. 706.

[3]Ibid., p. 706.

Fig. 2--The Effect of Difference in Profile for Some Typical Irrigated Soils*



*Source: Sprinkler Irrigation, Sprinkler Association, 1955, p. 38.

city. Moisture holding capacity depends upon several properties. These are soil pore space, texture, structure, and organic content.

The pore space of soils is the percentage of the soil's volume occupied by air and water. The pore space of sands and gravels is smaller than the pore space of clays. Soil particles in clays are smaller, leaving more room for air and water. Pore space which governs the amount of water the soil is capable of holding ranges from about one-third in sands to about two-thirds in heavier clays. In addition, the texture of the soil governs the speed with which water can enter the soil. Fine textured soils, do not readily admit water. Therefore, while having a great capacity for moisture storage such soils might, in fact, not be able to utilize the greater capacity because of this limitation.

A method of classifying soil according to texture has been prepared by the U. S. Department of Agriculture. This scale of classification is given below.

Texture	Diameter in Millimeters
1. Fine gravel	2-1
2. Coarse sand	1-1/2
3. Medium sand	1/2-1/4
4. Fine sand	1/4-1/10
5. Very fine sand	1/10-.05
6. Silt	.05-.002
7. Clay	.002-below

This classification will also provide a means for determining pore space and the quantity of water which can be absorbed by the soil. These can be done by computing total rainfall plus other additions of water and subtracting run-off and other losses.[4]

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[4]Sprinkler Irrigation, Sprinkler Irrigation Association, 1st Edition, 1028 Connecticut Ave., N. W. Washington 6, D. C., $6.50, p. 40.

A third characteristic which governs water holding capacity is the structure and organic content. A granular or crumbly structure in soil is better for irrigation because it is helpful to the soil in retaining water after once it has entered the soil storage reservoir.

The soil reservoir has a higher capacity for water when the organic content is high. However, soils high in organic content do not readily release the water to plant roots. Therefore, while the soil holds more moisture, the added moisture is not available to plants.[5]

A study was made of the water holding capacity of some irrigated soils in Oklahoma. This study showed that "the depth of water per foot of soil was 0.73 inches for sand, 1.43-2.21 for sandy loam, 2.21-2.64 for sandy clay loam, 2.41-2.68 for clay loam, and 2.69-3.21 for clay."[6]

Intake Rate of Soils

The rate at which soils absorb moisture from rainfall or other means of water application is called the intake rate. This rate varies on different soils and also within the same soil in a different location. The determination of an intake rate for an irrigation system is one of the most important considerations of planning, since it is necessary to maintain balance between the storage capacity, intake, and use of water. The intake rates of soil are governed by the slope, intensity, duration of application and other factors. It is from these

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[5] Ibid., p. 40.

[6] Walter G. Knisel, Jr., The Water Holding Capacity of Some Irrigated Soils of Oklahoma," Unpublished M. S. Thesis, Dept. of Agricultural Engineering, Oklahoma A. & M. College, May 1955.

factors that irrigation requirements are determined.

Slope is figured by the drop in feet for 100 linear feet. For example, a slope of 2 indicates a decrease of 2 feet in elevation for 100 feet in length. As the slope of land increases, the less water enters into it. Hence more water must be added in order to provide a safety factor to compensate for the water lost through additional run-off. The greater the slope the larger the safety factor needed to provide sufficient infiltration.

Another factor which governs the amount of water intake is the intensity of application. Intensity refers to the amount of water which is applied or falls upon the soil surface in a given length of time. The intensity of application of water to soil is important for the following reason. The maximum intake rate of a soil is governed by the size of the surface pore openings. When the rate of application becomes greater, whether from rainfall or irrigation, than the intake rate, a surplus of water upon the soil surface becomes evident. If the application rate continues faster than the intake rate the surplus water is lost through surface run-off.

Duration of application also is important in the intake rate. The intake rate of soil at the beginning of the application of water is relatively higher than at any other time. After the initial period of absorption the intake rate becomes less and less as the soil reservoir begins to fill. When the reservoir is filled to capacity then the soil will absorb no more water.

The intake rate will also be influenced by the type of vegetative cover. This varies from slightly higher rates of intake for crops with

small root systems.

The condition of the soil or the manner in which it is prepared to receive moisture is another factor which needs to be considered in irrigation farming. Poorly conditioned soils waste water and do not promote maximum returns under high water costs. The basic intake rate of soils as determined by the Sprinkler Irrigation Association are:[7]

Soil Types	Intake Rates Well Conditioned Soils	Intake Rates Poorly Conditioned Soils
Coarse sands	0.75-1.00" 1 hr.	.50" 1 hr.
Fine sands	0.50-0.75" 1 hr.	.35" 1 hr.
Fine sandy loams	0.50" 1 hr.	.30" 1 hr.
Silt loams	0.40" 1 hr.	.27" 1 hr.
Clay loams	0.30" 1 hr.	.25" 1 hr.

The above table is a guide for computing an approximate intake rate for a particular soil type.

Effective Depth of the Soil

The effective depth of the soil is the soil zone which can be used as the moisture holding reservoir. This zone varies anywhere from the surface layer to depths greater than root penetration. The effective depth must then be considered as being the root zone of plants.

Factors which limit the effective depths of soil are claypans, hardpans, rocks, and plowpans. These conditions all have the same effect, because each is a relatively impervious layer below which the available soil moisture cannot be used effectively. Root growth is limited to the zone above the layer, therefore, causing a lack of development in the root system.

This condition of soils requires more and lighter applications of water in order to be effective in producing crops. Fewer irrigations

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[7] Op. Cit., Sprinkler Irrigation, p. 56.

but heavier applications of water would only fill the reservoir to capacity, then waste the remainder in surface run-off.

Evaporation is higher in soils which have a shallow effective depth, since the soil moisture is closer to the surface which limits the effectiveness of the upper soil layer in the role of a mulch.

Percolation

Percolation is one of the least known characteristics related to soil. This process takes place when the gravity pull is greater than the tenacity between water and soil particles. When the gravitational force pulls the soil moisture downward beyond the reaches of the plant root system, it is called gravitational water.

Gravitational water moves through the subsoil at a rate commensurate with the texture of the subsoil. Subsoil infiltration functions exactly the same as surface infiltration, except that percolating waters are moving out of the zone of usefulness to plants.

There are few data on percolation of any consequence because of the number of variables which must enter into such calculations. A method of calculating percolation rates would be to compare the evaporation and transpiration losses to moisture holding capacity of the soil. The losses other than evaporation and transpiration from the soil reservoir would be due to gravity or percolation.

The rate of percolation is a governing factor or limitation to irrigation as the loss by this process causes a decrease in the available moisture in the soil reservoir. Therefore, it can be assumed that a soil and subsoil having a moderate rate of percolation are more desirable for irrigation.

CHAPTER IV

THE MOISTURE REQUIREMENT AND RESPONSE OF CROPS UNDER IRRIGATION

By proper water management the operator is able to exert considerable control over the quantity and quality of the crops he produces. There are two major factors which determine the amount of water an operator should apply if he is to efficiently utilize water under a system of irrigation. They are consumptive use of water and control of the level of soil moisture. Another factor is that of response of crops to the irrigation process.

Consumptive Use of Water

Consumptive use of water is the total amount of moisture evaporated plus the amount transpired by plants during the growing season.

The transpiration process includes all the water, from any source, used by plants during growth and development. This process is not necessarily related to the quality of the crop, however it is directly related to the quantity of the yield. A severe lack of soil moisture will result in diminished yield.

Water used in transpiration is absorbed from the soil reservoir by plant roots. It may either be used in building plant tissue or may be transpired from the leaf surfaces into the atmosphere. In this latter function water has served much the same as the human blood stream in carrying plant food to plant tissue. Since the plant has no pump which returns the water to the soil for re-use, this moisture leaves the plant through evaporation.

Evaporation describes the process by which water, instead of being used by plants, is lost from the soil reservoir by the reaction of water to the rays of the sun. These losses occur when water rises to or near the soil surface from the water reservoir by capillary action. The sun causes the water to form into vapor which rises into the atmosphere and is moved away by the wind.

Evaporation losses can be controlled to a degree by the vegetative cover, soil texture, condition, or by the number of applications of irrigation water.

Consumptive-use efficiency is the degree of efficiency with which water is used by plants. Factors which affect consumptive use efficiency are rainfall, stored soil moisture, net irrigation requirement, and control of evaporation losses.

The effect of rainfall upon consumptive-use efficiency is noted when the quantity of water entering the soil reservoir becomes more than is desirable for moderate plant use. This causes an increase in evaporation losses since the level of soil moisture has been increased. The rise in soil moisture content increases the capillary force which pushes more water towards the soil surface from whence it is evaporated.

The quantity of stored soil moisture is governed by the size of the soil reservoir which in turn is limited by the soil profile, the texture, and the other factors of limitation. The shallower the soil reservoir the higher the level of soil moisture that must be maintained for crop production because of the increase in the rate of evaporation. Also claypans and hardpans at shallow depths impose restrictions on the root system, thereby confining the roots to a smaller space. This smaller zone from which the plant may receive water restricts the amount of water which can be used by the plant. In turn the plant is limited in

the amount of water which can be used for transpiration. Lack of moisture for transpiration, coupled with a higher rate of evaporation in shallow soils, results in the inability of plants to withstand even short periods without the addition of water from some source.

The net irrigation requirement is the total quantity of water needed for the soil less the quantity held in that reservoir from the last application. This factor is governed by the soil texture, condition, and efficiency of consumptive use. It is important to consider those factors at the time of irrigating as these relationships are closely associated with economic feasibility of resource use.

As is explained in the preceding paragraphs, consumptive-use efficiency is governed largely by the control which the operator has over evaporation losses. Attention should be given to these factors in order that costs may not be prohibitive, labor can be minimized, and production may be maintained at a high level.

Consumptive-use studies for Oklahoma are in the preliminary stages of development. The need for this information has been only recently expanded to include a larger portion of the state. Some of the results are given below.

A study by Musick, of "Consumptive Use of Water by Corn, Grain Sorghum, and Forage Sorghum," at Fort Reno, Oklahoma, Livestock Experimental Farm, reached the following conclusions.

"The peak daily transpiration rate for corn was .345 inches; grain sorghum, .290 inches; and forage sorghum, .381 inches. The peak monthly rate for corn was 9.22 inches; grain sorghum, 8.60 inches; and forage sorghum, 11.61 inches. The seasonal transpiration and consumptive use were 22.29 and 26.70 inches respectively for corn, 18.25 and 21.91 inches for grain sorghums, and 21.74 and 23.68 inches for forage sorghum. Short moisture stresses in the corn and forage sorghum significantly decreased the yield, whereas, no significant

effect was noted for grain sorghum. The effect of doubling the recommended application of nitrogen did significantly increase the yield of forage sorghum, corrected to standard moisture content, 2.8 tons per acre."[1]

The "Irrigation Guide," published by the Soil Conservation Service, contains data on consumptive use of water by plants, but these data have proven to be inaccurate and are in the process of recalculation.[2]

Control of the Level of Soil Moisture

In order to adjust the amount of water applied commensurate with the need of plants, the operator must be capable of controlling the level of soil moisture. The reasons for this are evidenced by the moisture consumption of plants. The plant in its early stages uses very little water in development. As development proceeds toward maturity the plant reaches a point of high consumptive use. This peak is called the peak consumptive-use rate. After this point is reached the plant begins to use less and less water in transpiration. This decrease continues until the plant has reached maturity. As the water requirement decreases, smaller applications are required in order to supply the plant requirement without unnecessary waste of water through evaporation.

In many crops the moisture level of the soil governs the quantity and quality of yield in crops. The control which the operator has may, in effect, be the governing factor between high or low quality and high or low yields.

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[1]Musick, Jack Thomas, "Consumptive Use of Water by Corn, Grain Sorghum, and Forage Sorghum, Oklahoma, 1954," Unpublished M.S. Thesis, Dept. of Agricultural Engineering, Oklahoma A. & M. College, 1954.

[2]"Irrigation Guide for Oklahoma," U. S. Dept. of Agriculture, Soil Conservation Service, Oklahoma City, Oklahoma, 8 pp.

Maintaining a moisture content as high as could be physically utilized during periods of peak consumptive use may mean a sacrifice in water application efficiency and consumptive-use efficiency. Usually a compromise average will have to be found between quantity and quality and increased water requirements.

Irrigation requirements for some soils are available from the "Irrigation Guide for Oklahoma." This guide is the extent of the present available knowledge. The data are relevant only where variables approximate the description and texture of soils, effective root zone depth, adapted crops, adapted irrigation methods of design, intake rate for each design method, and estimated field efficiency. These and other data are given in the Irrigation Guide, but some are inapplicable and others are not applicable until the revisions are published.[3]

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[3] Ibid., Irrigation Guide.

CHAPTER V

CLIMATOLOGICAL FACTORS AFFECTING IRRIGATION

Climatological factors govern whether irrigation is needed and, to a great extent, whether it is profitable. The major factors which regulate desirability and profitability from irrigation are the amount and distribution of precipitation, the duration and frequency of drouths, the temperature, and the length of growing season. Wind velocity, a relatively minor climatic factor, must also be considered since it is either governed by or is a variable of the major climatic factors.

Precipitation

Precipitation includes rain, snow, and all other forms of moisture falling to the earth's surface measured in inches of water. Snow and ice are converted into water equivalents by conversion factors. The average annual precipitation in Oklahoma ranges from 56 inches in the Southeast corner to 17 inches in the Western tip of the Panhandle. (Fig. 3).[1]

Precipitation falling during April through September is considered to be more beneficial to crops than rains of the Fall and Winter months as this is the growing season for most plants. During periods when soil moisture carry-over is adequate for supplying plant requirements, rainfall during the growing season is, of course, less important. The average warm-season precipitation for Oklahoma ranges from 28 inches in the Southeast corner to 12 inches in the Western tip of the

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[1]Climate and Man, Yearbook of Agriculture, 1941, p. 1073.

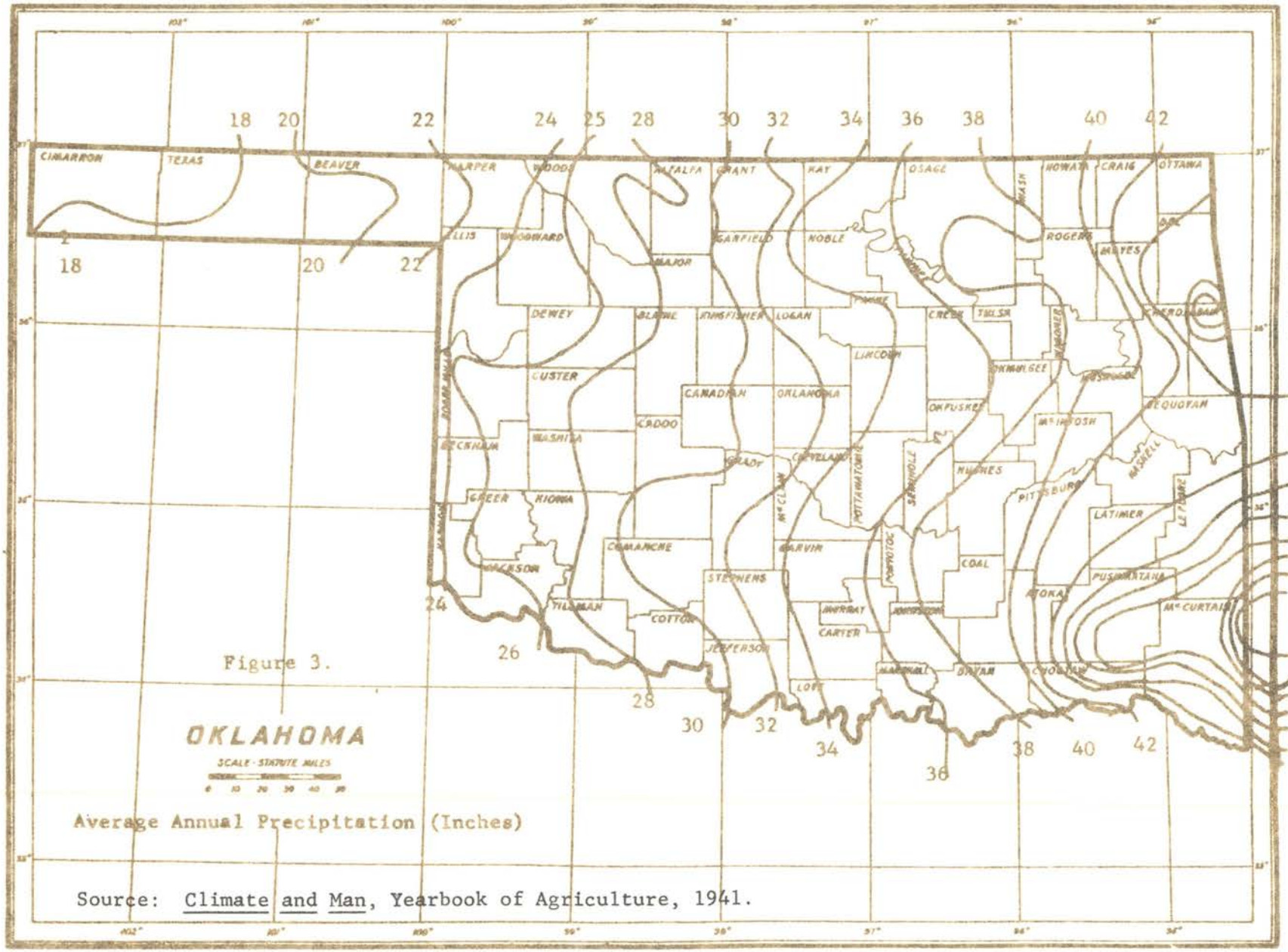

Figure 3.

Average Annual Precipitation (Inches)

Source: Climate and Man, Yearbook of Agriculture, 1941.

Panhandle. (Fig. 4).[2]

Precipitation may be distributed evenly throughout the year or it may occur in relatively uneven amounts. An analysis of annual precipitation shows deviations from the average to be extremely high in Oklahoma. High intensity storms in areas of low rainfall in the western part of Oklahoma may deposit from one-half to three-fourths of the total annual rainfall in a few hours. This irregular distribution of rainfall may or may not add enough water to soil for adequate development of plants. Even in eastern Oklahoma where the average annual rainfall is as high as 40 to 50 inches per year, and where the variations from normal are less pronounced, crops are materially affected by periods of too little or too much rainfall.[3]

The distribution of rainfall is the prime determinant of whether or not irrigation is needed. During high rainfall periods moisture may be so unevenly distributed that irrigation is needed if a sufficient amount is to be available for crop production. On the other hand, it is possible that in a low rainfall period moisture is so well distributed that it all becomes available for crops and supplemental water is not needed.

Drouths affect plant development by allowing the soil moisture to become used without replenishing the soil moisture reservoir. This lack of replenishment may be severe enough to deprive the plant of

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[2]Ibid., p. 1072.

[3]"Report to the Governor of Oklahoma on the Problem of Municipal and Industrial Water Supplies for Oklahoma," Prepared by the Conservation of Natural Resources Committee, Oklahoma Society of Professional Engineers, January 9, 1953, p. 5.

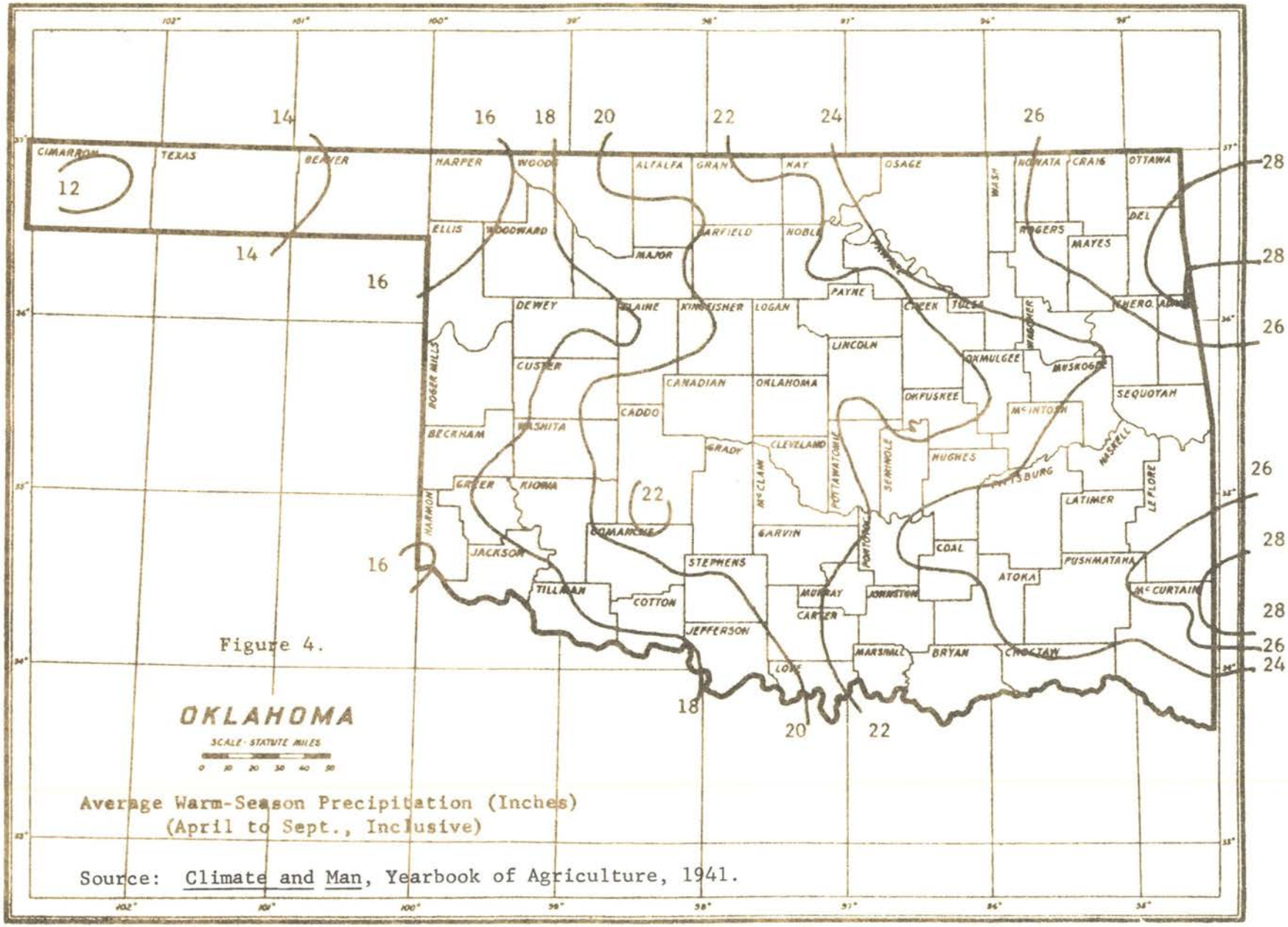

Figure 4.

Average Warm-Season Precipitation (Inches)
(April to Sept., Inclusive)

Source: Climate and Man, Yearbook of Agriculture, 1941.

sufficient moisture, to the point of actually killing it through starvation for plant nutrients or the lack of water in sufficient quantities for transpiration. Twenty-day drouths occurred on the average 2.5 times a year during a 20 year period, and the average number of thirty-day drouths was 1.125 times per year during the same period. (Fig. 5 and 6).[4]

Occasionally severe drouth periods occur such as were experienced from 1952-1955. There are records of other periods of two or three years duration in which the total precipitation was abnormally low. These low precipitation periods do not produce enough moisture to replenish the soil reservoir and provide moisture for crop production. During such extended drouths, farm production is comparatively low, thereby lowering farm income.

Research data indicate that long, severe drouth periods occur in cycles of approximately 20 years in length. Throughout these periods soil moisture content is low, and since quantity and quality of crop yield depends upon soil moisture content, it follows that quantity and quality of crop yields will also be relatively low during drouths. Conversely, soil moisture content may be high during periods of high rainfall, hence the quantity and quality of yields will also be high. Assuming that these relationships are true, and also assuming that adequate resources are available, the farm operator can consider trying to overcome drouth through irrigation. (Fig. 7).[5]

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[4]"Socio-Economic Atlas of Oklahoma," Oklahoma Agricultural Experiment Station, Miscellaneous paper, 1936.

[5]Op. Cit., Report to the Governor of Oklahoma, p. 5.

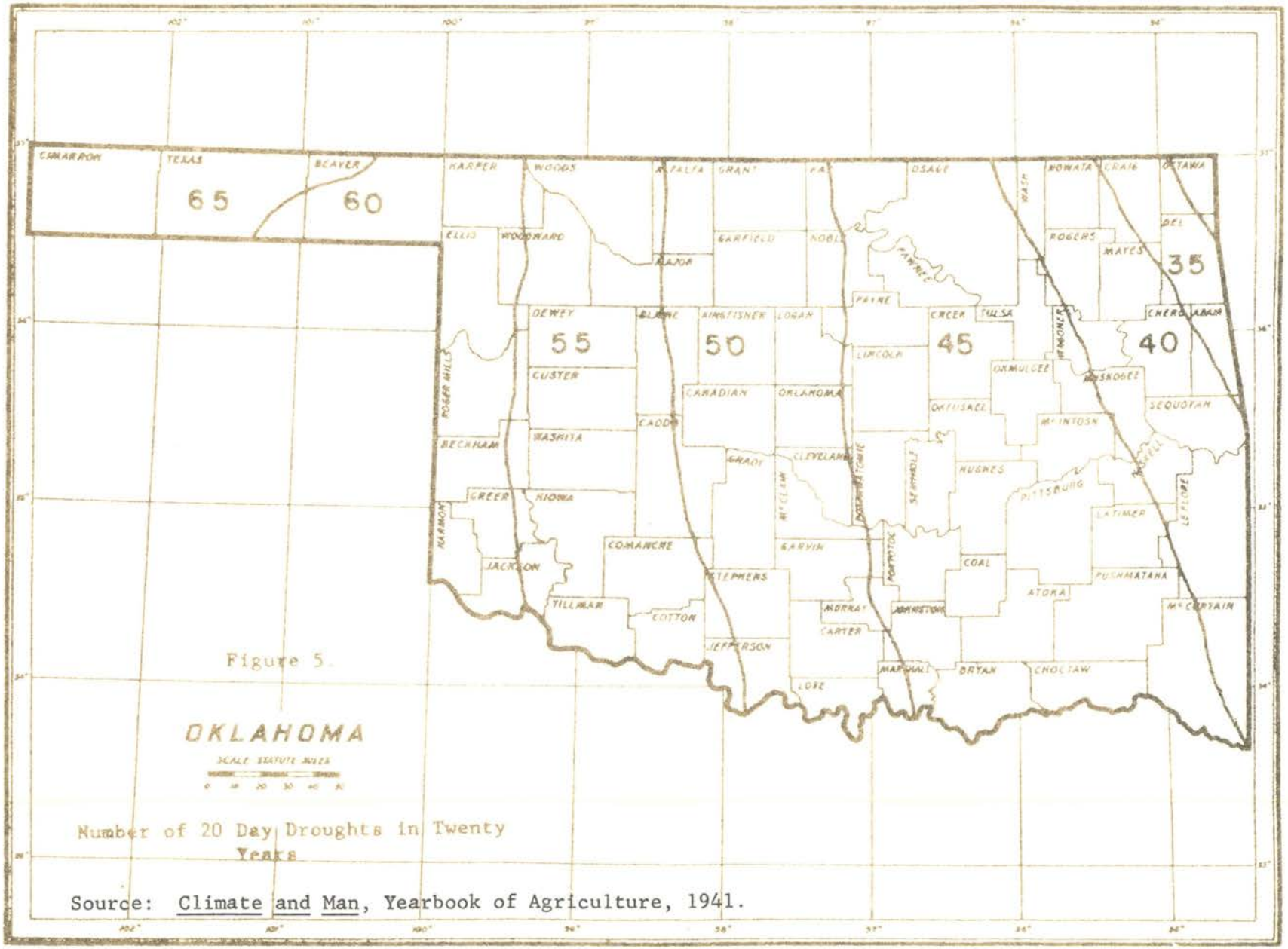


Figure 5.

Source: Climate and Man, Yearbook of Agriculture, 1941.

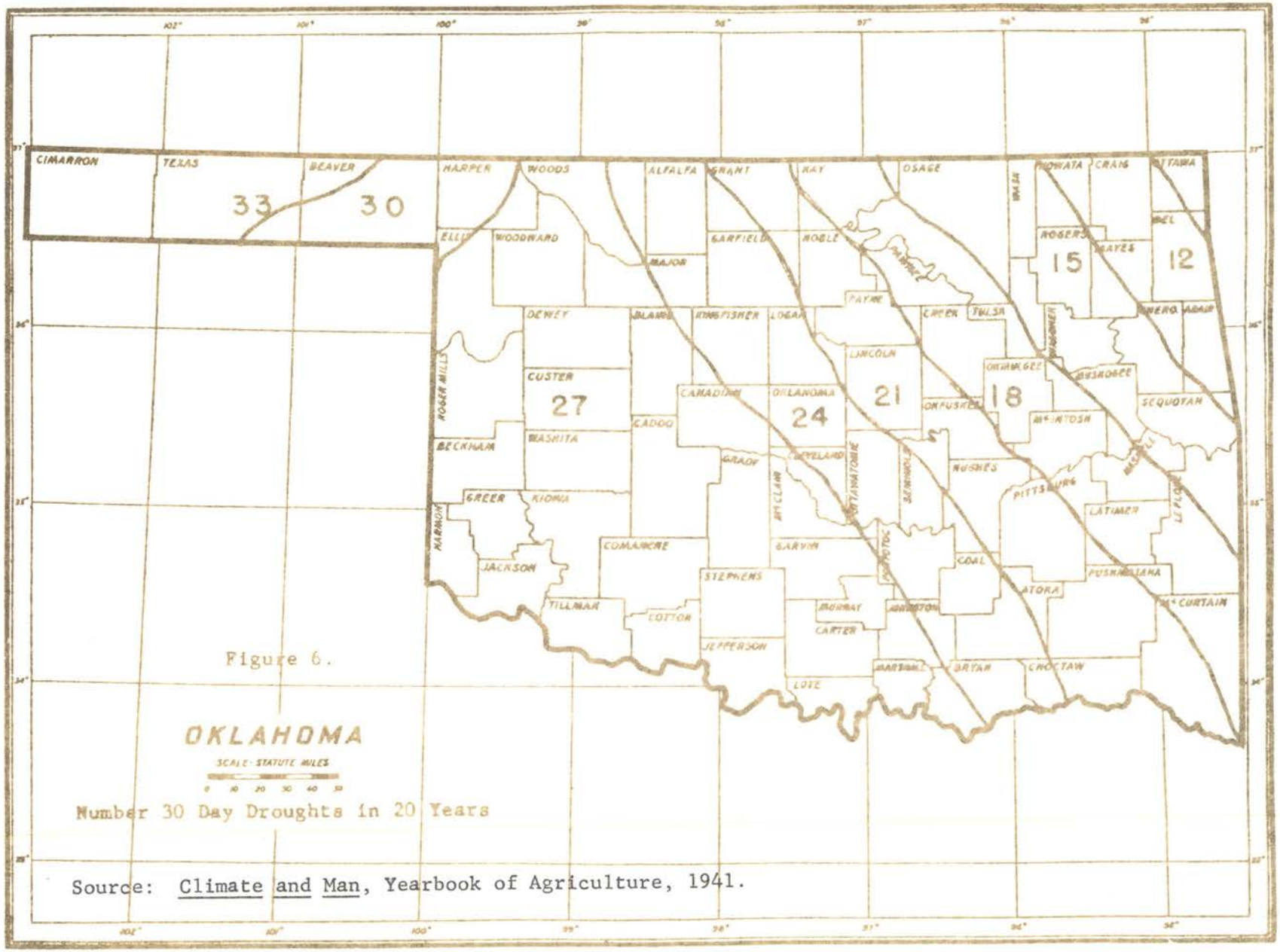
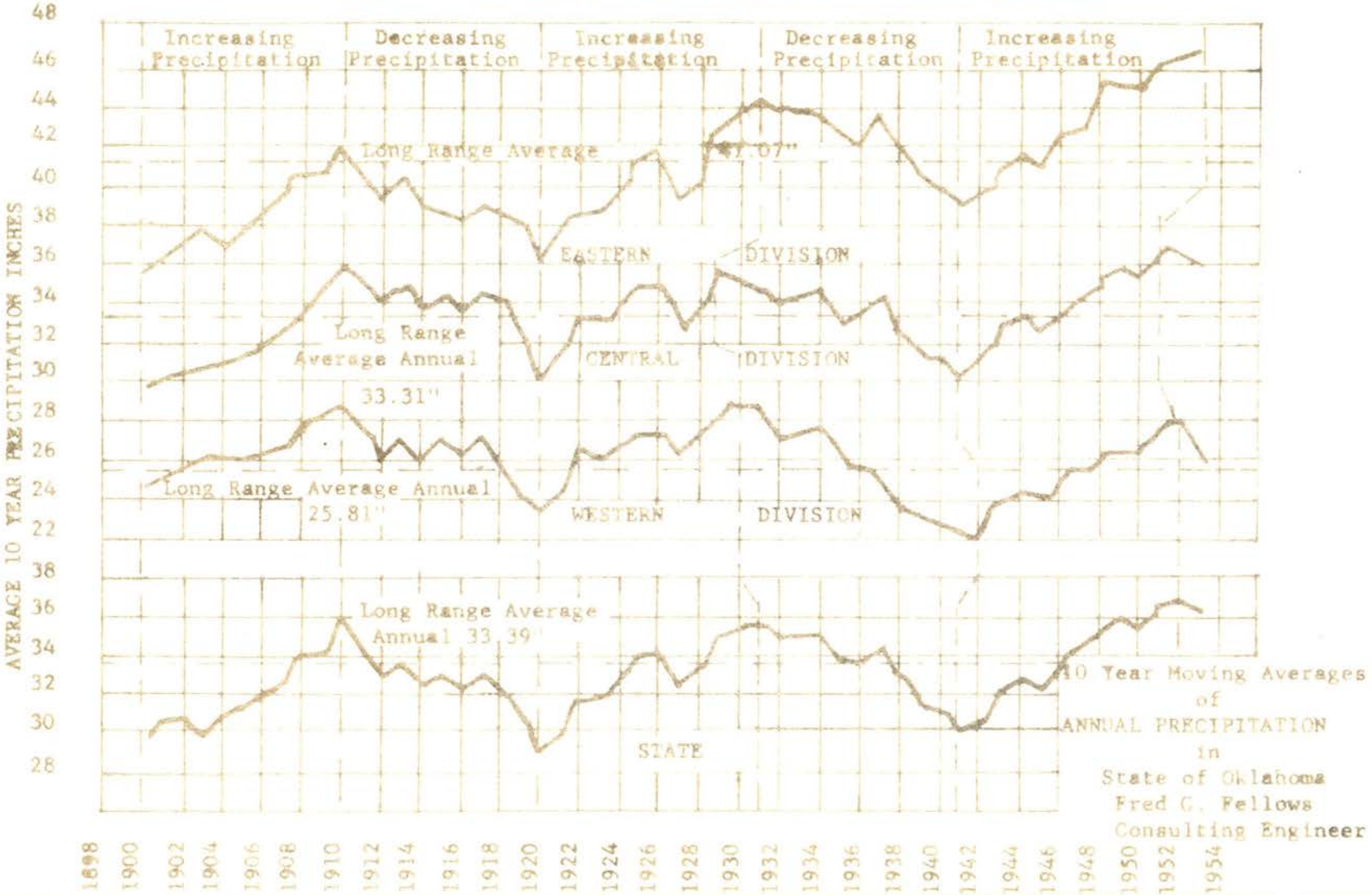


Figure 6.

Source: Climate and Man, Yearbook of Agriculture, 1941.

Fig. 7. Ten Year Moving Averages of Annual Precipitation*



(Note: Each point denotes average for preceeding 10 years.)

*Source: Climate and Man, Yearbook of Agriculture, 1941.

Temperature

The temperature extremes for Oklahoma range from 20 degrees below to 125 degrees above zero Fahrenheit. The annual temperature averages 60.8 degrees. The mean temperature through June, July, and August was 80.6 degrees for the year. The mean temperature through November, December, January, and February was 42.3 degrees.[6]

Temperature is one of the most important climatological factors in irrigation, since it regulates the rate of consumptive use of soil moisture through evaporation and transpiration. As pointed out earlier, consumptive use of water takes place when the temperature turns soil moisture into vapor. As temperatures increase, consumptive use increases. During the Summer months, when temperatures are highest, consumptive use is at its peak, conversely, in the Winter when temperatures are lower consumptive use is negligible.

Growing Season

The growing season is determined by the number of days from the last killing frost in the Spring and the first killing frost in the Fall. Although the exact dates vary from year to year, an average figure is useful in studying the growing season. (Figs. 8, 9, 10). The frost-free period ranged from 240 days in the Southeast to 180 days in the western tip of the Panhandle.[7]

The growing season is an important consideration in irrigation. If a farm operator is to irrigate he must select his crops with growing

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[6]"Climatological Data," U. S. Weather Bureau, Oklahoma, 1953 yearly summary.

[7]Op. Cit., Climate and Man, p. 1071-1072.

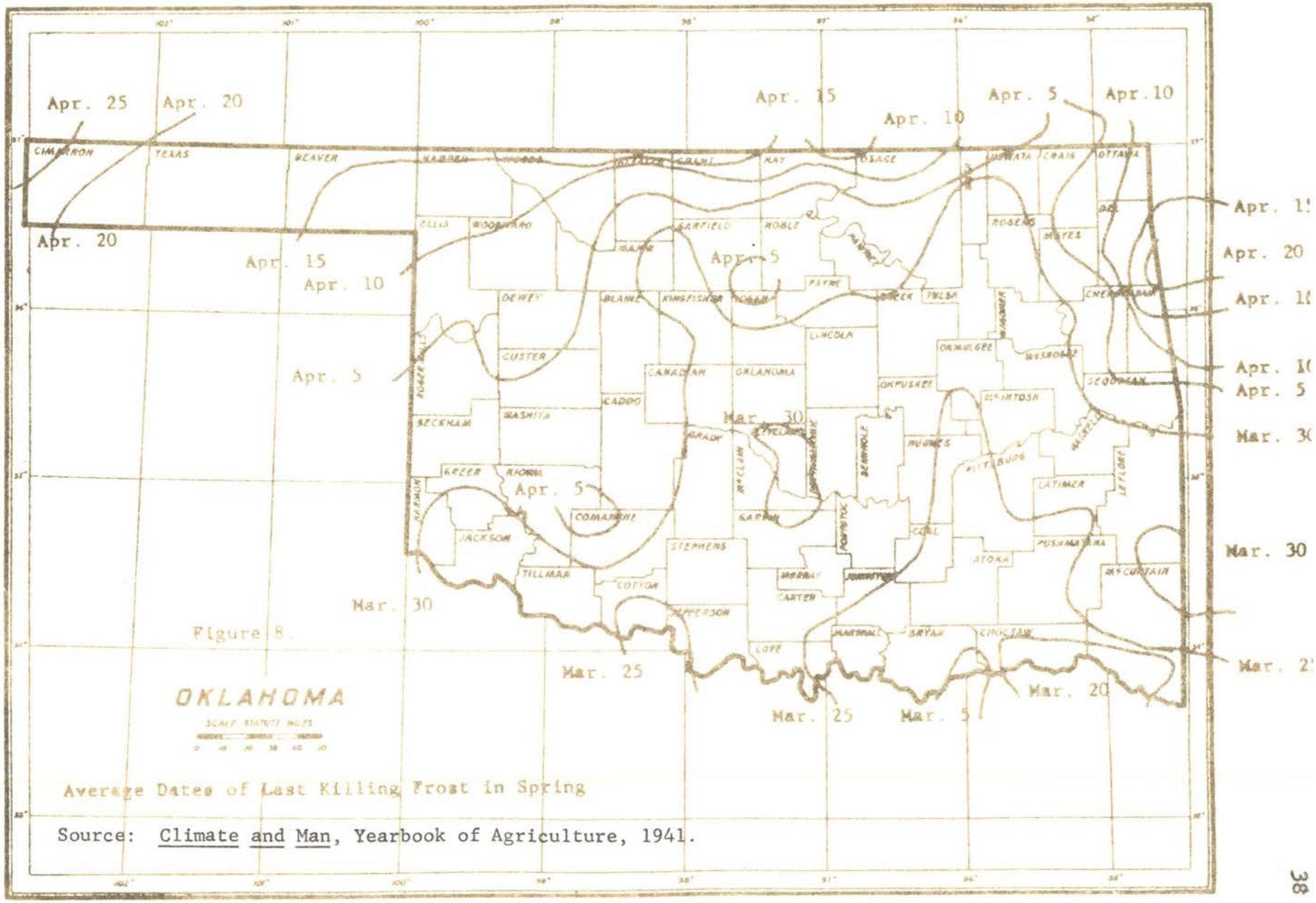

Figure 8.

Average Dates of Last Killing Frost in Spring

Source: Climate and Man, Yearbook of Agriculture, 1941.

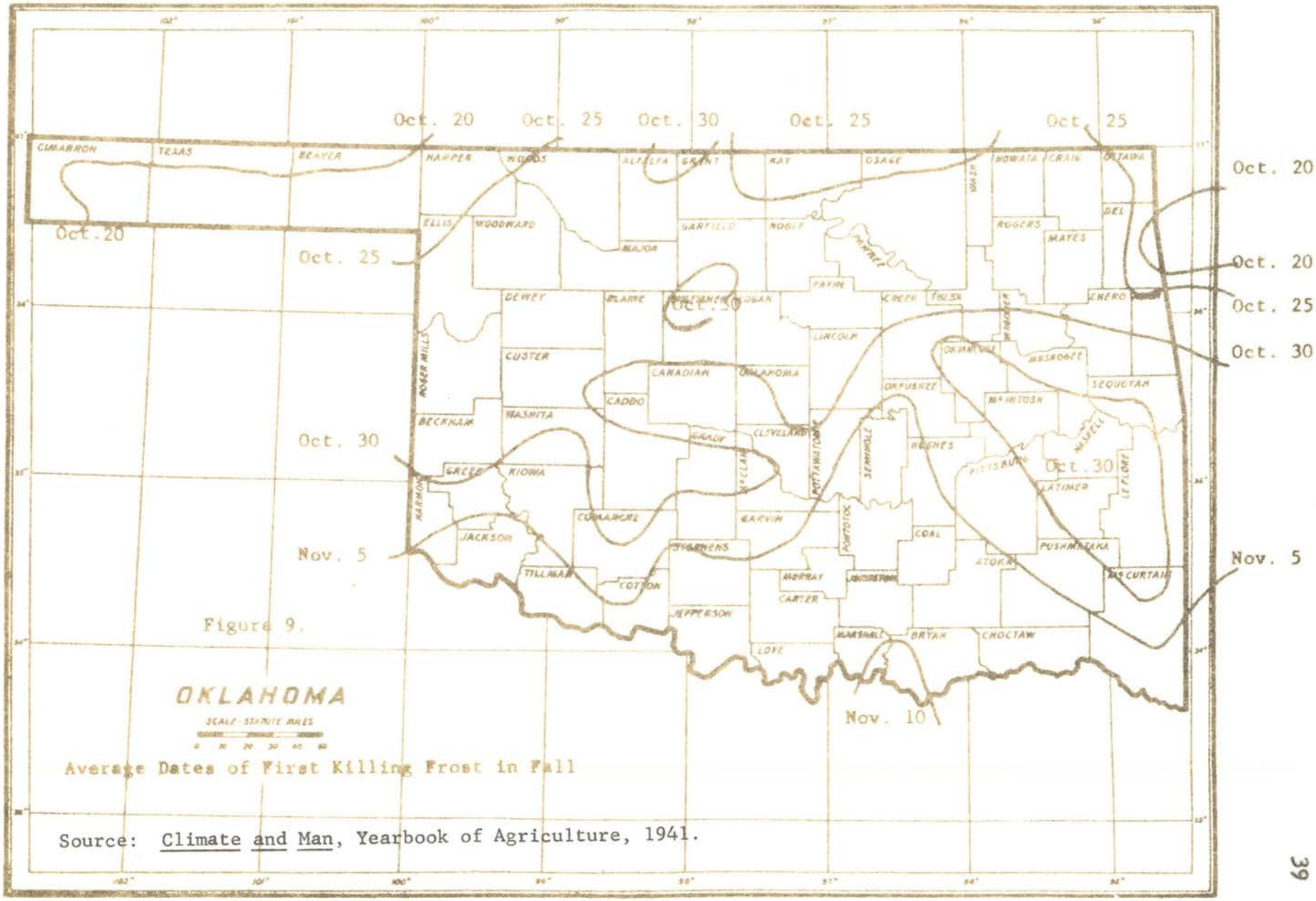

Figure 9.

Average Dates of First Killing Frost in Fall

Source: Climate and Man, Yearbook of Agriculture, 1941.

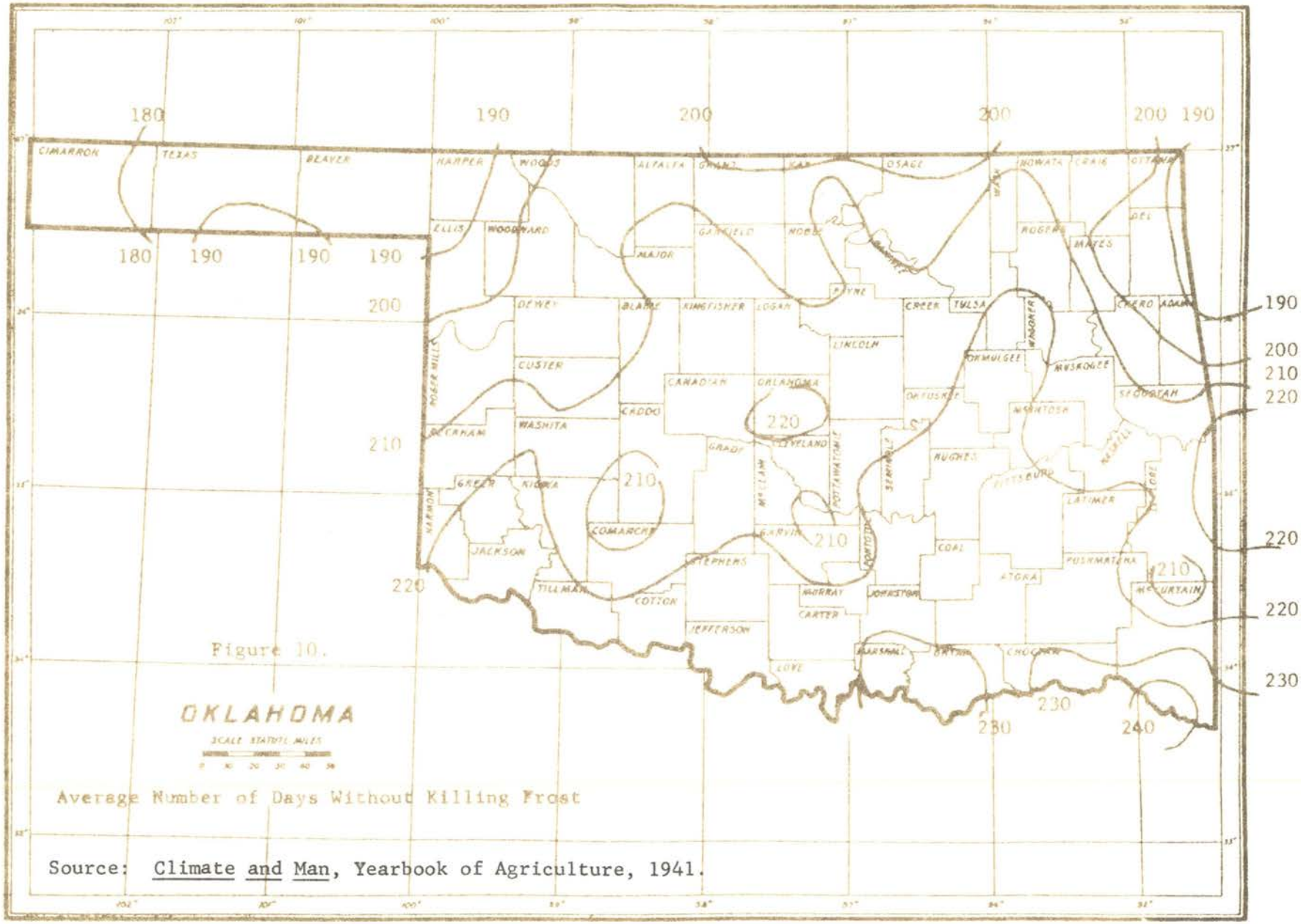

Figure 10.

Average Number of Days Without Killing Frost

Source: Climate and Man, Yearbook of Agriculture, 1941.

periods adapted both to the farming area and to irrigation. However, it does not follow that a crop adapted both to the growing period and to the soil, is capable of producing an economically justified yield under irrigation.

Wind Velocity

Wind velocity is the speed the wind moves over the earth's surface. This climatic variable is the most unpredictable and least understood of all climatic conditions. Wind velocities in Oklahoma range from complete calms to storms of destructive force.

The speed at which the wind moves over land surfaces will be an important factor in regulating the relationship between temperature and consumptive use of water. It is known that evaporation is more rapid with higher rates of wind velocity, particularly when they are dry. Likewise, since transpiration includes evaporation from leaf surfaces, the transpiration process is increased. Consequently, consumptive use increases with increase in velocity. However, the exact extent to which wind velocity affects consumptive use is not known. The high degree of variability in wind velocity within a given period makes a study of the relationship of wind velocity and consumptive use of water impractical.

The prevailing wind in Oklahoma blows from a southerly direction in the Spring and Summer and from a northerly direction in the Fall and Winter. The direction from which the wind comes affects temperature. Winds from southerly directions usually are warm and tropic while winds from northerly directions usually are cold and arctic. Winds from the south and southwest bringing hot and dry air, increase temperatures, thereby causing corresponding increases in consumptive use of water.

Humidity, another important climatic variable, has an opposite effect upon consumptive use. This variable refers to the amount of moisture held in the air. Periods of high humidity in Oklahoma generally result when winds carry humid air into the area, usually from the Gulf of Mexico. Often, immediately following rains during high temperature periods, the atmosphere will register a high degree of humidity, 90-98 degrees. When humidity is high, consumptive use is usually lower. Air which is heavily laden with moisture cannot take on as much additional moisture as can dry air which causes deceleration in the consumptive use processes.

Cloud formations tend to form layers which restrict the direct sunlight, thereby decreasing temperatures. Therefore, days in which a large mass of cloud formations are present will have a relatively low maximum temperature. Hence, consumptive use is decreased by cloudy conditions.

One idea common among farmers is that an area frequently subjected to hot, dry winds may not be suitable for irrigation as plant transpiration may be more rapid than the ability of the plant to take moisture from the soil. There is not sufficient evidence to substantiate the opinion, yet observations by farm operators indicate some degree of truth in the idea.

Climate in relation to irrigation should be studied in order to determine such factors as the level of moisture content to be maintained in the soil, the crops to be grown, and variations in applications needed due to climatic conditions. These decisions should aid in developing a stable, well rounded, and economical irrigation system for farms.

CHAPTER VI

IRRIGATION WATER RESOURCES IN OKLAHOMA

In order for water to be available in large enough quantities for irrigation use, it must be retained in a reservoir of suitable size and availability. There are two types of reservoirs which contain suitable quantities of water for irrigation; surface and underground reservoirs.

Surface Waters*

Surface water is the precipitation of all kinds impounded or flowing upon the surface of the earth. Impounded water is that held in lakes and ponds caused either by damming up natural waterways, streams, and rivers, or by storing surface run-off or drainage water in artificial lakes. Flowing water is that in streams of rivers, not retained by dams or other obstructions. Another source of flowing water is found in springs fed from underground water.

In 1952 there were 665 lakes in Oklahoma, ranging in size from ten acres on the smallest to 93,080 surface acres on Lake Texoma the largest. They have a combined surface acreage at a capacity of approximately 260,000 acres. The total quantity of water detained in these reservoirs is approximately 6,433,000 acre feet at storage capacity. Other large lakes in the state are in various stages of completion, which together have a

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*A general summary of Oklahoma's surface water resources occurs in the Planning and Resources Board Booklet, Oklahoma's Water Resources.

combined surface acreage of approximately 234,000 acres, and a storage capacity of approximately 6,607,000 acre feet.[1]

There are, in addition to these lakes, approximately 95,000 farm ponds in Oklahoma of less than ten surface acres in size. The number of acre feet of water stored in these reservoirs is not known, but they are limited for irrigation uses by size and annual rainfall.[2]

The major rivers of Oklahoma, from which water in sufficient quantity and of acceptable quality could be obtained are; the Arkansas, Canadian, Cimmaron, Illinois, Grand, North Canadian, Salt Fork, and Verdigris Rivers and Wolf Creek in the Arkansas River Basin. In the Red River Basin they are the Blue, Kiamichi, Little, North Fork, and Salt Fork, and Washita Rivers, and Muddy Boggy Creek. These larger streams usually flow the year round. However, there may not be sufficient water to provide for large scale irrigation projects in drouth periods.

Other smaller streams, creeks, and branches are capable of supplying water for irrigation at times but most of them dry up during periods of critical moisture needs.

In some areas of the state where large claypan or hardpan formations are found, the U. S. Government is in the process of constructing large reservoirs for irrigation and flood protection. Therefore these reservoirs have a dual function, providing water for irrigation, and decreasing the hazards of down-stream floods. These reservoirs will permit the retention of run-off water which may be placed back upon the land in a more uniform

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[1] Ibid., pp. 8-18.

[2] Ibid., Oklahoma's Water Resources, p. 12.

manner, thus allowing it to be used for irrigation development.

Springs may provide sufficient water for irrigation, but these are few and their limitations are many. Usually their limitations are location, yield of water, and quality of water.

The pattern of flow of surface water in wet and dry cycles is highly variable, depending upon the length of the wet or dry season. If precipitation is normal or above, then rivers, streams, and other flowing waters are relatively deep. The reverse is true during dry periods. Consequently, since most lakes and reservoirs depend upon rivers and streams as a source of supply, these reservoirs will also become relatively low on water during dry periods.

Quantity and quality of water in an area should be carefully evaluated before developing irrigation systems. Quantity is a relationship between available or potential supply and the consumptive use. Quality is dependent upon the content of different materials or constituents in the water. Some of these constituents which affect water quality are salts, silt, and industrial wastes.

Some streams in Western Oklahoma pick up salts when flowing over aklaline deposits. The presence of these salts in the water lessens its value for irrigation. Total salt content may be as much as 2,000 parts per million and be usable for some crops such as milo, rape, kale, cotton, bermuda grass, rescue grass, and Western wheat grass. Other crops which are moderately tolerant of salt such as small grains, alfalfa, brome, fescue, oats, and others cannot be irrigated with water which has a salt content this high. Crops with relatively low salt tolerance such as vetch, peas, celery, potatoes, white dutch clover, alsike clover, red

clover, and ladino clover may require relatively pure water, 100-150 parts per million.[3]

Silt affects quality of water because of its tendency to fill up pore spaces in soils with small particles of clay, thus lessening the moisture holding capacity of the soil, consequently, the value of that soil for irrigation.

Industrial wastes pollute water by contamination with salts, oil, and other foreign materials. These constituents of water seriously limit its use for irrigation.

Water quality can be improved to some extent by adding gypsum to salted water, settling silt in tanks, and mixing suitable water with unsuitable water to lessen the over-all content of salt in total water. For example, water of low enough salt content to be used on moderately tolerant or slightly tolerant crops, may be obtained by dilluting the water high in salt content with water low in salt. This mixture may provide enough suitable water for irrigation to meet quantity requirements for moisture.

Surface waters available for irrigation in many western sections of the state are limited by the water flow in relation to the land area, inadequate rainfall to provide run-off to fill reservoirs as well as the quality factor. The relatively wide but shallow stream beds do not provide suitable or adequate water storage capacity in that the area benefited may not be sufficient to justify flooding of large areas of usually superior land. The eastern section of the state has, however, plenty of

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[3] Op. Cit., Sprinkler Irrigation, p. 407.

water but not enough lands suitable for irrigation.

Ground Water*

Ground water in Oklahoma occurs in sand, gravel, limestone, dolomite, and gypsum formations. These formations range in age from the Cambrian and Ordovician of the Arbuckle group to the recently laid stream sediments. Where porous, permeable geological formations are found near the surface, and contain no undesirable soluble minerals, moderate to abundant water supplies are found. Where the formations are not so favorable, enough can usually be found for "stock water" or "domestic use" on most farm units. These formations are known as aquifers. The principal known aquifers in Oklahoma as classified by the Oklahoma Geological Survey are:[4]

A. Unconsolidated sediments, mainly sand and gravel.
   1. Alluvium
   2. Terrace deposits
B. Unconsolidated or slightly consolidated sediments, mainly sand and gravel.
   3. Tertiary and Quarternary deposits (Ogallala)
C. Bedrock formations.
   4. Trinity sand
   5. Rush Springs sandstone
   6. Garber and Wellington formations
   7. Clear Fork and Wichita formations
   8. Nelagoney and Vamoosa formations
   9. Boone Limestone
   10. The Arbuckle group including the Roubidoux formation

The alluvium aquifers occur along all major rivers and streams beneath the flood plains or bottom lands, but it is the thickest along the larger rivers. These aquifers formed from sand, gravel, and clay

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*Source--From the summary on ground water in the Planning and Resources Board bulletin, "Oklahoma's Water Resources."

[4]Oklahoma Geological Survey, Oklahoma University Campus, Geology Building, Norman, Oklahoma.

deposits may be up to 100 feet thick. In many places the alluvium is an abundant water producer as the coarse texture of the subsoil permits water to flow freely through the soil, quickly replenishing the aquifer from percolation. The average pumping lift in the alluvium may range from ten to 50 feet, depending upon the location. The high percolation characteristic, also makes it subject to infiltration of foreign material. Pollution from oil-fields and industrial wastes has forced abandonment for all types of uses of some of the State's most productive alluvium deposits.

The terrace deposits occur in the northwestern one-fourth of the state and in some sections along the Texas border in the southwestern section. These are formed from stream-laid sand, gravel, and clay deposits where the streams have shifted laterally to another location, and become covered with dune-sand or wind-blown, sand-drifted hummocks. This condition allows rapid intake or percolation of rainfall. However, these deposits are in the area of the state where rainfall is lowest and distribution is most uneven. Often terrace deposits occur above the water table or they are too shallow to produce water in sufficient quantity to meet irrigation requirements. Although, when these deposits are found in the proper situation they do provide an ample supply of water. The average pumping lift ranges approximately from ten to 250 feet.

The Tertiary and Quarternary deposits (often referred to as the Ogallala formation) occur in the High Plains of Texas and Oklahoma. They are composed of calcareous sands, gravels, and sandy clays and range in thickness from 200 to 300 feet. Nearly all water used for domestic and municipal uses in the High Plains area is secured from this aquifer.

Hardness and salt content of the water averages from 200 to 300 part per million, which makes it fair to excellent for irrigation. The average pumping lift in this area also has a broad range, approximately ten to 250 feet.

The Trinity sand formation occurs along the Southern boundary of Oklahoma from Love County to the Arkansas border. Water from this aquifer has a high concentration of sodium bicarbonate, although the content varies considerably within the area. Individual wells producing from this aquifer have produced as high as 300 gallons per minute. At higher pumping rates sand was drawn into the water which damaged pumping equipment. The average pumping lift from this aquifer is approximately 100 to 250 feet.

The Rush Springs aquifer, in Caddo and the adjoining counties in central Oklahoma, covers an area of about 2,100 square miles. This aquifer is thin in the eastern section, but in the western section it is over 300 feet thick in places. The average pumping lift from the aquifer is approximately 100 to 250 feet. It is formed from a sandstone which is more porous than usually found at this depth due to the removal of calcium carbonate and calcium sulfate by water solution. These salts cause the water to be hard in some localities, but in most areas it is suitable for irrigation. The average yield of this aquifer ranges from 100 to 225 gallons per minute depending upon the location.

The Garber and Wellington formations are located primarily in southeastern Garfield, Logan, Oklahoma, and Cleveland Counties. This is presently considered the most important aquifer in Oklahoma for municipal and industrial uses. It is composed of sandstone and shale, with an average thickness of 400 feet in the water bearing zone. The water is high in

dissolved solids, but is soft, with high concentrations of sodium bicarbonate and sodium sulfate. Yields as high as 300 gallons per minute are obtained but drawdown in the slow flowing sandstone is relatively high. The average pumping lift to the surface ranges approximately from 100 to 250 feet. Several large cities and towns draw heavily from this aquifer for water supplies; Norman, Nichols Hills, and Edmond are the larger ones. Although Enid is in Garfield County, its water supply is drawn from the Cimmaron terrace deposits nearer that city.

The Clear Fork and Wichita formations are found in the Southwestern and Southcentral sections of Oklahoma. They consist of red shale and sandstone. The water from these formations is relatively soft and contains large amounts of sodium bicarbonate, sodium, and chlorine. Yields up to 175 gallons per minute have been obtained from wells tapping this aquifer. The average pumping lift ranges approximately from 100 to 250 feet.

The Nelagoney and Vamoosa formations are found in a band from northeastern Osage County to southern Seminole County. The Northern section of this aquifer is from the Nelagoney sandstone formation, and the Southern section is formed from the Vamoosa sandstone. They are formed of coarse sandstone, conglomerate, and interbedded with shale. The acquifer is from 250 to 600 feet thick with an average pumping lift to the surface ranging from approximately 100 to 250 feet. Hardness of the water ranges from 12 to 600 parts per million from south to north, which provides good to dubious irrigation water. Yields of water from this aquifer averages only 50 to 150 gallons per minute in the southern section but has lower yields in the northern section. Individual high

yielding wells may provide sufficient quantities of water for irrigation, if found, but no definite conclusions can be made from the present available information.

The Boone Limestone formation is found in northeastern Oklahoma in the Ozark section. It averages 300 feet in thickness and has many large fissures and cracks, therefore, a high water holding capacity. Furthermore, it is in a rather high rainfall section which supplies it with large amounts of percolating water, due to the coarse texture of the soil and subsoil. The waters of this aquifer are generally soft and of good quality in most places. Yields per individual well are highly doubtful, since like other limestones the yields are generally low unless a crack or fissure is tapped. The average pumping lift to the surface ranges from approximately 100 to 250 feet.

The Arbuckle group of formations are found in the Arbuckle Mountains section of Murray, Johnston, and Carter Counties and also in the Wichita Mountains of Kiowa County. They are usually found in limestone formations where underground channels and waterways have come to the surface in the form of springs or artesian wells. The water in the Arbuckle Mountains section is high in calcium and magnesium and low in sodium. The opposite condition is found in the Wichita Mountains section where analyses reveal a high content of sodium and a low content of calcium and magnesium. Yields from these aquifers depend upon striking one of the underground waterways or upon obtaining water from one of the surface springs. The water supply for Ada is obtained from Byrd's Mill Spring in the Arbuckle Mountains section. It yields from three to 18 million gallons per day depending upon the wetness of the season. The formation follows the surface away from the countains for a few miles then dips

to so great a depth that it is impractical to drill wells to them. At such great depths they are generally highly mineralized. The average pumping lift to the surface for the shallower portions of the aquifer ranges from approximately 100 to 250 feet. The deeper zones may be over 1,000 feet in depth.

The Rubidoux formation is found in northeastern Oklahoma mainly in Ottawa County, at depths of 1,000 to 1,300 feet below the surface. It is a water bearing sandy and sandstone section yielding on an average of from 200 to 250 gallons per minute, but yields have been obtained up to 600 gallons in certain localities. The water in this formation is moderately hard and increases in hardness as depth increases.

Water tables and artesian conditions influence the sources of underground water found in Oklahoma too. The water table is the upper limit of the zone of saturation in the aquifer and also occurs outside the aquifer where suitable conditions exist. Artesian conditions occur where a permeable stratum is completely surrounded by an impermeable stratum, the surface of the permeable stratum is exposed at a high elevation, and is also exposed at a low elevation. Water flows down the permeable stratum by percolation and becomes a flowing well at the lower elevation. Yields vary widely and depend upon the location and size of the stratum.

The patterns of flow in ground waters are similar to those of surface water; high in wet years from good replenishment and low in dry years due to constant drainage from wells and other losses, except that evaporation is less from underground storage than for surface storage.

The general information concerning Oklahoma's surface and ground water has been discussed primarly only so far as it pertains to irrigation.

For a specific section of Oklahoma the Geological Survey Reports on water resources are the best source of information for planning the development of a water supply for a municipality or a farm irrigation system at the present time.

The available information on irrigation water in Oklahoma, gives evidence that in several sections irrigation has a high potential for additional development. But, the considerations cannot be based upon a study of water alone, the other major factors, soil, crops, and climate must also be considered in making an analysis for irrigation development. Water limitations are evident mostly in the Western sections of the state due to the limited amounts of water available. Also, for the entire state irrigation may not be feasible in many places due to the high costs incurred in obtaining large enough quantities of water for irrigation.

Oklahoma Water Law Summary*

Oklahoma law has placed irrigation as third in preference rank, other water using functions having first priority on impounded or flowing waters.

"Preference shall be given, first to domestic and municipal water supply--; second, to supplying water used in the processes of manufacture,--and for maintaining sanitary conditions of stream flow; and third, for irrigation, power development, recreation, fisheries, and other uses."

These preferences are ranked in the same manner for surface and for ground water rights.

Since irrigation has been classed lower in preference to municipal and industrial uses, these large water consumers may use their water first, while irrigation users along with others, may not be able to

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*Source--Title 82, Oklahoma Statutes, 1951.

obtain any water. This condition was noted in some areas through the recent drouth years from 1952 to 1955.

In 1949 the legislature enacted the "Oklahoma Ground Water Law," which makes ground water subject to appropriation and requires an application similar to that required for obtaining surface water rights.

The term"rights" refers to the right to use water in accordance with the law. In Oklahoma rights are assigned by the Oklahoma Planning and Resources Board. The assignment of these rights is to be based on three principles laid down by law; they are:

1. Beneficial use is the basis, the measure, and the limit of the right to use water.
2. Water is public property.
3. The development of Oklahoma's water resources should satisfy the greatest need and the most beneficial use.

The procedure for obtaining these rights is outlined in the statutes. These statutes require that an application be made to the Board for both surface and ground water rights.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

From the standpoint of soils, there are 2,012,000 acres of land physically suited to irrigation development in Oklahoma, yet, due to limitations of other natural resources it has been estimated that only 372,000 acres can be irrigated. The major physical and biological factors, singularly or collectively, restricting irrigation development in addition to soils, are topography, climate, water resources, and crop adaptation. These are usually classified in such general categories as the unsuitability of lands, flooding hazards, and inadequate drainage. In addition, in the western sections the quality and quantity of available water are major problems. For Oklahoma as a whole, the problem of economic feasibility of irrigation will remain indeterminate until the physical and biological sciences secure performance information in the numerous combinations of resources.

The purpose of this study has been to discover the interrelationship as well as the impact of divergent characteristics of resources upon resource development for agriculture in order to prepare the framework for an economic analysis of irrigation in Oklahoma. This was accomplished by:

1. Appraising the extent of the integration of physical, biological, and hydrological factors which influence irrigation farming.
2. Assembling the basic irrigation data available from prior research, related to Oklahoma.
3. Delineating the deficiencies in basic information on the overall problem of irrigation research.

Knowledge of the factors which influence irrigation is a prime determinant in measuring the economic feasibility or justification for irrigation. If a farm operator, through observation, experience, and inquiry, can understand the probability of his control over the performance of these basic resources, he is in a position to reduce the uncertainty relative to the quality and quantity of the product and within certain limits, should be in a more desirable position for realization of income expectation.

Irrigation was practiced in Oklahoma as early as 1890 but the research studies of basic resources during the period before 1900 were few and dealt very lightly with irrigation and the resources affecting it. The history of research in the sciences related to irrigation followed a rather definite pattern. The initial studies were generally descriptive, followed by more comprehensive detailed classification in the area of study. Despite the large number of independent, uncoordinated studies made into the separate areas of irrigation resources, studies were initiated for the puspose of resource integration but only seldom were independent studies directly related to the problem of utilizing resources for irrigation.

Research objectives in the period from 1901 to 1950, with few exceptions, were for the purpose of extending the area of knowledge in a particular physical resource. The extension of knowledge in the properties of soils, climate, hydrology, and others left much to be done before present problems of resource use could be resolved. Unfortunately, "irrigation studies" were made in the specific physical or biological science areas and only one resource was analyzed. These specific resource studies continued until the physical scientists began to examine the resource response

in irrigation systems that had developed which required a broader base when other factors were involved.

The practice of integrated or coordinated studies in the separate sciences necessitated retracing some of the specific studies in order to establish functional relationships. Specific studies have way to general studies, but only broad classifications were used in the initial integrated studies and comprehensive studies must await the outcome of these efforts. This type of study should be fruitful as the farm operator must develop his irrigation practices in accordance with the potentiality of the resources available. It will be necessary to make future studies more specific in order to provide meaningful data.

The resources about which a farm operator must have more information if he is to be a successful irrigator are, soils, crops, climate, and water resources. These broad classifications designate the major sciences concerned with developing new information.

Where water is available, the farm operator must determine the irrigable qualities of his soil. These basic soil qualities are texture and permeability, as they govern pore space, moisture holding capacity, intake rates, and sometimes the effective moisture depth of the soil. These properties determine not only the irrigability of a soil but are related to the irrigation practices, such as, application rates of water, time intervals of irrigation, and irrigation efficiency. Also these basic soil qualities exert influence over losses of soil water from evaporation. The operator's control over these influences can improve his irrigation efficiency.

Irrigation operating costs can be regulated or minimized by studying the soil. Costs, such as, pumping and labor costs are determined by

by the length of time needed to fill the reservoir. Study of the factors affecting these costs will help determine the economic justification of irrigation practices.

Closely associated with the above is the study of crops, their moisture requirements and response under irrigation with regard to the consumptive-use of water and the operator's control over crop quality and quantity of yield. These have proven to be limiting factors in many areas where soil and water are adequate.

Climate must be included in related studies or irrigation as climatological factors have an immeasurable impact upon irrigation practices. Climatic factors such as precipitation, drouth, temperature, growing season, and wind velocity determine, to a degree, whether irrigation can be profitable. If the climatic factors are optimum for plant growth, irrigation may not be feasible unless new technology destroys the balance. On the other hand, if one or more of these climatic factors is not at the optimum, irrigation may be the means of making farming highly profitable. Studies of climate in relation to the economics of irrigation are inadequate in view of the significance of this factor on the profitability or economic justification of irrigation.

Water as a resource may be and probably is the most important single factor in a study of irrigation. Such problems of water as quality, quantity availability, and depth are the determinants of water as a resource. Studies of these factors must be closely integrated with the other resources in view of the direct influences which they exert upon the development of irrigation.

Another important factor governing the economics of water use is the legal implication of water resources law. The Oklahoma Statutes

give preference for water rights to (1) domestic and municipal uses, (2) manufacturing and sanitation, and (3) to irrigation, power development, and others. This rank of preference is determined by the beneficial use of water to society. Beneficial use thus becomes the basis, the limit, and the measure for granting water rights to users of water. This factor may also affect the economics of water use particularly in years of low rainfall when moisture is deficient.

The major irrigation problems of eastern Oklahoma are the adaptability of soils, moisture holding capacity, drainage, percolation, and sometimes the uneven distribution of rainfall. For western Oklahoma, the adaptability of soils, the quality and quantity of available water, and low annual rainfall are the important problems.

Economic justification of irrigation is dependent upon the impact of the factors included in this study. They are the determinants not only of the feasibility, but also of the profitability of irrigation. Therefore, these areas of research need to be explored more fully before establishing extensive irrigation systems in Oklahoma.

Conclusions

1. Development of the remaining 81.5 percent of the land physically capable of irrigation in Oklahoma depends largely upon intensive, integrated studies into the basic resources influencing irrigation.
2. Soils must be classified for irrigation and studies made of the moisture holding capacity, intake rates for surface and subsurface soils, effective depths of soils, and percolation. When these studies are completed and integrated, enterprisers contemplating adoption of irrigation will be adequately informed of the physical and biological limits of

their soils, crops, and other resources.

3. The surface and subsurface soils must be studied in order to determine water losses, recharge to aquifers, and other information.

4. The moisture requirements and response of crops to additions of water must be analyzed in order to discover the seasonal demands of the plant for water. Also, to determine the extent to which a farmer can actually control the quality and quantity of his yield.

5. Climatological factors must be studied in their roles as governing forces over certain phases of irrigation in order to determine whether or not irrigation can be used. Also, to partly determine how much water is necessary and the effects which climatic variables extend over irrigation development.

6. Water resources must be considered in the light of their occurrence, quality, quantity, pattern of flow, and the economics of water application. Also, the legal phase of water rights, and the preferences alloted by law must be considered in the study of water use.

7. The basic data pertaining to Oklahoma's irrigation resources are inadequate or unavailable and often are inaccurate. Therefore, farm operators do not have a source for the types of information essential to make judgments related to changes in resource use.

8. A comprehensive economic analysis of the problems affecting irrigation farming must await an evaluation of the available physical and biological resources.

9. Irrigation studies must consist of an integration of the basic research in the resources, the long range needs of irrigation, the legal aspects of irrigation, the potential additions to incomes of farmers, and eventually to additions to the gross product of the economy of Oklahoma.

Recommendations

From the information obtained in the course of this study it is recommended that an economic analysis be made to discover means of overcoming the factors limiting economic development of irrigation in Oklahoma.

It is further recommended that;

A. Basic research be instigated to discover information not covered in the present store of knowledge, such as, percolation rates, economics of climatology, and economics of water resource use.

B. Present and future studies be enlarged to encompass the entire irrigation scheme in terms of long range operation.

C. The individual agency research should be assembled, compared, checked, edited, and disseminated under a central agency of government, created for this purpose. This organization would coordinate the research information and also closely screen the inapplicable research from the reports.

D. Irrigation and irrigation resource research should be progressive and handled in terms of long range projects instead of being put aside in favor of short "flurries" in demands for other information.

E. The information should be written in a less technical style in order that farm operators and less technical personnel may be better able to utilize the information.

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APPENDIX A

DEFINITIONS OF TERMS USED

Some of the terms common to irrigation studies are listed below. The definitions are those which are applied in common usage and no special interpretation is given them in this thesis.

1. Acre-foot--an acre-foot is commonly thought of as being that quantity of water which is required to cover one surface acre of land to a depth of one foot. It contains 325,850 gallons and will provide sufficient water for one year to either 5 people, 22 cattle, 100 chickens, 6 hogs or 2 horses.

2. Aquifer--an aquifer is a ground-water basin. This is a formation composed of either sand, gravel, limestone, dolomite, sandstone, gypsum or a combination of these, in which ground water is stored after being percolated through the earth.

3. Consumptive Use of Water--this term refers to evaporation and transpiration of water. This may occur in streams, ponds, lakes or from the soil itself in the form of evaporation, plus that amount used by the plants in filling their growth requirements then moves off into the atmosphere by transpiration processes.

4. Drawdown--a term used to define the reaction of the water level when water is being pumped from the well. There is a tendency for the level to decrease to a certain point. This is the "drawdown" of that well.

5. Discharge of Ground Water--means that amount of water discharged from an aquifer by effluent seepage, evaporation, flow or pumping from wells, underflow in the aquifer, and transpiration by plants.

6. Effluent Seepage--is the water which flows out of the zone of saturation and into a stream whose surface is lower than the water table.

7. Evaporation--as it applies to ground water is when the water table nears the surface of the land--ground water may be discharged by evaporation. Factors governing the rate of evaporation are temperature, wind, velocity, humidity, type of soil, and depth to water.

8. Expectable Yields--are discovered only after research in the general area. This is found by comparing yield, drawdown, and recharge, then selecting a figure in gallons per minute which can be obtained from pumping that well.

9. Flucuations of the Water Level--are continuous changes in rise and fall of the level of the water table in an aquifer. The flucuations are

caused by variations in the recharge to and discharges from the underground reservoir. The water table level depends upon the balance between recharge and all the forms of discharge such as evaporation, transpiration, seepage, pumpage and underflow.

10. Ground Water--the pores of permeable rocks below the surface are partly or completely filled with water. This water is termed "subsurface water." The portion of this water which completely fills the pores of the permeable rocks is called "ground water." Ground water is said to be found in the "zone of saturation." Those porous materials which lie above the zone of saturation are said to be in the "zone of aeration." This is divided into (1) The capillary fringe, at the bottom, (2) The intermediate belt, and (3) The belt of soil water, immediately below the land surface.

11. Hardness of Water--refers to the parts or number of solid particles per million particles of water.

12. Movement of Ground Water--refers to a tendency of ground water to seek an equilibrium. For instance, moving from a higher location to a lower area. Commonly, this is known as a tendency of liquids to "seek their own level."

13. Percolation or Percolating Waters--are terms which apply to defining a certain process which water goes through in entering the earth. On the surface this is known as infiltration. When water moves on into and through the layers of soil and porous rocks it becomes known as percolating waters, which may run either lateral vertical, or both. The process is termed percolation.

14. Pumpage--is a term relating to a comparison of the total quantity of water pumped from a well and the total quantity of water stored there.

15. Recharge of Ground Water--an aquifer receives water from several sources. The act of receiving this water is known as "recharge." The methods of recharge are infiltration of precipitation from streams which introduce outside water into the catchment area of the aquifer, and from seepage of another aquifer.

16. Safe Yield--is a term relating to a comparison of the yield of a well and the amount of water which it is capable of producing. This also refers to an aquifer in the same sense. It is a comparison between yield, recharge, and total quantity of water.

17. Surface Water--is water in lakes, ponds, rivers and streams stored either naturally or artificially for any purpose whether for municipal, industrial, irrigation or domestic use.

18. Transpiration--is the process used by plants whereby moisture is discharged into the atmosphere during the process of plant growth. It may be water taken from the root zone, the zone of aeration, or the capillary fringe which is in turn supplied by the zone of saturation.

19. Underflow--occurs when two aquifers are in contact below the earth's surface. Water from one flows into the other one. The rate of flow depends upon the hydraulic gradient or difference in height of the two aquifers.

20. Water Table--a term applied to the upper level of the zone of saturation. It is where the porous rocks and materials in the earth are filled to capacity with water.

APPENDIX B

BASIC IRRIGATION DATA FOR OKLAHOMA

(Explanation of the Irrigation Guide for Oklahoma)*

1/ Soil Description--A brief description of the principal soil series, with the name given to identify it. Also, the basic intake rate is given in inches per hour.

2/ Moisture Holding Capacity per Foot Increment of Depth--This column indicates the amount of water, in inches, which can be held, available to plants, in the first, second, and third foot increments of depth.

3/ Adapted Crops--The crops adapted to irrigation on the soils named in column one.

4/ Adapted Irrigation Method of Design--These are the irrigation methods of design which are recommended for Oklahoma by the Soil Conservation Service at the present time. They are:

(1) Border method--For drilled and row crops with slopes of one foot per 100 feet or less.
(2) Furrow method--For row crops with slopes of 0.5 feet per 100 feet or less.
(3) Corrugation method--For drilled crops when slope is one foot per 100 feet or less.
(4) Contour ditch method--For use where erosion is not a problem. Also, for drilled crops on soils where bordering is not practical.
(5) Sprinkler method--For all slopes except those subject to erosion from rainfall. Erosion control practices must be established.

5/ Design Intake Rate--This is the rate at which soil will absorb water when it is at one-half of available moisture. The rate varies for each method of design. It is measured in inches per hour.

6/ Estimated Field Efficiency--The ratio of the depth of water stored in the soil reservoir and consumptive use of water per application of water.

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*Irrigation Guide for Oklahoma, United States Department of Agriculture, Soil Conservation Service, Oklahoma City, Oklahoma, 8 pp.

IRRIGATION GUIDE FOR OKLAHOMA 3/
TABLE 1 OF 6

Soil, Description and some typical types 1/	Moisture holding capacity in/foot 2/	Adapted crops 3/	Adapted irrigation method 4/	Intake rates of methods given in./hour 5/	Estimated field efficiency 6/
	Increments of depth		Design		
Deep, fine textured, very slowly permeable, and	2.0"	Cotton	Level Row	0.48	80
		Sorghums (row)	Graded Row	0.48	70
		Sudan (row)	Level Border	0.40-0.70	80
		Blue Panacium			
		Castor Beans			
Deep, medium textured, very slowly permeable soils	2.0"	-			
		Small Grains	Graded corrugation	0.53	70
		Austrian Winter-Peas	Contour ditch	0.53	50
Foard		-			
Tillman					
Kirkland		Alfalfa	Semi-graded border	0.41	75
Renfrow			Graded border	0.41	70
Parsons			Contour ditch	0.41	50
Cherokee			Sprinkler	0.40	75
Bethany					
Brewer		-			
Pullman		Tame Pasture	Graded border	0.60	75
Durant			Contour ditch	0.60	50
Tabler			Level border	0.60	80
Woodson			Sprinkler	0.3 - 0.4	75
Comanche		-			
The above soils will have a basic intake rate of from 0.10" to 0.20" in./hour.		Drilled sorghums	Semi-graded border	0.48	75
		Sudan	Graded border	0.48	75
		Blue Panacium			
		-			

IRRIGATION GUIDE FOR OKLAHOMA 3/
TABLE 2 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth	(in rows)	Design		
Deep, Fine textured, slowly permeable and	1.7	Cotton	Level row	0.75	80
		Sorghums	Graded row	0.75	70
		Sudan	Level border	0.75	80
		Castor beans	Sprinkler	0.4 - 0.7	75
		Blue Panacium			
Deep, medium textured, slowly permeable soils	1.7	-			
		Small grains	Graded corrugation	0.77	70
			Contour ditch	0.77	50
			Sprinkler	0.4 - 0.7	75
Abilene		-			
Taloka					
Denton		Alfalfa	Level border	0.71	80
Dennis			Graded border	0.71	70
Houston			Contour ditch	0.71	50
Okemah			Sprinkler	0.4 - 0.7	75
Richfield		-			
St. Paul		Tame pasture	Level border	0.85	80
Summit			Graded border	0.85	70
Zaneis			Contour ditch	0.85	50
McLain			Sprinkler	0.5 - 0.8	75
Miller		-			
Osage		(drilled)			
Dale		Sorghums	Level border	0.75	80
Lela		Sudan	Graded border	0.75	70
Lanoke		Blue panacium	Sprinkler	0.4 - 0.7	75

continued

IRRIGATION GUIDE FOR OKLAHOMA 3/
TABLE 2 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
		Sweet corn	Level row	0.79	80
			Graded row	0.79	70
These soils will have a basic intake rate of approx. 0.5"/hr.					
same as above	same	Onions	Graded row	1.2	70
		Irish potatoes	Sprinkler	0.6 - 1.0	75
		Carrots			
		Spinach	Graded row	1.2	70
			Sprinkler	0.6-1.0	75
		Sweet potatoes	Graded row	0.85	70
			Sprinkler	0.5 - 0.8	75
		Lettuce	Graded row	1.2	70
			Sprinkler	0.6 - 1.0	75

IRRIGATION GUIDE FOR OKLAHOMA 3/
TABLE 3 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
Deep, fine textured, moderately permeable, and	1.5	Cotton	Level row	1.9	80
		Sorghums	Graded row	1.9	70
		Sudan	Level border	1.9	80
		Castor beans	Sprinkler	up to 1.0	75
		Blue panacium			
Deep, medium textured, moderately permeable soils	1.5	-			
		Peanuts	Level row	2.4	80
			Graded row	2.4	70
			Level border	2.4	80
Bates			Sprinkler	up to 1.0	75
Carey		-			
Woodward		Small grain	Graded		
Chickasha		Vetch	corrugation	1.94	70
Choctaw		Austrian	Contour ditch	1.94	50
Choteau		winter peas	Sprinkler	1.94	75
Grant		-			
Noble		Alfalfa	Level border	1.8	80
Pond Creek			Graded border	1.8	70
Reinach			Semi-graded	1.8	75
Norwood			border		
Ruston			Contour ditch	1.8	50
Teller			Sprinkler	up to 1.0	75
Vanoss		-			
Tipton		Tame pasture	Level border	2.1	80
Yahola			Semi-graded		
Canadian			border	2.1	75
Noble			Contour ditch	2.1	50
Port			Sprinkler	up to 1.0	75

continued

IRRIGATION GUIDE FOR OKLAHOMA
TABLE 3 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
Portland		-			
Bowie		Summer legumes	Level row	2.1	80
			Graded row	2.1	70
Basic intake			Level border	2.1	80
rate of approx.			Graded border	2.1	75
1.5"/hr.			Sprinkler	up to 1.0	75
		-			
		Sweet corn	Level row	2.0	80
			Graded row	2.0	70
same as above	same	(drilled)			
		Sorghums	Level border	1.9	80
		Sudan	Semi-graded		
		Blue panacium	border	1.9	75
			Sprinkler	up to 1.0	75
		-			
		Sweet potatoes	Level row	2.1	80
			Graded row	2.1	70
			Sprinkler	up to 1.0	75
		-			
		Irish potatoes	Level row	2.4	80
		Carrots	Graded row	2.4	70
		Onions	Sprinkler	up to 1.0	75
		-			
		Spinach	Level row	2.4	80
			Graded row	2.4	70
			Level border	2.4	80
		-			
		Melons	Row	1.8	70
			Sprinkler	1.0-	75

IRRIGATION GUIDE FOR OKLAHOMA 3/
TABLE 4 OF 6

Soil, Description and some typical types	Moisture Holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
		Cotton	Level row	2.37	80
		Row Sorghums	Graded row	2.37	70
		Row Sudan	Sprinkler	1.5 up	75
		Castor Beans			
Deep. moderately	1.4	Blue panacium			
coarse textured	1.4	-			
moderately and	1.4	Tame pasture	Sprinkler	1.5 up	75
rapidly	1.4	-			
permeable		Drilled sorghums	Semi-graded		
		Sudan	border	2.37	70
Amarillo		Blue panacium	Level border	2.37	80
Dalhart			Sprinkler	1.5 up	75
Brownfield		-			
Cleburne		Small grain and	Graded		
Hanceville		Vetch	corrugation	2.43	70
Stephensville			Sprinkler	1.5 up	75
Enterprise		-			
Minco		Alfalfa	Semi-graded		
Pratt		Sweet clover	border	2.26	70
Tipton			Corrugation	2.26	70
			Level border	2.26	80
Basic intake			Sprinkler	1.5 up	75
rate approx.		-			
2.0 in/hr.		Peanuts	Sprinkler	1.5 up	75
		-			
		Summer legumes	Level row	2.65	80
			Graded row	2.65	70
			Sprinkler	1.5 up	75

continued

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Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
		Sweet corn	Level row	2.50	80
			Graded row	2.50	70
			Sprinkler	1.5 up	75
same	same	Sweet potatoes	Level row	2.65	80
			Graded row	2.65	70
			Sprinkler	1.5 up	75
		Irish potatoes Carrots	Sprinkler	1.5 up	75
		Melons	Level row	2.32	80
			Graded row	2.32	80
			Sprinkler	1.5 up	75

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Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
Deep, coarse textured moderately and slowly permeable soils	0.8	Cotton	Sprinkler	2.0	75
	1.1	Row Sorghums			
	1.4	Row Sudan			
	1.4	Blue panacium			
	1.4	Castor Beans			
	1.4	-			
Brownfield		Rye-Vetch	Sprinkler	2.0	75
Daughtery		-			
Nimrod		Alfalfa	Sprinkler	2.0	75
Norfolk		-			
Miles		Peanuts	Sprinkler	2.0	75
Pratt		-			
Stidham		Summer legumes	Sprinkler	2.0	75
		-			
Basic intake rate approx. 2.5"/hr.		Melons	Sprinkler	2.0	75
		-			
		Sweet corn	Sprinkler	2.0	75
		-			
Deep, coarse textured, moderately and moderately rapidly permeable		Sweet potatoes	Sprinkler	2.0	75
	0.8	-			
	1.0	Irish potatoes	Sprinkler	2.0	75
	1.0	Carrots			
	1.0	-			
	1.0	Drilled Sudan Sorghum	Sprinkler	2.0	75

continued

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TABLE 5 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
Arkansas Canadian Enterprise Pratt Yahola		Blue panacium			
Basic intake rate approx. 3.0"/hr.					

The second list of soils has the same basic adaptations

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Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
Shallow, fine and medium textured slowly permeable soils	1.7 1.7	Row Sorghum Blue panacium Row Sudan	Level row	1.2	80
			Graded row	1.2	70
			Semi-graded border	1.2	70
			Sprinkler	0.4 - 0.8	75
			Level border	1.2	80
Ellis Enders Eram Weymouth		Sown Sorghum Sudan Blue panacium	Level border	1.2	80
			Semi-graded border	1.2	70
			Sprinkler	0.4 - 0.8	75
Basic intake rate approx. 0.5"/hr.		Tame pasture	Level border	1.2	80
			Semi-graded border	1.2	70
			Contour ditch	1.2	50
			Sprinkler	0.4 - 0.8	75
Shallow, fine and medium textured, moderately permeable soils	1.5 1.5	Small grain and Vetch	Graded corrugation	1.2	70
			Contour ditch	1.2	50
			Sprinkler	0.8	75
Darnell Linker Lucien Mansker Quinlan	Basic intake rate approx. 1.5"/hr.	Alfalfa	Semi-graded border	1.2	70
			Level border	1.2	80
			Contour ditch	1.2	50
			Sprinkler	0.4 - 0.8	75

continued

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Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
same	same	Summer legumes	Level row	1.2	80
			Graded row	1.2	70
			Level border	1.2	80
			Semi-graded border	1.2	70
			Sprinkler	0.4 - 0.8	75
		Row Sorghums	Level row	2.4	80
			Graded row	2.4	70
			Level border	2.4	80
			Semi-graded border	2.4	70
			Sprinkler	0.4 - 1.0	75
		Sown Sorghums	Sprinkler	0.4 - 1.0	75
		Sown Sudan	Contour ditch	2.4	50
		Tame pasture			
		Small grain and Vetch	Graded corrugation	2.4	70
			Contour ditch	2.4	50
			Sprinkler	0.4 to 1.0	75
		Alfalfa	Contour ditch	2.4	50
		Sweetclover	Sprinkler	0.4 - 1.0	75

continued

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TABLE 6 OF 6

Soil, Description and some typical types	Moisture holding capacity in/foot	Adapted crops	Adapted irrigation method	Intake rates of methods given in./hour	Estimated field efficiency
	Increments of depth		Design		
		Peanuts	Level row	2.4	80
			Graded row	2.4	70
			Sprinkler	0.4 - 1.0	75
		Summer legumes	Level row	2.4	80
			Graded row	2.4	70
			Level border	2.4	80
			Semi-graded border	2.4	70
			Sprinkler	0.4 - 1.0	75

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