DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 13

IRRIGATION SYSTEMS IN TEXAS.—HUTSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1898

IRRIGATION REPORTS.

The following list contains titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts; Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W. J. McGee; "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION SYSTEMS IN TEXAS

BY

WILLIAM FERGUSON HUTSON

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, November 26, 1897.

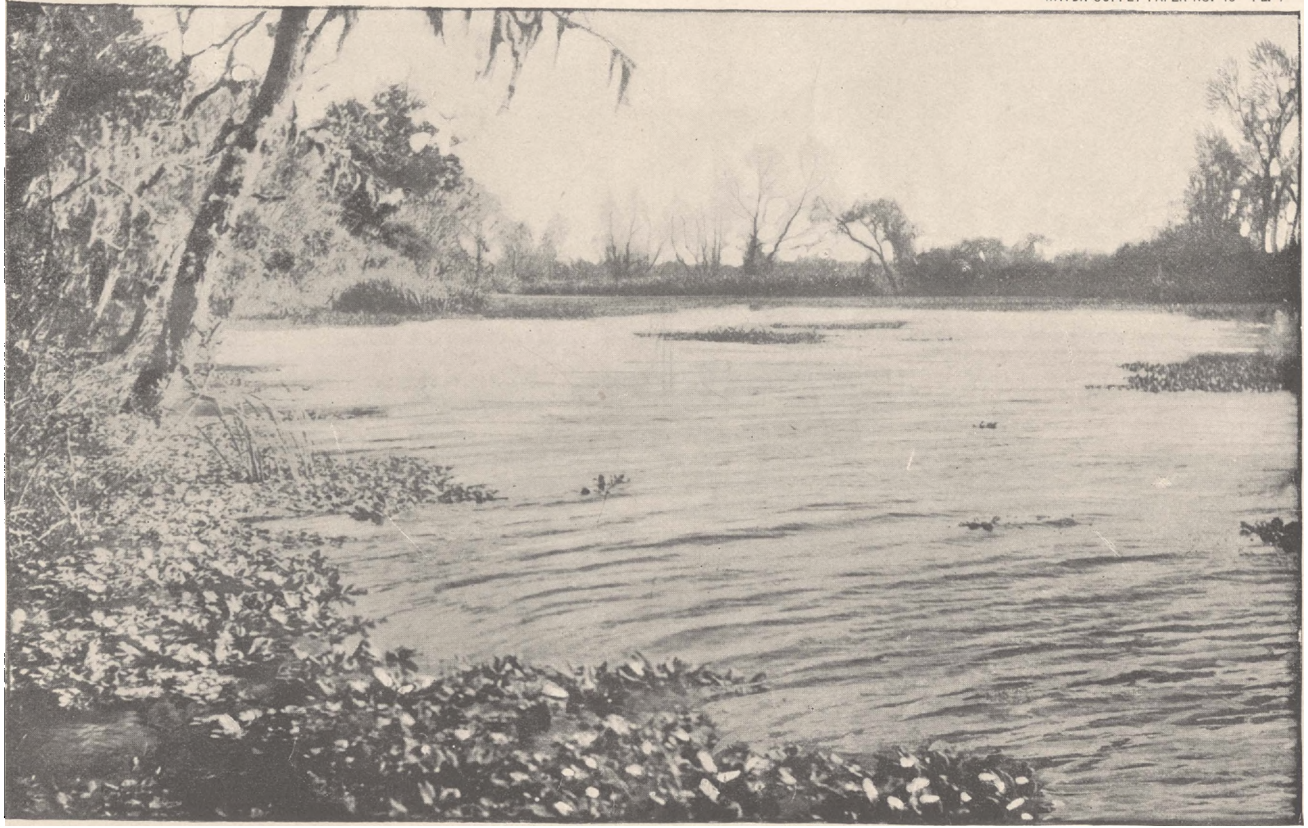
SIR: I have the honor to transmit herewith a paper entitled Irrigation Systems in Texas, by William Ferguson Hutson, and to recommend that it be published in the series of pamphlets on Water-Supply and Irrigation. This manuscript was prepared in accordance with a request made to Prof. J. H. Connell, director of the Texas Agricultural Experiment Station. Professor Connell found that it was impossible for him to give the necessary time to field investigation and the preparation of a report of results, and therefore recommended that the work be intrusted to Mr. Hutson. The field work was carried on during May and June of 1897; the paper was written during July and transmitted early in August. The data were necessarily accumulated in a relatively short time, and the author considers the paper somewhat in the light of a preliminary report. A number of illustrations used in this paper have been obtained through the courtesy of Mr. Robert T. Hill, geologist of this Survey, from his paper in Part II of the Eighteenth Annual Report.

In the preparation of this manuscript for publication considerable liberty has been taken with the arrangement and the manner of presentation. While the statements of fact have been preserved, such changes have been made in the character of the paper as seemed necessary to bring it into harmony with the series as a whole. In particular a somewhat arbitrary geographic arrangement has been adopted in place of one based on considerations of quantity of rainfall, as it appeared undesirable to make the assumption that irrigation is governed by questions of mean annual precipitation.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



RUN-OFF OF SAN MARCOS SPRING.

INTRODUCTION.

By F. H. Newell.

In the report upon Agriculture by Irrigation, prepared for the Eleventh Census, 1890, all the facts obtainable at that time concerning irrigation in Texas were presented and discussed. It was found by the enumeration that there were in the whole State 623 persons irrigating farms, having an aggregate area of 18,241 acres, or an average of 29 acres irrigated by each person. This did not include the smaller kitchen and flower gardens, of which there were probably hundreds, or even thousands, watered by means of city supply or windmills. The definition of "a farm," adopted for the purpose of the census, included "all staple nurseries, orchards, and market gardens owned by separate parties which were cultivated for pecuniary profit and which employed as much as the labor of one able-bodied workman during the year." The land which was irrigated formed on an average only 2.43 per cent of each farm, showing that irrigation where used was practiced on only an inconsiderable portion of each landowner's holding.

Since 1890 there has been considerable progress made in the development of irrigation, and interest has been stimulated by the success recently attained in various localities. This later investigation in Texas has, therefore, been made for the purpose of procuring fresh information, especially concerning the recent developments. The facts are of interest not only to the people of that State, but to a less degree to those of the whole United States, for Texas embraces such a wide range in topography and climate that success attained within its boundaries suggests the advisability of the same line of action in some other locality. On account of this great diversity of natural conditions, irrigation has been developed along many different lines. Not only is water diverted from creeks and larger rivers, but in some localities it is held by storage, in others it is pumped from ordinary wells, and in still others it is obtained from artesian wells. Where the conditions are favorable, the swiftly flowing streams are employed in pumping a portion of their own water up to the top of the adjacent banks, or the ever-present winds of the prairies are utilized by means of windmills to bring a needed supply of moisture from far underground. In short, in the broad stretch of country from the humid lands on the east to the arid region on the west, from the semitropic glades of the south Gulf coast to the high plains of the interior, is to be found almost every variety of physical condition and of mechanical device for supplying needed water to the soil.

When we consider the State of Texas—in area nearly a tenth of the whole United States, and with a population less than that of the little State of Massachusetts, sparsely scattered even in the humid portion, with enormous areas of rich soil but poorly tilled—the question arises, Why should irrigation be practiced? Agriculture by this method is necessarily intensive farming—a method which should be practiced amid a dense population, and one where success is attained only by thorough tilling and careful attention to details. Why then should this be taken up in a State where fertile land is so cheap and where great areas have not been touched by the plow? The answer lies in the fact that many farmers are beginning to discover that larger profits can be made by carefully tilling a small area than by attempting to diffuse their efforts over plantations of considerable size, and that in order to produce the largest yield from a given outlay of time and labor it is necessary to insure the presence of sufficient moisture at the right time. This lesson, however, has not been universally learned. The education of the great majority of farmers or planters has been such as to make them adhere to old methods, and often it is only after object lessons have been many times repeated that they are willing to concede that their broad farming is not the most profitable.

Included within the State of Texas are lands upon which irrigation was practiced as early as, if not earlier than, in any other portion of the United States, and it would thus seem that this method of agriculture should have spread and be more generally practiced than it is. It is a fair question, Why, if irrigation is so profitable, has it not become the rule rather than the exception? The answer can probably be found in the character and training of the population and in the unfriendly attitude of the laws of the State toward the development of irrigation works. The very extent of the State—the enormous areas of land that might be had almost for the asking—has tended to make the farmer look down upon little methods and disregard the small economies and the attention to detail so essential in intensive agriculture. Thus the tendency has been to leave irrigation to the Mexican, who originally practiced it, and to regard it as something almost unworthy of the consideration of a "white man." The time has come, however, for a change in general sentiment. A more diversified farming has been introduced, together with better methods, brought in to a certain extent by immigration from other States. The rapid growth of the Territories to the northwest, which are dependent for their agriculture upon irrigation, has stimulated a desire and an endeavor to attain like results by similar means, and opportunities which before have been neglected are being seized upon.

Before any considerable development can take place in irrigation, upon either a large or a small scale, facts must be known concerning the water supply. If this is to be obtained from a river, it must be known whether the low-water flow is sufficient for the purpose and whether the floods are of such size as to sweep away structures which should be permanent. Even in the case of individuals intending to pump water from the ground, questions are first asked as to whether the ground water is sufficient in volume and whether it can be obtained at a depth near enough to the surface to be profitably raised. The answer to all questions of this kind must come primarily through a comprehension of the geology of the country. Ignorance of the volume of some of the larger streams has already resulted in serious disappointment, and probably in heavy loss, to several large enterprises, and it is probable that other works of this character will not be carried out until the investors have a better knowledge of the physical conditions, of drought, and of high water. From a knowledge of the underground conditions it is possible to foretell the depth to the water-bearing strata and the general character of these, and to base estimates upon the quantity which may be obtained by properly constructed wells. Matters of this kind must be investigated if the resources of the country are to be neither underestimated and neglected nor overstated and made the basis of loss to credulous investors.

With the measurement and study of surface streams and the accumulation of facts concerning the underground structure, with reference to the amount and quality of the water available, there are closely joined considerations of methods and cost of lifting the water up to the lands to be irrigated. No general rule can be laid down as to how much any given individual can afford to expend in obtaining a water supply for irrigation. Each case must be considered on its own merits, alike as to methods and machinery, the amount of water needed, and the character and ultimate value of the crop. As a general rule it may be said that for the field crops as ordinarily cultivated irrigation, especially by pumping, will not pay; but in diversified farming, where personal attention is given by the owner to every detail, expensive methods of storing or pumping water have in the long run been found highly profitable. In order to bring out the divergence in practice there have been assembled in the following table the more important facts obtainable concerning the cost of water by the various methods described in the following pages.

This table gives in the first column the page upon which the irrigation system is described and in the next column the name in abbreviated form. In the third column are a few words to indicate the character of the system—whether the ordinary canal or ditch diverting water from a river by means of a dam, or a mechanical device, such as a windmill or pumps driven by steam or gasoline. In the next column is given the lift in feet where water is raised by pumping, and next to this the capacity of the pump or ditches in cubic feet per second. This column also gives the total amount delivered in acre-feet in 12.1 hours, since 1 cubic foot per second flowing for this length of time will cover 1 acre a foot in depth. To the acreage two columns are devoted—the first giving the total area irrigable, or the amount which it is estimated each system will cover; and the second, the area actually watered, this applying usually to the year 1896. Beyond this is given the total cost of the system, and, wherever practicable, the cost per acre. This latter column, in the case of the larger ditches, shows the amount asked or paid per acre for water rights. The last column gives the estimated annual cost per acre for water, figures for this being rarely obtainable.

Comparison of capacity and cost of various systems of water supply in Texas.

Page.	Name.	System.	Pump.	Lift in feet.	Capacity, second-feet.	Acreage.		Cost.		
						Irrigable.	Irrigated.	Total.	Per acre.	Annual per acre.
26	Catron	50 H. P. engine.	Menge	8	11.14		500	$1,500	$3	
29	Stubenrauch	8-foot windmill.		25		15	7	300	43	
29	do	12-foot windmill. *a*				30		485	16	
31	Lytle	Dam and ditch				300		25,000		
31	Lewis	do				50	10	200	20	
31	Metcalf	do					470		7	$0.75
32	Glenn	do				350	250	3,500	14	
32	McGee	do				250	75	1,500	20	
32	Swinden	80 H. P. *b*	Centrifugal		6.84	400				
33	Baker	32 H. P. engine. *d*	Worthington.		2.72	80	75	2,000	27	*c*6.00
33	Willis	Turbine			.11		5			
33	Alldridge	20 H. P. engine. *e*			1.00	75				
33	Lindsey	30 H. P. engine. *f*			1.87		40	2,000	50	
34	Vanderstucken	18 H. P. engine.	Menge		2.60		100	1,500	15	
39	Richards	Water wheel.			.20		3			
39	Garrett	do			.32		12			
43	Upper Labor	Ditch				600	100			2.00
46	Trueheart	Ditch *g*			30.00	1,500	400	18,000	15	2.50
46	Kampman	Artesian well.			2.32	1,000	250	3,000		
47	Pickett	40 H. P. boiler *h*	Blakeslee	50	1.67	400	100	2,500		*c*4.00
48	Crandall	10 H. P. boiler. *i*	Blake	48	.20			295		
49	Simmons	2½ H. P. gasoline.			.07		10	450		
49	Experiment	5½ H. P. gasoline.		48	.05	20				
55	Grover	100 H. P. boiler *j*	Menge	48	14.00	500	70	5,000		1.00

a Combined water power and irrigation.
b With reservoir.
c Approximate.
d Operating cost, $7 a day of twelve hours.
e Can water 5 acres per day.
f Operating cost, $3 per day of eleven hours.
g Water rights held at $15.
h Costs 12½ cents per hour to operate.
i Pumps into reservoir.
j Operating expenses, $4.25 per day.

Comparison of capacity and cost of various systems of water supply in Texas—Continued.

Page.	Name.	System.	Pump.	Lift in feet.	Capacity, second-feet.	Acreage.		Cost.		
						Irrigable.	Irrigated.	Total.	Per acre.	Annual per acre.
56	Miller	40 H. P. boiler	Double	39	.29	140	70	$3,000		
56	Del Rio	Dam and ditches.					3,600	25,000		$0.50
58	Urbahn	80 H. P. boiler	Pulsometer	65	1.11	125	50			
58	Sterneberg	Windmill					3	220		
58	Charleston	12-foot windmill. *a*		30			5	425		
59	Closner	25 H. P. engine	Centrifugal		10.58		100			
59	Rabb	50 H. P. boiler	Menge	18	20.00		200	2,000		
59	Brulay	100 H. P. boiler	Centrifugal	22	17.82	300	200			
59	Goodrich	14-foot windmill.		10			18	300		
60	Wayland	3 windmills		50		25		505		
60	Murray	8-foot windmill. *a*		124			1¼	222		
63	Margueretta	Dam and ditch				40,000	6,000	150,000	$10	1.50
64	Pecos R. I. Co	do				20,000	600	35,000	5	.50
64	Grand Falls	do							15	1.25
65	El Paso					30,000	3,000	220,000		2.00

a With reservoir.

In looking over this statement probably the first observation that one will make is the wide diversity of costs and results. This is partly accounted for by the fact that these figures are for the most part mere estimates and are open to the suspicion of being exaggerated to serve individual interests in one case or another. In particular the volume or capacity of the ditches is usually overstated, and concerning the pumps very little is known beyond the maker's estimates, prepared for the purposes of selling his machinery. Judging from these and similar statements, the first and annual cost of water from the large ditches is very low, being from $10 to $15 per acre for water rights and from 50 cents to $1.50 per acre for annual maintenance. The cost of water per acre by pumping is usually much more, and may range from $20 to $50 per acre, or even higher.

The small cost of water from gravity ditches in Texas, as well as in other States, is more apparent than real. As a rule the larger canal companies base their selling price for water rights upon the assumption that the work will cost a certain sum and that several thousand acres will be irrigated and subsequently sold. In this assumption the corporations have often been disappointed, the work costing far more than anticipated and the sales of water right with or without land being exceedingly slow. The promoters have appreciated the fact that these lands can not be sold unless the first and the annual cost of water is kept down to the lowest figure. The struggle to maintain the property upon the small returns has often resulted in the system going into bankruptcy or being kept in very poor condition. Sometimes, also, the estimated supply of water has not been sufficient; and thus, from one cause or another, the landowners, although nominally paying a small price for their water rights and for the annual maintenance of these, in point of fact ultimately pay a very large price for an insufficient supply. This should be borne in mind in making comparisons between the cost of water as usually given by irrigation companies and the outlay required in the case of pumping machinery.

The expense of lifting water for irrigation must, as a rule, be far greater than that of diverting a supply by gravity, but in many places circumstances or conditions are such that the former is the only method practicable. Where considerable areas are watered and the lift is small the extra cost may be more than compensated by the convenience and the possibility of controlling the source of supply. The pumping plant as a means of insurance against drought, even in humid regions, is coming to be recognized as a good investment. If properly protected from the weather it may stand for months or years without use, ready in times of deficient rainfall for immediate service in saving a crop that otherwise would be a failure.

One of the notable features in connection with pumping is the apparently low efficiency attained when one compares the amount of water which it is claimed a pump delivers with the acreage actually cultivated. Two reasons for this are apparent: The first is that the pumps may not be run to their full capacity or the water may not be used upon as large an area of ground as possible. But the principal reason often lies in the fact that the capacity of the pump is greatly overrated, and few purchasers ever make systematic tests of the amount of water actually delivered. Many disappointments have resulted from farmers attempting to irrigate with too small a volume of water. They have assumed that the pumps were delivering a certain quantity, say 2 cubic feet per second, when in fact they were raising on the average only one-third or one-quarter of this. It is almost impossible to judge by the eye as to the amount when flowing in a pipe or trough, and they have declared that the ground was not favorable for irrigation when in reality they were trying to accomplish the impossible feat of spreading water from a stream too small to traverse the ground. The real source of trouble has not been with the soil or the method, but with the insufficient supply. This difficulty might be remedied by the construction of a small reservoir or tank, into which the pumped water could accumulate for a few hours and from which a stream of considerable volume could be drawn when an application of water to the soil was to be made. This has often been neglected, to the detriment of the owner.

The amount which can be reasonably expended per acre in procuring a water supply for irrigation is, as stated above, a problem for which no general rule can be given. Much depends upon the character of the crop, and particularly upon the price for which it sells. If there is always a good market for the produce, the next consideration is the skill of the irrigator. The man who is thoroughly experienced in applying water, using only the proper amount, can often afford to pay twice as much for it as can his neighbor who uses a greater quantity and obtains a smaller yield.

The quantity of water needed varies so widely that broad assumptions must be made in order to prepare any estimate of cost. Under ordinary circumstances it may be said that an amount of water equaling 12 inches in depth is sufficient in Texas for a crop season. In other words, an acre-foot of water, or 43,560 cubic feet, will irrigate an acre. A pump delivering at the rate of a cubic foot per second, or 448 gallons per minute, will give nearly 1 acre-foot in twelve hours. Assuming that this water can be held in a reservoir and that the pump is run daily for one hundred days, it should irrigate 100 acres. The cost of water rights where the supply is assured may be taken safely at $15 per acre, or for 100 acres at $1,500. This amount under these assumptions would be a fair allowance for the cost of a pumping plant.

The annual cost of maintenance of works where the water is carefully used may range from $1.50 to $2 per acre. If the pump above mentioned furnishes through the season water at the rate of 1 acre per day, the cost of operating should not exceed this amount—$1.50 to $2. This sum is relatively small for fuel and repairs, and could not be made to include attendance, and therefore it is necessary or desirable that the pumping machinery should be nearly automatic and not require constant attention. These conditions are almost impossible of attainment. Any such statement, therefore, serves as a standard for ideal conditions rather than as an example of what may be realized.

The growth of irrigation in Texas has been retarded not so much by the character of the climate or soil, or by any natural condition, as by artificial obstacles, partly legal but consisting mainly in the lack of training of the farming population. What is needed here, as in most parts of the Great Plains region, is men who know how to irrigate—how to produce the best results under given conditions. In the arid regions, where farming without irrigation is impossible, men learn the business thoroughly; but where a small amount of success can be attained by the careless tilling of large areas the farmers are apt to go on year after year following the old ways, getting a crop when the seasons are good and trusting to chance, hoping in years of drought that the next season will be better.

By the development of small irrigation works in various parts of the State farmers are becoming accustomed to the use of water and are appreciating the benefits to be derived from having an assured amount of water. It will be necessary, however, for these small plants to multiply many times before the construction of large works can be undertaken with fair assurance of financial success. When by the multiplication of small pumping plants in various localities a considerable body of successful irrigators has been established, it will be possible to construct great canals from the larger rivers, bringing water to thousands of acres of rich lands, and to dispose of water rights at remunerative prices. The small pumping plants may therefore be considered as the necessary forerunners of more economical and efficient systems which will render possible a dense population along the fertile valleys where now farming is precarious and often unprofitable.

IRRIGATION SYSTEMS IN TEXAS.

By William Ferguson Hutson.

GENERAL STATEMENT.

During the last few years general interest has been aroused in irrigation, and its importance to many portions of Texas is being better appreciated. At this time a discussion of the development of irrigation and its present condition may afford instructive suggestions not only to citizens of the State, but to persons in other parts of the country. The variety of geologic and climatic conditions and the mixed population have given rise to many methods of practice, so that in Texas there may be found representatives of nearly every system of irrigation occurring in the United States. Every degree of excellence may be noted, from that of modern machinery for raising water down to the most primitive devices for supplying it to the field. In the arid and semiarid portions of the State the methods of the early Spanish settlers are employed. Most of the cultivation is done by Mexican laborers or tenants, who cling to the old systems. Thus on most of the ditches the distribution of the water is by the Spanish method of days and hours, each holder of a water right having the use of the ditch in his turn.

The methods of applying the water are usually copied from those of the Mexicans, which consist of flooding the crops by means of little embankments or ridges of earth from 6 inches to a foot in height, so arranged as to convert the fields into checks of a size often absurdly diminutive. This system of watering has, indeed, been very largely modified by most of the American irrigators, so as to facilitate the use of machine tools in handling the crop; but the water is still wastefully used. It is to be hoped that in the present general development of irrigation more progressive methods will be inaugurated for both the distribution and the application of the water.

The early history of irrigation in Texas is hidden in the unwritten annals of the past. Several of the valleys of the Trans-Pecos country show signs of having once supported a teeming population. The lines of their irrigation canals can yet be traced for miles, while arrowheads, stone implements for grinding corn, and other relics can be found in considerable quantities. It must, however, be left to the archæologist to determine who these aboriginal irrigators were and the probable antiquity of their work. The Pueblo Indians say that these ditches were made by the Yuma Indians, who were driven gradually westward by the Comanches and Apaches, finally settling in their present home on the Colorado River. On the Rio Grande below El Paso are several ditches, which are probably the oldest now in use in the United States. They were built by the Pueblo Indians, who, according to their traditions, migrated to this place from New Mexico at a very early date, certainly before the advent of the Spaniards under Coronado. This explorer mentions finding well-established systems of irrigation among the Indians in this vicinity in 1540, when he passed on his expedition northward. The old Spanish mission ditches around San Antonio, mentioned on later pages, are also worthy of note as among the oldest in the United States.

RETARDATION OF DEVELOPMENT.

Taking into consideration the climatic conditions and the object lesson furnished by the old ditches, it is somewhat remarkable that irrigation has not been more generally developed in Texas. The causes for the slow growth of this method of agriculture in the State as a whole are found in the persistent attempts of the settlers to extend methods of farming applicable in the humid East, and in the existing laws modeled on those of the well-watered region. There has been in Texas, as well as throughout the whole of the Great Plains region of the United States, a belief, founded upon hope and the representations of interested land agents, that the rainfall would increase as settlement progressed and tracts were brought under cultivation. In the subhumid region the annual fluctuations of water supply are always relatively large, but no permanent increase is shown by official records. The average distribution of rainfall in the western part of the State is favorable for agriculture, 19 per cent of it coming in the spring and 36 per cent in the summer, but in spite of this the crops are often either a total or a partial failure. In the country near the arid line this is the case about three years out of every four, because of the fact that a drought almost invariably occurs during the growing season, rendering useless all of the rain that falls afterwards.

Another cause of delay in irrigation development has inhered in the customs of the people. Their chief interests have been in cattle, and the results of so many years of nothing but stock raising have left them with neither the knowledge nor the inclination for the laborious occupation of the farmer.

But the principal bar to the spread of the industry has been the unsatisfactory condition of the laws relating to it. So long as the common-law doctrine of riparian rights was recognized as the only one having any force in the State, irrigation on a large scale was out of the question. At common law the riparian proprietor is entitled to have the water flow through his land in quanity and quality as it was wont to do when he acquired the title thereto. There have been several instances in the past where progressive men who wished to use the water from some stream on their lands were prevented by actions brought or threatened for infringement of the riparian rights of the owners of the property lower down.

In 1875 and in 1888 laws were passed by the legislature for the encouragement of irrigation enterprises, but in both cases they proved inadequate. In 1895 the twenty-fourth legislature passed a new law regulating "the aquisition and use of water for irrigation, mining, milling, the construction of waterworks for cities and towns, and for stock raising." This law applies only to those portions of the State in which "by reason of the insufficient rainfall, or by reason of the irregularity of the rainfall, irrigation is beneficial for agricultural purposes." By this law the unappropriated waters of the above-mentioned portions of the State are declared to be public property, and provision is made for the appropriation of the same by private persons or corporations for the uses mentioned above. The riparian rights of a person owning property along such waters are recognized to the extent that the waters can not be diverted to his prejudice without his consent, or without condemnation proceedings carried on in a manner similar to those used in obtaining land for public purposes. The appropriator first in time is first in right. The law provides ample means for certifying to the appropriation and for regulating and protecting the corporations which may be organized for the purpose of using the waters thrown open to use by it. This middle course, in regard to the doctrine of riparian rights, is that adopted in California, Washington, and Oregon, and seems to have been successful in those States.

In 1897 there was passed by the twenty-fifth legislature a joint resolution to amend the constitution of the State by adding thereto a section which provides for the formation of irrigation districts without regard to county lines. Under the terms of this such districts could only be formed west of a line drawn through the State in a general north-south direction at about the eastern boundary of what is here described as the semiarid region. This amendment proposed that irrigation districts should be bodies corporate and have all of the rights and liabilities of ordinary irrigation corporations. They might issue bonds to cover cost of construction of their irrigation works, subject to the same restrictions as county and city bonds. The indebtedness for the construction of irrigation works in these districts could be created only by a vote of the majority of the landowners resident in the district and having lands susceptible of irrigation by the proposed works. The proposed amendment was submitted to a vote of the people at a special election on August 3, 1897, but was rejected by a heavy majority.

THE USE OF WATER.

The "duty of water" is the term used to express the relation between the quantity of water used in irrigation and the area upon which it is employed. The present duty of water in Texas can not be ascertained with the data in hand, but is in most cases very low. The duty assumed by most of the projectors of new irrigating enterprises is 100 acres to the second-foot. This, in the semiarid section at least, ought to prove sufficient, for by the time the amount of land under irrigation from each canal reaches the maximum the people will have learned how to use the water more economically than at first, and the land will not require so much. A careful estimate of the amount of land under irrigation in Mexico, just across the international border at Eagle Pass, gives a duty of 137 acres to the second-foot. There the crops are mainly corn and cotton, the latter needing very little water.

The investigations upon which this discussion is based revealed the fact that there are in the State not only a great variety of gravity systems of supplying water but also all kinds of pumping devices operated by steam or gasoline engines and by water wheels or windmills. The latter are of more importance than the data obtained would seem to indicate. Throughout the arid and semiarid regions nearly every residence has its windmill to pump water for domestic uses, the surplus of which is often used to irrigate a few vegetables or fruits around the house. Although a small area is watered by each mill, yet the aggregate must be considerable. Data were obtained from the few plants constructed for irrigation use only, which will give an idea of the comparative merits of windmills as a source of irrigation. The least cost of a windmill-irrigation plant was found to be a little over $16 for each acre irrigated, the largest area watered by one wheel being 30 acres. This is in the humid portion of the State. In the arid portion half that amount is all that can be supplied. The average cost is about $47 for each acre irrigated, and the area commanded by each wheel amounts to only about 7 acres.

The number of acres irrigated from each steam or pumping plant varies from 5 to 1,000. The cost of these irrigation plants ranges from $15 to $50 for each acre irrigated. The efficiency of most of the pumping plants could and should be very largely increased. There is a great lack of experience shown in the management of many of them, and consequently they have not been operated at anything like their full capacity or made to pay a reasonable dividend on the money invested. Few of them have reservoirs into which to pump the water; thus they can be used only while the actual irrigation is going on, whereas to be operated economically they should be run day and night, at least during the irrigating season. There are a number of plants in the State with a capacity of as much as 2,500 gallons of water per minute. Such a plant, if worked to its full capacity, will give a stream equal to 5.57 second-feet. Allowing one-third for loss by seepage and evaporation, there is left 3.7 second-feet. The usual duty of water is estimated at 100 acres to the second-foot, but in new irrigation districts it very often amounts to only half as much. Even with this low estimate there should be more than 180 acres irrigated from the plant. Such a plant, it is estimated by H. M. Wilson, can be erected for $5,000; this will give a cost of $28 per acre irrigated.

For estimating the quantity of water used in irrigation, various units of measurement are employed. For bodies of standing water the cubic foot, or, where that is too small a unit, the "acre-foot" is used. The latter is the quantity of water that will cover an acre of ground 1 foot deep, or 43,560 cubic feet. The gallon is also very largely used for stationary bodies of water and for pumping plants, especially those for municipal supply. In considering flowing water some unit must be used which expresses the capacity of the stream in a given period of time. That most commonly used is the second-foot, or the number of cubic feet of water which flow by in a second of time. The "miners' inch," so generally quoted in California and Colorado, is not used in this State. In the following table are given some convertible units of measurement:

Units of measurement used in irrigation, with equivalents.

1 cubic foot=0.0283 cubic meter=7.48 gallons.
1 cubic foot of water weighs 62.4 pounds.
1 second-foot=449 gallons per minute=26,930 gallons per hour.
1 second-foot=50 California miners' inches.
1 second-foot=40 Arizona miners' inches.
1 second-foot for one day=1.9835 acre-feet.
1 second-foot for one day=646,317 gallons.
1 second-foot of water falling 10 feet gives 1.135 horsepower.
1 horsepower is given by 1 second-foot of water falling 8.8 feet.
1 gallon of water=231 cubic inches=0.13368 cubic foot, and weighs 8.34 pounds.
1,000 gallons per hour=0.037 second-foot.
1,000,000 gallons=3.07 acre-feet.
1,000,000 gallons per twenty-four hours=1.55 second-feet.
1 acre=43,560 square feet, or nearly 209 feet square.
1 acre-foot=325,850 gallons.

DISTRIBUTION OF RAINFALL.

The most important element of climate in its relation to the present discussion is precipitation. In Texas the rainfall is greatest in the eastern portion of the State and decreases steadily toward the west. This decrease is at the rate of about 4 inches every 60 miles, being about 50 inches in the extreme east and 9 inches at El Paso. The isohyetals, or lines of equal precipitation, run through the State in a general north-south direction, as shown by the map, fig. 1.

The customary definition of "arid region" is one having less than 20 inches of mean annual rainfall. This, however, is not sufficiently complete, for it does not take into account the distribution of the rain throughout the year. In certain parts of the country, where the greater portion of the precipitation occurs during the crop season, wheat and other cereals are successfully raised when the rainfall is far less than 20 inches; while in other parts of the United States, as,

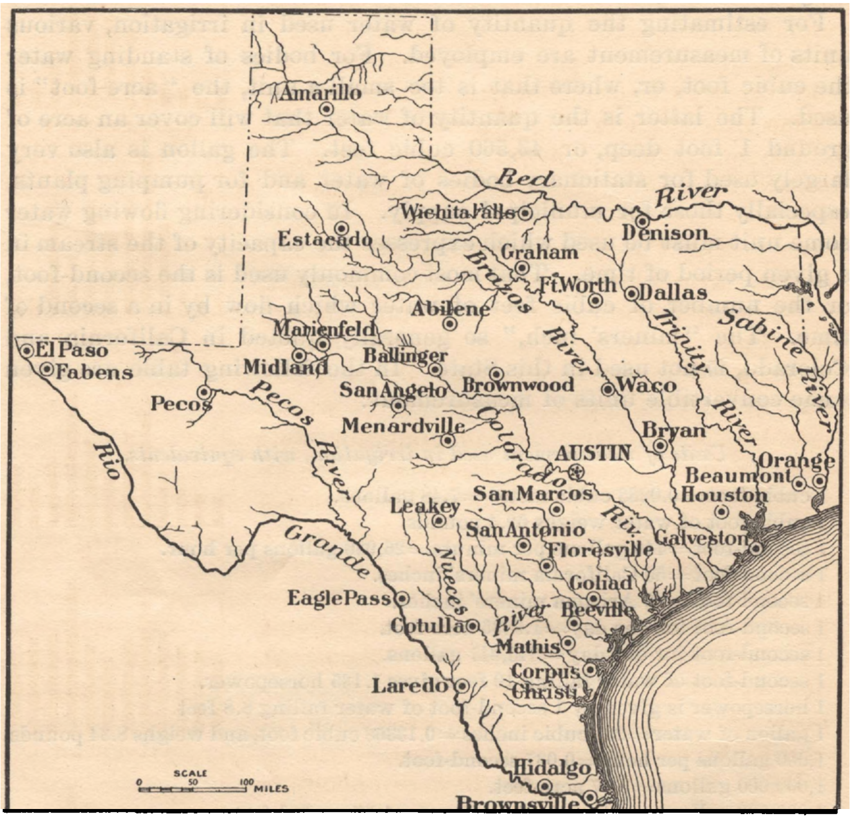


FIG. 1.—Index map of Texas.

for example, near the Pacific coast, where the greatest precipitation occurs during the winter months and the summers are practically rainless, irrigation is necessary during a part, at least, of the crop season. Thus the distribution by months is almost as important an element as the total quantity occurring during the year.

The accompanying diagram, fig. 2, shows the quantity and average distribution of rainfall by months at a number of selected stations fairly typical of the State as a whole. The first of these is Galveston, on the coast, in the eastern part of the State. Here the average rainfall for twenty-seven years is 49.6 inches. As shown by the diagram, the months of heaviest precipitation are September and August, but in every month except February an average of over 3 inches of rain has fallen. This is fairly typical of the distribution of rainfall along the Gulf coast. The diagram next above this is for Austin, where the average rainfall for thirty-nine years is 33.4 inches. Here, also, there is an excess of precipitation in September, and a second maximum in May. Relatively to these months, June, July, and August are somewhat dry; but in every month throughout the year there has fallen an average of over 2 inches of rain.

The next diagram in fig. 2 above that for Austin is that for Fort Clark or Brackettville. This is constructed from the average for twenty-nine years. The mean annual rainfall is 22.7 inches. Fort Clark is remote from the coast, and the distribution of its rainfall, though somewhat similar to that at Austin, having maxima in September and May, shows reduction in quantity, especially during the winter months. Next above the diagram for Fort Clark is that for Fort Elliott, situated far up in the Panhandle of Texas, near the Oklahoma line. Here the quantity and distribution are fairly typical of the Great Plains area. The diagram is derived from the mean of observations extending over eleven years and giving an annual average of 23.2 inches. The month of greatest rainfall is May, September being below the average. The rainy season may be said to extend from April to August.

In the upper part of fig. 2 are two diagrams illustrating the typical distribution of rain in Trans-Pecos Texas. This has been named by General Greely the Mexican type of rainfall.[1] In these, particularly in the diagram for Fort Davis, obtained from twenty-six years' observations, the rainfall is seen to increase regularly from February to August and then to decrease rapidly to the end of the year. The greater part of the precipitation occurs during

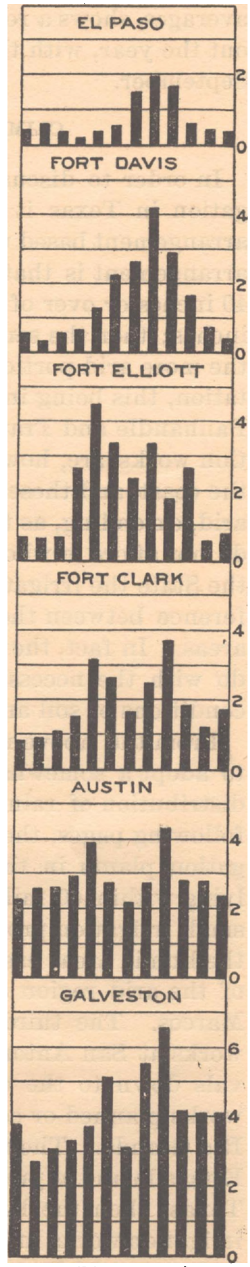


FIG. 2.—Diagrams of mean monthly rainfall at six stations.

[1] Nat. Geog. Mag., Vol. V, 1893, p. 51.

June, July, August, and September, at the time when most needed by many crops. The diagram for El Paso, from thirty-six years' averages, shows a relatively uniform but small precipitation throughout the year, with the exception of the months of July, August, and September.

CLIMATIC AND GEOGRAPHIC DIVISIONS.

In order to discuss the present condition and development of irrigation in Texas it is essential to pursue some systematic order of arrangement based upon climatic or geographic factors. The simplest arrangement is that of taking first the humid region, or that having 40 inches or over of rainfall; next the subhumid, with from 30 to 40 inches; then the semiarid, with from 20 to 30 inches of rain; and last the more arid portions, having less than 20 inches of annual precipitation, this being in the western part of the State, and including the Panhandle and Trans-Pecos regions. The greater part of the irrigation works are, however, in the southern half of the State, or near the coast, and these divisions, especially those of subhumid and semiarid, extending, as they do, in a north-south direction, though simple, do not afford a wholly satisfactory grouping. In the central part of the State the irrigation works are small, and there is no essential difference between those in the more humid and those in the semiarid areas. In fact, the actual amount of annual precipitation has less to do with the necessity for artificially applying water than the local conditions of soil and character of crops.

From the above-mentioned conditions it has been found desirable to adopt a somewhat arbitrary classification, based partly upon the distribution of rainfall and partly upon geographic position. In the following pages, therefore, a description will first be given of the irrigation plants in the humid area near the coast, particularly those lying within 50 miles or more of Galveston. Next in order are the small irrigation projects scattered about the center of the State from the humid areas east of Brazos River westward nearly to the borders of the arid region and southward to the vicinity of Austin and San Marcos. The third division is taken to include the old irrigation works at San Antonio, with small irrigation projects found at intervals down to the coast. Next in order to these are the irrigation works planned or constructed along the Nueces River and the lower Rio Grande. The fifth division to be considered is that of the Llano Estacado and adjacent areas, including the greater part of Panhandle Texas; then the lands watered by the Pecos River, and finally the irrigation works in Trans-Pecos Texas, extending to the extreme westerly end at El Paso.

DESCRIPTION OF IRRIGATION WORKS AND PROJECTS.

EASTERN GULF COAST REGION.

The humid part of the State may be considered as that having a mean annual precipitation of 40 inches or more. This comprises the greater part of the State east of the city of Dallas and of the lower Brazos River. The rainfall over this area is usually abundant, and irrigation in the northern and central portions of this humid region will not probably become of any considerable importance, but in the southern end, along the coast, there exist large tracts of land adapted to rice growing, and the greater portion of this will probably be used for this purpose.

This land is mostly a flat prairie, locally called swale land, covered with a coarse growth of grass and having such a gentle slope toward the sea as to be but little removed from a marsh during a large part of the year. It extends inland for several miles and is cut by numerous bayous, in which the tides from the Gulf ebb and flow and the waters gradually become brackish as they near the Gulf. Most of the rice farms lie along these bayous, and from them the principal supply of water is derived. The farms are so located as to insure a supply of fresh water. The soil along the bayous is much richer than the prairies and yields heavier crops.

The manner of cultivating and irrigating is very different from the South Carolina system, where the water is held by artificial storage reservoirs or raised above the level of the fields by the action of the ocean tides, which back up the flow of the rivers at each tide to a height sufficient to reach the fields. In this part of Texas storage reservoirs are used in only a few cases, most of the fields being supplied by pumps placed on the banks of the bayous and operated by steam power. The land is laid off in much the same way as on the eastern plantations. The work in this State is newer and therefore rougher, but the main features are the same. The fields are surrounded by low levees to hold the water on the land, and are ditched to permit drainage at the lowest point.

Nearly all of the land planted with rice is irrigated, as those who have attempted to grow it without irrigation have lost their crops two years out of five and made only very short crops during the other three years. As previously stated, the water is supplied to the fields by pumps run by steam power, rotary pumps of the Menge pattern being most frequently used. These are operated by engines of from 10 to 70 horsepower or more, and have a pumping capacity of from 1,500 to 8,000 gallons per minute, or from 3.34 to 17.82 second-feet. The lift varies from 9 to 12 feet, and the pumps are run night and day during the irrigating season, which lasts from sixty to ninety days, thus delivering from 400 to 3,000 acre-feet of water. For the prairie farms the water is carried in canals, either on the surface or excavated but little below it and confined by levee walls on each side, for a distance sometimes of 1½ miles.

The area in rice is increasing rapidly. One planter, Mr. J. E. Broussard, of Beaumont, has 750 acres this season (1897), whereas last season he had but 250 acres. He estimates that the total area watered from Taylors Bayou alone, in Jefferson County, in 1897, was 8,500 acres. From his statements the following facts were derived: Planting of early rice is begun in March, from about the 15th to the 25th, if ground and weather are suitable, and continued until the 1st of June. Many persons plant as late as the 15th of June, but this is probably too late to make a good crop. As soon as the rice is up to a height of 6 or 8 inches, if the ground becomes too dry for it to grow well, the usual practice is to give it a good soaking, but not to hold the water very deep upon it the first time. As soon as the rice becomes well rooted, the land is flooded and the attempt is made to keep it in this condition until the rice is ready for harvest. Most farmers turn the water off about two weeks before harvesting, although there is considerable difference in this matter. The size of field inclosed under each set of levees depends altogether on the lay of the land; if very level, there may be as much as 50 acres in one "cut," but where the land has much fall the average piece under one set of levees will be about 5 to 8 acres. The lands are so level that when the water is from 4 to 6 inches deep over the lowest part it will wet the highest portions. The depth of flooding rice in this section is about 5 or 6 inches; some farmers prefer deeper water, while others do not care for so much. Experience has shown that when water is held very deep on rice all the time the quality of the grain is not so good; it is sufficiently heavy but is somewhat "chalky." There are several farms that have from 500 to 1,000 acres under cultivation in rice. The average yield is reported to be 40 bushels to the acre of rough rice, or 10 barrels of clean. One hundred pounds of rough grain will make about 72 pounds of clean rice.

Mr. F. H. Catron, of Orange, has been one of the most successful planters. He has been irrigating since 1891 with a Menge pump, operated by a 50-horsepower steam engine, pumping from a bayou into a surface ditch 1 mile long and 20 feet wide, the lift being about 8 feet. The total cost of the canal levees and ditches was $5,000, and the engine and other parts of the pumping plant cost $1,500. The pumping capacity is 5,000 gallons per minute, or 11.14 second-feet. In 1896 he irrigated 500 acres of rice.

Irrigation of orchards and gardens is resorted to in this humid region, particularly in the vicinity of Galveston and Houston. This is due largely to the fact that artesian water can be had, and the land is so nearly level that water can be readily applied. In spite of the abundant rainfall, experience has shown that fruit and garden crops are greatly improved in quantity and quality by the application of moisture during a portion of the year, particularly at times of summer drought. Operations on a considerable scale have not been attempted, but many small gardens are being watered. Nearly all of this land requires drainage, and this is especially the case when irrigation is introduced. The prairie land in this region is not notably rich, but it is easily worked, and as a rule ground water is near the surface.

The source of water for the city of Galveston is at the suburban town of Alta Loma, 18 miles distant from Galveston. Here are 27 wells 7 inches in diameter and 3 wells 9 inches in diameter, from 750 to 850 feet deep, all located in a direct north-south line, 300 to 750 feet apart, making a total distance from end to end of 16,350 feet. The wells, at 2 feet above the ground, showed a static pressure of from 5 to 7 pounds per square inch. Water is derived from several horizons, and the combined flow is 12 million gallons per day, or 18.60 second-feet. The pressure is sufficient to deliver 5 million gallons daily, or 7.73 second-feet, at the city of Galveston, 18 miles away, through a 30-inch pipe having a fall of 1 foot to the mile. A portion of this 30-inch pipe is depressed about 10 feet for a distance of 2½ miles, from the mainland to the island, under West Galveston Bay. These wells have been flowing for three years. The cost for the installation of the entire plant was $790,000. Analysis shows that the water is usually pure, and the people of Galveston are highly gratified in having a water supply of such excellence.[1]

The water-bearing strata underlying this portion of Texas are so uniform in character that contractors do not hesitate to guarantee a flow of from 25,000 to 50,000 gallons daily, or 0.04 to 0.08 second-feet, for a specified size of well at any point in or near Galveston County. There are 5 artesian wells at and about Clear Creek, 1 at Shell Siding, 10 in the vicinity of Dickinson, 2 at North Galveston, 1 at Texas City, several at Hitchcock, 2 or 3 at Alta Loma in addition to those already mentioned, and 2 at Arcadia, making a total of not fewer than 55 for the county. In some localities sufficient flow for smaller wells is obtained at a depth of 490 feet, though occasionally the extreme depth of from 1,000 to 1,100 feet is required.

Water for irrigation is also provided by using windmills. There is a stratum of water-bearing sand at a depth of from 30 to 60 feet which furnishes an abundant supply for irrigation by the smaller land holders and market gardeners. For example, Mr. H. Sampson, an orchardist near Alvin, has a surface well 12 inches in diameter and 36 feet deep, in which he put an 8-inch tubing. He asserts that from 15,000 to 30,000 gallons can be pumped from it daily by a windmill of sufficient size. Within the town limits of Alvin, Mr. W. H. Nash has a similar well which he states has never been pumped dry by a 10-foot windmill. He irrigates all the berry and garden crops which he

[1] Engineering News, Vol. XXXIX, No. 9, March 3, 1898.

thinks it advisable to grow in between the trees of a 10-acre bearing pear orchard.

This will convey a brief but positively reliable idea of the underlying water supply of the Texas coast for irrigation purposes. It remains to add a word concerning the use of water for irrigation purposes in this section. The structure of the soil is somewhat peculiar in that it is naturally subirrigated; that is to say, there is plenty of water within from 7 to 15 feet of the surface. An ordinary barnyard well does not exceed in most instances 10 to 12 feet in depth. Almost all the varieties of trees planted in the orchards here readily send their roots to this and greater depths, and hence for commercial orchards irrigation is not essential. This is especially true if timely, judicious, and frequent cultivation be given. With the berry grower and market gardener the conditions are different. His crops must be made within a specified period to obtain the best results and greatest returns. To accomplish this it is essential that a good supply of water be at command to force the crops when conditions of great heat and drought develop. At the same time it should be noted that perhaps 90 per cent of the berry growers and gardeners have not yet provided irrigation works, and they have been, in a measure, doing business with a small but very uncertain margin of profit. They have hoped each year that it would not be necessary for them to irrigate. Two successive seasons of drought, however, have induced them to prepare to avail themselves of the ample supply of water. Within two years from this time probably the greater part of the most intelligent berry and truck growers will be fully equipped with an irrigation plant of some description.

The advantages of having irrigation facilities were abundantly illustrated in 1896. Those who had such equipments were not only selling more products at the same time that their neighbors were offering theirs, but were selling long and profitably after their less fortunate competitors could not produce sufficiently to make an attempt at marketing advisable. This is especially noteworthy in the case of the strawberry growers in the coast country.

CENTRAL TEXAS.

This second division has been arbitrarily drawn to include the irrigation plants, mostly small in size, situated within the central part of Texas, from about the vicinity of Brazos River westerly to the edge of the arid region, and from the vicinity of Austin, on the south, northerly through the State. This area falls between the lines of mean annual precipitation of 20 and 40 inches, and thus includes the tract of country having sufficient rainfall to raise crops in ordinary seasons. The precipitation is fairly uniformly distributed by months, as shown by the diagram of mean monthly rainfall at Austin in fig. 2 (p. 23). The black, waxy soil which covers a considerable portion of this district is retentive of moisture and resists droughts, as does the land along the Brazos and Colorado river bottoms, located mainly within this area. The region to the south and southeast of Austin, although having the same mean annual precipitation, has not been included in this division, because the rapidly increasing temperature toward the Gulf, as well as the different character of the soil, renders irrigation somewhat more essential and its development is more nearly comparable to that of the arid region to the west.

In this central portion of Texas, where crops are raised successfully each year, irrigation is not felt to be a necessity except by truck farmers and nursery men, and many of these have introduced it in a somewhat experimental way. The results, however, demonstrate its value, and this method of cultivating the soil is being extended. Water is usually obtained from a well or small storage reservoir, and pumped by means of a windmill, or occasionally by a small steam engine.

The most easterly of the irrigation works in this section are those at Mexia, near the head of Navasota River, a tributary of the Brazos, and near Bryan, on Brazos River, at the State Agricultural and Mechanical College. At this latter point storm waters are impounded in a reservoir formed by building an earthen dam 10 feet in height and 100 feet long across a small draw. This covers about 1 acre, and from it so far about 7 acres have been regularly irrigated, the crops watered being garden truck and alfalfa. In addition to the storm waters, the reservoir is so situated as to receive the waste water from the college ice factory and from the natatorium when necessary, but as this water, coming from an artesian well, carries in solution considerable mineral matter, it is not allowed to enter the reservoir to any considerable extent.

At Mexia, in Limestone County, J. W. Stubenrauch has been very successful in the use of a small irrigation plant for fruits and vegetables. This consists of a dam across a ravine, catching the storm waters and forming a tank covering about an acre of ground. From this the water is lifted to a height of 25 feet by an 8-foot windmill into an earthen reservoir 50 feet long and 100 feet wide. This reservoir is now being enlarged to have double the present capacity. The total cost of the system was $300, including 700 feet of piping; 7 acres have been irrigated, but it is estimated that 15 acres could be watered. Mr. Stubenrauch is also putting in another system with a reservoir covering an acre of ground, the dam having a height of 5 feet above the outlet pipe, for filling which he will use a 12-foot wheel. This he expects will enable him to irrigate 30 acres at one time. He states that the total cost, including 600 feet of 2½-inch pipe for discharging the water into the reservoir, was $485. He pumps from a storage tank made by damming a big ravine.

In the northern end of this district—that is, north of the Colorado

River—irrigation is little practiced. There is a well-developed plan to irrigate a large tract of exceptionally fertile land in the Wichita River Valley. The storm flow of this river is to be stored at a favorable site about midway of its course. The catchment area above this storage basin will be about 1½ million acres. The area to be irrigated is about 270,000 acres.

Careful flood-flow determinations indicate that the supply is largely in excess of requirements. The region has a rainfall of about 28 inches, which it is necessary merely to supplement. That is, the duty of water here will be comparatively large. In fact, the greater part of the area is at present utilized as farm land. But, though the lands are rich and easily tillable and the average yield is considerable, there is yet a disastrous variability of yield on account of droughts. Therefore, relating to a subhumid rather than to an arid region, the project will have this advantage over irrigation undertakings in the

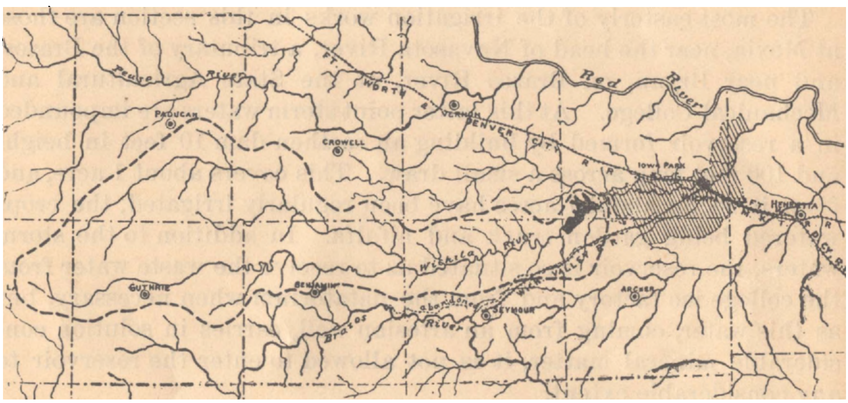


FIG. 3.—Map of drainage basin of Wichita River.

arid lands proper, that the amount of water needed for abundant crop yield is comparatively small. The plan, which has been developed fully, is based upon careful and elaborate engineering work. Before the present reservoir site was chosen, other possible sites, along the Pease River to the north and the Brazos River to the south, were examined with a view to diversion of these streams to the same lands. The present selection appears to be an exceptionally fortunate one. The depth to bed rock at the dam site is slight and the river valley here is constricted to a canyon.

The dam is to be of earth, 80 feet high, designed to hold water to a depth of 70 feet. Both spillway and outlet are to one side, well away from the dam—the spillway over bed rock, the outlet through a tunnel in bed rock. The capacity of the reservoir will be about 12,000 million cubic feet, or about 275,000 acre-feet. There will be two canals, designed to irrigate both slopes of the Wichita Valley. At their head these canals will have a width at bottom of 40 feet, a depth of 8 feet, and a grade of 1 foot to 5,000 feet. The total cost is estimated at a little over $1,000,000.

Careful determinations of flood flow made by the company's engineer, Murray Harris, indicate that the supply is much more than ample. They are as follows:

	Acre-feet.
During the first week in January, 1897, about	59,687
From March 28 to April 4, 1897, about	98,714
From April 25 to April 29, 1897, about	174,472
From April 29 to May 15, 1897	330,579
Total	663,452

Farther south, near Brazos River, in Young County, not far from Graham, are reported two small gardens irrigated by windmills, such as are found scattered all through the semiarid region.

The Lytle Water Company, in 1897, began to build a dam across Lytle Creek at Abilene, in Taylor County, the main object being to furnish good water to the town, but it is also expected to irrigate 300 acres by a canal 1½ miles long. The dam is of earth, riprapped with rock on the inner slope and sodded on the outer. It is 800 feet long, raises the water 15 feet, and has a masonry spillway of 300 feet. The total cost of the plant will be about $25,000. The reservoir formed by the dam will cover 120 acres and have a capacity of 300 million gallons, or 920 acre-feet.

On the ranch of Hugh Lewis, 8 miles north of Ballinger, in Runnels County, is a stone dam built in 1896 across a small creek which originates in a spring a short distance above. The dam is 80 feet long, raises the water 6 feet, and supplies a ditch some 200 yards in length. Ten acres in fruit and vegetables were irrigated in 1896, but at least 50 acres could be covered. The total cost was from $150 to $200.

In Tom Green and Irion counties the water facilities furnished by the Concho River and its numerous branches and tributaries are among the finest to be found anywhere. These have only been partially used by individuals and small companies in separate systems, making the cost of maintenance much greater than if consolidated. Nevertheless, they have been fairly successful, and have certainly reduced the cost of living in that section, making foodstuffs, especially vegetables, much cheaper and more abundant. There are ten of these plants reported in those two counties; three on the South Concho, one on the Main Concho, and two each on the North Concho, Spring Creek, and Dove Creek. The total area irrigated is 3,200 acres, 2,000 being in Tom Green County and 1,200 in Irion County.

The plants of C. B. Metcalfe, of San Angelo, and J. J. Glenn, of Water Valley, may be taken as types of the systems in vogue. Mr. Metcalfe's canal takes its water from the east bank of the South Concho River 12 miles south of San Angelo. It is 4 miles long, with an average top width of 12 feet, bottom width 8 feet, and depth of water 1.5 feet. It was begun in 1887 and the first mile was completed the next year, but it was not entirely completed until 1896. It takes its water by means of a brush-and-stone dam 200 feet long and 7 feet high, which extends across the river and cost about $500. The main ditch cost $500 to the mile, and the laterals, of which there are three, cost $250 to the mile, making a total cost, with incidentals, of $7 to each of the 470 acres now irrigated. The repairs, which are maintained by the tenants, may be estimated as amounting in labor to 75 cents per acre. The crops irrigated in 1896 were: Johnson grass, 40 acres; cotton, 120 acres; corn, oats, wheat, truck, etc., 220 acres; total, 380 acres.

The ditch of J. J. Glenn is located on the North Concho 1½ miles west of Water Valley, and is 3 miles long, 8 feet wide on top, 4 feet wide on bottom, and 2½ feet deep. It was first used in 1886, and is supplied with water by a rock dam across the river, 100 feet long, with an average height of 8 feet. The total cost of the system was $3,500, and it commands 350 acres, of which 250 have been irrigated, two-thirds in cotton and the remainder in the different sorghums and oats.

The most successful field crops in this region are oats and cotton, the former producing from 30 to 90 bushels with great certainty, and the latter usually 1 and sometimes 1½ bales to the acre. Corn is a poor crop, by reason of the dry winds, but sweet potatoes, melons, and celery do very well, especially the last named.

In Sterling County there are two systems on Concho River, only one of which has been reported in full. It is located 5 miles from Sterling City and is owned by the McGee Irrigation Company. The main ditch is 2 miles long, has a top width of 6 feet, is 4 feet wide at the bottom, and carries about 1 foot of water. It was begun in 1892 and first used in 1894. The water is raised by a loose-rock dam, 125 feet long and 6 feet high, built across the river. The total cost was $1,500, and it commands 250 acres, only 75 of which are really irrigated. The principal crops, in the order of their importance, were cotton, corn, sorghum, oats, sweet potatoes, alfalfa, and vegetables. Repairs are maintained by each stockholder doing his share of the work on the ditch.

At Brownwood, in Brown County, about 120 miles east of the above works, considerable interest has been taken in irrigation during the last few years, there being a large area well located for irrigation on a considerable scale. This scheme was abandoned for lack of capital to complete it. Meanwhile several steam pumping plants have been erected for irrigating smaller areas. The most important is that of the Swinden Pecan Orchard Company. This consists of a centrifugal pump operated by an 80-horsepower engine and pumping 3,000 gallons per minute, or 6.84 second-feet. The water is carried by a flume

4,000 feet long to a reservoir formed by building an earthen dam 4,000 feet long and with a height varying from 2 to 15 feet. The dam is at the foot of gently sloping land, and forms a triangular reservoir covering 55 acres. The reservoir is designed to irrigate the 400 acres of level land lying between it and Pecan Bayou, from which the water is pumped to fill it. A small stream is also dammed and turned into the reservoir. The 400 acres commanded by the reservoir are planted in pecan trees, making the largest orchard of this kind in the world. The irrigation plant was put in mainly to enable the owners to practice truck farming and small fruit growing between the rows of trees while waiting for the latter to mature. The soil is a rich black and chocolate loam. The great mistake that has been made in this plant is in having the reservoir so large and shallow. Evaporation and seepage are in this way so increased as to become a serious source of loss.

Immediately east of this, in Mills County, are several pumping plants on Colorado River. That of J. B. Baker, 11 miles southwest of Goldthwaite, was completed in 1896, and consists of a 32-horsepower boiler operating a Worthington pump. The plant cost $2,000, and the expense of operating it is about $7 a day of twelve hours. It has a capacity of 1,220 gallons per minute, or 2.72 second-feet, and commands 80 acres, 75 of which were irrigated. The crops raised were corn, cotton, and oats. J. D. Willis, of Ratler, has attached pumps with a capacity of 50 gallons per minute, or 0.11 second-foot, to the shafting of his gin and grist mill, irrigating 5 acres in fruits and vegetables. The power is furnished by a turbine under a 5-foot head of water from a dam 300 feet long across Colorado River. At Regency, G. W. Alldridge, with a 20-horsepower engine, pumps 450 gallons per minute, or 1 second-foot, and reports that he can water about 5 acres per day, which would give 50 to 75 acres under command of his pump. None of these men use reservoirs.

On the south side of Colorado River, in San Saba County, J. H. Lindsey owns a steam pumping plant on the river, 20 miles north of San Saba. It consists of a 30-horsepower engine and a pump with a capacity of 840 gallons per minute, or 1.87 second-feet. The plant cost $2,000 and is worked eleven hours a day at an expense of $3, irrigating 40 acres in corn and cotton. There are also several small areas irrigated in this county from the numerous springs which issue from among the hills. The total amount of these is 250 acres. Farther down the river, in Burnet County, the only irrigation reported is one windmill irrigating a garden 50 feet long and 150 broad, and also 1¾ acres watered by a spring and reservoir. Both are very successful.

At the head of San Saba River, in Schleicher County, William L. Black has been irrigating since 1894 with a plant consisting of a 6-horsepower engine, pumping 580 gallons per minute, or 1.29 second-feet, and a 6-foot overshot wheel with a capacity of 167 gallons per minute, or 0.37 second-foot. The latter is run day and night, no reservoir being provided, and the total area irrigated is 50 acres, in corn, potatoes, and sorghum. With his water wheel he uses four 10-inch cylinders worked horizontally, and with the engine a link-belt box elevator, which gives satisfaction. Farther east, in Menard County, on San Saba River, is a pumping plant owned by Emile Vanderstucken and consisting of an 18-horsepower steam engine operating by a belt a Menge centrifugal pump with a capacity of 1,167 gallons per minute, or 2.60 second-feet. The total cost of the plant was $1,500. No reservoir is used, the water being carried in a flume to the highest point on the land and distributed by ditches. On account of the abundance of rain in 1897 it was used but very little. In 1896 it was operated from March to September, irrigating 100 acres and making good crops, with practically no rain.

The following description relating to the condition of irrigation in the vicinity of Menardville is taken from a statement prepared by Mr. Robert S. Dod, of Brady, Texas, county surveyor of McCulloch County. This method of agriculture has been a great success in this vicinity, as is evident to anyone passing through the county examining the fields and conversing with the farmers. The system has not always been successful, but early failures were mainly the result of inexperience and arose from accidental and not from essential defects. Mistakes have been gradually remedied, and by well-directed energy and enterprise great improvements have been brought about, progress being still made toward even better methods.

On crossing San Saba River 5 miles below Menardville, the traveler enters upon the irrigated part of the narrow valley lying between the river and the low hills, and is impressed by the signs of energy and activity. The fences are good and in repair; the gates have two hinges and swing clear of the ground; the fields are clear of grubs and clean of weeds; the ditches are straight and well shaped and clean; the cotton as seen when visited stood 28 to 30 inches high all over the fields, of good color and as clean as possible. The corn was 10 feet high or over, and the dark green of its leaves was accounted for by the water running in the furrows at its roots. To the right was an orchard of peach trees filled with fruit, and beyond this a stubble field already plowed and harrowed, ready for reseeding for another harvest. Near this field stood the stacks, the proof of the success of that crop at least, yielding their stores of grain to the efforts of the busy crowd about the thrasher. The active movements of the men at work there and in the neighboring fields, and the rate at which the teams traveled carrying the grain to the barn and returning to the field, showed that the success apparent everywhere was due to systematic, well-directed effort—the kind of effort that men put forth when reasonably certain of the reward of their labor. Such animation men do not display when disappointment and failure year after year have sapped their energy and made them cynically hopeless of success, when under "dry farming" they have degenerated into the almost brutish attitude of contentment with surroundings that could be improved and toleration of losses that might be avoided.

All the way from the river to Menardville the road passes through irrigated farms showing success in proportion to the amount of care and labor expended on them. The vegetable gardens, the orchards, the green lawns, and the flowers and vines around the houses make this valley the picture of contented prosperity. The farmers with whom conversation was had gave many facts applicable in contrasting their methods and results with those of the dry-land farmer. They raise from 1 to 2 bales of cotton per acre, the difference in yield depending largely on how much damage the worms do in a given season and how much rain falls in August. The drier this month the better the cotton crop. On new land with few worms and a dry August 2 bales would be expected. Their corn yields from 40 to 80 bushels per acre. One man suggested that a light rain or shower was needed when the pollen was ripe in order to obtain the best results. Oats yield from 50 to 80 bushels per acre. During the years from about 1888 to 1895 the farmers irrigating in Menard County were raising from 1 to 2 bales of cotton to the acre, 40 to 50 bushels of corn, and 80 or more of oats, while in contrast to this their neighbors without irrigation were working perhaps equally as hard, bringing together what little cane and fodder could be raised to save the stock from starving to death, and producing only enough marketable stuff to keep the interest on the mortgages paid up, and perhaps not even that.

These beneficial results are produced by a little water and a deal of hard work. The water rate is $2 per inch, and 1¼ inches will irrigate an acre of their land, so that $2.50 per acre and a little extra work make the difference between one-third of a bale of cotton and 2 bales; between no corn and 40 to 50 bushels; between 80 bushels of oats and a dead failure.

It has been proved by experience that one man can not give proper attention to more than 25 acres of this irrigated land. He will need help in cultivating if he plants corn and cotton, but could tend rather more land put in small grain. He will require for these crops a little over an inch of water per acre, and will need to turn the water on about every twenty days.

At Menardville corn and cotton are irrigated by running the water down the furrows between the rows from openings in the ditch. The amount of labor required for the operation and to make the water run properly depends upon the general level of the field and the care with which the furrows are laid off with regard to the slope. Small grain and fodder crops are laid off by throwing two furrows together, back to back, as a border, every 8 or 10 steps, to hold the water, and flooding the land between these borders. Some farmers use an Acme harrow to finish off the land after planting, running it between the borders so that the small furrows left by it help in directing the flow of the water.

As to the amount of water required per acre, one man who irrigates 40 acres of land uses 40 inches of water, and occasionally needs a little more. On another farm they use 15 inches of water on 12 acres of garden truck. On the upper part of the ditch above town the water is measured and distributed by the inch; that is, if a man wants 20 inches of water, the gate opening on his ditch is set for a 20-inch flow and so remains through the season, giving him his 20-inch constant flow. From town down they use the water in rotation, as, owing to a mistake originally made in laying out the distributaries, the use of water above interferes with the flow below. So they alternate every seven days, those above using all the water that reaches them for that time, and then the lower owner having all the water for the next seven days; this farmer, having some 500 acres under irrigation, distributes the water over them as necessary.

The amount of water required for an acre of ground here is more than that needed for sandy fields. The soil at Menardville is a clayey loam containing a large proportion of lime. Both soils require the same amount of water for the first irrigation, but the sand packs and requires less at each succeeding irrigation, whereas it is claimed that the limy loam seems to rise instead of pack, and requires as much water for the later irrigation as for the first.

The ditch which supplies these farms is nearly 10 miles long. The dam is built across San Saba River some 4 miles above Menardville and returns to the river some 5 miles below the town. The charter was obtained by the Vaughan Agricultural and Improvement Company in 1874, and the ditch was built soon after. It is claimed that this company put $12,000 in the work. This was excessive, an extra expense being incurred by the refusal of right of way in one instance, forcing the company to make a cut 16 feet deep and several hundred feet long. Further, the methods of work were rude and costly. Wheelbarrows were used to move the dirt, and in the cut the dirt was thrown on staging and passed from man to man. There are 97 shares in the company, valued at $180 each. One year $1,200 was spent in improvement; another year $1,000 in the same way; but the ditch pays all running expenses, cost of improvements, and 10 per cent on the shares at the above quotations.

The grade of the ditch after construction was found to be irregular and unsuitable, so work has been done each year—cutting and filling, to reduce the slope above Los Mores flume to a nearly uniform grade of 30 inches to the mile. At the flume is a fall of 14 inches in 128 feet. At the point of the mountain where the ditch curves with the hill and runs through rock it is lessened in size and has a much steeper grade. The grade of 30 inches to the mile was established experimentally, and satisfies as nearly as possible the necessity of avoiding silting on the one hand and erosion on the other. The ditch runs through coarse gravel part of the way, and there is a heavy loss from percolation.

The straightening of the ditch, reduction of the grade, and tightening of the dam have given an available flow of water sufficient to irrigate 2,000 acres of land, which is the amount estimated to be under irrigation from this ditch at the present time. This taxes the flow to its full capacity.

The dam is built of rough limestone quarried at the spot, averaging, where seen on the front of the dam, 2 by 3 feet by 10 inches, laid in courses without cement. The blocks are tied by bolts fastened to a log under the dam at the bottom and passing up through the dam and fastened at the top by taps to cross-ties lying along the top. The dam is slightly concave and is about 200 feet long and 5½ feet high at the middle of the front, with an irregular batter. It is 13½ feet wide on top at the center. It rests partly on rock, partly on gravel, and is backed with earth with a slope of nearly 2 to 1.

The water stands within a few inches of the top of the dam and runs over at every rise in the river. There must be 10 or 12 feet of water passing over it at times, judging from the high-water marks. Below the dam is a pile of loose bowlders which holds the leakage through the dam and forms a water cushion to receive the fall. The dirt is washed from the back of the dam at every high rise, and is at once replaced when the rise goes down, by scraping the dirt from the north side of the river. The dam backs the water up about 500 yards, the deepest hole being about 15 feet. The water is taken out on the south side 100 or more yards above the dam and carried in a cut to the sluice gate a little below the dam.

A section of the ditch made a few hundred yards below the sluice gate gave the following: top, 15.2 feet; bottom, 8 feet; depth, 2.7 feet; wetted perimeter, 16.5 feet; area, 29.83 square feet; maximum surface velocity, 2.17 feet per second; mean velocity, 1.54 feet per second. The velocity was measured for 100 feet above and below the section, where there was no very great difference in the dimensions of the ditch. The fall of the surface was found to be at this point 0.1 foot in 195, or 1 foot in 1,950, or 2.7 feet in a mile. This, with a coefficient of $N=0.03$, would give a velocity of 1.57 feet per second, which is very nearly the observed velocity of flow. This gives a discharge of 46 cubic feet per second, or 2,300 inches, estimating 50 inches to 1 foot.

Taking the estimated acreage irrigated as 2,000 acres, we have from our calculated flow a little over 1 inch per acre, which is the allowance in actual use, as above stated, and a water duty of 44 acres per cubic foot per second of flow for the water entering the main ditch. These measurements were made at but one point and can be considered as only approximate for the whole ditch. For accuracy they should be repeated at a number of points and proper allowance made for percolation and leakage. In general, the estimate is that three waterings of 4 inches will make a crop. From the above it is readily seen that before a calculation can be made with any degree of certainty as to what water is necessary to irrigate a crop in this country, there must be further experiment and careful consideration and comparison of

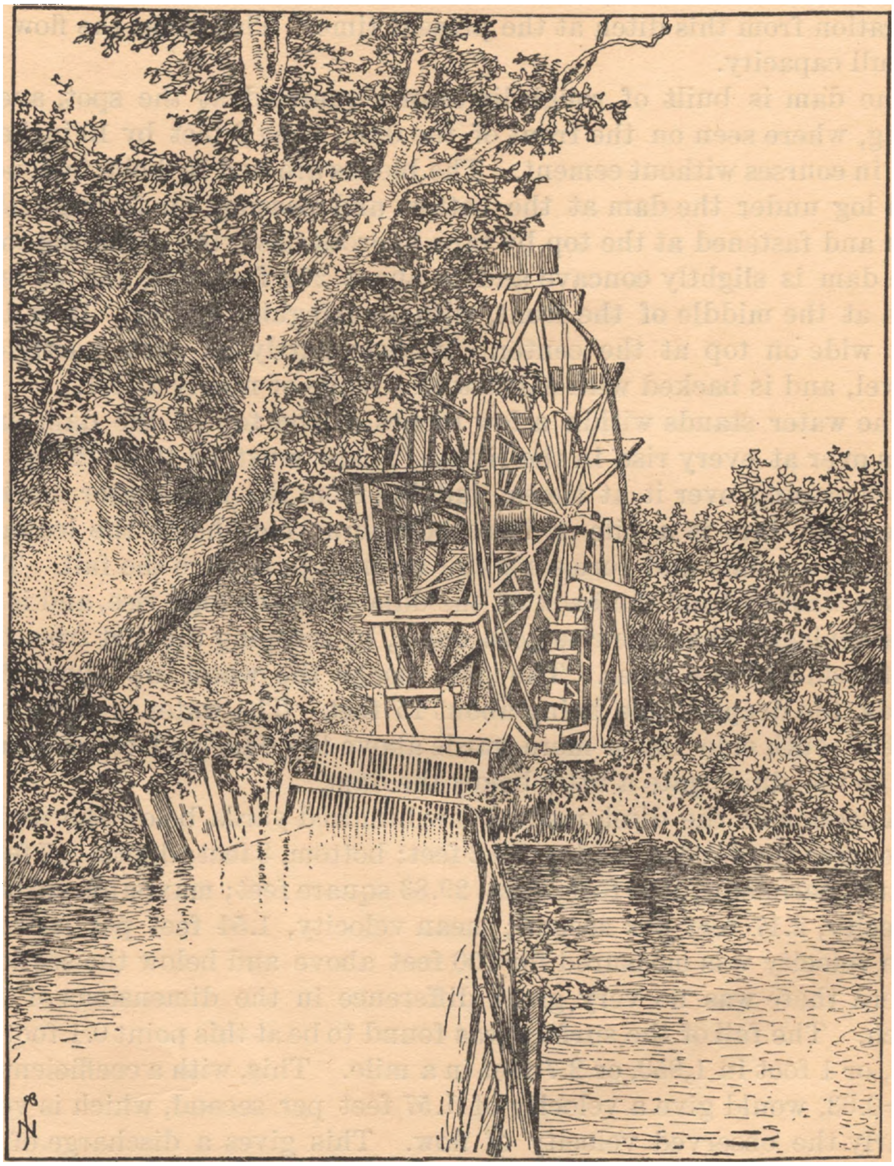


FIG. 4.—Water wheel and wing dam turning current against wheel.

soil and subsoil, percolation, evaporation, and the best method of applying the water to the crop. The duty at Menardville is, under the present system, 44 acres per cubic foot of flow per second, or a trifle under 1¼ inches per acre.

At San Marcos is found a system of water wheels for raising water for irrigation. They are all of the same type, consisting of an under-

PORTION OF WATER WHEEL, SHOWING BUCKETS RAISING WATER.

shot wheel of a size varying according to the height of the river bank. The wheel is run by the direct current of the river, which is quite swift, and is brought against the wheel either by a wing dam of planks, which turns the current against it, or by a ditch taken out about 50 or 100 yards above. The river, coming from immense springs which burst out about three-quarters of a mile above the town, as shown on Pl. I, is not subject to rises, the only flood on record having occurred when a flood in the Guadalupe backed up the water of the San Marcos for eight hours. This renders secure this seemingly unsafe way of locating a wheel. There are three of these wheels on the river, all used by truck gardeners. The wheels are of wood and are the simplest form of undershot wheels, with a metal bucket fastened to the perimeter of one side of the wheel, in front of each paddle, as shown in Pl. II and fig. 4. These buckets fill in succession as the wheel turns and empty into a trough above, thus raising the water very nearly to the height of the diameter of the wheel.

The wheel owned by Capt. John Richards (Pl. II) is the oldest and the one on which all of the others are modeled. He states that before he built it he tried a number of pumps, which required too much attention and repairs, and afterwards several kinds of water wheels, with no satisfaction until he finally hit on the present arrangement of his buckets, which has lasted satisfactorily for about ten years. The wheel runs day and night, and needs no attention save oiling twice a week. It is 20 feet in diameter and 8 feet wide, and is supplied with water by a ditch 150 yards long, taken directly from the river and running through low ground to the wheel. It pumps into an artificial reservoir of about 50,000 gallons capacity. The average speed is three revolutions per minute, and in that time it raises about 90 gallons, or 0.20 second-foot. The water is used to irrigate 3 acres of grapes and vegetables for the market.

The wheel at D. C. Garrett's place, shown in fig. 4, is larger and carries 16 buckets of 6 gallons capacity, pumping on an average 144 gallons per minute, or 0.32 second-foot. He uses no reservoir and irrigates about 12 acres in vegetables.

These wheels furnish a cheap and convenient method of irrigation, being easily built, and running expenses being practically nothing. They are highly successful at San Marcos, but would not be elsewhere where the conditions are not similarly favorable. Here the river has a swift flow and steep banks, from which the wheel may be hung with relatively little expense for scaffolding, and the stream, coming from a great spring, has an even flow summer and winter.

At Austin, the State capital, is one of the largest hydraulic works of the country, impounding water of Colorado River. Although this was built primarily for the purpose of furnishing power, there was at the same time a belief that the surplus water could be used for irrigation above the lowlands along the river at times of summer drought.

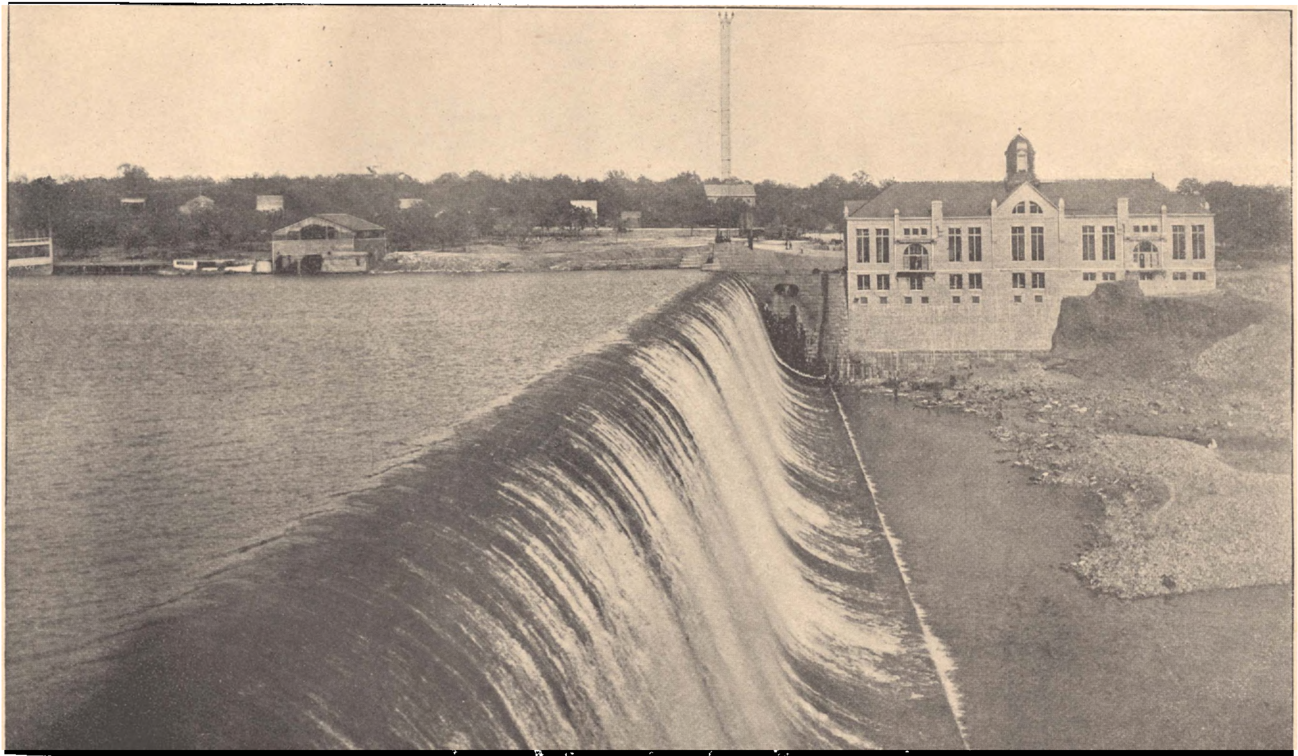
This project for thus employing the surplus flow of the stream was abandoned, if not completely destroyed, by the low water of the summer of 1896, when the surface of Lake McDonald was lowered some 5 feet below the crest of the dam. Thus, although there is an immense amount of surplus water carried by the river, it is probable that other works must be built to utilize it, for the steady increase of demands for power tends toward the requirement that the stored water shall be held for this use during the summer months.

The dam at Austin was built by the city with the intention of supplying water for municipal purposes and power for lighting and for manufactures. It is located at a point about 2 miles west of and above the city, where the river flows in a narrow valley between limestone cliffs. At this point the Colorado River drains about 40,000 square miles, and has a usual summer flow of 1,000 second-feet. In times of flood it rises to from 200,000 to 250,000 second-feet, a contingency which necessitated the construction of a strong masonry dam which could be submerged by the highest floods.

The dam is 1,150 feet long, with the crest 60 feet above low-water mark and having a maximum height of 70 feet. It is 66 feet thick at the bottom and 16 feet wide on top, constructed of solid limestone rubble laid in imported Portland cement, faced on each side and on the top with cut granite blocks from the same quarries that furnished the stone for the State capitol. In order to provide for the great volume of water coming down the river in flood times the dam was so designed as to allow the surplus water to flow over it in a sheet of uniform thickness along the entire length. To avoid the impact and erosive action of the falling water, which may sometimes be as much as 15 feet in depth at the crest, the front of the dam was given the shape of a reversed curve of ogee form. This allows the water to glide down its face without shock and expend its force in a horizontal direction against the pool in front of the toe.

There are three iron sluice pipes 36 inches in diameter inserted in the dam, near the west end, for use in possible emergencies. The total cost of the dam, exclusive of the sluice pipes and engineering expenses, was $611,300; the latter amounted to some $58,000 more. The total cost of the whole enterprise, including dam, power house, electric lighting, and waterworks system, was nearly $1,400,000. Lake McDonald, formed by the dam, is over 25 miles long and averages three-fourths of a mile wide. The power available is estimated at about 14,000 horsepower. The power house, shown in Pl. III, is located on the same side of the river as the city and just below the dam. The water is carried directly to the turbines through iron penstocks.

The water for the city is pumped from the lake into the mains, the pumps being directly connected with the turbines operating them. The management is preparing, however, to move these pumps some



AUSTIN DAM AND POWER HOUSE.

distance down the river to beds of gravel forming natural filters, from which perfectly clear water can be obtained at all times. This is the same water as that in Lake McDonald, but it is purified by filtering through these beds. It will be obtained by sinking cribs in the gravel and pumping from them by electrical energy transmitted from the power house. At present the amount of work done varies from 800 to 3,000 horsepower. This is employed for waterworks and electric lighting, and for running all the car lines and most of the manufacturing enterprises in the city, such as planing mills, printing presses, and many others. It has been demonstrated that it is cheaper for a man who uses no more than 200 horsepower to rent his power from the city in the form of electrical energy and to use an electric motor instead of a steam engine.

Up to the present time most of the earnings of the plant have been spent in improving and adding to it; but it is hoped that in the near future these will increase and materially relieve the people of the heavy burden of taxation under which they now labor and enable them to pay off the debt incurred in construction.

Another notable water power which may in the future be partly used for irrigation is that supplied by the Comal Springs at New Braunfels. These springs burst from the base of the hills at many points for a distance of a mile or more and form the head waters of Comal River. New ones can be made at any time by blasting in the limestone rock along the line of those already existing. The fall is so great for the first half mile that no difficulty is found in carrying the water by a simple canal to the point where the accumulated flow can be utilized to good advantage. At present the power is used to operate a cottonseed-oil mill, a flour mill, and an electric-light plant owned by the Landa estate, on whose property the springs are situated. The power used amounts to about 500 horsepower, which can be increased almost indefinitely, if desired.

SAN ANTONIO AND VICINITY.

Under this head is included a description of irrigation works at San Antonio, and also in the areas southerly and southeasterly near San Antonio and Guadelupe rivers down to the Gulf coast. The irrigation ditches at San Antonio are historically the most interesting in the State, for here are found the earliest systems and structures, which have been in use for more than a century. Additional interest is derived from the association of the ditches with the early missions and with the efforts of the Franciscan fathers to settle the Indians upon these lands and employ them in agriculture. The old missions, now in ruins, were rendered habitable by these ditches, and the lands adjacent were the garden spot of the frontier, making possible the growth of the city which now is the center of civilization and trade of the Southwest. These ditches are now almost completely concealed by the ancient trees and the luxuriant verdure that line the banks, and through the lapse of time they have assumed the character of natural drainage channels, so that it is almost impossible to believe that they were artificial works. The facts concerning the origin and present condition of these ditches were obtained mainly from Mr. Z. O.

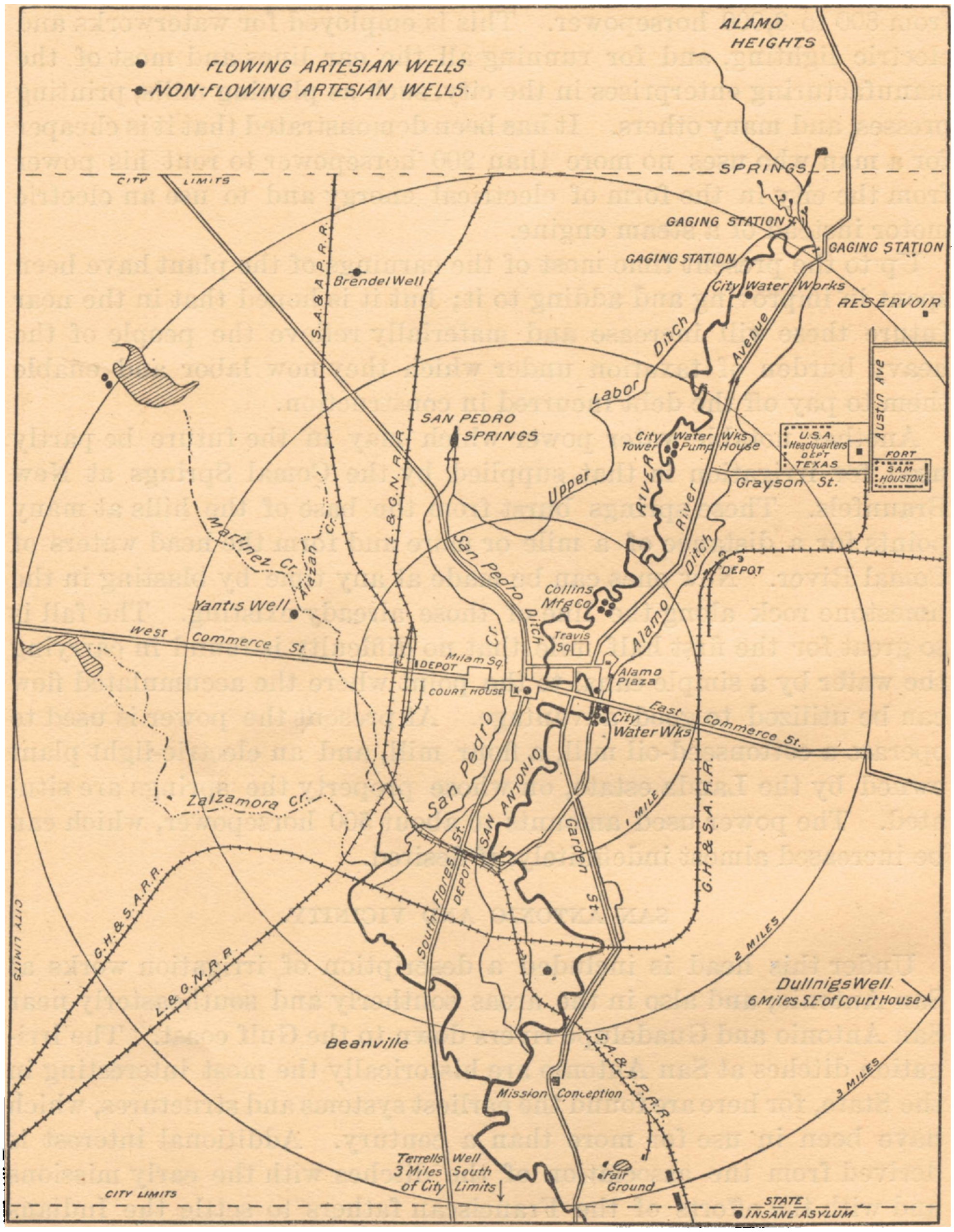
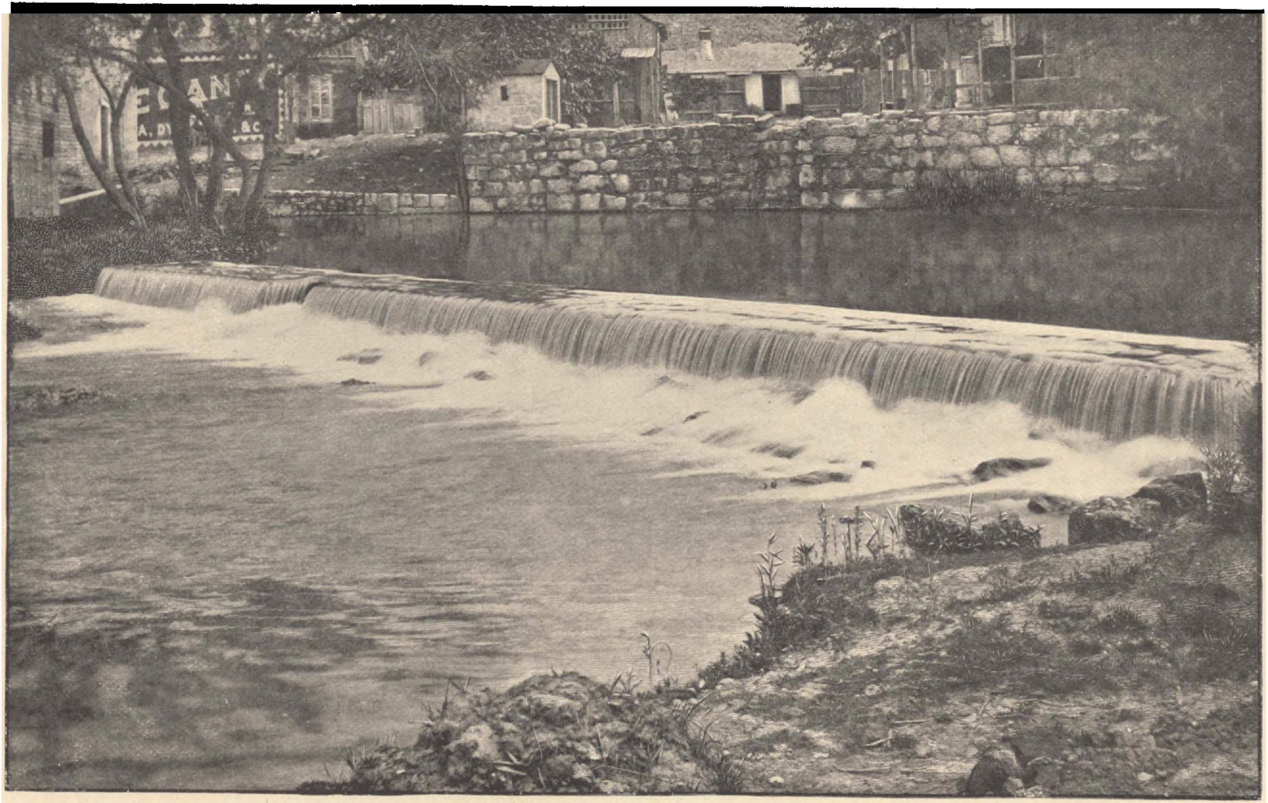


FIG. 5.—Map of ditches and artesian wells at San Antonio.

Stocker, of San Antonio, who has made a thorough study of them, both from an interest in the subject and with a view to developing irrigation enterprises in the vicinity. A view of the river, illustrating its size and character, is given in Pl. IV.



SAN ANTONIO RIVER AT MILL BRIDGE.

The original mission ditches built by the Franciscan fathers between the years 1716 and 1744 are the Pajalache or Conception ditch, the Alamo Madre, the San Jose, the San Juan, and the Espada ditches, all dug to supply the lands belonging to the respective missions. In addition to these mission ditches there was one, the San Pedro, which supplied water to the Villa Capital de la San Fernando, settled in 1730 by the emigrants from the Canary Islands; and one built much later than any of the others under the superintendence of the governor, Baron Ripperda, for the supply of the citizens of the town, and called the Upper Labor ditch.

Beginning at the head of the San Antonio River, as shown on fig. 5, this last-named and most recent of the Spanish ditches is the first encountered. It was begun in 1776 and was ready for use in 1778, under the general direction of the royal governor, care having been taken that no infringement of the prior rights of the five missions and Canary Island settlers should occur. The work was done by those citizens who desired to enlist themselves for that purpose, each furnishing his own tools and at the completion of the ditch receiving a share of the land commanded by the ditch under royal grant, on the condition that he should aid in keeping the ditch and all its appurtenances clean and in repair, and hold himself, with one horse, arms and ammunition, in readiness at all times to meet the enemies of his king. The lands were divided into lots called "suertes" (suerte meaning luck or chance), each one containing the amount of land that could be irrigated by the ditch during a given space of time, usually a day, but sometimes less. The assignment of suertes was always accomplished by lot. The original grade and side slope of these ditches are unknown, but the latter is quite steep, probably about $\frac{1}{4}$ to 1, or at most $\frac{1}{2}$ to 1, yet on all of them the banks, owing to the character of the soil, have withstood the elements remarkably well. The ditches will be described in the order in which they are met with in descending the river.

The Upper Labor ditch takes its water from one of the large springs at the head of the river by means of a loose-rock dam. The ditch follows the contour of the land on the west side of the river and ends in the San Pedro Creek, and once commanded about 600 acres of land, of which only about 100 acres are now irrigated and used as truck gardens. Water rent is $2 per acre. In 1877 the city replaced the old loose-rock dam by a masonry one and built an extension to the ditch, called the Alazan branch. The latter was abandoned in 1896, because the land irrigated was devoted to residences.

The Alamo Madre ditch, built between 1718 and 1744 to supply water to the Alamo Mission and irrigate its lands, derives water from the river on the east side, at a point just opposite the Labor ditch, by means of a low dam. The ditch then follows the contour of the land and runs through the business part of the city. Its length is 6 miles, and it irrigated about 900 acres, of which only about 220 are now cultivated.

San Pedro ditch was commenced in 1738, and furnished water to the Villa de la San Fernando, the parish church of which, now

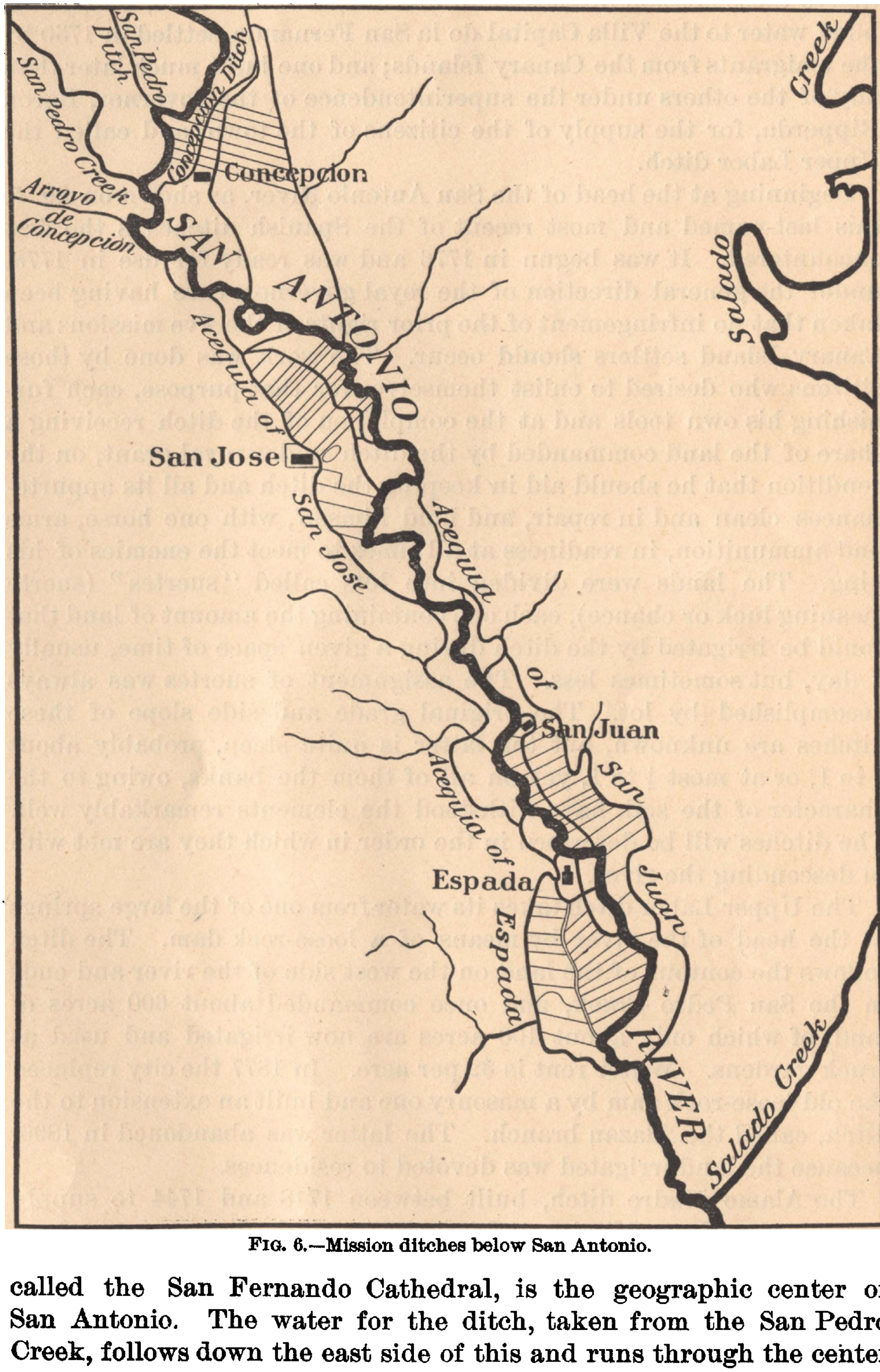
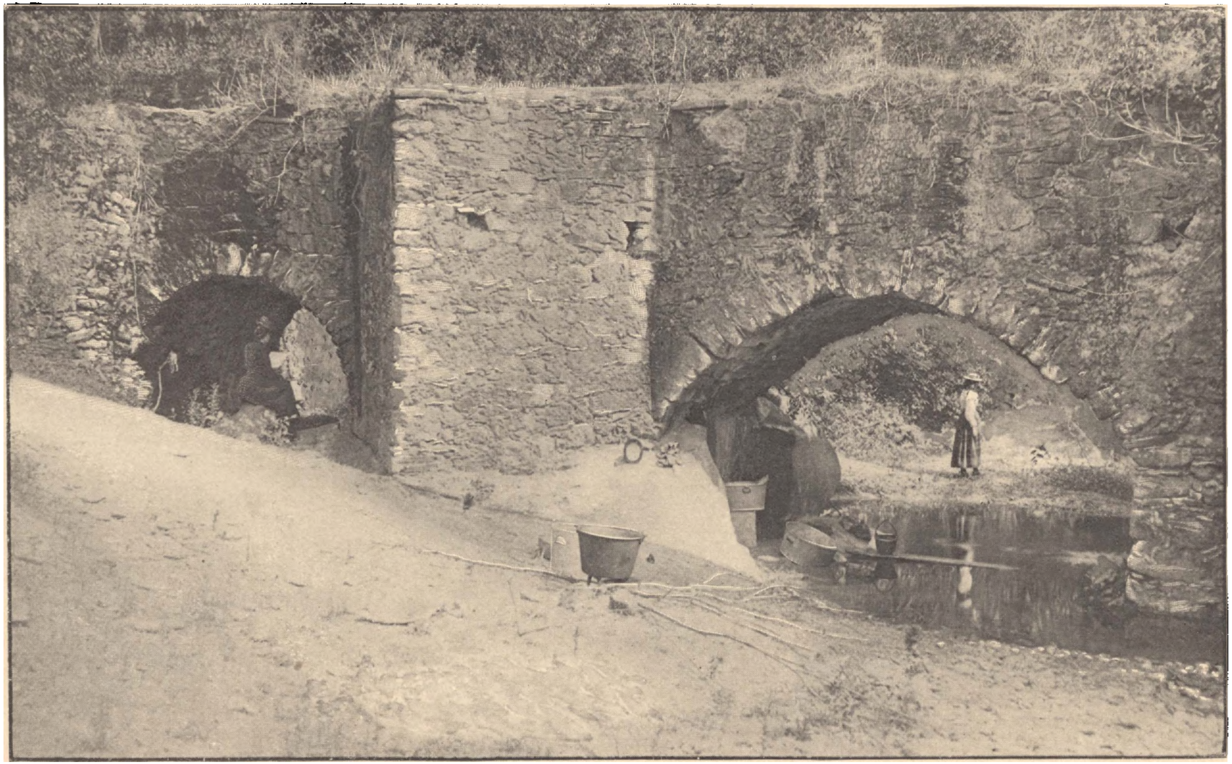


FIG. 6.—Mission ditches below San Antonio.

called the San Fernando Cathedral, is the geographic center of San Antonio. The water for the ditch, taken from the San Pedro Creek, follows down the east side of this and runs through the center



OLD STONE AQUEDUCT CARRYING ESPADA DITCH ACROSS PIEDRAS CREEK.

of the city, irrigating 430 acres of land below town. Its length is about 4 miles and it is 2 feet deep and 6 feet wide. The management of the above-mentioned ditches long since passed out of the hands of the landowners and into those of the city authorities, and is intrusted to a ditch commissioner appointed by the mayor. The annual water rent is $2 per acre. The general location of this and lower ditches is shown in fig. 6.

The next ditch of importance is the Concepcion, built in 1729, and abandoned in 1869 after being in use one hundred and forty years. This was discarded on account of the dam, which was in the center of the city, causing much damage from overflow when there was a rise in the river. This ditch was constructed to furnish water to the Mision de la Concepcion, and was the largest of all the old ditches.

The San Jose ditch was built, probably, about 1720, to supply water and irrigate the lands of the mission of that name, 5 miles below the town. The water was taken from the San Antonio River, on the west side, at a point about 2 miles above the mission, and, following the contour of the land, ran through the mission and returned again to the river about 1 mile below, after irrigating 600 acres. This ditch was abandoned in 1860 on account of the repeated washing away of the loose-rock dam across the river.

The San Juan ditch taps the river on the east side at a point opposite the mission San Jose. It follows the contour of the land and carries its water down to the mission of the same name. It was built in 1731 and is still in use. It irrigates over 500 acres of land, which rent with water for $7.50 an acre per annum.

The Espada is the last ditch taken from the San Antonio River, though one of the earliest in point of construction. It takes its water from the river on the west side at a point 6 miles below the city by means of a loose-rock and brush dam 270 feet long, and built on a natural ledge of rock extending across the river, making the total height of the obstruction 8 feet. This dam consists of layers of brush weighted by loose rock, with gravel and earth thrown in in front, forming a very effective dam, the rock becoming gradually cemented together by a deposit of lime salts from the water. It crosses Piedras Creek on a stone aqueduct, shown in Pl. V, which consists of a series of massive arches that seem in as good preservation to-day as when constructed, more than a century and a half ago. The old Mexican who lived close by asserted that he had seen the water in the creek, in time of flood, flow over the top of the aqueduct, sometimes topping it by as much as 6 feet.

This ditch fell into disuse about twenty years ago and was abandoned until 1895, when A. Y. Walton, jr., who owned several suertes of land, organized the owners of the lands commanded by it into a company (the Espada Ditch Company), cleaned out, widened, and deepened the old ditch, repaired the dam, and made some change in its course, the total cost being about $3,000. The ditch is now 3 miles long, with a bottom width of 5 feet, and carries 10 second-feet of water. It commands 400 acres, of which 300 are irrigated. The annual cost of keeping the ditch in good working order amounts to 25 cents per acre. The principal crops are 100 acres in corn, 150 acres in cotton, a considerable area in Johnson-grass meadows, and the rest in truck gardens for the city market. The appearance of the crops under these ditches, even in a time of such abundant rainfall as the first half of 1897, is a remarkable proof of the value of irrigation. The land is mostly an alluvial valley soil, very productive when watered. On irrigated fields it is customary to make at least a bale of cotton to the acre, while the average on unirrigated fields for the last five years has hardly been more than one-fourth of that. Truck farmers raise all kinds of vegetables, from early spring until frost, in the greatest profusion.

Three-fourths of a mile above the head of the dam which supplies Espada ditch is the head gate of the Trueheart ditch, the only modern canal taken from the San Antonio River. This was begun in August, 1895, and completed in May, 1896, at a cost of about $18,000; it has a total length of 10 miles and is designed to carry 30 second-feet of water. There is no dam, the canal entering the river directly and the head gates being of wood with brick abutments. The cut for the first 3,000 feet averages 14 feet in depth, with a bottom width of 6 feet. It now carries much less than the registered amount of water, a freshet having washed away the head gates and largely filled up the first few hundred feet of the canal, allowing only about 1.5 second-feet of water to enter it. This is, however, amply sufficient for the land at present under irrigation, which is this year (1897) about 400 or 500 acres, though the canal commands 1,500 acres. The principal crops are alfalfa, Irish potatoes, corn, cotton, and vegetables. The water rights are held at $15 per acre, and the annual rental is $2.50 per acre, but all of the land irrigated so far belongs to the owners of the canal. This canal has seven flumes, one of which, shown in fig. 7, is 1,000 feet in length, with an average height of 20 feet. It carries the water across a valley at Minita ranch, 11 miles from San Antonio. The slope is given as ½ to 1.

There is some irrigation practiced in and near San Antonio from artesian wells, a view of one of which is shown on Pl. VI.[1] The most extensive is that of H. D. Kampman, who has a well on his place with an estimated flow of 1½ million gallons in twenty-four hours under 20 pounds pressure, or 2.32 second-feet. This well is 970 feet deep, and was drilled at a cost of $3,000. It is allowed to flow on 250 acres of the owner's land, this, being in alfalfa, needing only a small portion of the water. It has been stated that this well would irrigate 1,000 acres of land through a system of ditches or storage tanks. A

[1] For details see paper by Robert T. Hill in Part II of Eighteenth Ann. Rept. U. S. Geol. Survey, p. 290.

ARTESIAN WELLS AT CITY WATERWORKS, SAN ANTONIO.

second well near the same place discharges about one-third as much water.

Below the city of San Antonio is an irrigation farm which is probably unique in the State, but which may be considered as being typical of others in various parts of the United States. This is the sewage farm, to which is brought for purification and disposal the waste from the city. This method of disposal is one which is rapidly growing in favor, not only in arid and semiarid regions but in humid countries as well, being extensively practiced in New England and in various European countries. The city sewage farm consists of about 400 acres, subdivided into a number of small tracts or gardens sufficient in area to take all of the present output of sewage. These gardens occupy a space about 400 feet square. Near them are a

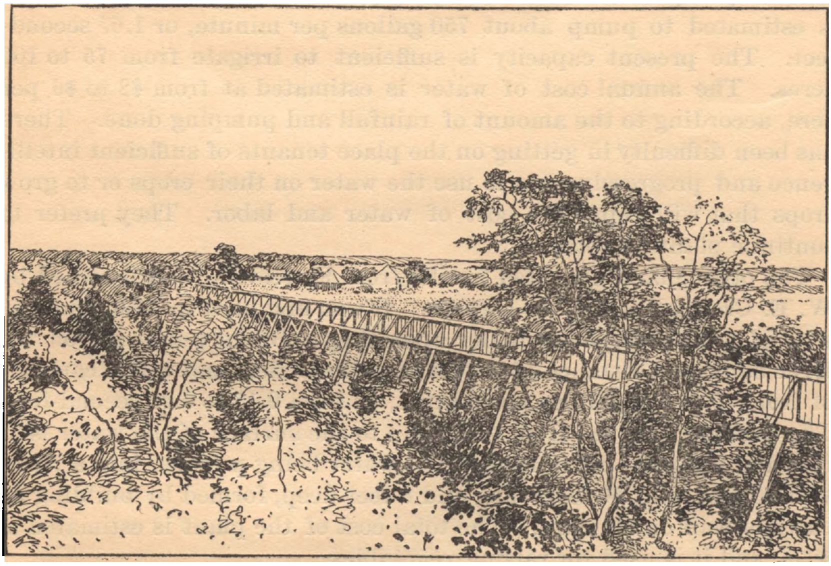


FIG. 7.—View of flume on Trueheart ditch.

number of broad basins surrounded by low dikes to receive the flow from the sewer outlet when water is not wanted on the gardens. It is intended to plant most of these basins in crops which will not be injured by a considerable amount of water, so that the surface will be covered by vegetation throughout the greater part of the summer.

Along San Antonio River below the city are several pumping plants operated by steam. A small one at Elmendorf, owned by C. M. Rounds, is very conveniently arranged for supplying water to a dwelling house and also for irrigating purposes. The water is pumped into an elevated wooden cistern near the river bank and thence piped to another cistern at the house and to the garden and orchard.

Thirty miles below, on the same river, near Floresville, in Wilson County, are reported two more similar plants. That of A. G. Pickett is the more important. It was set up in 1893 and consists of a 40-horsepower steam boiler, operating a Blakeslee duplex steam pump, which is connected to the boiler by a 2-inch steam pipe. From 12 to 15 horsepower only is used at present, it being the intention of the owner to extend his plant by the addition of more pumps as more land is brought under irrigation. The average distance from the pump to the water is 15 feet, and the average lift is 50 feet. There is no reservoir, the water being pumped directly into the ditch. The total cost of the plant is estimated at $2,500, and it requires one man at a cost of 12½ cents per hour to operate it. The pump is covered by high water in the river from two to four times a year. This plant was built with an idea of irrigating from 300 to 400 acres, and has sufficient boiler capacity, but will require additional pumps. The present pump has a 7-inch suction pipe with a 6-inch discharge, and is estimated to pump about 750 gallons per minute, or 1.67 second-feet. The present capacity is sufficient to irrigate from 75 to 100 acres. The annual cost of water is estimated at from $2 to $6 per acre, according to the amount of rainfall and pumping done. There has been difficulty in getting on the place tenants of sufficient intelligence and progressiveness to use the water on their crops or to grow crops that will repay the cost of water and labor. They prefer to continue planting cotton.

The other plant is located 7 miles from Floresville, and is owned by W. E. Crandall and J. O. Dewees. It was first used in 1896, and consists of a 10-horsepower boiler operating a Blake pump set on the river bank at a distance of 70 feet from the boiler, and with a capacity of from 75 to 100 gallons per minute, or from 0.17 to 0.22 second-foot. The average distance from the pump to the surface of the water is 22 feet and the total lift is 48 feet, the water being pumped into a reservoir 50 feet long, 50 feet wide, and 8 feet deep, formed by building an earthen wall on all sides. The total cost of the plant is estimated at $295, and it is used for raising vegetables.

About 50 miles easterly from Floresville is located the enterprise of the Buchel Power and Irrigation Company. The plant is located 3 miles west of Cuero and is to consist of a permanent stone-and-concrete dam across the Guadalupe River, which, when completed, will be 165 feet long on the crest, or 200 feet long including abutments, 23 feet high, and will raise the water 10 feet above the usual water level. The dam was begun in December, 1896, and in June, 1897, was about one-half completed. The 10-foot head of water will be used to run turbines which will operate force pumps, raising the water a total height of 60 feet to a reservoir about 500 feet distant from the dam. From this reservoir canals will lead to the land to be irrigated. The reservoir is to be an artificial one with earthen banks, and is calculated to have a capacity of 10 million gallons, or 30 acre-feet. The area to be irrigated consists of rich valley land along the east bank of the Guadalupe River, 2,000 acres of which are owned by the company and will be first put under ditch. If successful with this tract, the company expects to extend the system to cover 2,000 more acres of the same valley. The growth of all varieties of crops is contemplated, but especially alfalfa, fruits, and vegetables. Guadalupe River has an estimated average flow of 800 second-feet, and with the 10-foot head it is expected to develop about 700 horsepower. Probably one-third of this will be used for irrigation, the remainder being converted into electrical energy and carried to the town of Cuero.

South of Cuero about 30 miles, near Goliad, G. W. Simmons has put in a plant consisting of a 2½-horsepower gasoline engine and a pump with a capacity of 33 gallons per minute, or 0.07 second-foot. The water is obtained from a small stream across which has been placed a

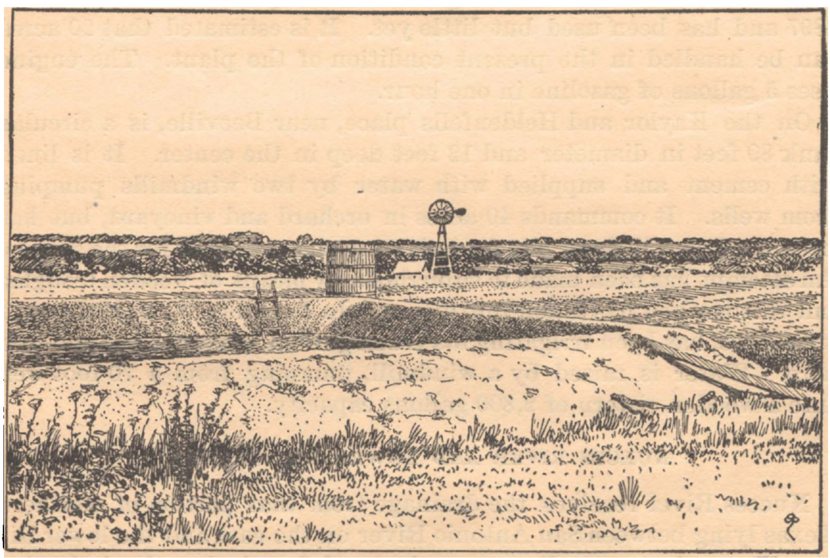


FIG. 8.—View of irrigation tank at Beeville experiment station.

wooden dam 60 feet long and 3 feet high, and is raised 20 feet and pumped directly into the ditch. The total cost was $450, and the plant, while it has not been fully tested, is expected by its owner to irrigate 10 acres.

In Bee County, at the State subexperiment station, under the direction of S. A. McHenry, superintendent, is a pumping plant erected for the purpose of irrigating the orchard and lands devoted to horticultural experiments. It consists of a 5½-horsepower gasoline engine and a windmill, pumping from a well 74 feet deep, in which the water stands 32 feet. The pump has a cylinder 3½ inches in diameter by 36 inches long, with a 24-inch stroke when run by the engine and a 9-inch stroke when the windmill is used. The capacity with the engine is 24 gallons per minute, or 0.05 second-foot. The water is forced 600 feet to a reservoir at a height of 16 feet above the top of the well. The reservoir is 32 feet long, 52 feet wide, and 8 feet deep, and contains about 100,000 gallons, 0.3 acre-foot. It was built by excavating 4 feet deep and building earthen walls of the same height around it, the total cost being $140. On account of the very porous nature of the soil, all tanks in this region must be lined with some artificial material—cement, asphalt, or coal tar. That at the experiment station (shown in fig. 8, p. 49) is lined with a mastic consisting of 73 per cent sand, 25 per cent coal tar, and 2 per cent lime. The sand and lime are mixed together and the tar is boiled until it will string and is mixed hot with the other ingredients. It is spread on the bottom and sides while hot at the rate of 52 pounds to the square yard. On top is put a varnish formed by boiling pure coal tar and flashing it with a lighted match to burn off the light oils. The plant was completed in 1897 and has been used but little yet. It is estimated that 20 acres can be handled in the present condition of the plant. The engine uses 5 gallons of gasoline in one hour.

On the Kaylor and Heldenfells place, near Beeville, is a circular tank 80 feet in diameter and 12 feet deep in the center. It is lined with cement and supplied with water by two windmills pumping from wells. It commands 40 acres in orchard and vineyard, but has been used very little of late for irrigating and not at all for the grapes. An attempt has been made to subirrigate by means of wooden troughs, but this method has fallen into disuse. In Beeville, W. C. McDowell, since 1893, has been irrigating his truck garden, consisting of one-half acre. Water is raised by a windmill, pumping from a 70-foot well into a wooden cistern of 2,800 gallons capacity.

NUECES RIVER AND LOWER RIO GRANDE.

Nueces River receives the drainage from that portion of southern Texas lying between San Antonio River on the east and the lower Rio Grande on the west. For convenience of description the irrigation projects within this drainage basin are given in geographic order from the head waters to the Gulf, and after these the similar enterprises along the Rio Grande from the mouth of Pecos River southeasterly.

On the head waters of Nueces River, about 4 miles northeast of Leakey, is a brush-and-stone dam across Frio River 45 feet long and 2 feet high, built in 1896. This supplies a ditch 2 miles long, with a top width of 5 feet, bottom width of 3 feet, and depth of 3 feet. It was first used in 1897, and commands 300 acres, of which 115 have been cultivated. Sixty acres are in cotton, 50 in corn, and the remainder in oats and vegetables. Two miles below on the same river is a ditch irrigating 50 acres. Toward the east, on Turtle Creek, in Kerr County, a small amount of land is irrigated, and in Bandera County 300 acres are irrigated by small ditches taking water from Frio River.

At Batesville, and southerly at Carrizo Springs, on the west side of

Nueces River, is a considerable amount of irrigation, or rather a large number of irrigation plants operated by windmills, and at the latter place some irrigation from flowing artesian wells. The appliances are of the usual type, and the acreage commanded by each man is very small, and consequently expensive. In Zavalla County are also 3 miles of ditches and 500 acres under irrigation from artesian sources.

A number of schemes have been proposed for bringing under irrigation considerable areas along Nueces River, especially about the middle portion of its course. The success attained by the present methods, though crude, has been such as to encourage others to attempt the construction of better devices. Actual work has been held back to a considerable extent by the defective laws, but since the passage of more favorable legislation in 1895 several projects have been revived.

Nueces River, with its tributaries, has a catchment area of about 20,000 square miles. The amount and distribution of rainfall throughout this territory is such that, with the sandy soil, a comparatively small amount flows, even in the main stream. Few of the tributaries can be said to be perennial in flow, many becoming nearly or completely dry at certain seasons of the year. The Nueces itself and several of its tributaries, such as the Frio and Lena, head in large springs on the edge of the plateau. Here are admirable localities for diverting water for irrigation. On leaving the plateau country the streams tend to diminish, a considerable portion of the water being lost in the sandy channels, occasionally reappearing when forced to the surface by impervious strata. Throughout the area to the south of the line of the Southern Pacific Railroad the perennial flow is so small or uncertain that irrigation on a large scale must depend upon storage reservoirs holding storm waters.

By consulting a map it will be seen that Nueces River flows from its head in a general southerly direction, but at a point about 35 miles west of Cotulla it turns toward the east. At this point the wagon road between Cotulla and Carrizo Springs crosses by means of a bridge. The region west of the river contains a number of long, deep, narrow bodies of water, known as Soldier, Espantosa, and Caimanche lakes. The two former are practically parallel to the course of the river and are connected by a slough or arroyo, while the northern end of Espantosa Lake is connected in a similar manner with the main channel of the river. In time of flood the water rushes through the connecting channel into Espantosa Lake and returns again to the river, either through an independent channel which issues from the south end of Espantosa Lake direct to the river, or through Soldier Slough or Lake, which in its turn discharges its water through a channel connecting it with the river. In other words, in time of flood the river splits into two, one portion passing through the main channel and the other being diverted to the west, passing through the lakes and returning again to the river.

Caimanche Lake is quite different in its nature from the two just mentioned. It lies northwest of the Espantosa about 3 miles, and at an elevation of 15 feet above the latter. This lake gathers the water of a large drainage basin, extending from the Rio Grande divide on the south to many miles beyond the Southern Pacific Railroad on the north, a region containing springs and an easily obtainable supply of artesian water. Its water is discharged through Espantosa Slough into Nueces River, and ordinarily its volume is double that in the main channel of the river itself before its junction with Espantosa Slough. It is proposed to convert Caimanche Lake into a storage reservoir by means of an earthen dam 1¾ miles in length and 20 or 25 feet in height. The area of the reservoir at the height of 170 feet

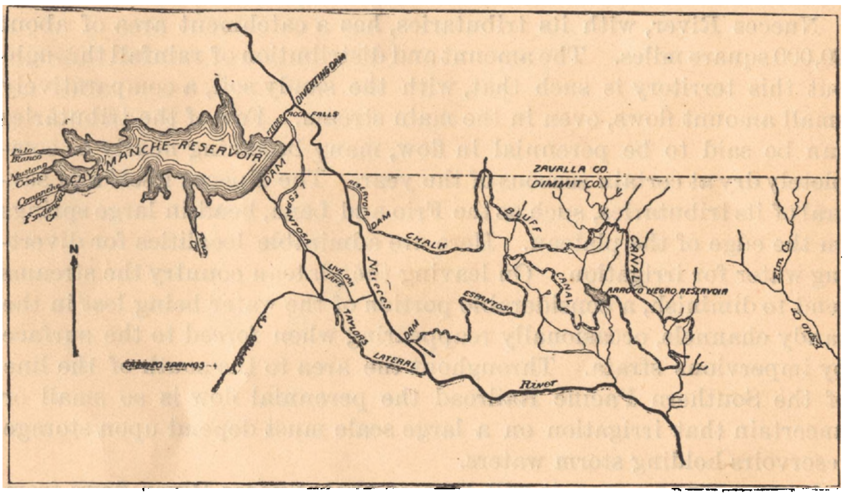


FIG. 9.—Map of the proposed Caimanche reservoir and canals.

above an assumed datum will be 8,500 acres; at 177 feet, or with a dam 20 feet high, it will be 10,000 acres; and at 185 feet it will be 12,500 acres. The original estimates were made for a 20-foot dam, but it has since been concluded that a dam 25 feet high is equally feasible and will make a much greater volume of water available. The spillway will be constructed 5 feet below the crest of the earthwork. Though in possession of no accurate data as to the hydrography of the drainage basin, the projectors are confident that the flood discharges are sufficient to fill the reservoir several times in the course of a year. In addition to the natural drainage of the basin, they expect to avail themselves of the waters of the main stream of the Nueces.

The old channel, connecting the northern extremity of Espantosa Lake with the river, has been already mentioned. Except in flood seasons, no water enters the lake through this channel, there being a high, rocky barrier in its center, known as Rock Falls. By constructing a diversion dam on the Nueces River below the point where the slough to the Espantosa leaves it, and by cutting a channel 1¾ miles long from the upper side of Rock Falls into Caimanche Lake, the river and the reservoir can be connected.

To use the water so stored it is proposed to pass it down the slough connecting Caimanche and Espantosa lakes, through the Espantosa, and finally into the river channel. From the channel it is to be diverted by means of a dam some distance below the Carrizo Springs bridge into a canal on the east bank of the river. Soldier Slough,

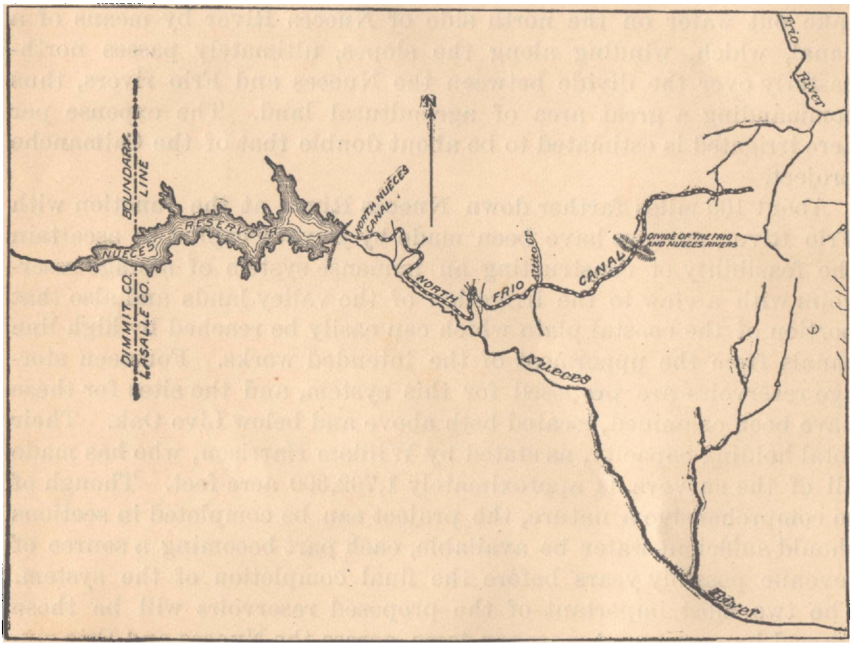


FIG. 10.—Map of proposed Nueces reservoir and canal.

already mentioned, must also be closed by a dam of the same height as the diversion dam on the river. These dams themselves would impound a considerable quantity of water; just how much has not been estimated. At the lower diversion dam the company expect to avail themselves of, first, the water impounded by the dam itself; second, the natural flow of the river; and, third, the storage water of Caimanche Lake. After a diversion line of less than a mile the water of the canal can be taken out on the land. The grade adopted is 1 foot to the mile. The land covered by the canal is among the richest in Texas, well adapted for corn, cotton, sugar, or alfalfa, and the upper-line canal would reach very fine fruit lands. Allowing as much as 2 feet of water per acre per annum, it is estimated by the promoters that there will be sufficient to irrigate 50,000 acres.

About 35 miles below the diverting dam on the Nueces River turning water into Caimanche Reservoir, the river passes from Dimmit County into Lasalle County, and for about 10 miles below the county line the valley widens, the topography being favorable for the creation of a reservoir. By constructing a masonry dam 2,600 feet long and 50 feet high in the center, it is proposed to create what is known as the Nueces Reservoir, having an area of 12,700 acres. Such a reservoir would receive all of the waste and seepage water from the storage works and irrigation canals above, but, being situated on the main line of the river, would be subject to floods. It is proposed to take out water on the north side of Nueces River by means of a canal, which, winding along the slopes, ultimately passes northeasterly over the divide between the Nueces and Frio rivers, thus commanding a great area of agricultural land. The expense per acre irrigated is estimated to be about double that of the Caimanche project.

About 100 miles farther down Nueces River, at the junction with Frio River, surveys have been made by private capital to ascertain the feasibility of constructing an immense system of storage reservoirs with a view to the irrigation of the valley lands and also that portion of the coastal plain which can easily be reached by high-line canals from the uppermost of the intended works. Fourteen storage reservoirs are proposed for this system, and the sites for these have been examined, located both above and below Live Oak. Their total holding capacity, as stated by William Harrison, who has made all of the surveys, is approximately 1,792,300 acre-feet. Though of so comprehensive a nature, the project can be completed in sections should sufficient water be available, each part becoming a source of revenue possibly years before the final completion of the system. The two most important of the proposed reservoirs will be those formed by permanent masonry dams across the Nueces and Frio rivers, respectively, at what are probably the outlets of ancient lakes, through the beds of which the rivers flow.

The total area which it is estimated may be brought under irrigation by the system of canals supplied by these reservoirs, if filled, is something over a million acres. The soils are principally of three general characters, known under the local names of black mesquite, sandy loam, and resaca lands. The black mesquite comprises most of the coastal slope and valley lands of this region. It is a dark, sandy loam of great depth and richness, easily cultivated, and capable of producing a considerable range of crops. The sandy loam proper is found in the live-oak lands, and is also fertile, though not so well adapted to a variety of crops as the black-mesquite soils. The resaca lands are dark and waxy, being composed of river silt, and possess the fertility always found in such soils. They have been but little cultivated as yet, owing to their liability to overflow. This latter fault could be remedied by the building of storage reservoirs, which would largely control the flood waters.

Farther down the river is the pumping plant of the Grover Irrigation Company, the most extensive of its kind in this region. It is located on Nueces River, 8 miles north of Mathis, and consists of a 100-horsepower boiler and a 75-horsepower engine, operating, by means of a belt, as shown in fig. 11, a Menge pump with an estimated capacity of from 5,800 to 6,700 gallons per minute, or from 12.92 to 14.92 second-feet. The pump is set in a well 8 feet in diameter, on the banks of the river, and connected with the water in the river by a tunnel 4 feet square. The average lift is 48 feet. There is no res-

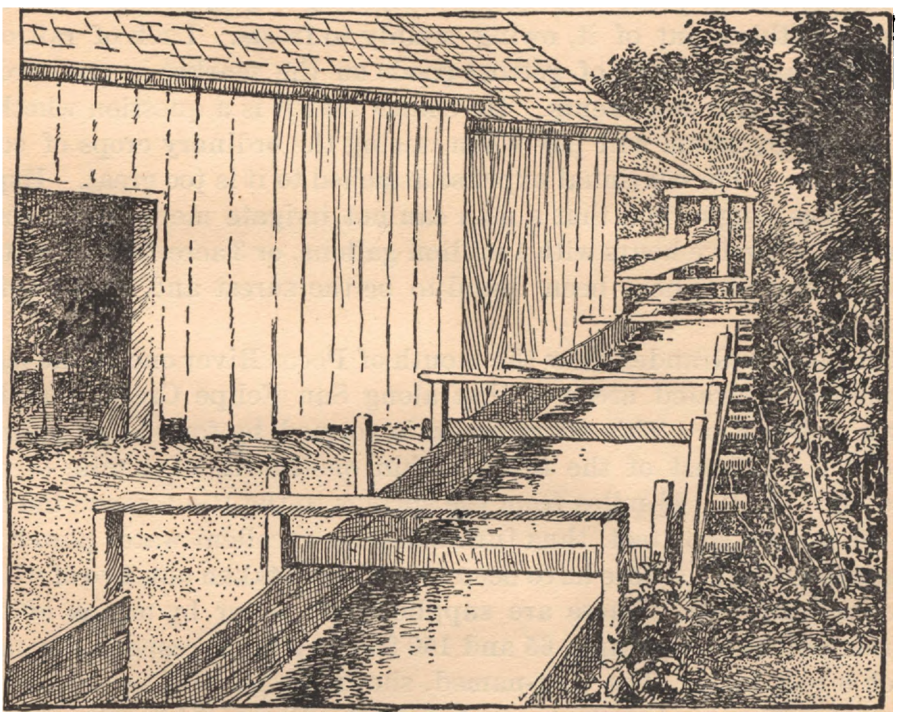


FIG. 11.—Pump and flume on Nueces River.

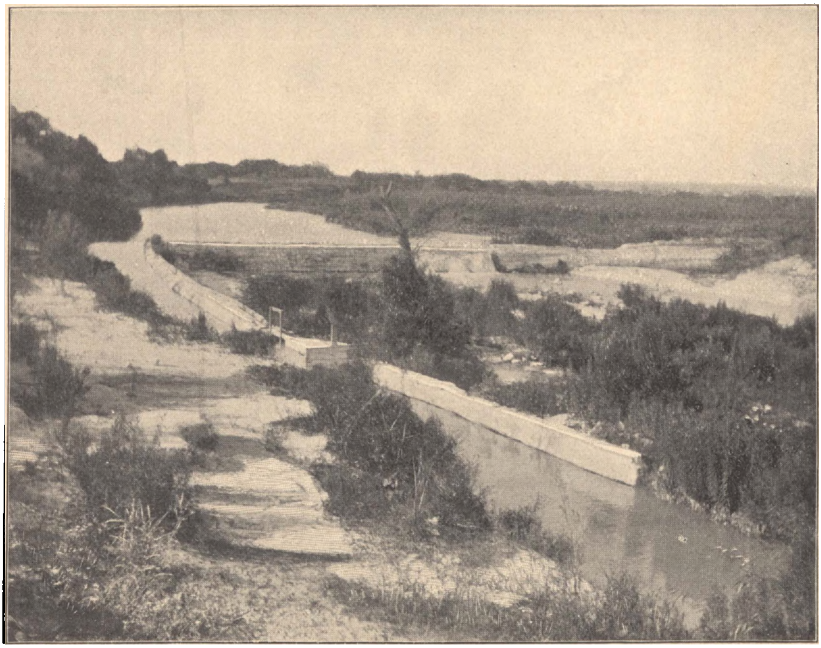
ervoir, the water being pumped directly into the ditch. The total cost of the plant is given as $5,000, and the running expenses, including engineer at $1 per day, fireman at 75 cents per day, 3 cords of wood at 60 cents, and 70 cents for oil and incidentals, amounts to $4.25. The manager states that he has watered 10 acres in twelve hours on land located near, but never more than half that amount on a tract three-fourths of a mile distant from the pump. This is apparently a low efficiency. The total length of the main ditch is 6,300 feet, with a top width of 6 feet and a bottom width of 2½ feet. It carries about 2 feet of water. This plant has not had a thorough test, as it has never been run steadily. Each individual owner has the use of it alternately for twenty-four hours. It is designed to cover

500 acres, but not more than 70 acres have ever been watered. The principal crops were corn and the vegetables of a truck garden, also a young orchard and vineyard. The corn is irrigated about twice in a season, but in 1897 it was irrigated only once.

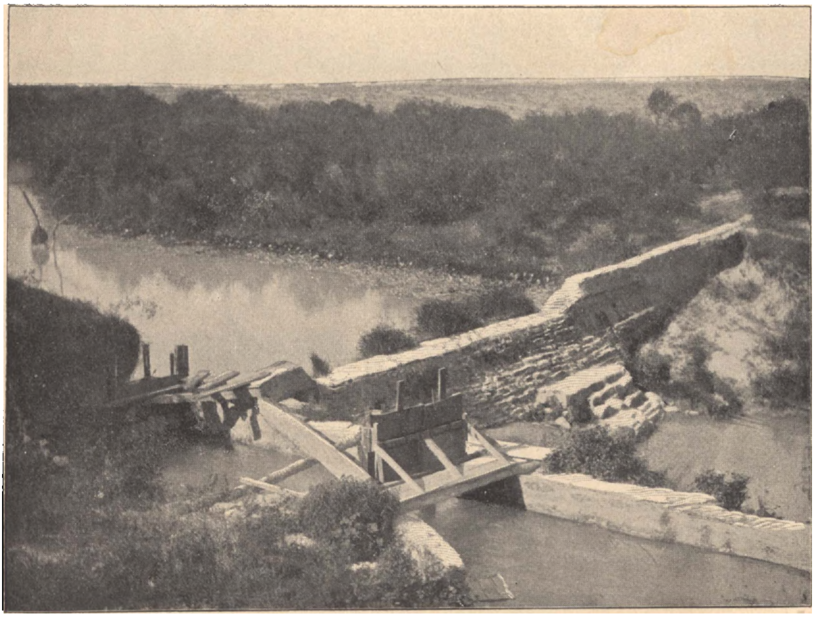
Five miles west of Mathis, on the same river, is a pumping plant owned by S. G. Miller and Lon C. Hill, which was built in 1893 and consists of a 40-horsepower boiler connected directly by a steam pipe with a double-action pump having a capacity of over 134 gallons per minute, or 0.29 second-foot, lifting the water a total distance of 39 feet at low stages of the river. The total cost of the plant was about $3,000, and it commands 140 acres in cultivation, of which not more than 70 acres have ever been irrigated. One of the owners states that he has had three years' experience irrigating vegetables, and has not made anything out of it, owing mainly to frosts. Lack of railroad facilities and difficulty of getting goods on the market in good order have been other detriments. He claims that it is a question whether irrigating by steam will pay when raising the ordinary crops of corn and cotton. The continual expense attached to it is too great. Experience has taught him that a man can not irrigate more than 4 acres per day of twelve hours with 1 million gallons, or 3 acre-feet, of water. Ribbon cane has here been found to be the surest and most paying crop tried.

On the Rio Grande below the mouth of Pecos River one of the most important irrigated areas is that along San Felipe Creek near the town of Del Rio. This short creek is formed by four large springs about 1 mile east of the town, within one-fourth of a mile of one another. In the 4½ miles from the springs to the Rio Grande the fall of the stream is 62 feet, thus furnishing an excellent water power for manufacturing. There have been four ditches taken out, two of which are for irrigation. These are supplied with water by means of two permanent masonry dams, 65 and 150 feet in length, respectively, and each 8 feet high. The first-named, shown on Pl. VII, *A*, is nearest the springs and is the starting point of the Madre ditch; the second, about a mile below, supplies the San Felipe ditch, as shown by Pl. VII, *B*.

These systems of water supply were first used in 1879. They are owned by the San Felipe Agricultural, Mechanical and Irrigation Company, in which the shares are held by owners of the land commanded by the ditches. The total cost of the enterprise was about $25,000, and the annual cost of maintaining it is about 50 cents per acre per annum. The main ditches measure about 4 miles in length and are 10 feet wide at the top, have perpendicular sides, and carry about 2 feet of water. The laterals are four in number, with an average width of 4 feet and a total length of 6 miles. The total area irrigated is 3,600 acres, in meadow, cotton, corn, gardens, orchards, and vineyards.



A. DAM SUPPLYING MADRE DITCH AT DEL RIO.



B. DAM FOR SAN FELIPE DITCH AT DEL RIO.

There are about 3,000 acres of irrigable land unutilized on the east side of San Felipe Creek. The land has mainly what is called an "adobe" soil. It is fertile when watered and seems peculiarly adapted to the grape and the pear. All kinds of fruits and vegetables are grown in profusion. On June 15 melons, plums, and apples were ripe. The impression made on the traveler who comes from the droughty and sun-scorched plains to such a spot is not soon forgotten. This cultivated tract has been so isolated from the rest of the agricultural world that none of the diseases which so reduce the profits of the grape or fruit grower elsewhere have been introduced as yet. Grapes produce from 6,000 to 10,000 pounds to the acre, and are mostly made into wine, the above yields giving from 10 to 16 barrels of wine.

East of Del Rio an attempt made to use the waters of Pinto Creek has been unsuccessful because the supply failed just at the season when it was needed. Dams for the purpose of storing the flow of the creek for use in the summer are necessary before anything further can be done. On Mud Creek, C. Vivian, by means of a solid masonry dam 100 feet long, irrigates several hundred acres of land.

At Eagle Pass, about 60 miles below Del Rio, there is a promising enterprise for irrigating a considerable area from the Rio Grande. This river, though dry each year near El Paso, has here a minimum flow of not less than 3,000 second-feet, due mainly to its tributaries, the Pecos and Devil rivers, in Texas, and the Concho, in Mexico. The company building the canal is called the Eagle Pass Irrigation and Waterworks Company. It is proposed to take out a canal with a capacity of 200 second-feet at a point on the river 35 miles above Eagle Pass, where a ledge of rock furnishes a natural dam site and opportunity for locating regulating works. From there the canal is brought down for 12 miles along the base of the hills, which here skirt close to the river channel. Two and one-half miles from its beginning it will empty into Pinto Creek, which will be dammed and will form a settling basin for the coarser silt and sand.

The dam across Pinto Creek will contain scouring sluices for the purpose of keeping the channel free from sediment and of letting the flow of the creek pass in time of flood. At the end of 12 miles the canal comes out on the valley to be irrigated. An old lake bed is surrounded by a semicircular line of ridges which abut on the river at the northern and southern ends. A similar line of hills bounds the Mexican side of the valley. Through this valley the river has cut its channel some 40 feet below the surface, leaving two-thirds on the Texas and one-third on the Mexican side. The canal is designed to skirt along this boundary line of ridges to the end of the valley, where it empties into the river after irrigating 20,000 acres. There is a plan to enlarge it at some time in the future and carry it to Eagle Pass to irrigate some 100,000 acres. The total length of the main canal, as it is to be built now, is 28 miles, with an average bottom width of 25 feet and carrying 3½ feet of water. It was begun in 1888, when 3½ miles were completed, and the work was then temporarily abandoned. There is little rockwork, and the expense will not be excessive. The estimates for the main canal complete are about $133,000. The side slopes are to be 1½ to 1 and the grade 13 inches to the mile. This is expected to give a current sufficient to largely prevent the deposition of silt from the water before it reaches the land. The land is very nearly level, with a descent down the river of 3½ feet to the mile. The soil is a fertile alluvial loam. The company, which owns all of the land to be irrigated, expects to largely reimburse the shareholders by selling farms of from 40 to 100 acres in area. The annual charge for water will be $1.50 per acre.

At Laredo, about 100 miles below Eagle Pass, considerable interest has been manifested in irrigation by means of pumping. One of the largest plants is that owned by Albert Urbahn, which was completed in 1897 and consists of an 80-horsepower boiler, operating a pulsometer with a nominal capacity of 1,000 gallons per minute, or 2.23 second-feet. The steam is conveyed to the pump directly from the boiler by a 4-inch pipe reduced 1½ inches, and the lift is 65 feet. The pump is operated twelve hours each day, having an actual capacity of 500 gallons per minute, or 1.11 second-feet, and is expected to irrigate 125 acres. So far only 50 acres have been watered. The land is planted in grapes, corn, sorghum, alfalfa, and tomatoes. The water is carried to the land in a 12-inch iron pipe, 2,000 feet long, with outlets at intervals, thus avoiding waste by seepage. The intention is to put in a pump which will utilize more or all of the power as soon as the agricultural situation warrants it. Another pumping plant owned by J. S. Taylor, a successful grape grower, is reported as consisting of two 80-horsepower boilers and a pump having a capacity of 1,250 gallons per minute. E. T. Lamphere has a 10-horsepower Weber gasoline engine with a triplex Van Wie pump, raising 300 gallons of water per minute. Attention is given to this about once in six or eight hours, and at one time during the summer, under pressure, the pump was operated continuously four days and nights, stopping only to oil the machinery.

Three miles from Laredo, L. D. Sterneberg has a windmill by which he pumps from the river when there is sufficient wind, irrigating 3 acres, except in the months of October and November. The cost of his outfit was $220. Three miles north of Laredo, C. A. Charleston has had better success with windmill irrigation than anyone else in that section. He uses a 12-foot wheel and pumps from a 30-foot well into a reservoir of 5,000 gallons capacity, irrigating about 5 acres. The total cost of the plant was $425. He finds his present reservoir too small and is building one of 300,000 gallons, or 0.92 acre-foot, capacity.

At Hidalgo, down toward the mouth of the Rio Grande, is a steam-pumping plant owned by Closner & Lipscomb. It consists of a 25-horsepower engine operating a centrifugal pump with a capacity of 4,750 gallons per minute, or 10.58 second-feet. The water is pumped from the Rio Grande and is used for irrigating 100 acres in sugar cane and corn.

In the vicinity of Brownsville, near the mouth of the Rio Grande, there has been considerable interest shown in irrigation by pumping. The plant of Rabb & Stark, located 6 miles east of Brownsville, on the river, was built in 1891, and consists of a 50-horsepower boiler and a 40-horsepower engine operating a Menge pump with a theoretical capacity of 9,000 gallons per minute, or 20 second-feet. The average lift is 18 feet, and the pump is run about twelve hours each day during the irrigation season. There is no reservoir used, the water being pumped directly into the ditches. The estimated cost of the plant is $2,000, and it irrigates 200 acres in sugar cane, cotton, and corn.

George Brulay, of Brownsville, also has a pumping plant worthy of attention. It is located 8 miles below Brownsville, in Cameron County, and was completed and first used in 1896. It consists of two boilers having an aggregate capacity of 100 horsepower and a 45-horsepower Morris centrifugal pump with a maximum pumping capacity of 8,000 gallons per minute, or 17.82 second-feet. The total lift required is 22 feet, and the pump is run about fourteen hours per day when used. It is designed to cover 300 acres, but so far only 200 acres planted in sugar cane have been irrigated.

E. H. Goodrich reports having put in a 10-horsepower Priestman engine on a resaca on his place, 6 miles north of Brownsville, in March, 1897, but has used it very little, owing to the favorable weather and the ditches not being finished. With two 12-foot windmills on the same place he irrigated last year about 35 acres in corn, cotton, and garden truck. He has also irrigated between 15 and 18 acres on his place 3 miles north of Brownsville with a 14-foot windmill, pumping from a well dug on the bank of a resaca. The distance to the water varies from 5 to 12 feet, and the pumps, which are three in number, empty into a flume connecting directly with the ditches. He is confident that he could have accomplished much more with the windmills if he had used a reservoir. The total cost of the last-named plant was $300.

LLANO ESTACADO.

The arid portion of Texas, or that part with an average annual rainfall of less than 20 inches, consists principally of the Llano Estacado and Trans-Pecos regions. These differ so widely in topography and climate that they should be discussed separately. The Llano Estacado has been described as a great plateau having an area of about 36,000 square miles and with an almost perfectly flat surface, which rises gradually toward the northwest. No rivers cross its surface and at only a few widely scattered localities, and for short distances, is flowing water to be found. The soil is of such character that it readily drinks in the rain which falls upon it. This water, or that part of it which is not soon evaporated, percolates downward and is reached by wells of from 40 to 200 feet in depth. Many of these wells are capable of furnishing a supply almost inexhaustible to ordinary means of pumping. The soil is too dry to be successfully cultivated without irrigation, and this can be practiced, if at all, only by means of water raised by pumps. Pumping is most cheaply accomplished by means of windmills, these being particularly successful owing to the almost constant winds that sweep across the plains.

Windmills have been used for many years to furnish water for stock purposes, and they have been tried successfully on a small scale for irrigation. The settlers of this region have learned to appreciate the value and limitations of devices of this character for raising water. Reservoirs or tanks are almost always used in connection with the mills. These are made by scraping away the surface soil and piling it in a continuous wall, forming banks from 4 to 6 feet high. The sides and bottom are made impervious by turning in a little water at a time and puddling the soil by driving horses or cattle about in it for a day or more. The following instances illustrate the progress within this area:

About the center of the Llano Estacado, in Hale County, T. W. Morrison owns a plant consisting of two aermotor wheels, 8 and 12 feet in diameter, respectively, pumping from wells 50 feet deep, with water at 20 feet below the surface. Each windmill lifts the water 35 feet. One wheel is used for supplying the residence; the other pumps into a reservoir 125 feet long and 100 feet wide and 4 feet deep. This irrigates from 5 to 6 acres, besides furnishing water for the stock. His wheels have been in use since 1891. J. H. Wayland, of the same county, has three aermotors pumping from wells 35 to 60 feet deep into a reservoir 300 feet long, 75 feet wide, and 6 feet deep, and expects to irrigate 25 acres, of which 15 were irrigated in 1896. The total cost of the wells, pumps, wheels, and reservoir was $505. The total cost of the plant, which must include land and fencing, is given as $1,000. Southeasterly from here, at Emma, in Crosby County, J. W. Murray has an 8-foot windmill pumping from a well 174 feet deep, with water at 124 feet. He pumps into barrels, from which he irrigates about 1½ acres. The total cost was $222.

Along the Texas and Pacific Railroad, especially at Midland and Marienfeld, there has been considerable interest taken in this form of irrigation. It is claimed by a man of experience—A. Rawlins—that two 8-foot aermotors, pumping from wells 40 feet deep, with water sufficient to keep a 4-inch pump running into a tank 100 feet square, with a 6-foot bank, will give sufficient water to irrigate 10 acres in fruits and vines the first year, 12 acres the second year, and

15 acres the third. Grain and garden vegetables, which require more water, will cut down the average. Fifteen head of horses will puddle a tank satisfactorily. He is irrigating 10 acres in cotton with two 12-foot aermotors, pumping from wells 125 feet deep into a tank 65 feet square.

This region is so sparsely settled and accessible with such difficulty that it has not been practicable to obtain full information concerning the small irrigating plants scattered here and there. Sufficient has been learned, however, to justify the belief that this method of agriculture is becoming a more and more important factor in the development of this area, reducing the cost of supplies, and thus aiding in the main industry, that of cattle raising.

Willard D. Johnson, hydrographer of the United States Geological Survey, states that at not more than half a dozen places in the Panhandle, probably, is there irrigation, from a single plant, of more than a small garden patch, and that of these but two show any development worth mentioning. These two are headquarter ranches of large cattle companies. At the majority of such cattle-ranch headquarters, however, there is absolute barrenness. The exceptions are the "L. E." ranch, on Romero Creek, a small spring-fed tributary of the Canadian from the north, and a ranch on Adobe Wall Creek, another spring-fed tributary of the Canadian from the north. As a result of irrigation, practically from springs, these two large ranches are able to supply themselves with a variety of vegetables and fruits, and in addition grow several hundred acres of alfalfa and other forage crops.

At the "L. E." ranch the garden produces much more abundantly than is demanded for the needs of the ranch, and much of this extra produce is given away to neighbors. The fruit trees which bear successfully are the apple, pear, peach, apricot, nectarine, plum, and cherry. Of shade trees about the house there are locust, ash, willow, osage orange, and cottonwood. There is also a vineyard yielding several varieties of excellent grapes. This ranch was visited by Mr. Johnson. The other ranch, not visited, is reported to have more alfalfa and about an equal display of garden produce. Each of these ranches is located below the edge of the plains, in the little valley of a spring creek of which it uses all the water. More can be done in each case by storage, which, in fact, is contemplated in the case of the "L. E." ranch. The great "X. I. T." company does a little in irrigation at several of its headquarter ranches, but much less than might easily be accomplished.

The two garden spots referred to are notable object lessons to the whole of the Panhandle. Spring creeks in the region are not numerous, but only in these two cases have they been fully utilized, and the examples thus set are destined to be rapidly imitated.

Of the future of irrigation here in general, it may be said that there is opportunity for but the little indicated, at these widely scattered spots, but that this little will prove to be just that small amount needed for rendering practicable the utilization of the high plains for stock raising, under conditions that will be bearable for those who have to live upon these great pasture lands for the conduct of the stock industry.

PECOS VALLEY.

Pecos River rises in the northeastern portion of New Mexico and flows in a general southerly course through the southeastern part of that Territory, crossing the western prolongation of Texas and finally entering the Rio Grande at about the lower third of the length of that

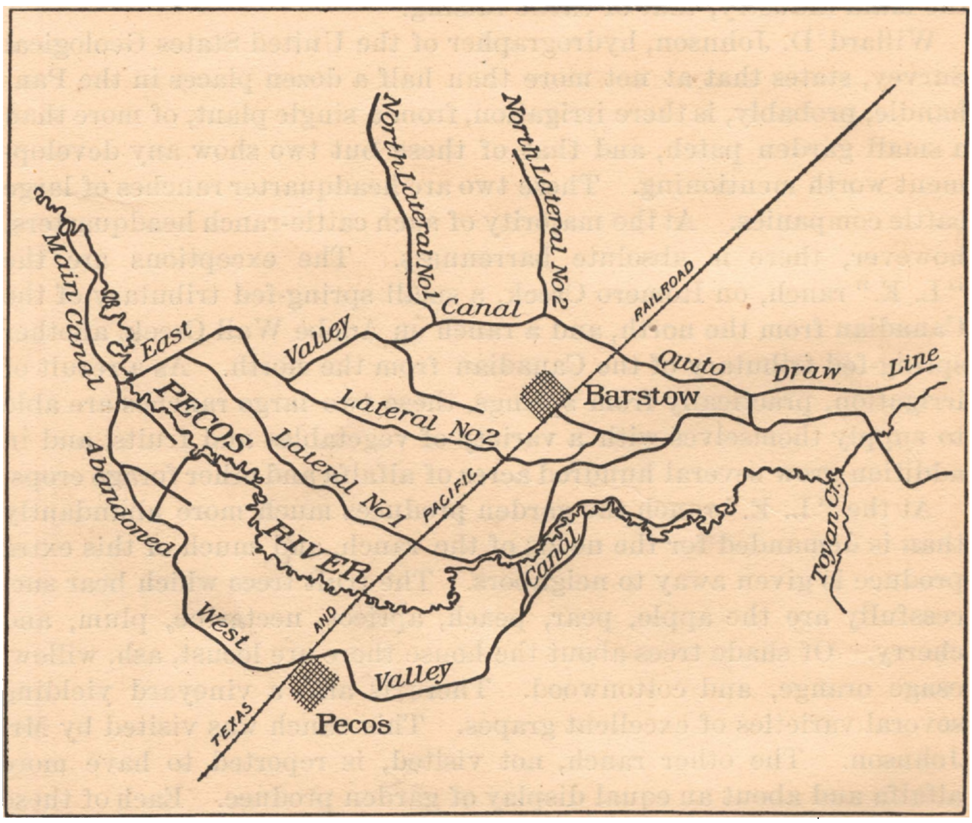
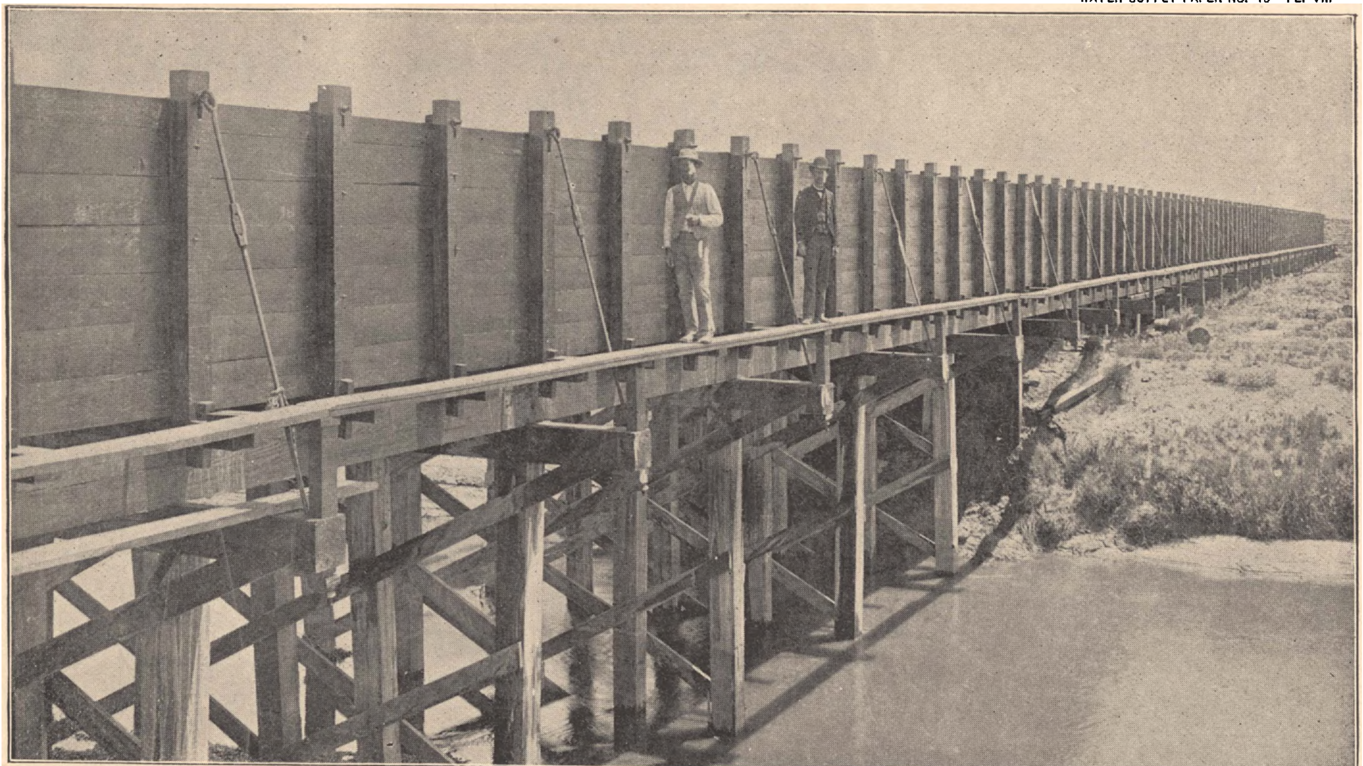


FIG. 12.—Map showing location of Marguerretta Canal.

stream. It is supplied to a considerable extent by water from large springs which issue from the limestone rocks of the region, of which Roswell is now the principal town. These maintain the perennial flow of the river, the run-off from the catchment basin being irregular in character and shrinking at times to relatively small amounts. Large irrigation works have been constructed in the vicinity of Roswell and at points below, utilizing the greater part of the summer flow of the river, so that during the dry season of the year little water crosses the Texas line. That which does flow in the stream is largely derived from the seepage of irrigated lands above and is heavily charged with alkaline salts. Irrigation canals have, however, been constructed



FLUME ACROSS PECOS RIVER.

along the valley in Texas, principally near the town of Pecos, at the crossing of the Texas and Pacific Railroad. The valley is fertile, and where properly irrigated large crops are produced.

The most important irrigation system along the river in Texas is the one nearest the New Mexico line, known as the Margueretta Canal. This was begun in 1887 by the Pioneer Canal Company, afterwards consolidated with the Margueretta Canal Company, which now owns the whole system. Water is diverted by means of a brush dam, it being deemed impracticable to build a masonry structure in the sandy river bid. The dam is 90 feet long and 5 feet high. The canal is built, as shown in fig. 12, on the western side of the river for 3 miles, then crosses the stream on a flume (shown in Pl. VIII), and runs in a general easterly direction for 12 miles. There is also a branch continuing down the west bank for a considerable distance, being the main part of the old Pioneer Canal; but this has been abandoned, there being no farms in cultivation for more than a mile or so below the flume. The dimensions of the main ditch are: top width, 30 feet; bottom width, 18 feet; depth of water, 4½ feet. There are three principal laterals, with a bottom width of 12, 6, and 8 feet, respectively.

The canal was first used in 1889, and the extent of land irrigated by it is steadily increasing. The total cost of the system was over $150,000, and the acreage it is designed to cover is about 40,000, only 6,000 of which are as yet under cultivation. The water rights are sold at $10 per acre, a permanent right guaranteeing 25 inches of water to the acre. The annual rental is $1 and $1.50 for each acre served with water. The principal crop is cotton, of which there are about 3,500 acres. The other crops cultivated are alfalfa, sugar beets, and all kinds of forage plants, fruits, and vegetables.

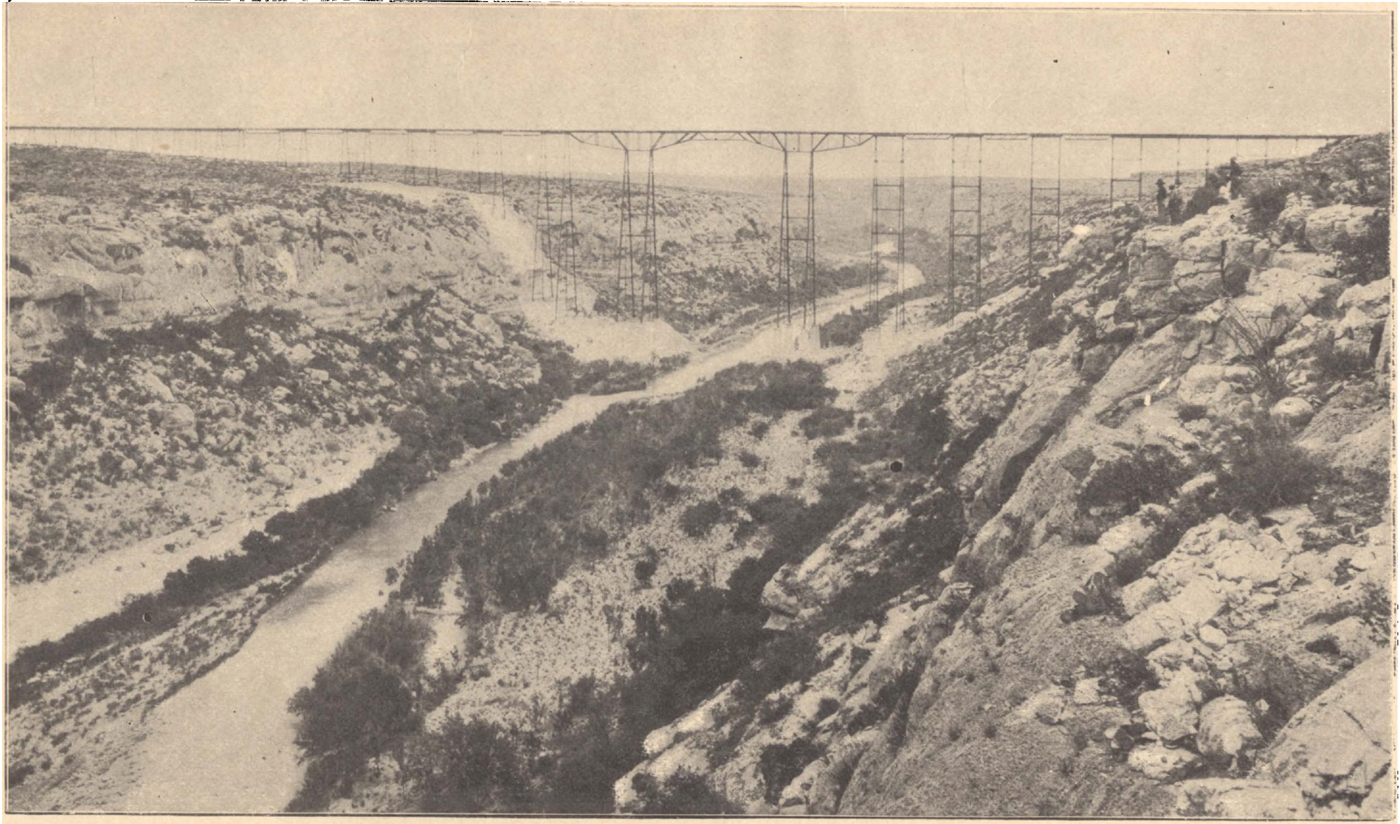
Sugar beets tested in 1896 showed between 14 and 20 per cent of saccharine matter. Peaches, apples, and grapes do well. Cotton averages 500 pounds of lint to the acre. The annual rainfall is about 12 inches. Owing to the high elevation (2,700 feet) the seasons are much later than in most of the irrigated parts of the State. The enterprise seems to have been conducted with energy and care, the canals and head gates are well planned and well built, and all together the scene about Barstow, the center of the irrigated portion, has a general air of healthy growth and prosperity that is very pleasing to the eye after the many miles of desert scenery between it and El Paso. There are, however, a number of problems that must be solved before agriculture will be successful in all places. Much of the land is impregnated with what is known as alkali. At first this does not prove troublesome, but after a few years of cultivation it may be brought to the surface by injudicious treatment. The river water used in irrigation continually adds to the supply of this mineral matter. The only remedy so far applied is drainage, this being as important in its way as irrigation. The land is very nearly level, and considerable care will be required to provide means by which the accumulated alkali can be washed from the soil. One of the principal crops is alfalfa, which sells at $8 per ton on the cars at Pecos and at $10 per ton retail.

Flowing wells have been obtained in this valley near the town of Pecos. Most of this water contains mineral matter in solution, sulphur being especially noticeable. The water from the wells is used for domestic purposes and also for irrigating kitchen gardens and fruit and shade trees.

About 28 miles below Pecos is the canal of the Pecos River Irrigation Company, on the west side of the river, running in a general southeasterly direction for 12 miles. It is the oldest ditch on the river in Texas, having been built in 1875 and 1876. It was enlarged in 1889 and used again in 1890, but has never been entirely completed in its enlarged condition. It takes its water by means of a brush-and-stone dam about 60 feet long and 5 to 6 feet high. The total cost of the undertaking is given as about $35,000, and the cost of the water rights as from $2.50 to $5 per acre, with an annual assessment of 50 cents per acre. It is designed to irrigate 20,000 acres, but only 600 were irrigated in 1896. There is complaint that the water supply was very short for several years, especially in 1892, 1893, and 1894, just after the dam at Eddy, New Mexico, was completed. The flow has increased since then, but the river becomes quite low and the water bitter in March and April of each year. On this account it is fortunate that the season is so late here that cotton is not planted before April 15, corn about May 15, and alfalfa in June. The soils and crops raised on them are similar to those at Pecos and Barstow.

The Grand Falls Irrigation and Improvement Company takes out a canal 4 miles below the headgates of the one just discussed, but on the opposite side of the river. It was begun in 1896 and is finished for 16 miles; it is supplied by a brush-and-stone dam across the river, 100 feet long and 7 feet high. The water rights are valued at $15 per acre and the annual assessment is $1.25 per acre.

On Comanche Creek, near Fort Stockton, in Pecos County, are two farms irrigated from ditches. That of the Southwestern Irrigation Company is nearest the head of the creek; it is on the east side, 6 miles in length, with top width of 7 feet, bottom width 6 feet, and depth of water 2½ feet. It is filled by means of a loose-rock dam 20 feet long and 6 feet high. More than 1,000 acres have been cultivated, though only 400 were tilled in 1896. The principal crops were alfalfa and corn. The 200 acres in alfalfa gave an average of 5 tons to the acre, the alfalfa being cut five times. Corn yielded 25 bushels to the acre. The lands are cultivated entirely by the company owning the canal. The only other ditch of importance is that of the Rooney Irrigation Company. It runs on the west side of the creek for a distance of 7 miles, its dimensions being 12 feet wide on top, 8



PECOS CANYON AT SOUTHERN PACIFIC RAILWAY BRIDGE feet wide on bottom, and having water 3 feet in depth. It was built in 1875 and commands 1,200 acres, of which 1,000 were irrigated in 1896. The principal crops were corn, wheat, oats, cotton, and alfalfa.

At the lower end of its course Pecos River flows through a narrow canyon, illustrated on Pl. IX, taken from Part II of the Eighteenth Annual Report[1] of this Survey. This shows the new bridge of the Southern Pacific Railroad crossing 10 miles above the Rio Grande.

TRANS-PECOS TEXAS.

That portion of the State west of Pecos River is commonly known as Trans-Pecos Texas. It is a peculiar country, rough and mountainous, with no perennial streams. The storm waters rush out upon the lowlands and are rapidly absorbed in the sandy plains, from which the mountains rise abruptly as isolated peaks or ranges. The soil of these plains is of remarkable fertility and when watered produces abundantly. Irrigation, however, is practicable only by means of storage reservoirs holding the storm waters. Such reservoir sites occur in many places, and several of them have been mapped by the topographers of the Geological Survey.

Trans-Pecos Texas is bounded on the west and south by the Rio Grande, from which water is taken for irrigation mainly in the vicinity of El Paso. There are, however, a few tracks watered by small lost streams, there being in particular about 75 acres irrigated from Lympia Creek.

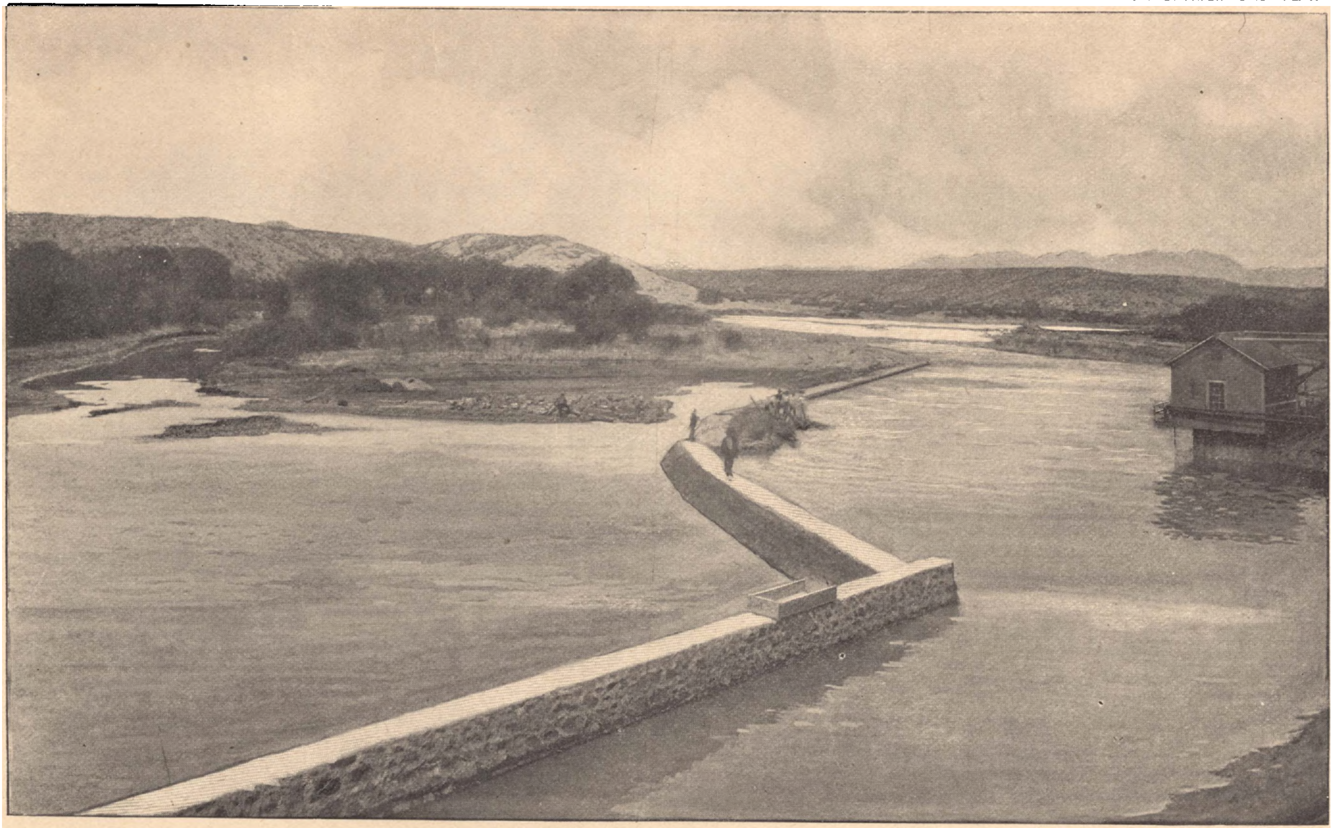
At El Paso the principal canal is that owned by the El Paso Irrigation Company. It was begun in 1889 and completed in 1891. Later the affairs of the company were put into the hands of a receiver, and the property was bought at receiver's sale by Thomas Worthington, of Manchester, England, the trustee for the bondholders. It begins 1 mile northwest of the town of El Paso and runs in a generally southeastern direction for 30 miles. At the beginning its width is 30 feet, but it gradually diminishes to 15 feet at Fabens, where it returns to the Rio Grande. Water is diverted by a masonry wing dam, extending diagonally up the river for about 300 feet and about half way across, as shown in Pl. X. The original cost was approximately $150,000, and some $70,000 has since been expended for protection from overflows and for repairs. The water rights under the new management have not yet been issued. The yearly water rental is $2 per acre. The canal was designed to cover 30,000 acres; 3,000 were irrigated from it during 1896.

There are three old Mexican ditches taken from the Rio Grande below El Paso on the American side, at Ysleta, Socorro, and San Elizario, irrigating from 1,000 to 1,200 acres each. The total area watered in the county is estimated at 8,000 acres. Irrigation has been practiced

[1] Geology of the Edwards Plateau and Rio Grande Plain, adjacent to Austin and San Antonio, Texas, etc., by Robert T. Hill and T. Wayland Vaughan, Pl. XXV, p. 208.

here probably longer than in any other part of the United States. The old Spanish records say that when this pass of the river was first reached by the exploring party of Coronado, villages of Indians were found on the Mexican side on the site of the present town of Juarez and on the American side at Ysleta and below. These Indians had a system of irrigation of seemingly great antiquity, which has been continued and carried on by the descendants of the aborigines and those of their conquerors continuously for three hundred and fifty years.

During the spring of 1897 the large canal was damaged by the flood that submerged so much of the town of El Paso. This flood reached its height on May 26 and quickly subsided. The banks were badly cut and the canal was completely obliterated in some places. The truck gardens and orchards near the city were flooded and damaged, a layer of mud about 3 inches thick being deposited over the surface. It was noticeable that while most trees withstood the flooding comparatively well, the peach trees were almost uniformly killed. Fortunately for the farmers lower down, a portion of the river cut for itself a fresh channel, curving inward, crossing the canal, and then recrossing it at the last point at which the banks were damaged. In this way they have been supplied with water and are able to save their crops, which otherwise would have been ruined.



WING DAM OF EL PASO IRRIGATION COMPANY; LOOKING UPSTREAM.

INDEX.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893–94, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett; and "Preliminary report on the artesian waters of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the calendar year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton; and "Reservoirs for irrigation," by J. D. Schuyler.

Water Supply and Irrigation Papers.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton, 1898.
13. Irrigation systems in Texas by W. F. Hutson, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.

In press:

14. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood, 1898.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

The maximum number of copies available for the use of the Geological Survey is 1,000. This quantity falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules, or who have furnished data. Requests made for a certain paper and stating a reason for asking for it are granted whenever practicable, but it is impossible to comply with general demands, such as to have all of the series sent indiscriminately.

Application for these papers should be made either to Members of Congress or to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.