DEPARTMENT OF THE INTERIOR
JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 716—D

NATURAL-GAS RESOURCES AVAILABLE TO DALLAS AND OTHER CITIES OF CENTRAL NORTH TEXAS

BY

E. W. SHAW AND P. L. PORTS

Contributions to economic geology, 1920, Part II
(Pages 55-89)

Published November 17, 1920

WASHINGTON
GOVERNMENT PRINTING OFFICE
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NATURAL-GAS RESOURCES AVAILABLE TO DALLAS AND OTHER CITIES OF CENTRAL NORTH TEXAS.

By E. W. Shaw and P. L. Ports.

NATURE OF THE PROBLEM AND PREVIOUS WORK.

The acute shortage of gas in Dallas and other cities in north Texas during the winter of 1919–20 led to an urgent request from Mayor Frank W. Wozencraft, of Dallas, that the United States Geological Survey make an examination of the gas resources of the region with a view to determining whether the shortage was due to exhaustion of underground supplies or to some nongeologic cause such as inadequacy of wells or transportation equipment, lack of proper adjustment of prices, or wasteful consumption.

In 1915 a similar call had come from the cities of Dallas and Fort Worth, and an examination of the principal source of supply—the Petrolia field—and other more or less productive or promising territory led to the conclusion that all known Texas fields as at that time developed would not fully meet the growing demand of these cities for more than a year or two and that it would be wise to extend the pipe lines to fields in southern Oklahoma. This was done, and as a result of the added supply thus made available and of the curtailment of industrial use the needs of the gas-consuming communities have been fairly well met for three years. The main conclusions set forth in the first report [1] are as follows:

PETROLIA FIELD.

Original quantity of gas in the field.—The volume of pore space occupied by gas and the original rock pressure and also the relation between decline in pressure and percentage of depletion indicate that the original quantity of gas in the Petrolia field, measured at 8 ounces above atmospheric pressure, was about 120 billion cubic feet.

Ratio between percentage of depletion and amount marketed.—Statistics of production indicate that about 37 billion cubic feet of gas from the Petrolia field have been delivered to consumers. This quantity is about 75 per cent of the reduction of supply in the ground. The question whether or not this per-

[1] Shaw, E. W., Matson, G. C., and Wegemann, C. H., Natural-gas resources of parts of north Texas: U. S. Geol. Survey Bull. 629, pp. 73–75, 118–119, 126, 1916.

centage should be larger is beyond the scope of this report, but it may be remarked that many gas fields show a greater waste.

Present capacity.—The Petrolia field as now drilled and equipped is capable of producing more gas per day than it has ever been called upon to produce. The limit of its daily capacity depends in part upon engineering considerations not discussed in this report, such as the handling of wells and pipe lines, but it is probably at least twice that of any demand which has been made upon it.

Capacity in near future of the field as now drilled.—The daily capacity of the wells in the field is steadily decreasing, and indeed the field as a whole is doubtless rapidly approaching its limit in rate of production. While the demands upon it have been steadily growing, its capacity has been diminishing because of reduction of supply and pressure, and before many years have passed the supply will no longer meet the demand.

Capacity in distant future of the field as now drilled.—If no new gas wells were drilled the production would not only fall below the demand in a few years, but in 10 years the output would probably be too small to be worth transporting.

Increase of capacity through new wells to known sands in the proved field.—The capacity of the field may be kept up for a few years by new wells drilled to known sands within the proved field, but the present wells are rather evenly distributed and closely spaced, so that increase of output through new wells can not be great.

Increase of capacity through finding new sands in the proved field.—More gas can probably be found in some parts of the field by drilling deeper, for sands having favorable structure, texture, and stratigraphic and lithologic relations lie below the sands now producing. A few small gas-bearing lenses of sand lie above the producing sand, and though these lenses contain much less gas than the so-called deep sands they should not be overlooked.

Increase of capacity through finding new productive area adjoining the field.—The daily capacity of the field may be increased by new wells drilled outside the proved field to sands now producing. The structure of the field indicates that the actual area of the gas pool is probably twice that of the area now producing, though a part of the new area may yield oil instead of gas. The production can not, of course, be doubled by simply doubling the producing area, for gas has been slowly moving from the undrilled ground to the producing wells, so that throughout most if not all of the undrilled parts of the pool the original gas content and pressure in the sands have been reduced, though not so greatly reduced as in the developed part of the pool.

Increase in marketed supply through greater care in handling wells.—The depletion of the original supply of gas at Petrolia is evidently considerably greater than the quantity of gas marketed, the loss incidental to the production of oil being especially noteworthy. The output could be increased by handling the wells somewhat differently, but the work of properly caring for the natural supply must be left to the engineers.

Life of the field.—If all the gas at Petrolia could be delivered to consumers in Dallas and Fort Worth and other cities now drawing on the Petrolia supply it would probably last them, at the present rate of consumption, about 6½ years. If an estimate is made of the increase in consumption that will probably occur if the supply is adequate and no advance is made in the price, proper deduction being made for necessary losses in production and marketing, the estimate of 6½ years must be reduced to about 4 or 5, and if further allowance be made for unnecessary losses, it must be reduced to 3 or 4 years, and a shortage will be felt in cold weather still sooner.

OTHER FIELDS.

Other discovered pools northwest and west of Dallas and Fort Worth, particularly those at Strawn and Moran, have noteworthy quantities of gas, though not so much as Petrolia, and these supplies would be available to the cities if the pools were near to each other or to the existing pipe lines.

Undiscovered pools of gas and oil undoubtedly exist in the area described in this report, and some of them will probably be large enough to warrant the building of individual pipe lines. If several of them were developed at once, however, sufficient gas would be made available to justify the construction of lines to groups of pools. The search for new pools must be pushed with vigor if the present output is to be maintained or increased.

* * * * * * *

Gas has been found at Baileyville, Koose, Thornton, Groesbeck, Mexia, Wortham, Currie, Richland, Corsicana, Powell, Chatfield, Mabank, Cash, and Cooper. At only three of these places have wells furnished gas in commercial quantities, and at only two have wells furnished oil, but the significance of the presence of gas in the area between Baileyville and Cooper is not affected by the commercial value of the discoveries that have been made. These discoveries show the presence of gas-bearing sands through this belt, and investigations indicate that the dip of the beds here is not uniformly toward the southeast but is interrupted by terraces and minor reversals of dip. Structure favorable to the accumulation of oil or gas, similar to that at Mexia, Groesbeck, Powell, and Corsicana, will no doubt ultimately be discovered in this region, which is therefore regarded as a possible oil and gas field.

* * * * * * *

CONCLUSIONS REGARDING OKLAHOMA.

In conclusion, it may be stated that the gas resources of central and southern Oklahoma are sufficient, if protected from waste and properly handled, to furnish supplies to such cities as Dallas and Fort Worth for years to come. The gas is, however, for the most part distributed over large areas in many pools of comparatively small size, and it may prove unprofitable under present conditions to build pipe lines of sufficient extent to collect it. Among the larger gas pools may be mentioned the field south of Checotah, in McIntosh County, which is at present being drilled. The large supplies of gas in the immediate vicinity of the Healdton oil field are worthy of careful consideration, especially since the bringing in of the new gas well near Fox, north of the field, which suggests the possibility of the presence of other gas pools in this vicinity.

In 1918 an estimate of the quantity of gas remaining in the Petrolia field was made by G. S. Rogers,[2] in connection with an investigation of the helium resources of the country. Rogers examined critically the data and methods used by Shaw three years before, checked the results, with the help of new facts gained from the behavior of the field in the intervening period, and concluded that Shaw's estimates of original reservoir capacity and quantity remaining in 1915 were correct and that in July, 1918, between 13 and 20 billion cubic feet remained in the pool. He remarks that if the remaining gas were used at an average rate of 15,000,000 cubic feet a

[2] Rogers, G. S., Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121 (in press).

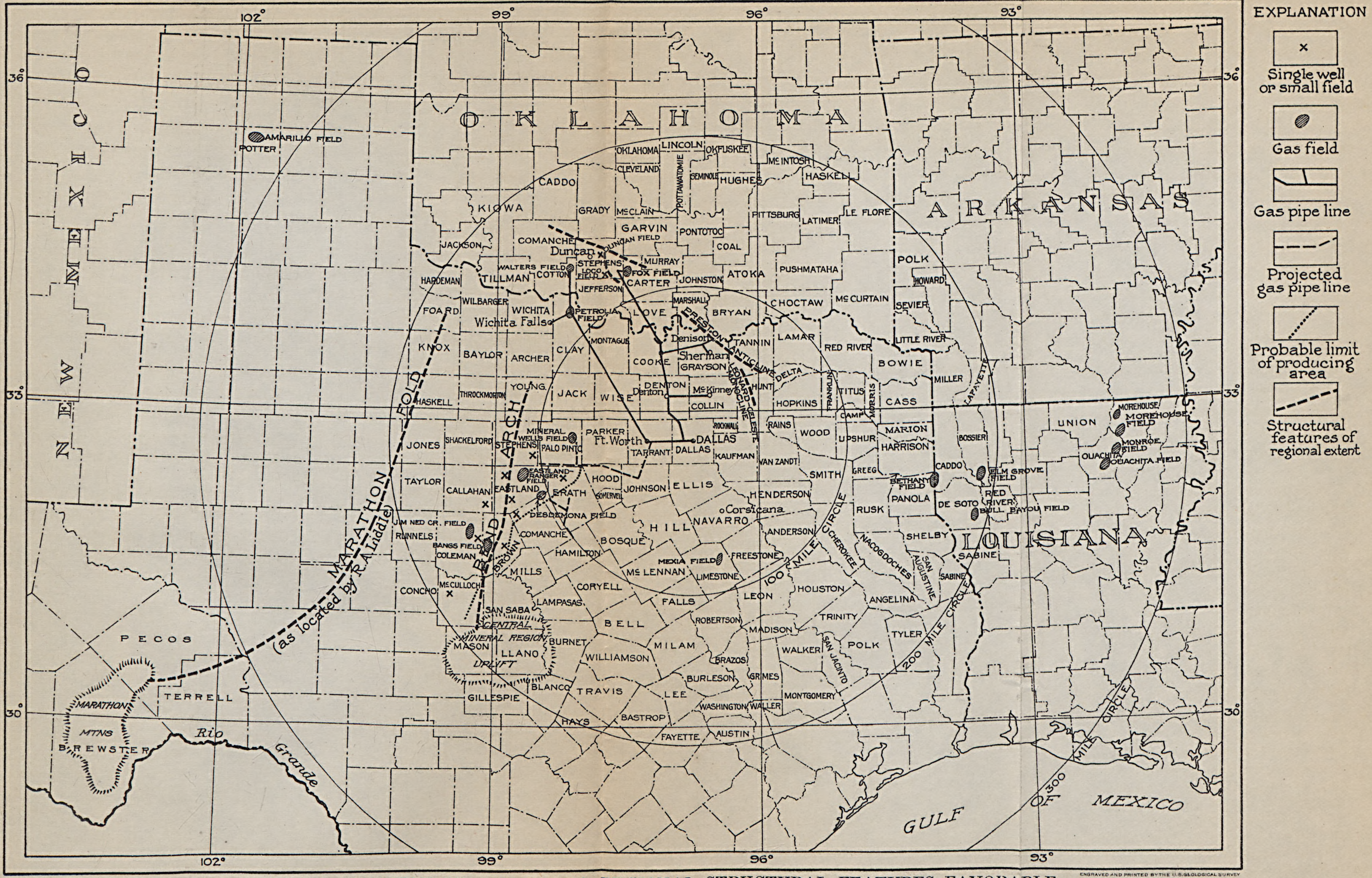
day the field would last two and one-half to three years. Since his estimate was made, however, the Lone Star Gas Co. has contracted with the Navy Department to reduce the output of the field to 10,000,000 cubic feet a day. Also since that time gas has been discovered on the Martin farm, about 2 miles west of the main part of the field, and the question has arisen whether the Martin wells are to be regarded as being in the Petrolia field, and whether their gas is a part of that in the Petrolia pool.

The evidence at present available indicates that in the middle of 1918 there was 20 to 25 billion cubic feet of recoverable gas in the Petrolia pool, including the Martin gas, and that at the end of March, 1920, there remained 8 or 10 billion cubic feet of recoverable gas, for at that time the entire field seemed to contain only 12 to 15 billion cubic feet of gas, and of this about 4 or 5 billion cubic feet will never reach the consumer, for the reason that some will be left underground and some lost on its way to market. The method of computation is outlined on the following pages.

In the matter from the previous report quoted above it is concluded on the basis of geologic evidence that undiscovered pools of gas and oil undoubtedly exist in the region, and in the text and figure on page 20 of that report the favorable general structure west of Fort Worth is pointed out. Since Bulletin 629 was published the great oil and gas bearing territory centering around Ranger has been developed, and the question arises, What relief may Dallas and other communities suffering from gas shortage expect from these fields? The conclusion reached in the present report is that the discovered fields contain enough gas to supply the domestic demands of these communities for several years, and that there are undoubtedly still some undiscovered gas pools in the region.

A preliminary summary of the present situation was contained in a telegram from the Director of the United States Geological Survey to Mayor Wozencraft on February 3. The results of the investigation harmonize with this summary but allow particularization where at first only generalization was possible. The telegram follows:

Gas resources north Texas, although limited and being rapidly depleted, are not yet nearing exhaustion. If a well-considered drilling program be followed, adequate pipe line and compressors be installed, waste reduced, and industrial consumption eliminated, remaining supplies will meet needs of residences in Dallas and other cities now served probably five to ten years. With industrial consumption in summer cost of domestic service would be somewhat lower than otherwise, but life of fields would be correspondingly shortened. Geologic conclusions of full report will therefore probably be favorable, for apparently Texas still has considerable gas, though it would have had much more if waste had been kept within reasonable bounds. Engineering problems of gathering and transporting gas and economic problems of rates, restrictions in classes of use,



MAP SHOWING LOCATION OF GAS FIELDS, REGIONAL STRUCTURAL FEATURES FAVORABLE FOR GAS, AND DISTANCE OF GAS POOLS FROM DALLAS

Scale 1:5,000,000

0 50 100 150 Miles

reduction of peak load, and general conservation will then remain to be solved, though it is fairly obvious that gas can be supplied for a few years at prices and in quantities that will enable it to compete successfully with other fuels.

In a later telegram to Mayor Wozencraft dated February 25 the Director stated:

Conclusions will doubtless show sufficient gas economically available for several years' domestic demand. Petrolia, best pool yet discovered, now probably 90 per cent exhausted. West Texas pools promising but need careful development, pipe lines, compressors, and reduction of waste. Capacity southern Oklahoma pools medium to small, but their aggregate volume sufficient to supply reduced demand at least two years. Undoubtedly several important undiscovered pools in Texas, but several years necessary to find and develop them. Great need is reduction of waste and determination by business men of price for fair return to invested capital under good management to stimulate search for gas independent of oil and to conserve the large but limited supplies.

ACKNOWLEDGMENTS.

The citizens of north Texas and in particular the officials of the city of Dallas and those of the Lone Star Gas Co. cooperated heartily in every way possible toward the success of the work. Mayor Frank W. Wozencraft and Chief Engineer Ed C. Connor were especially helpful. The officers of the Lone Star Gas Co., the Dallas Gas Co., and the Fort Worth Gas Co. allowed free inspection of their records, supplied maps, and assisted in making observations and collecting data. Numerous geologists and others connected with different companies have been called upon for aid, and all have assisted without reserve. Robert T. Hill, who has done many years of effective work on Texas geology, rendered especially valuable assistance.

LOCATION AND AREA.

The region in which Dallas and other cities are interested as a source of natural gas may be arbitrarily defined as that portion of Texas lying east of the 100th meridian and north of the 31st parallel, together with the southern two tiers of counties in Oklahoma, or it may be said to include all territory within 200 miles of Dallas. (See Pl. VIII.) The assignment of precise limits is impracticable and unsatisfactory, for the reason that the availability of a gas supply depends not only on distance from points of use but on other factors, such as magnitude and compactness of market. The business of producing and marketing natural gas involves not only the cost of gathering, transporting, and distributing the gas and ordinary overhead expenses but provision to meet an irregular demand. As the underground supply in any field is not unlimited the expenses of these several classes must be distributed equitably over the supply available. Pipe lines alone commonly cost more than $25,000 a mile and depreciate so fast that they may have to be replaced within a few years. The salvage of pipe and other equipment on the exhaustion of the gas supply is often very expensive. If the underground supply is large and occurs in a small area and if the gas sand is thick and large-pored, so that the wells yield a large amount per day, gathering costs will be correspondingly low. If the closed pressure is high and the supply large, compressing and transportation costs will tend to be low. If there is a demand for a large amount of gas at the delivery end of the pipe line and along its course, if the consumers require large quantities per day, and if the points of consumption are close together, or if there are many good-sized towns along the line, costs will tend to be low. The cost of reading meters and collecting bills is lower per thousand cubic feet for the large consumer than it is for the small consumer. Lastly, if there is a great variation in demand per day, pipe and other equipment must be installed for the peak demand, and the unit cost of service will be higher than if the demand were uniform.

These nongeologic considerations are cited to emphasize the fact that the geologic problems of existence, location, extent, and compactness of underground supplies and character of the reservoir are only a few of the factors that enter into the business problem of whether or not the supplies can be got to market for a price per thousand cubic feet that the consumer is willing to pay. Natural gas has been transported with profit to markets considerably farther than 200 miles from the source of supply, but this has been done under favorable circumstances, such as a large quantity of available gas, many cities and towns along the line, and good-sized cities at the end of the line. Perhaps the most noteworthy example has been the transportation of West Virginia gas to cities in Indiana. The gas at Mexia is less than 100 miles from Dallas, but it can not be brought to Dallas at a profit because the amount is small. Indeed, it would not pay the cost of transportation and marketing if the quantity were several times as great as has been discovered up to the present time. On the other hand, if northwestern Louisiana, 200 miles from Dallas, had a large surplus, or even if the Amarillo field, 350 miles distant, included several very large pools in open-pored sands, it might be feasible to bring gas from these sources to Dallas.

The general problem, with one or more phases of which this paper has to do, is in part an examination of the prospects of finding new fields, in part an appraisal of known pools not yet connected with the pipe-line system, and in part the determination of means of adjusting the diminishing supply of natural gas in the old fields to the increasing needs of rapidly growing cities. When the gas fields of north Texas were first called upon to serve Dallas and other cities, the supply of gas in sight appeared to be ample for years to come.

Now, even though additional supplies have been found, the growth in population, with the consequent increase in the number of gas consumers, has overtaken the rate of new production, and an acute shortage is felt.

The cities and towns of north Texas now using natural gas for fuel and lighting are Petrolia, Fort Worth, Bellevue, Bowie, Sunset, Alvord, Decatur, Rhome, Bridgeport, Irving, Arlington, Dalworth, Dallas, Gainesville, Sherman, Denison, Whitesboro, Denton, and McKinney, which receive their supply through one company, the Lone Star Gas. Co. of Dallas, and Electra, Burkburnett, Abilene, Albany,

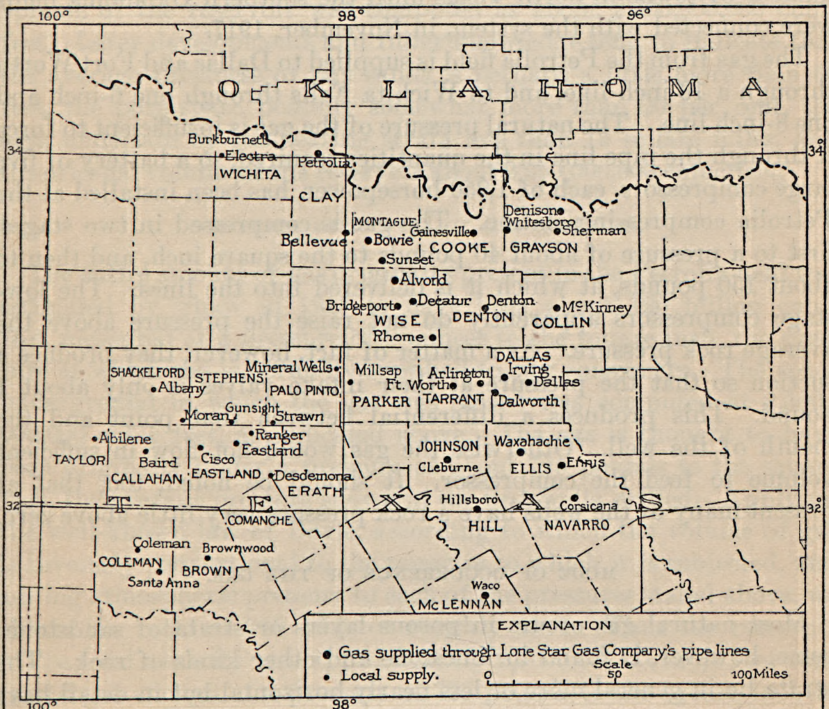


FIGURE 2.—Map showing cities and towns in north Texas using natural gas.

Moran, Mineral Wells, Baird, Cisco, Eastland, Ranger, Thurber, Desdemona, Coleman, and others, which are served by local producing gas companies and are supplied by near-by fields. (See fig. 2.)

FIELDS NOW SUPPLYING NORTH TEXAS.

PETROLIA FIELD.

HISTORY AND PRESENT CONDITIONS OF DEVELOPMENT.

The first important gas field to be developed in north Texas was the Petrolia field of Clay County. Although it had been known as an oil field for some years, its development as a gas field did not begin until October, 1907, when the first gas well was brought in. The next year two other gas wells were drilled, furnishing an ample supply for the town of Petrolia, about 2 miles distant, and for drilling operations in the field.

By 1909 the gas development had reached a stage that demanded a greatly enlarged market, and a 16-inch pipe line was laid to Fort Worth and Dallas, respectively, 94 and 135 miles away. About the same time service was extended to Wichita Falls, 18 miles from Petrolia. This field furnished the entire supply of gas for a large number of towns in north Texas until the southern Oklahoma fields were connected with the system, in November, 1917.

The gas from the Petrolia field is supplied to Dallas and Fort Worth through a 16-inch line, and to Wichita Falls through one 6-inch and one 8-inch line. The natural pressure of the gas is insufficient to force it through the pipe line in the quantities required, so a battery of five large compressors, each of 1,250 horsepower, has been installed at the Petrolia compressing station. The gas is compressed in two stages, first to a pressure of about 40 pounds to the square inch, and then to about 150 pounds, at which it is delivered into the lines. The low-stage compressors apparently do not raise the pressure above the average rock pressure. As a matter of fact, however, they produce a suction so that the pressure at their intake valves is only about 1 pound. This produces a differential between that point and the mouth of the well. Otherwise the gas would not flow in sufficient volume to feed the compressor. It should be noted, too, that at present many of the wells have a rock pressure very little above zero.

MODE OF OCCURRENCE OF THE GAS.

Most natural gas occurs in porous layers or strata of sandstone; some, however, is found in limestone and other kinds of rock. The strata lie in general more or less nearly horizontal but in detail have an undulating or wrinkled form. The pay "sands," as the beds containing the gas are called, are usually overlain and surrounded by closer textured rock which prevents the escape of the gas. Wrinkles or arches of approximately circular form are called domes; those of elongated outline are called anticlines. Innumerable variations and combinations of these forms occur. Where oil is associated with the gas, it is generally found below the gas, presumably because of its higher specific gravity; where water is present it commonly forms the lowest member of the series, for the same reason.

Examinations of specimens of the producing sands of the Petrolia field made in connection with Shaw's investigations in 1915 showed that they have an average porosity between 20 and 25 per cent. In this field there are three principal producing sands, at different levels or horizons; their aggregate thickness is 30 to 40 feet. The total area underlain by these producing sands, as outlined more or less clearly by dry holes, considered in connection with the structure as inferred from well records and from surface outcrops, is 12 to 15 square miles. With these data at hand it is a simple matter to compute the space originally occupied by the gas. At the time of the earlier estimate the average thickness of the pay sands was inferred to be 30 feet, the pore space 20 per cent, and the areal extent of the pool 15 square miles. From these figures the apparent total original volume of the reservoir was computed as about 2,500,000,000 cubic feet. Later developments and fuller knowledge tend to indicate that the average thickness of pay sands is perhaps a little more than 30 feet, the pore space possibly somewhat more than 20 per cent, the area underlain by gas-bearing strata less than 15 square miles, and the original volume of the reservoir about 2,250,000,000 cubic feet.

PREVIOUS ESTIMATES OF GAS RESERVES.

The entire amount of gas originally present in the Petrolia field was estimated by Shaw in 1915 to have been about 120 billion cubic feet, measured at a pressure of 8 ounces to the square inch, the pressure at which gas is normally supplied to city consumers. The space underground in which the gas was stored was computed at 2,500,000,000 cubic feet, as indicated above. The gas is thought to have been originally under a pressure of about 725 pounds to the square inch, the average pressure shown in the first wells drilled. Applying the well-known law of Boyle, according to which the volume of gas is inversely proportional to the pressure to which it is subjected, and adding atmospheric pressure to each of the pressures stated above, we obtain the ratio of 740:15.5, or roughly 48:1. Thus the reservoir whose total capacity was approximately 2,500,000,000 cubic feet contained gas enough at a pressure of 725 pounds to the square inch to occupy 120 billion cubic feet at a pressure of 8 ounces to the square inch. Later developments and additional facts indicate a total volume of about 110 billion cubic feet (see p. 66), but the probable degree of correctness of the earlier figures is remarkably high considering the hazardous nature of attempts to estimate quantities of underground gas.

In 1918 Rogers made an estimate of the quantity of gas then remaining in the Petrolia field, and concluded that Shaw's earlier inferences as to the original capacity of the reservoir and the volume of gas contained in it were both correct. Some of Rogers's conclusions are as follows:

1. A study of the curve showing decline in rock pressure indicates that at the present rate of production the field will be exhausted at the end of 1920,

but that if the production is decreased to 12 or 15 million cubic feet a day the field will probably last at least a year longer, provided water does not invade the gas sands.

2. An estimate of the quantity of gas remaining in the ground indicates that 13 to 20 billion cubic feet is still available, or a supply of 15 million cubic feet a day up to some time in the year 1921.

3. There is reason to believe that a small pool may be found about 2 miles west of the field.

It is worthy of special note that Rogers clearly foretold the discovery of the Martin gas.

NEW ESTIMATE OF QUANTITY OF GAS REMAINING.

The total amount of gas marketed by the Lone Star Gas Co. from the Petrolia field from 1910 to 1919, inclusive, is shown in the following table:

Rock pressure, open-flow capacity, and production of Petrolia field, including Martin wells, 1910–1919.

Year.	Average rock pressure Jan. 1.	Open flow Jan. 1.			Gas marketed during the year by Lone Star Gas Co. (thousand cubic feet).
		Number of wells tested.	Combined open flow (thousand cubic feet).	Average per well (thousand cubic feet).	
1910					1,583,080
1911					5,175,196
1912	659				7,186,322
1913	621				10,089,135
1914	511				9,683,293
1915	318	41	365,090	8,904	8,999,837
1916	239	43	272,345	6,484	8,945,522
1917	174	46	190,503	4,141	6,101,167
1918	87	45	75,855	1,686	5,579,088
1919	54	43	34,604	1,081	3,602,686
1920	65	34			

The total quantity of gas marketed from the field can not be stated with precision, but for 1915 to 1919, inclusive, it ranged from 7 to 10 billion cubic feet annually. The quantity produced from 1907 to 1910 is not known but may be estimated at about 10 billion cubic feet.

The decline in closed pressure is illustrated in figure 3 and that in open-flow capacity in figure 4.

The amount of gas lost from the reservoir but not marketed is not known, but enough data are available to make possible an estimate of value. It is known that for the United States as a whole more gas has been lost than has been marketed—that the underground loss plus the loss from blowing off wells plus the quantity used more or less efficiently in the field but not sold, plus the large quantity lost along gathering lines, main lines, and distributing lines amounts to more than all the gas that has been delivered to both industrial and

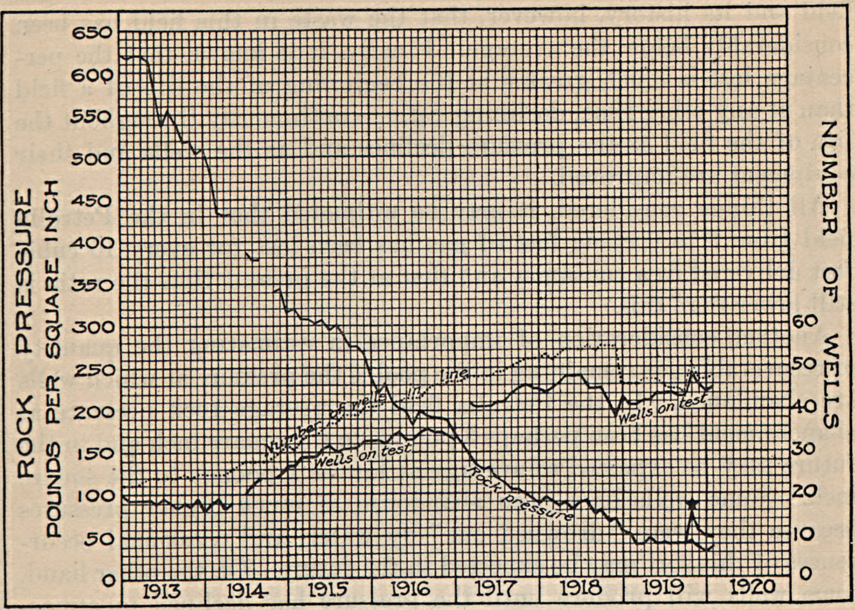


FIGURE 3.—Curve showing decline in rock pressure, number of wells in line, and number on test in Petrolia gas field, Tex. Curve marked ★ represents seven new wells in Martin field, rock pressure 50 to 605 pounds.

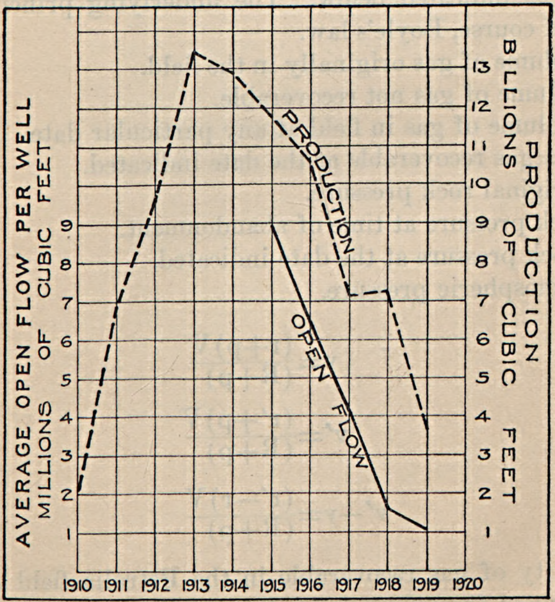


FIGURE 4.—Curve showing decline in open flow per well and total production in Petrolia gas field, Tex. Open-flow tests made January 1 of each year.

domestic consumers. It is evident from a study of the Petrolia gas field and its history, however, that the waste in this field has been considerably below the average. Finally, it is known that the percentage lost is much greater at the beginning of the life of a field than at any other time, declining rather continuously throughout the life of the field as the pressure declines and as the wells and their equipment are improved.

All things considered, it may be estimated that in the Petrolia field from 3 to 6 cubic feet of gas has been lost for every 10 cubic feet delivered to a consumer and that at the present time the ratio is still lower than this.

Another consideration of importance in estimating the quantity of recoverable gas remaining in the pool is the pressure at which wells are abandoned. In the Petrolia field the average rock pressure at abandonment has been perhaps 3 pounds to the square inch and in the future may be expected to average as low as 2 pounds to the square inch. Some wells have been abandoned at much higher pressures because they were "drowned out" by water, and occasional occurrences of this sort may be expected in the future. On the other hand, some wells will produce until the pressure has declined to atmospheric pressure, and some will no doubt be pumped until it is considerably lower still.

The problem of estimating the gas remaining in a field may be worked out as indicated below. The underlying principle of this solution is, of course, Boyle's law.

Let V=volume of gas originally in the field.
v=volume of gas not recoverable.
v'=volume of gas in field at any particular date.
$v'-v$=gas recoverable at the date indicated.
R=original rock pressure.
r=rock pressure at time of abandonment.
r'=rock pressure at the date indicated.
p=atmospheric pressure.

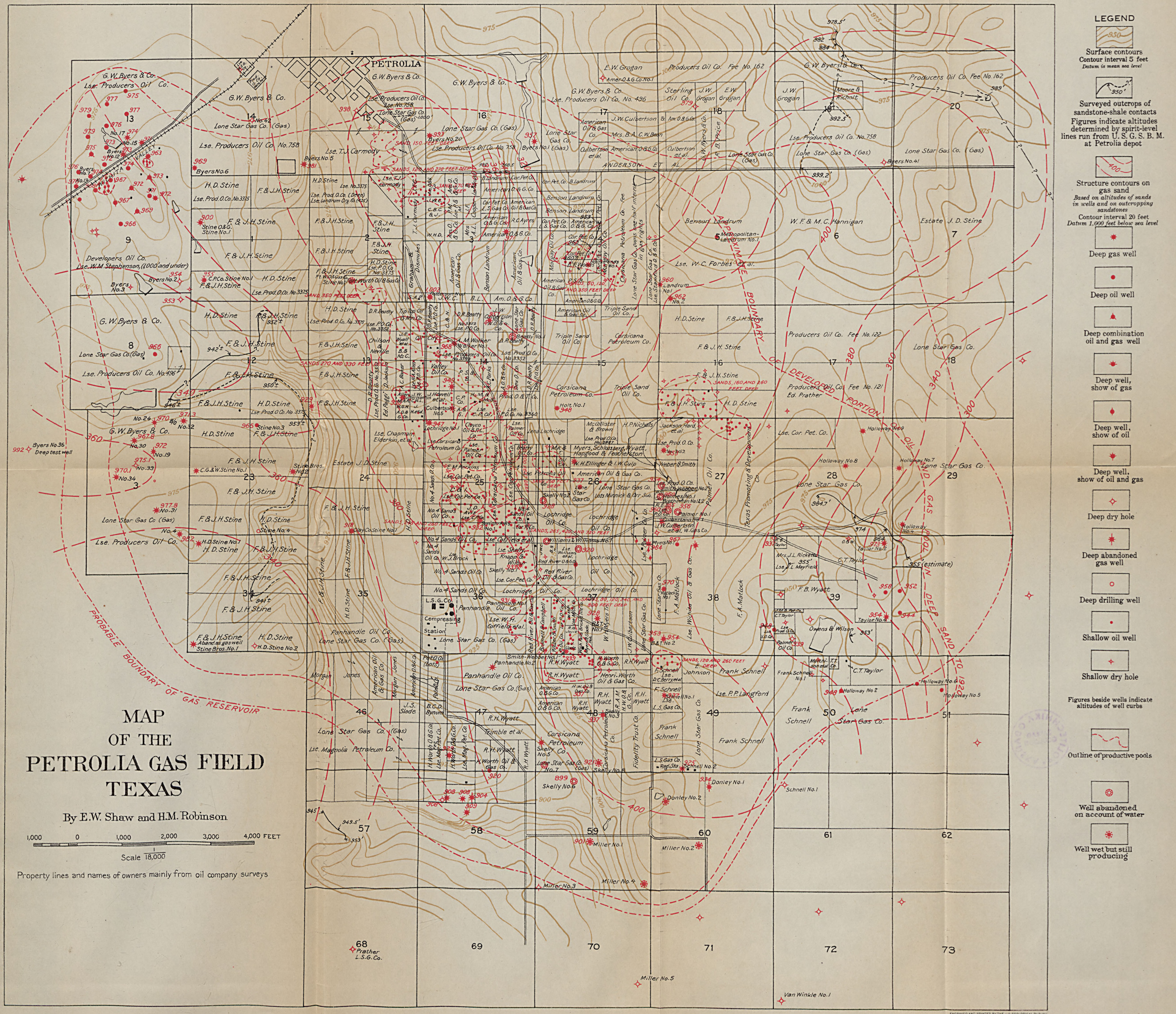
$$v=\frac{(r+p)V}{(R+p)}$$

$$v'=\frac{(r'+p)V}{(R+p)}$$

$$v'-v=\frac{(r'-r)V}{(R+p)}$$

The quantity of gas recoverable in the Petrolia field January 1, 1920, is computed from these formulas as follows:

V=110 billion cubic feet, original volume (revised estimate).
R=725 pounds, original rock pressure.


MAP
OF THE
PETROLIA GAS FIELD
TEXAS
By E.W. Shaw and H.M. Robinson
1,000 0 1,000 2,000 3,000 4,000 FEET
Scale 1/18,000
Property lines and names of owners mainly from oil company surveys
LEGEND
Surface contours
Contour interval 5 feet
Datum is mean sea level
Surveyed outcrops of sandstone-shale contacts
Figures indicate altitudes determined by spirit-level lines run from U. S. G. S. B. M. at Petrolia depot
Structure contours on gas sand
Based on altitudes of sands in wells and on outcropping sandstones
Contour interval 20 feet
Datum 1,000 feet below sea level
Deep gas well
Deep oil well
Deep combination oil and gas well
Deep well, show of gas
Deep well, show of oil
Deep well, show of oil and gas
Deep dry hole
Deep abandoned gas well
Deep drilling well
Shallow oil well
Shallow dry hole
Figures beside wells indicate altitudes of well curbs
Outline of productive pools
Well abandoned on account of water
Well wet but still producing
PETROLIA
PROBABLE BOUNDARY OF GAS RESERVOIR
BOUNDARY OF DEVELOPED PORTION
OIL AND GAS POOL IN DEEP SAND
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

$r'=85$ pounds, rock pressure January 1, 1920 (average for entire sand).
$r=2$ pounds, rock pressure at which field is abandoned.
$p=14.4$ pounds, atmospheric pressure.
$v'-v=10,900,000,000$ cubic feet.

This is the theoretical quantity of gas recoverable and does not allow for losses or for the effect of water encroachment. The losses may be estimated at 20 to 25 per cent.

WATER ENCROACHMENT.

The past and probable future extent of water encroachment in the Petrolia field can best be inferred from the behavior and distribution of wells that have partly or wholly "gone to water." Eleven wells have been abandoned on account of flooding, and five wells are at present showing more or less water. The total number of gas wells drilled in this field is about 79, of which 48 are now producing.

The mode of water encroachment is fairly clear from a study of the individual wells that have "gone to water." Beatty No. 1, north of the center of the field and considerably off the structural axis, was abandoned about January, 1918, at a rock pressure of 90 pounds. Skelly No. 2, south of the Beatty well and near the highest part of the sand, was abandoned as early as 1913 at a pressure of 300 pounds. Other wells in other parts of the field were abandoned at pressures of 0, 50, 90, and 120 pounds. These observations indicate that water is advancing into the gas reservoir but that the principal mode of advance is from below up rather than from the borders inward.

The wells that have "gone to water" are not scattered indiscriminately over the field but are distributed in more or less well-defined groups. (See Pl. IX.) The order in which water troubles developed in the Miller and Donley wells, on the south edge of the field, indicates that water is creeping up the south flank of the dome. On the other hand, some of the earliest wells to be drowned out were near the top of the dome. In these wells, however, water from higher strata may have entered through faulty packing and penetrated the producing sand. The effects of water encroachment, though serious, are local, and the field as a whole is not being systematically inundated.

In view of the facts above stated some allowance should obviously be made for the retardation of the decline in closed pressure caused by water advancing into the gas reservoir. Apparently the area of the gas pool has been reduced by 1 or $1\frac{1}{2}$ square miles, and the capacity of the reservoir has been correspondingly reduced, being now about 90 per cent as great as it was originally, if the sands are fairly uniform in thickness. At least 10 per cent should therefore be deducted from the estimate of 10,900,000,000 cubic feet given above, leaving 9,810,000,000 cubic feet as the estimated quantity of gas that in the future can be delivered into the mains from the Petrolia field.

There is no way of determining the future rate of water encroachment except by inference based upon the probability that a fairly uniform rate of flooding will be maintained and that wells near those already flooded will go out in their turn. As the rate of general depletion of the field has far exceeded the rate of water encroachment, it is not probable that any large portion of the remaining supply will be cut off by this agency.

MARTIN WELLS.

The relation of the Martin wells to the main part of the Petrolia field is not definitely established and promises to be a matter of considerable controversy. In the foregoing discussion they are regarded as constituting a part of the Petrolia field for reasons set forth in the following paragraphs.

The wells are on the N. H. Martin farm, about 3 miles southwest of Petrolia. There are four producing gas wells, and a fifth is nearing completion.

Data concerning the Martin wells.

Name.	Date completed.	Total depth (feet).	Depth of producing sand (feet).	Initial closed pressure (pounds to the square inch).	Initial open flow capacity (cubic feet).	Notes.
Martin No. 5	May 31, 1918	1,788	[a] 1,671–1,683 [b] 1,782–1,788	510	5,570,000	Making water and oil.
Martin No. 7	Jan. 27, 1919	....	....	....	8,500,000	
Martin No. 9	Oct. 14, 1919	1,740	....	605	38,800,000	
Martin No. 10	....	....	....	....	....	
Martin No. 11	Feb. 20, 1920	1,710	[a] 1,683–1,693 [b] 1,713–1,720	425 510	8,277,120 14,844,976	

[a] Upper sand. [b] Lower sand.

Sufficient data are not at hand for a complete and satisfactory computation of the total volume of gas for each sand, and the following figures must be regarded as tentative. It seems almost certain from the available well data that the structure precludes any great extension of the present pool toward the north, east, or south, and that extensions toward the west are problematic, with the best prospects toward the northwest. The fairly rapid decline of closed pressure with moderate output supports the inference that the reservoir is small.

Apparently the wells are drawing gas from an area of about 1½ square miles. The sands seem to have an average total thickness of about 18 feet, and on the assumption that their pore space amounts to 20 per cent and that the original closed pressure was 550 pounds, the total volume of gas present would have been 5,500,000,000 cubic feet. This estimate seems to be moderate, and there is reason to believe that more complete data will raise rather than lower the figure. The gas marketed from these wells from November, 1919, to February 1, 1920, amounted to 937,081,640 cubic feet. It seems probable that several hundred million cubic feet additional has been drawn from the pool but for various reasons unmarketed. The original volume of gas has probably been reduced by 1,500,000,000 cubic feet. The decline in closed pressure of the wells has been nearly 50 per cent, but it is thought that at a distance from the wells the pressure is much higher, especially as the gas has been withdrawn so rapidly that the pressure has not had time to become equalized.

POSSIBILITY OF NEW POOLS.

Other outlying pools or arms of the main pool may be discovered. About 30 wells have been drilled in the territory immediately around the Petrolia pool, in a belt wide enough to include the Martin wells, and seven of these became producing oil or gas wells. This result would give a ratio of dry holes to producing wells of 4 to 1, and would suggest that extensions and new marginal pools should be sought at a greater distance.

The deep test well of the Lone Star Co., Byers No. 36, just west of the producing area, disclosed the fact that the strata underlying the known producing sands are similar in character and arrangement to those above, though at this point the whole series was barren. It might be well to drill a deep well in the center of the field at the southwest corner of block 5, near Culbertson well No. 5, which appears to have struck the "lime" near its highest point. This would be approximately at the center of the dome.

Very few if any undrilled locations still lie within the known limits of the pool. A study of the map and other data leads to the suggestion that a well be drilled about the center of block 16. The suggested location would be about 2,250 feet southeast of Landrum wells Nos. 1 and 2, which have declined in rock pressure at a uniform rate from 295 pounds in 1915 to 40 pounds at the present time. The suggested location would be 2,600 feet northeast of Jackson well No. 1, which was abandoned several years ago; 3,000 feet northwest of Holloway well No. 8, which came in at 110 pounds in 1918 and now registers zero; and about the same distance northwest of Holloway No. 9, which came in at 140 pounds in 1918 and now has a pressure of 35 pounds. The best that could be expected from this location would be a well with a pressure of perhaps 50 pounds and a relatively small open flow.

Curves showing the decline in rock pressure and open flow for the Petrolia field are given in figures 3 and 4. Records of production are also shown for comparison in figure 4.

SUMMARY FOR PETROLIA FIELD.

Below is a summary of conditions in the Petrolia field, including the Martin wells, at three different periods in the history of the field:

1907.

Original closed pressure of pool, pounds to the square inch	725
Original absolute pressure of pool (=gage reading+atmospheric pressure) pounds to the square inch	740
Area of pool square miles	12–15
Average thickness of pay sand feet	30–40
Average pore space of pay sand per cent	20–25
Original capacity of reservoir (revised estimate), billion cubic feet	2¼
Original gas content measured at 8 ounces above atmospheric pressure (revised estimate), billion cubic feet	110

September, 1915.

Average closed pressure of active wells, pounds to the square inch	288
Average pressure midway between wells, pounds to the square inch	375±
Average pressure in marginal territory and in lenses having poor connection with wells, pounds to the square inch	650±
Average pressure through entire pool, pounds to the square inch	435
Average absolute pressure for entire pool, pounds to the square inch	450
Quantity of gas marketed billion cubic feet	37
Estimated quantity of gas lost do	13
Estimated quantity of gas remaining (allowing for some water encroachment) billion cubic feet	70

February, 1920.

Average closed pressure of active wells in old Petrolia field..........pounds to the square inch..	49
Average closed pressure of Martin wells..........do..	305
Average pressure midway between wells in old Petrolia field..........pounds to the square inch..	70±
Average pressure in marginal territory and in lenses having poor connection with wells..pounds to the square inch..	175±
Average pressure through entire pool including Martin farm..........pounds to the square inch..	85±
Average absolute pressure for entire pool..........do..	100
Estimated quantity of gas marketed....billion cubic feet..	70–80
Estimated quantity of gas lost..........do....	20–25
Estimated quantity of gas remaining (allowing for some water encroachment)..........billion cubic feet..	12–15
Estimated future underground loss, including gas finally left in sand and that lost to other sands, billion cubic feet..........	2–3
Estimated future loss above ground...billion cubic feet..	1–2
Estimated quantity of gas remaining in pool, including Martin wells, that can be delivered to the mains, billion cubic feet..........	9–10

FOX FIELD.

GENERAL FEATURES.

The Fox field is in Tps. 2 and 3 S., Rs. 2 and 3 W., Carter County, Okla., about 10 miles north of the Healdton oil field, where there are several gas wells, one of which had an initial open flow of 40,000,000 cubic feet a day. The gas at Healdton, being considered of secondary importance to the oil, has not been conserved. In November, 1917, a 16-inch gas line was laid to Dallas from the southeast corner of Stephens County, Okla. This line is about 115 miles long. From its northern extremity an extension of 12-inch pipe, 8½ miles in length, taps the Fox field.

The Fox field now contains 12 wells, the first of which, northwest of the village, was completed in October, 1915. This well had an initial daily open flow of 18,000,000 cubic feet. The average daily open-flow capacity of the producing wells in the field on February 1, 1920, was 7,700,000 cubic feet. As many as five producing sands, all of which are believed to be of Pennsylvanian age, are penetrated in some of the wells. These sands range in depth from 1,400 to 2,300 feet. One or two wells produce from shallow sands less than 1,000 feet deep. A typical well log showing the relative position of the five sands is given below.

Typical well log of Fox field, Okla.

[Tucker No. 1, Phillips Petroleum Co., sec. 29, T. 2 S., R. 3 W. Drilled June 16, 1918. Rock pressure 695 pounds to the square inch. Open flow 33,900,000 cubic feet a day.]

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Surface	Gray	Soft	6	6	
Sand	White	do	27	33	
Red bed		do	32	65	
Shale, sandy	Gray	do	40	105	
Rock	Red	do	8	113	
Sand	White	do	25	138	
Rock	Red	do	10	148	
Sand	White	do	12	160	
Rock	Red	do	25	185	
Sand	White	do	24	209	
Rock	Red	do	28	237	
Sand	White	do	28	265	
Rock	Red	do	85	350	Fresh water at 138 feet.
Sand	White	do	10	360	
Rock	Red	do	45	405	Fresh water at 360 feet.
Sand	White	do	45	450	
Rock	Red	do	135	585	
Sand	White	do	20	605	
Shale	Blue	do	45	650	
Shale, sandy	do	do	50	700	
Rock	Red	do	125	825	
Sand	White	do	40	865	
Rock	Red	do	7	872	
Shale	Blue	do	103	975	
Rock	Red	do	60	1,035	
Shale	Blue	do	15	1,050	
Rock	Red	do	10	1,060	
Shale	Blue	do	44	1,104	
Sand	White	do	100	1,204	
Shale	Blue	do	26	1,230	Dry sand.
Sand	White	do	55	1,285	Do.
Shale	Blue	do	20	1,305	
Sand	White	do	7	1,312	
Shale	Blue	do	8	1,320	
Shale, sandy	do	do	10	1,330	
Shale	do	do	50	1,380	
Sand	White	Hard	90	1,470	
Shale	Blue	Soft	20	1,490	
Do	Brown	do	20	1,510	
Do	Blue	do	35	1,545	
Lime	White	Hard	15	1,560	
Shale	Blue	Soft	35	1,595	
Lime	White	Hard	23	1,618	
Gas sand	do	do	32	1,650	
Shale	Blue	Soft	13	1,663	1,500,000 cubic feet of gas.
Sand	White	do	10	1,673	Dry.
Shale	Blue	do	27	1,700	
Dry sand	White	do	44	1,744	
Gas sand	do	do	3	1,747	
Shale	Brown	do	10	1,757	
Gas sand	White	Hard	5	1,762	
Lime shell	Brown	do	8	1,770	
Shale	do	Soft	28	1,798	
Sandy lime	Gray	Hard	6	1,804	
Shale	Brown	Soft	31	1,835	
Sandy lime	Gray	Hard	6	1,841	
Shale	Brown	Soft	9	1,850	
Sharp sand	White	Hard	40	1,890	33,000,000 cubic feet of gas.

PRODUCTION.

The average closed pressure in the Fox field in November, 1917, was about 720 pounds to the square inch. By February, 1920, it had fallen to 141 pounds. (See fig. 5.) This decrease would indicate that the field is at present about 80 per cent depleted. The gas marketed from this field since November, 1917, amounts to about 17 billion cubic feet. All things considered it may be inferred that about 5 billion cubic feet can in the future be recovered and marketed from this field. A separate estimate of losses and of gas used in field operations is not needed for this preliminary estimate, because it is probable that the proportion of such gas to the total withdrawals from the pool will not change materially in the future. Any estimate must be regarded as tentative, for the available data concerning area, thickness, and porosity of sands, etc., are not as full as could be de-

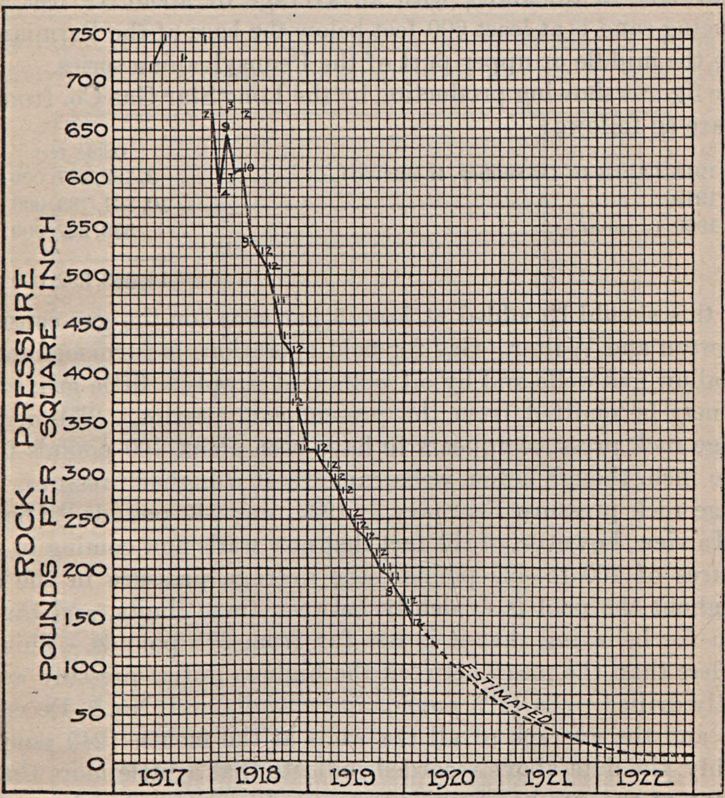


FIGURE 5.—Curve showing decline in rock pressure in the Fox gas field, Okla. Figures on curve indicate number of wells tested.

sired, and there is always the chance of considerable error in determining underground gas reserves.

There is a reasonable hope that the field may be extended, and much prospecting is now being done in adjacent areas.

WALTER FIELD.

The Walter or Keys field lies in the northeast quarter of Cotton County, Okla., north of the town of Walter. The field supplies both oil and gas, many of the wells coming in as gas wells and later yielding oil. The highest recorded initial rock pressure was 825 pounds to the square inch. The Sanders well No. 1, in sec. 3, T. 2 S., R. 10 W., and the Skelton well No. 1, in sec. 1, T. 2 S., R. 11 W., came in at that pressure. Each of these wells had an open-flow capacity of about 18,000,000 cubic feet a day. Several of the wells had a greater initial capacity, but the average for the field is about 10,000,000 cubic feet a day. The wells are 2,100 to 2,300 feet deep, and most of the gas is found in one sand, which is recorded in the well logs as ranging from 7 to 27 feet in thickness, with an average of about 12 feet. The producing sand is at least 600 feet below the base of the Permian and lies in the middle or upper part of the Pennsylvanian series.

The figures showing production by the Lone Star Gas Co. from this field are as follows:

	Cubic feet.
1918 (April to December, inclusive)	3,192,977,000
1919	10,831,193,000
1920 (January)	539,222,000
	14,563,392,000

To this should be added at least 5 per cent for the gas consumed at Lawton and Walter. Gas for field operations is furnished mainly by shallow gas wells and by oil wells that supply a little gas, so this item may be omitted from the present computation. The original average rock pressure appears to have been about 700 pounds to the square inch, though a few wells came in at a higher pressure. The average rock pressure February 1, 1920, was 240 pounds. (See fig. 6.) In view, however, of the fact that new walls now coming in show pressures of 400 to 525 pounds, the average pressure in the sand throughout the pool is evidently between these limits, and there is reason for believing that it is not far from 375 pounds. This is a little less than the mean between the highest initial pressure among recently drilled wells (525 pounds in Schwalbe well No. 2, December, 1919) and the average of all the wells at the mouth (240 pounds). Roughly, the data above recorded indicate that a little more than 50 per cent of the gas has been withdrawn from its natural reservoir. The recoverable and marketable supply remaining is therefore about 13 billion cubic feet. This must be regarded as only a very rough approximation, but it is probably not far from correct.

The problem of water encroachment and the fact that more than one company draws gas from this field add some uncertainty to the computation of the reserve supply. Competing companies in a field tend to increase the rate of depletion, owing to the fact that when one company gets a gas well the other companies that control adjoining leases are practically forced to drill or their gas will be drawn out. The principle is not essentially different from that operating in oil fields, but the effects are felt more quickly and extend over a larger area. Water troubles are already appearing in this field, and the utmost care should be taken by the operators to guard against them.

OTHER FIELDS.

The fields above described include all that have thus far furnished gas to Dallas, Fort Worth, and other north Texas towns, with the exception of some small pools that have supplied gas to certain towns south of Dallas but are now so completely exhausted as to be negligible.

The rapid depletion of the fields in use at present is graphically illustrated by the accompanying curves of decline in rock pressure

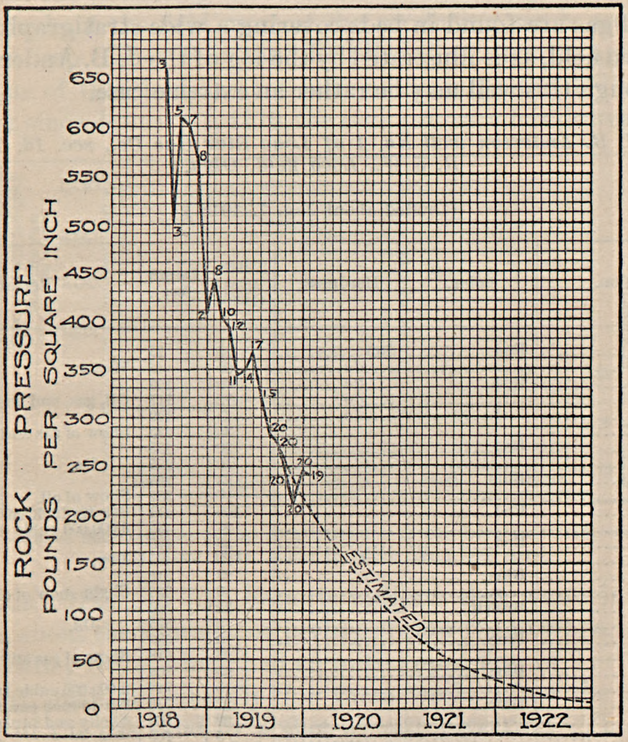


FIGURE 6.—Curve showing decline in rock pressure in the Walter gas field, Okla. Figures on curve indicate number of wells tested.

(figs. 3, 5, and 6). To counteract this exhaustion, pipe lines to other fields, described in the following pages, are being constructed as rapidly as conditions permit.

LOCO FIELD.

Special interest attaches to the Loco field at this time, as it is just being connected with the system that supplies the north Texas towns. It is a field of small area, lying almost wholly within secs. 9, 10, 15, and 16, T. 3 S., R. 5 W., near the southern edge of Stephens County, Okla. Wegeman and Heald[3] refer to it as lying along a curve of which the Healdton dome, 10 miles to the southeast, forms one extremity, and the Duncan dome, 15 miles north-northwest, forms the other. They state that this curve

appears to encircle the west end of the Arbuckle Mountains, forming, so to speak, a cross fold to the low arch which lies between the Arbuckle and Wichita uplifts. It is not meant to imply that the Healdton, Loco, and Duncan fields are situated on one long anticline. They are in fact three separate domes, but they lie in such a relation to one another as to suggest that they are more intimately connected in origin with the Arbuckle uplift than with the Wichita. The Duncan field lies north of the low arch between the two mountain uplifts, and the Loco and Healdton fields lie south of it.

Oil and gas are found in beds covering a wide stratigraphic range in the Loco field, as is illustrated by the log of the J. B. Anderson well No. 1, though this well may be rather an extreme case.

Log of J. B. Anderson well No. 1 of Lone Star Gas Co., sec. 16, T. 3 S., R. 5 W., Loco field, Okla.

[Drilled about Jan. 1, 1918.]

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Shale	Red	Soft	25	25	
Sand		do	20	45	Water.
Shale	Red	do	60	105	
Sand		do	12	117	Oil, gas, and water.
Shale	Red	do	73	190	
Sand			35	225	Show of gas and oil.
Shale	Red		30	255	
Sand			10	265	Do.
Shale	Blue		23	288	
Sand			17	305	Show of oil.
Shale	Red		108	413	Set 12½-inch casing.
Sand			23	436	6,000,000 cubic feet of gas.
Shale	Red		39	475	
Sand			20	495	Dry.
Shale	Blue		23	518	
Sand			10	528	Slight show of oil.
Shale	Brown		32	560	
Sand			15	575	Do.
Shale	Blue		15	590	
Sand			28	618	Show of gas and water.
Shale	Blue		85	703	
Sand			15	718	2,000,000 cubic feet of gas.
Shale	Blue		22	740	Set 10-inch casing.
Sand			20	760	Shelly and broken.
Shale			5	765	
Lime			23	788	
Sand			12	800	Slight show of oil.
Lime			5	805	
Sand			10	815	Slight show of oil and gas.
Do			5	820	
Shale	Blue		10	830	
Sand			21	851	8,000,000 cubic feet of gas.
Shale	Blue		86	937	Set 6⅝-inch casing.
Sand			12	949	
Shale	Blue		4	953	
Do	White		2	955	
Do	Blue		12	967	
Shell and sand			2	969	Water.
Lime			1	970	
Sand		Hard	5	975	
Shale	Blue		10	985	
Sand and lime			10	995	
Sand			5	1,000	Show of oil.

[3] Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, pp. 23–24, 1916.

Log of J. B. Anderson well No. 1 of Lone Star Gas Co.—Continued.

Formation.	Color.	Hardness.	Thickness (feet).	Depth (feet).	Remarks.
Shale	Blue		55	1,055	
Sand and shale			7	1,062	
Slate	Blue		330	1,392	
Lime shell			3	1,395	
Slate	Blue		5	1,400	
Shale	do	Soft	65	1,465	
Lime shell			3	1,468	
Shale	Blue		99	1,567	
Sand			3	1,570	
Water					

None of the producing sands in this well lie deeper than 851 feet, and throughout the field most of the producing sands are less than 1,000 feet deep. They lie in the "Red Beds," of Permian age.

The gas of this field has not been used except for drilling operations, yet since January 1, 1916, the rock pressure has decreased about

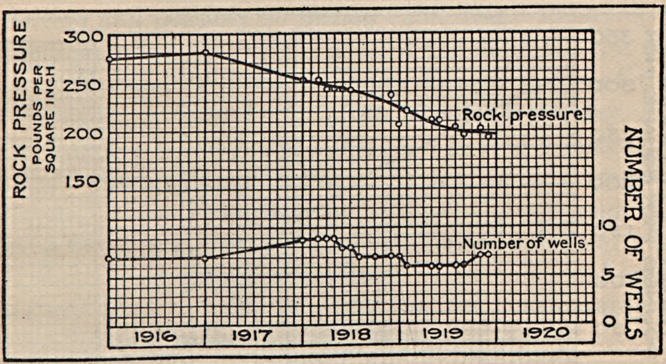


FIGURE 7.—Curve showing decline in rock pressure in the Loco gas field, Okla. In some wells tests were made in more than one sand.

90 pounds. (See fig. 7.) Reports indicate that waste in this field has been about the average, or perhaps below the average. One well, the Ida Billey No. 5, which had an initial open flow of 9 or 10 million cubic feet, blew off steadily for three weeks after the accidental opening of the gas sand by a shot of nitroglycerine. The well was drilled with a rotary drill, and the sand was penetrated without being noticed. A lower oil sand was struck, and after this was exhausted and the well abandoned the gas sand was opened by a shot set off in an effort to dislodge the casing. The well finally had to be plugged. No other important losses have occurred in this field.

The amount of gas used for drilling is roughly estimated at 7,500,000 cubic feet per well, which, for 35 wells, would be 262,500,000 cubic feet; the amount of loss due to oil wells producing from the same sand and to leakage is estimated at 200,000,000 cubic feet for the Ida Billey well and 100,000,000 cubic feet for all others, or 300,000,000 cubic feet. The original pressure in the pool was about 300 pounds to the square inch, and the present average closed pressure of the wells is above 185 pounds. At points distant from wells the pressure, to judge by initial pressures of new wells, is probably 225 pounds. It follows that the original volume was at least 1,465,000,000 cubic feet, and the amount remaining is at least 900,000,000 cubic feet, of which perhaps 700,000,000 cubic feet may be recovered and marketed. The decline in closed pressure is shown in figure 5.

The geologic conditions afford ground for hope that this field may be extended in a direction slightly west of north and perhaps also to the southeast, though until a detailed survey is made no great reliance can be placed on this inference.

DUNCAN FIELD.

About 10 miles north of the Loco field is the Duncan field. The curve of decline in rock pressure for this field (fig. 8) indicates that

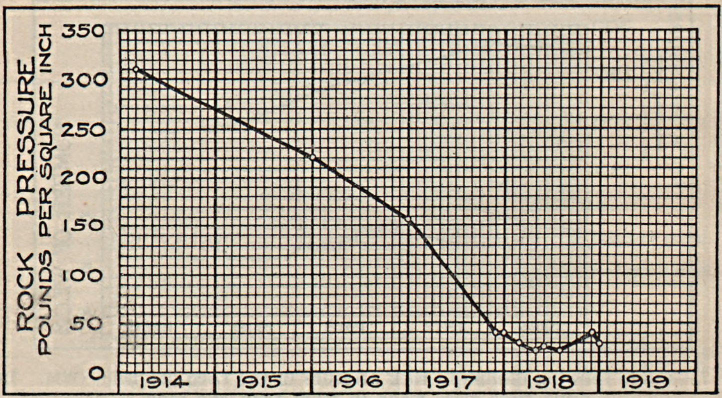


FIGURE 8.—Curve showing decline in rock pressure in the Duncan gas field, Okla.

as a prospective source of supply for north Texas cities it may be disregarded.

MINERAL WELLS FIELD.

The promising gas fields of Palo Pinto County, Tex., have not yet been drawn upon except for local use, but pipe lines are rapidly being pushed toward them, and their supply will soon be available for the north Texas cities. The Mineral Wells field lies in the east-central part of the county, near the town of Mineral Wells. Perhaps the mineralized water at this locality was related to the same set of conditions that gave rise to the oil and gas pools.

The field produces mainly from one sand in the Strawn formation, at a depth of about 1,000 or 1,100 feet. The thickness of the sand, as calculated from available well logs, ranges from 8 to 21 feet, and averages 14 feet. The producing area covers about 8 square miles. The data at hand do not show the original rock pressure, but it was probably not far from 420 pounds to the square inch. The hydrostatic head for wells 1,050 feet deep is about 450 pounds; hence this estimate may be a little low. The earliest wells of which complete records are at present available had initial rock pressures of 270 to 365 pounds. These wells were by no means the first in the field, so it must be assumed that the original rock pressure was well above that at which they came in. A porosity of 20 per cent is assumed. The total volume of gas is thus computed to be about 18 billion cubic feet. As the corrections to be made are nearly all of a plus character, arising from probable development of new territory, discovery of new sands, and the fact that the original rock pressure is conservatively estimated, it is probable that the estimate could safely be raised to 25 billions. Some of the supply has already been drawn for local use at Mineral Wells, and some has been lost through the more or less careless methods usually attending the development of a new field. Still there seems to be good reason for believing that there remains available at least 15 billion and possibly 25 billion cubic feet. Relatively this is not a large amount of gas for the area of the field, but the wells are of rather small capacity. Fifteen representative wells of this field show an average open flow of only 1,820,000 cubic feet a day.

A much deeper sand, at about 4,000 feet, having a closed pressure of about 1,400 pounds to the square inch, has been penetrated in one or two places. After the exhaustion of the shallower sand, this sand will afford a new but at present unascertainable volume of gas in reserve. It should be borne in mind that the difficulty and expense of recovering gas from a depth of 4,000 feet are considerably greater than for shallower depths.

EASTLAND FIELD.

The Eastland County field lies mostly north of the town of Eastland. The producing sands are in the Bend series, at an average depth of about 3,000 feet and extend eastward to the county line, merging into the Ranger field. This field contains much oil, and as oil production is much more profitable than gas production, it is spoken of as an oil field. Nevertheless the high rock pressure and the large open flow of the "gasser" scattered throughout the field indicate an abundant gas supply, in spite of the waste that has been involved in an overdiligent search for the more valuable oil. The gas and oil are mainly in the same sand, and sooner or later most of the gas wells, if allowed to "blow," will begin to yield oil. It was in an attempt to obtain oil that the Barker No. 1 well was allowed to blow at the rate of about 42,000,000 cubic feet a day for three months. The Railroad Commission has lately put a stop to such practices in the interest of conservation of natural gas. This waste of gas in order to obtain oil emphasizes the need of conservation, which can be accomplished by enacting and enforcing properly drafted laws and by putting the prices of the two commodities more nearly on a parity, so that there will be as much incentive to save the one as the other.

The irregular occurrence of gas in this field makes estimation of the quantity extremely difficult. Very little gas from the field has been used commercially, but the large wastes have made a noteworthy depletion. Only the roughest sort of an estimate can be made of the amount available at present. The average open flow is about 20,000,000 cubic feet a day, and the average rock pressure is about 650 pounds to the square inch. The amount of gas originally in the field can hardly have been less than 100 or 200 billion cubic feet and of this 10 to 20 billion cubic feet has already been used or wasted.

Data regarding the wells in Eastland County are given in the following table:

Data concerning Eastland County wells.

Name and number of well.	Owner.	Depth of gas sand (feet).	Tests.			Remarks.
			Date.	Rock pressure (pounds per square inch).	Open-flow capacity (M cubic feet).	
Cooksey No. 1	Jackson Refining & Oil Co.	3,360	Sept. 25, 1919	[a] 900	2,809	Gas dry.
Summeral No. 1	States Oil Co.	1,740	Sept. 23, 1919	[a] 700	50,000	Gas dry. Open flow Oct. 1, 1919, 11,640,000 cubic feet.
W. D. Snead No. 1.	Texolean Co.	1,920-1,927	Oct. 10, 1919	750	13,447	Well blowing open through 8¼-inch pipe supplying fuel for 20 rigs.
Barker No. 1	....	3,630	Oct. 17, 1919	[a] 1,000	42,532	Nov. 13, 1917, making 10 barrels of oil a day.
			Nov. 13, 1919	....	42,532	
			Jan. 1, 1920	....	34,000	
C. J. Harrell No. 1.	Mid Kansas Co.	1,920-1,960	Oct. 16, 1919	[a] 750	47,000	Mudding in gas to drill deeper.
Thraves et al. No. 1.	Texas Co.	1,785-1,790	....	800	40,000	Nov. 1, 1919, open flow, 26,000,000 cubic feet.
Harrell No. 1	Ranger	....	....	900	100,000	
Miller No. 2	Mother Pool Oil Co.	....	....	250	700?	Aug. 30, 1919, was making 10,000,000 cubic feet of gas; shut in September, 1919.
Beard No. 1	Folsom Oil Co.	1,700	....	650	8,000	
Kincaid No. 1	Ardizone-Braden.	1,758-1,761	....	[a] 300	6,000	Sept. 6, 1919, drilled to 3,220 feet; 20 barrels of oil.
C. J. Harrell	Ranger-Texas	1,730-1,733	Nov. 1, 1919	[a] 800	....	Jan. 28, 1920, well leaking gas badly.
Harmony Church Lot No. 1.	Mildren Oil & Gas Co.	1,720-1,781?	Nov. 21, 1919	....	17,000	Nov. 21, 1919, struck gas at 1,725 feet; drilled 6 inches into the sand.
			Nov. 24, 1919	....	39,288	
			Dec. 2, 1919	....	26,000	Feb. 3, 1920, fixing to mud-in to drill deeper.
Jim Harrell	States Corporation.	1,762-1,774	Jan. 1, 1920	....	12,852	Gas slightly wet.
J. C. Harrell	do	....	Dec. 10, 1919	....	35,408	Gas dry.
			Dec. 20, 1919	....	34,489	
			Jan. 1, 1920	....	31,076	
			Feb. 3, 1920	510	25,000	Slightly wet; making little salt water.

[a] Estimated.

Data concerning Eastland County wells—Continued.

Name and number of well.	Owner.	Depth of gas sand (feet).	Tests.			Remarks.
			Date.	Rock pressure (pounds per square inch).	Open-flow capacity (M cubic feet).	
O. E. Meador No. 1	Mid-Kansas Co.	3,095-3,110	Oct. 16, 1919	38	850	Using this gas for boiler fuel.
Bowles No. 1			Sept. 5, 1919	550	[a] 20,000	25 drilling wells using gas; makes considerable gasoline in drips.
Hogg No. 5	Sinclair Oil & Gas Co.		Sept. 5, 1919	500	880	15 drilling rigs using gas.
Crowell No. 1		2,610-2,621	do	[a] 150	974	
Crowell No. 2		2,602-2,610	do	140	2,304	Slightly wet.
Cypert No. 1		2,485	Oct. 3, 1919	405	19,419	Shows little water; no oil.
Cypert			Dec. 5, 1919	255	13,000	
Vaught No. 1	Atlantic Petroleum Co.	2,492-2,500	Sept. 3, 1919	460	2,735	Sprays gasoline, water, and oil when blowing; supplies gas to 10 drilling rigs. Later record, Feb. 28, 1920, gives sand at 2,490-2,497 feet, total depth 2,532 feet, 20,000,000 cubic feet of gas; probably drilled deeper.
Vaught No. 2		2,582-2,588	Feb. 28, 1920		[a]25,000	75 barrels of oil; total depth 2,600 feet.
Emde No. 1	Plains Oil & Gas Co.	2,570-2,577	Sept. 4, 1919	500	5,443	20 drilling rigs.
Foot No. 2	Magnolia Petroleum Co.	2,922-2,927	Sept. 5, 1919	950	20,000	
W. B. Lewis No. 1	Burmosal Co.	2,780-2,783	Dec. 3, 1919		11,000	Not completed.
Shellenberger No. 1	Southern California Drilling Co.				877	Total depth 2,700 feet; Dec. 3, 1919, fishing for tools.
Shellenberger No. 2	do	2,833-2,838	Nov. 12, 1919	450	19,000	
Shellenberger No. 1	Osceola Drilling Co.	3,048, 3,060	Dec. 3, 1919		1,042	Total depth, 2,850 feet.
Brelsford No. 1	Prairie Oil & Gas Co.	3,048, 3,060	Feb. 13, 1920	860	12,250	Gas dry; leaking badly.
Shorter White No. 1.	Quaklin Petroleum Co.		Dec. 22, 1919		4,186	Not complete; fishing for tools.
B. A. Davis No. 1	Vulcan Oil Co.		Feb. 13, 1920		13,678	Making a little oil; blowing through trumble trap.
Rickard No. 1	Texas Co.		do	590	5,253	Gas leaking around casing.
Rickard No. 2	do	3,535-3,542	Nov. 25, 1919		31,000	Total depth, 3,542 feet; making 100 barrels of oil.
A. L. Duffer No. 1	do		Nov. 8, 1919	145	[a] 8,000	
A. L. Duffer No. 2	do				10,000	Total depth, 3,695 feet.
A. L. Duffer No. 6	do		Nov. 8, 1919	480	[a]14,000	Total depth, 3,220 feet.
Patton No. 1	Humble Oil & Refining Co.		Jan. 3, 1920	200	378	Spraying oil.
L. A. Hightower No. 1.	Texas Co.		Nov. 8, 1919	408	[a] 3,000	Total depth, 3,606 feet.
Dountain No. 1	J. M. Sullivan Drilling Co.		Jan. 8, 1920	595	6,500	Gas dry; packing blew out trying to shut in well.
Scott No. 1	Humble Oil & Refining Co.		Jan. 3, 1920		5,213	
Schoor No. 1	do	3,122-3,148	Dec. 31, 1919	850	2,522	Gas wet; total depth 3,791 feet; plugged back to 3,200 feet.

[a] Estimated.

RANGER FIELD.

No sharp line of demarkation exists between the Eastland and Ranger fields. Each produces oil and some gas, the Ranger field mostly casing-head gas. Immediately west and southwest of the town of Ranger are two small groups of wells whose capacities are given in the following table:

Wells near Ranger.

	Rock pressure (pounds per square inch).	Open-flow capacity (cubic feet per day).
Duffer No. 1	145	8,000,000
Duffer No. 2	....	10,000,000
Duffer No. 5	110	20,000,000
Duffer No. 6	480	14,000,000
Patton No. 1	200	378,000
Patton No. 5	325	1,533,000

These wells do not promise a large ultimate output. If there were a pipe line near by, and if their pressure were somewhat higher, so that they would feed into the line, they would add perceptibly to the supplies of the region.

MINOR FIELDS.

The Mexia-Groesbeck field of Limestone County was not regarded by G. C. Matson [4] as of great promise and has followed the predictions of decline very closely. It may be disregarded, as it has practically reached the point of exhaustion.

The northern Louisiana fields are only about 160 miles from Dallas and are not beyond consideration so far as distance is concerned, but their available supply of gas is insufficient to warrant the expense of a line into north Texas. They produce little surplus above the demands of the markets they already supply.

West of Dallas and Fort Worth there are small scattered pools, none of which would justify a pipe line, but which are of interest owing to the encouragement they offer in the search for larger pools.

The Desdemona field, at the junction of Eastland, Comanche, and Erath counties, contains 14 or 15 gas wells of moderate capacity. A pipe line has been surveyed from this field to Stephenville and Dublin, both in Erath County. A few months ago this field was regarded by both oil and gas men as one of great promise, but the production of its wells has fallen off rapidly.

[4] Shaw, E. W., Matson, G. C., and Wegemann, C. H., Natural-gas resources of parts of north Texas: U. S. Geol. Survey Bull. 629, pp. 87–110, 1916.

A well yielding 50,000,000 cubic feet of gas daily has recently been completed in Erath County, just north of Exray, about 16 miles from the Desdemona field and but little farther from the Ranger and Mineral Wells fields. It is close to the nonproductive belt across Erath, Comanche, and Brown counties indicated by geologic conditions and dry holes.

Stephens County does not at present afford evidence of much gas though it includes good oil territory, and the oil contains a considerable proportion of gas. It is not unlikely that here, as in Eastland County, just to the south, there may be developed some gas wells interspersed among oil wells. Some of the Eastland gas wells are very near the Stephens County line.

Shackelford and Callahan counties supply enough gas for the use of local towns but do not promise at present a supply for transmission to other points, though considerable portions of these counties have not been tested and it is quite possible that they may have one or more valuable gas pools. Coleman County contains the Jim Ned field, and Brown County the Bangs field. These fields also are sufficient only for local use.

The only other developed gas pool west or northwest of Dallas is the Amarillo field, a few miles north of Amarillo. This field is reported to contain one of the largest wells on record, a well with a daily capacity of 107,000,000 cubic feet. Six wells in the field have a total open flow reported as 171,000,000 cubic feet. This field can not be regarded as an immediate source of relief to Dallas if indeed it can be regarded as available at any time. It is 270 miles northwest of the western extremity of the 18-inch pipe line that extends westward from Dallas and is 210 miles from Walter, Okla. There are probably no engineering difficulties in the way of laying a connecting line, but it is somewhat doubtful if a sufficiently large yield could be developed to warrant the great expense of piping the gas to Dallas and other north Texas cities.

PROSPECTIVE TERRITORY.

In the report on the gas investigation of 1915,[5] it was pointed out that the country extending 150 miles north and northwest of Dallas and Fort Worth offered great encouragement to the oil and gas prospector. Developments since that time have shown the correctness of this suggestion, and it may be safely assumed that there are still several undiscovered gas pools in this region. The reasons for this assumption are much the same as those stated in the earlier report, as quoted below. Testing has not yet been sufficiently thorough to show that all the pools of the region have been discovered.

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[5] U. S. Geol. Survey Bull. 629, pp. 62–65, 1916.

Geological indications.—The geology of the region extending north and west of Dallas and Fort Worth for 150 miles is, as already stated, generally favorable to the origin, accumulation, and preservation of gas and oil pools. All considerations, both practical and theoretical, point to the existence of undiscovered pools both of gas and of oil in the region. The favorable geologic conditions may be summarized as follows:

1. The rocks of the region belong to the Carboniferous and Cretaceous systems, which contain much gas and oil in other regions. Such rocks as the pre-Cambrian, which nowhere contain valuable pools of gas or oil, are not found or lie so far below the surface that they may be left out of consideration.

2. The general structure is favorable. The layers of rock have the form of a broad, shallow basin or geosyncline, and most of the gas and oil of the world occur in such general basins. The rocks lie nearly flat and at some places, particularly between Fort Worth and Red River, have a broad terrace form.

3. The details of structure are locally favorable. Though the beds lie nearly flat, their general attitude is at many places modified by irregularities of various kinds, and here and there they are undoubtedly arched up into well-developed domes and anticlines, as has been shown by observations made in similar basins elsewhere and by the conditions existing in those parts of this basin that have been tested.

4. The chemical composition of the rocks shows that they may have been the source of large quantities of oil and gas. Carbonaceous sediments, including coal, though not so abundant as in some other regions, are very common.

5. The physical nature of the rocks also shows that they are well suited to accumulate and retain gas and oil pools. They include many layers of open-textured sand of various degrees of porosity, in more or less lenticular beds. These sands make up less than half of the rock, a fact favorable to their retention of pools of oil and gas, because it makes the washing out of the beds with fresh water difficult or impossible.

6. The history of the rocks has been favorable to the accumulation and retention of pools. With the exception of those underlying Dallas, they have apparently not been tilted back and forth until all the fluids in the sands have migrated elsewhere. Salt water, which is taken as an indication of slight or no underground circulation, is found almost throughout the region, and it may be fossil sea water which has not shifted far since the beds were deposited.

7. The rocks have been under sufficient pressure to induce the degree of metamorphism required to separate the hydrocarbons that make up gas and oil but have not been so much compressed as to drive these fluids out of the region and leave nothing but carbonized remains. David White, in discussing this subject recently, has pointed out that the quality of gas and oil found in any rocks shows a relation to the stresses to which the rocks have been subjected and has suggested that gas pools are likely to be most numerous on the sides of an oil region that lie nearest to regions that have undergone greater stresses. According to this principle, gas pools should be most numerous on the east side of this oil and gas region.

The discovery of new pools may undoubtedly be hastened by careful studies of the rocks, made to determine the most promising places for drilling. Without such assistance in finding pools, the cities of Fort Worth and Dallas will probably fail to obtain abundant supplies of natural gas unless they draw supplies from Oklahoma or other distant fields. As the country is developed, and as the oil and gas resources become gradually exhausted, wildcat wells will no doubt increase in number and greater care will be taken to drill in the most favorable places. The search for gas and oil pools should begin with domes and anticlines, for they are by far most likely to contain such pools. Later explorations should extend to structures less favorable, and finally to regions in which the underground structure can not be determined because significant outcrops are poor or are lacking.

Inferences based on experience and on the doctrine of chances.—The proportion of wildcat wells that have been successful in the region under discussion indicates that if it were practicable to make tests of each square mile, a good many more gas pools would be found. Such a series of tests is, of course, as yet out of the question, but illuminating inferences may be drawn from the results of the somewhat random wildcatting and the proportion of successful wells. The importance of these tests becomes more obvious when we apply to them the law of probabilities and remember the fact that some counties, especially Parker, have had scarcely one deep test. If a township were known to contain a pool of oil a mile across, the chances of finding that pool by a random well would, of course, be 1 in 36. If a county covering 1,000 square miles contains one pool 3 or 4 miles across or having an area of 10 square miles, the chances of finding the pool by a random test are 1 in 100. Other considerations, of course, may enter into the problem, such as the fact that the well must be sufficiently deep and drilled with sufficient care to make an adequate test; nevertheless a single unsuccessful wildcat well drilled at random does not throw a great deal of light on the existence of gas and oil pools in a considerable area.

Later developments and surveys have brought to light additional facts concerning the stratigraphy and structure of the region, but many details are not yet known and can not be learned except by detailed and expensive surveys and long and careful study. Plate VIII shows some of the known or probable structural features of the region. Prospecting guided by additional surveys may open up several gas pools. Many tests have already been made in some of the promising areas, and their results should be carefully studied in connection with the results of detailed surveys, to obtain a more intimate knowledge of the formations and their attitude.

The cross folding between the Wichita and Arbuckle mountains of southern Oklahoma, as referred to by Wegemann and Heald, has already been mentioned. The geographic relation between the Wheeler and Fox fields suggests another fold parallel to the one just mentioned. Wegemann and Heald[6] speak of an anticline on the east bank of Red River 30 miles west and 8 miles south from the Healdton dome, in alinement with the Devol anticline of the Grandfield district.

Stephenson[7] has described the Preston anticline and the Leonard-Celeste monocline, extending from Marshall County, Okla., southeastward into Hunt County, Tex. The Preston anticline has produced some oil and gas. It is not known by the writers that any deep wells have been drilled near the axis of the Leonard-Celeste monoclinal "nose."

[6] U. S. Geol. Survey Bull. 621, p. 24, 1916.

[7] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 129, 1919.

The outline and structure of the Bend arch[8] are now fairly well known, but prospecting has proceeded more rapidly on the eastern flank than on the western. The Bangs and Eastland fields lie very nearly on the axis. Pools of small extent may still be found on or near the axis, and possibly on smaller structural irregularities east or west of the axis.

The Marathon fold, which is described by Beede and Liddle[9] as possibly extending from Brewster County northeastward into Foard County (see Pl. VIII), may prove favorable for the accumulation of oil and gas and doubtless will receive careful attention throughout its length.

CONCLUSIONS.

A summary of the available contents of the fields that are either in use at the present time as sources of supply for the north Texas towns, or presumably available for connection before the winter of 1920–21, is given below. The figures indicate estimated recoverable reserves of natural gas January 1, 1920.

	Cubic feet.
Petrolia field (including Martin wells)	10, 000, 000, 000
Fox field	4, 000, 000, 000
Walter field	13, 000, 000, 000
Loco field	700, 000, 000
Mineral Wells field	23, 000, 000, 000
Eastland and Ranger fields	150, 000, 000, 000
	200, 700, 000, 000

As shown by the curve of gross production of the Lone Star Gas Co. (fig. 9), the demand for 1920 may be estimated at 23,500,000,000 cubic feet. For 1921, a somewhat slower rate of increase being assumed, it may be 25,000,000,000 cubic feet. Predictions of this sort should not be carried too far into the future, owing to constant changes in conditions. If the necessary wells were drilled, pipe lines and compressors installed, and if the demand remained uniform at the estimated figure for 1920, the estimated supply of gas, 200,700,000,000 cubic feet, would last about 8½ years. There would be shortages in the winter due to the greater demand at that season. Figure 10 shows the seasonal variations in sales during 1919.

The present industrial consumption of gas in Dallas amounts to more than 50 per cent of the total amount of gas delivered. Any decrease in the volume used in this manner would of course increase the

[8] Hager, Dorsey, Am. Inst. Min. Eng. Bull. 138, p. 1109, 1918.

[9] Beede, J. W., Further notes on the structure near Robert Lee, Coke County, Tex.: Texas Univ. Bull. 1847, pp. 3–7 [1920].

Liddle, R. A., The Marathon fold and its influence on petroleum accumulation: Idem, pp. 9–16.

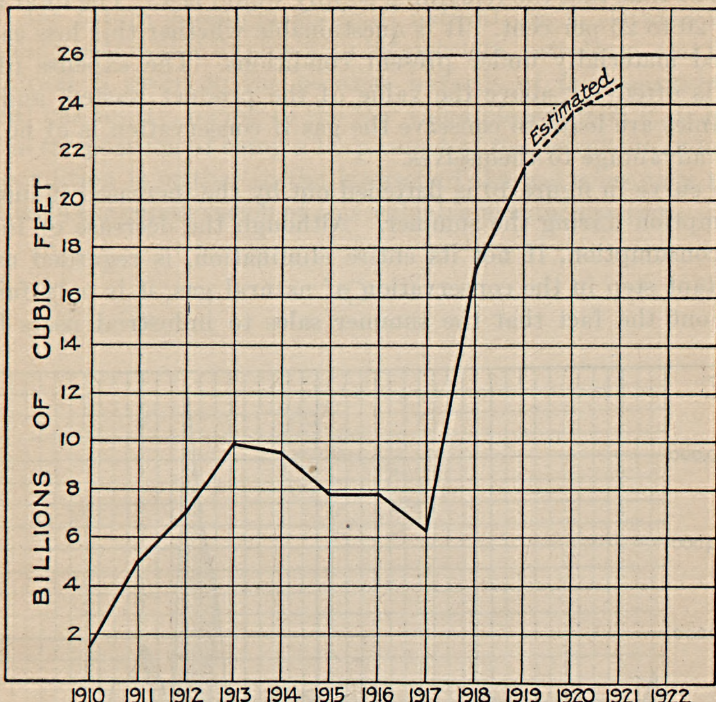

FIGURE 9.—Curve showing production of gas by Lone Star Gas Co., 1910–1919, and estimated production for 1920–21.

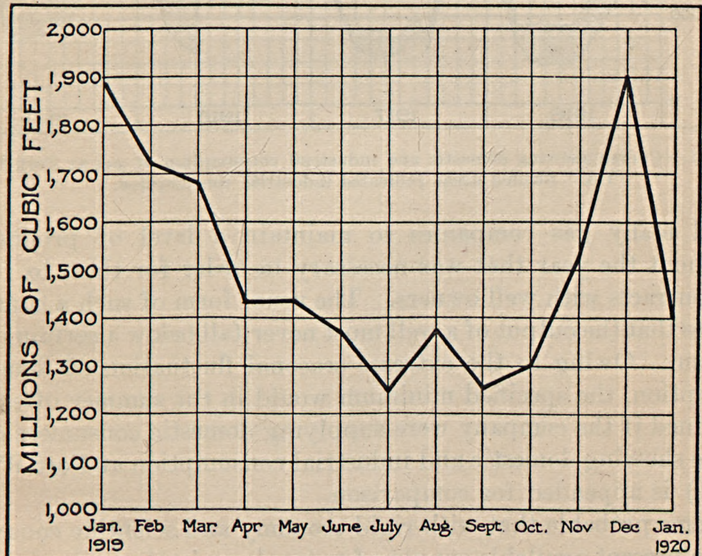

FIGURE 10.—Curve showing monthly sales of gas by Lone Star Gas Co., January, 1919, to January, 1920.

length of time that the remaining supply would last. The total leakage is 20 to 25 per cent. It is questionable whether this loss can be reduced materially under present conditions. The expense of repairs is often far above the value of the product wasted, and gas companies are loath to conserve the gas if conservation is of no economic advantage to themselves.

The curve in figure 10 is flattened out by the increased industrial consumption during the summer. Although the decrease of industrial consumption, if not its entire elimination, is regarded as an important step in the conservation of natural gas, it is only fair to point out the fact that the summer sales to industrial users have

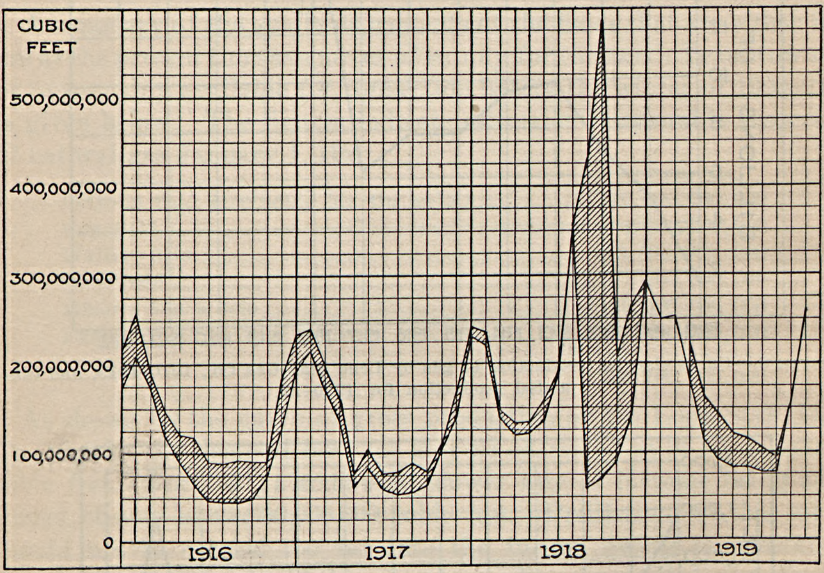

FIGURE 11.—Curves showing domestic and industrial consumption of gas at Fort Worth, Tex. Shaded areas indicates industrial consumption.

enabled many gas companies to maintain a level of production throughout the year that was necessary in order for them to fulfill their contracts with well owners. The usual form of such a contract provides that the output of a well must never fall below a certain daily minimum. Owing to the extreme seasonal fluctuation of domestic consumption, the specified minimum would in the summer often not be attained if the company were supplying domestic consumers only. A curve showing domestic and industrial consumption at Fort Worth (fig. 11) is appended for comparison.

It seems probable that with rigid economy and scientific conservation the present available supply of natural gas in the region around Dallas may be depended on to suffice for six to ten years, though there will be shortages nearly every winter. Little can be certainly predicted for future developments until natural gas is elevated to an economic position side by side with its associate, petroleum, and frank recognition is given to the peculiar hazards of the gas industry. Natural gas to-day, owing to the low value placed upon it, is essentially in the position of being a by-product of the petroleum industry. This condition is neither in the interest of the gas consumers nor a stimulus to the conservation of this valuable natural product.

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