TEXAS WATER COMMISSION

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INVESTIGATION OF GROUND-WATER CONTAMINATION, RHINELAND AREA KNOX COUNTY, TEXAS

By

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ABSTRACT

The study area covers approximately 6 square miles in the vicinity of the community of Rhineland in west-central Texas. The county has a subhumid climate and an average precipation of about 24 inches per year. The economy is dependent largely upon agriculture, and some of the cultivated land is irrigated with ground water.

The land surface is characterized by a relatively level interstream area capped by sand and gravel deposits of the Seymour Formation. The area is drained by the Brazos River, although tributary drainage is poorly developed owing to the permeable nature of the outcropping Seymour Formation.

Rocks of Permian age and overlying unconsolidated sediments of Quaternary age are exposed at the surface in the area of investigation. Soils which are developed locally belong to the soil series Miles fine sandy loam. The sediments of Quaternary age belong principally to the Seymour Formation, which together with hydrologically connected deposits of Recent age, form the principal aquifer in this section of Texas. Rocks of Permian age belong to the Vale Formation of the Clear Fork Group and consist of shale, thin beds of gypsum and dolomite, and some sandstone.

The Seymour Formation in Knox County constitutes a significant hydrologic unit which overlies about 185 square miles of the county. Ground water in the formation occurs under water-table conditions and moves north-northeast. The source of ground water in the formation is precipitation that falls on the outcrop.

A rise in water levels with an accompanying change in water quality in the Seymour Formation occurred primarily from 1900 until the 1940's. The rise in water levels during that period can probably be attributed primarily to the development of the land for cultivation and a marked period of above-average precipitation during the period of rise.

In the Rhineland area the depth to water in the Seymour Formation ranges from about 10 to 30 feet and the saturated thickness of the formation ranges between 10 and 20 feet. Short-term, recovery-type pumping tests, conducted during a previous investigation to determine hydraulic characteristics of the Seymour Formation in Knox County, indicate that the calculated coefficients of transmissibility ranged from 23,000 to 177,000 gallons per day per foot and the field permeability ranged from 1,000 to 14,000 gallons per day per square foot.

The water in the Seymour Formation is very hard. In general, the dissolved-solids content of the water ranges from about 500 to 1,000 parts per million. The water can be classified as a sodium bicarbonate water and in most places the chloride and sulfate ions are within recommended limits for drinking water. Although a high nitrate content is characteristic of ground water in the Seymour Formation, a satisfactory explanation for its origin has not been found.

Three types of water wells are in use in the Rhineland area: drilled, dug, and punched. In most cases only the punched wells appear to be constructed adequately to insure proper sanitary conditions at the well head. Drilled and dug wells in many instances do not have air-tight covers to preclude the entrance of foreign material from the surface into the well.

Sewage disposal in the Rhineland community is on an individual residence basis. Generally, septic tanks are constructed of steel, concrete, or cement rings. At most residences, kitchen wastes and washing machine effluent are discharged into shallow unlined holes or onto the ground surface.

Chemical analyses of water samples collected during this investigation indicate that the native chemical quality of ground water from the Seymour Formation in the Rhineland area is comparable to the quality of water from the formation in other areas of Knox County. However, analyses of water collected during previous investigations in the Rhineland area indicate the presence of ABS (alkyl benzene sulfonate). The presence of ABS, a synthetic organic chemical, in ground water is an indication of pollution from sewage or other man-made waste.

Bacteriological analyses of water samples from 44 wells indicate the presence of coliform organisms in 70 percent of the samples. The MPN ("most probable number") in the samples containing coliform organisms ranged from 3.6 to 11,000 per 100 milliliters of sample. Escherichia coli and Aerobacter aerogenes bacteria were isolated in several samples.

The relationship between the incidence of coliform bacteria and the method of water-well construction suggests that drilled and dug wells are more susceptible to contamination than punched wells, and this can apparently be related primarily to well-completion methods.

The high incidence of coliform organisms in samples from the wells indicates the existence of a general contamination problem. The principal source of the bacteria is considered to be domestic sewage which is discharged into cesspools and septic tanks in the community. Statistics suggest that the problem appears to be directly related to the type of well construction and sanitary conditions at the well head.

It is recommended that the Rhineland community develop a public ground-water supply with a source remote from the individual sewage disposal facilities now in use. If individual water-supply systems are to be continued, it is suggested that dug wells be abandoned, properly plugged, and replaced by punched wells or drilled wells that are properly cased and cemented. The citizens of Rhineland should be encouraged to provide sewage disposal facilities that will minimize the possibility of sewage contamination of the ground water.

INVESTIGATION OF GROUND-WATER CONTAMINATION, RHINELAND AREA KNOX COUNTY, TEXAS

INTRODUCTION

Purpose

The Texas Water Commission received a letter dated September 17, 1963, from Mr. Huey Rush, Superintendent of the Rhineland High School, Knox County, Texas, concerning bacteriological contamination of the school's ground-water supply. This problem seemed to exist throughout the area of the Rhineland community, and the assistance of the Water Commission was requested primarily for the purpose of defining areas of contaminated and uncontaminated underground water resources in the area.

A field investigation of the complaint was conducted by the writer during the period December 3, 1963 to January 19, 1964. This investigation was conducted for the purposes of (1) assisting the community of Rhineland in minimizing its contamination problem, (2) developing much needed basic data on the many geologic and hydrologic factors pertinent to biological ground-water contamination problems, and (3) providing a detailed report, within limits of the data collected during the field investigation, with the hope that such a report would assist in public recognition of this widespread health problem and would perhaps encourage improvements in both domestic sewage disposition facilities and water well completion practices in areas where geologic and hydrologic conditions are favorable for such contamination problems to occur.

Location, Economy, and Climate

The community of Rhineland is located in central Knox County, which is in west-central Texas (Figure 1). The community is in the D. G. Burnett Survey No. 16, Sub-Survey 10 approximately 6 miles north-northwest of Munday on State Farm to Market Road 267. This investigation covered an area of approximately 6 square miles, extending from the Brazos River southward approximately $2\frac{1}{2}$ miles south of Rhineland and extending about $\frac{1}{2}$ mile east and west of the Rhineland townsite (Plate 1).

Agriculture represents the principal source of income in the Rhineland area. Some of the cultivated land in the area is irrigated with ground water. The principal crop is cotton. A cotton gin and grain seed company are located in the community.

Oil is produced in areas south and east of Rhineland; however, at present there is no oil production within the area of investigation.

The climate in Knox County is characterized by wide variations in both temperature and precipitation. The average annual precipitation for the period 1931 to 1960 was about 24 inches. Most of this precipitation occurs from April to October. The mean annual temperature was about 64°F for the period 1910 to 1959. The annual net evaporation from a free water surface is approximately 52 inches.

A more detailed description of historical climatic conditions of the area is given by Ogilbee and Osborne (1962).

Topography and Drainage

The land surface of central Knox County is characterized by a nearly flat interstream area capped by sand and gravel deposits of the Seymour Formation. The regional land surface slope is to the east. Locally, however, the land surface slopes to the north-northeast. Similarly, regional drainage is toward the east, whereas local drainage is toward the north-northeast.

The area of investigation is drained by the Brazos River. Tributary drainage is poorly developed owing to the permeable nature of the outcropping Seymour Formation, and runoff occurs only during periods of heavy or excessive precipitation. Numerous minor ground-water seeps and springs contribute to the flow of the Brazos River along the escarpment of the Seymour Formation overlooking the river.

Previous Investigations

Prior to the present investigation, the Texas State Department of Health collected water samples from several water wells in the Rhineland area for bacteriological and ABS (alkyl benzene sulfonate) analysis. The samples were collected on April 17, 1963 and October 16, 1963 by V. T. Hancock, Sanitarian, State Department of Health, Lubbock, Texas. These investigations were initiated at the request of David C. Eiland, M. D., Munday, Texas, and Charles G. Markward, M. D., Knox County Health Officer. The laboratory results of this sampling program were reported to the Texas Water Commission in a letter dated November 21, 1963 from Mr. H. L. Dabney, Division of Sanitary Engineering, Texas State Department of Health, Austin, Texas.

Several reports containing general information on the geology and ground-water resources of Knox County and a few reports of local investigations for municipal ground-water supplies are available. A detailed description of the ground-water resources of Haskell and Knox Counties is given by Ogilbee and Osborne (1962). An investigation of alleged salt-water contamination of ground water was made by Draper (1960) in a local area south of Rhineland.

A list of reports of previous investigations is included in the Selected References of this report.

Acknowledgments

Appreciation is expressed to the people of Rhineland for their cooperation and to the Wichita County Health Unit, Wichita Falls, and the Texas State Department of Health, Austin, for performing the bacteriological and ABS analyses of water samples collected during the investigation. Acknowledgment of information furnished is also made to the staff of the Soil Conservation Service of the U.S. Department of Agriculture, Knox City, Texas. The report of ground-water resources of Haskell and Knox Counties (Ogilbee and Osborne, 1962) provided invaluable information and historical data for this report.

This report was prepared under the immediate supervision of S. C. Burnitt, Head, Subsurface Disposal Section, and under the general supervision of L. G. McMillion, Director, Ground Water Division.

Method of Investigation

During the course of this investigation special emphasis was placed on the following items:

1. Inventory of all water wells in the selected study area.

2. Compilation of historical ground-water quality data and collection of water samples from 26 water wells for chemical analysis. Collection of existing bacteriological analyses and sampling of water from 44 water wells for additional data. Determination for the presence of ABS was performed on 29 water samples.

3. Collection and interpretation of readily available subsurface geologic and hydrologic data.

4. Determination of surface elevation at various water wells by differential leveling.

5. Correlation and analysis of all data to determine the nature and magnitude of the contamination problem.

The basic data used in the preparation of this report are given in Tables 1, 2, and 3.

GENERAL GEOLOGY AND OCCURRENCE OF GROUND WATER

Rocks of Permian age and overlying unconsolidated sediments of Quaternary age are exposed at the surface in the area of investigation. The sediments of Quaternary age belong principally to the Seymour Formation. The Seymour Formation, together with hydrologically connected deposits of Recent age, represent the principal aquifer in the Osage Plains physiographic section of Texas. Figure 1 illustrates the general extent of these deposits in Texas.

The geologic units that are considered pertinent to this investigation are discussed briefly below. The descriptions of the various stratigraphic units are taken principally from Ogilbee and Osborne (1962).

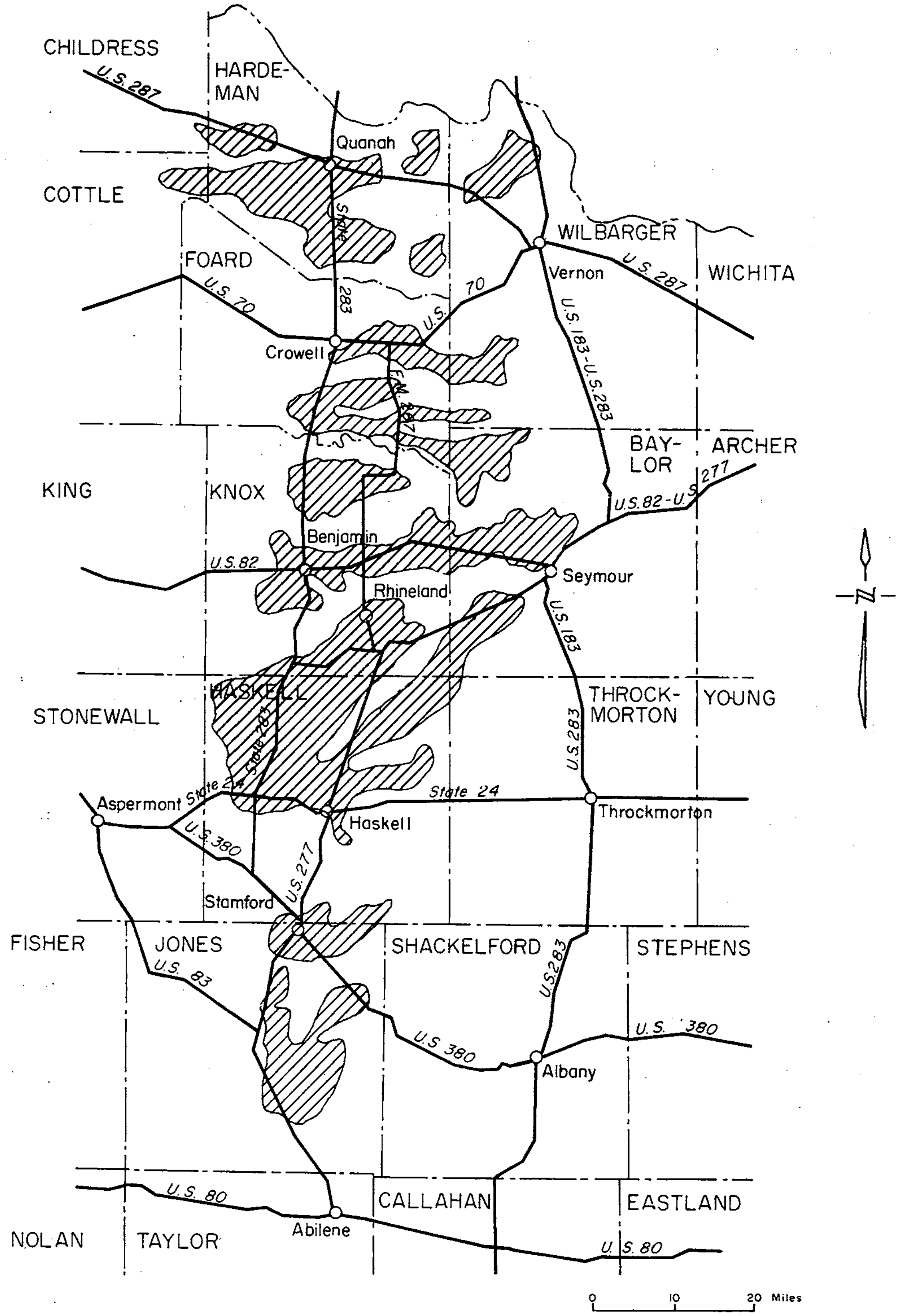

Figure 1

Map Showing Location of the Rhineland Area and Extent of the Seymour Formation in Texas

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Adapted from the Geological Highway Map of Texas: Dallas Geological Society, 1959

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Permian System

Clear Fork Group

Rocks belonging to the Clear Fork Group conformably overlie those of the Wichita Group and lie unconformably beneath the Quaternary deposits in Knox County. The Clear Fork Group consists mainly of red and gray shale containing relatively thin beds of limestone, gypsum, dolomite, and marl.

The Clear Fork Group is comprised of the Arroyo, Vale, and Choza Formations, in acscending stratigraphic order. In the area of investigation only the Vale Formation is encountered during the drilling of water wells. The Vale Formation is commonly referred to as the "red beds," and generally water wells completed in the overlying Seymour Formation are bottomed in the upper 1 to 3 feet of the Vale Formation. The Vale Formation consists of shale, thin beds of gypsum and dolomite, and some sandstone.

No water wells are known to produce water from the Vale Formation in the area of investigation. In some areas of Knox County, however, the formation contains saline water suitable for livestock-watering. Generally, the water has a high sulfate content and is commonly referred to as "gyp water."

The contact between the Vale Formation and the overlying Seymour Formation can be seen in the bluffs along the Brazos River north of Rhineland. At this location the Vale is primarily a friable red shale interbedded in places with gray to green shale. Springs and seeps occur at the contact of the two formations where ground water is discharged from the overlying Seymour Formation. Mineral precipitates, which are apparently the result of evapotranspiration, are noticeable on the surface of the rocks in the area.

Quaternary System

Pliestocene Series

Seymour Formation

The Seymour Formation crops out at the surface throughout most of the area of investigation. Ogilbee and Osborne (1962) describe the Seymour Formation in Haskell and Knox Counties as consisting of coarse-grained sand and gravel, fine-grained sand and silt, red and gray clay, and caliche. The upper part of the formation generally in composed of beds of fine-grained material and disseminated nodules of white to buff caliche. The lower part of the formation commonly consists of coarser material interstratified with lenses of clay. The gravel beds consist largely of rounded pebbles of chert, quartz, igneous rock, and limestone.

The thickness of the Seymour Formation in the area of investigation ranges from 0 to about 50 feet. Generally it is unconsolidated, but locally thin beds of sandstone and conglomerate are loosely cemented. Drillers' logs indicate that the individual beds of sand, gravel, and clay are not continuous over wide areas but grade laterally into beds of finer or coarser grained material.

The Seymour Formation is the principal source of ground water in Knox County. The water is generally hard and commonly has a relatively high nitrate content; however, it is suitable for domestic, stock-watering, and irrigation purposes.

Recent Series

Deposits of Recent age in Knox County occur as floodplain and terrace deposits in the valleys of the principal streams and as windblown sand and silt. These deposits in the drainage areas consist of sand and gravel commonly overlain by red clay and silt. The Recent deposits are similar to those of the Seymour Formation, and in some places it is difficult to differentiate between the two units. Some ground water occurs in sand and gravel of the Recent deposits in stream valleys. Ogilbee and Osborne (1962) report that the ground water in the Recent deposits is more highly mineralized than the water from the Seymour Formation. Available data indicate that none of the wells within the area of present study produce water from rocks of Recent age.

Soils

The soils in Knox County are characteristic of the parent geologic materials that crop out in the county. In the area of investigation the soils are derived primarily from the Seymour Formation and the Recent alluvium. No soil survey has been conducted in Knox County; however, a generalized soil map of the area has been prepared by the U.S. Department of Agriculture, Soil Conservation Service.

This map indicates that the soil type present in the area of Rhineland belongs to a soil series known as the Miles fine sandy loam. The Miles fine sandy loam is described as a nearly level to very gently sloping, deep, medium-textured, moderately permeable soil. This soil generally absorbs water readily; however, it erodes rather easily and requires careful management for protection from wind.

GROUND WATER IN THE SEYMOUR FORMATION

The Seymour Formation is the most heavily developed aquifer in the Osage Plains of Texas. In Haskell and Knox Counties, it constitutes a significant hydrologic unit which occupies an area of about 430 square miles. It overlies about 185 square miles of Knox County. Generally, sand and gravel beds typical of the basal part of the aquifer constitute the chief source of ground water, although the upper part of the aquifer, commonly consisting of finer grained material, yields water to wells locally.

The source of all ground water in the Seymour Formation is precipitation that falls on the outcrop area. The water in the formation generally occurs under water-table conditions; however, because of lenticular beds of clay in the formation, locally the water may be under sufficient hydrostatic pressure to rise in a well a short distance above the top of the water-bearing bed.

Prior to 1900, wells drilled through the Seymour Formation were reported to be dry or yielding very small amounts of water that was too highly mineralized for domestic or livestock use (Ogilbee and Osborne, 1962). According to

Ogilbee and Osborne (1962, pl. 6), the saturated thickness of the Seymour ranged from 0 to about 60 feet in the winter of 1956-57. The rise in water levels (increase in saturated thickness), with an accompanying change in water quality, occurred primarily from 1900 until the 1940's. The rise in water levels during that period can probably be attributed primarily to the development of the land for agriculture and a marked increase in precipitation during the period of rise. The application of conservation practices during the development of the land for cultivation apparently increased the opportunity for recharge and decreased the amount of water lost by evapotranspiration and runoff.

The rise in water levels illustrates the permeable nature of the Seymour Formation and its susceptability to recharge by precipitation or by fluids from other sources. The principal area of recharge to the formation is west of O'Brien and south of Rochester in Haskell County. Also, numerous small depressions in both Knox and Haskell Counties impound water during periods of heavy precipitation, part of which undoubtedly contributes to recharge of the aquifer.

Ground water in the Seymour Formation in Knox County generally moves toward the north-northeast from the areas of principal recharge. The direction and rate of movement varies from place to place because of differences in permeability, rates of recharge and discharge, and the configuration of the underlying Permian aquiclude. Figure 2 indicates that the regional slope of the water table averages about 10 feet per mile. The slope of the water table conforms generally to the regional slope of the land surface and to the slope of the surface of Permian rocks underlying the Seymour Formation.

Ogilbee and Osborne (1962) conducted short-term, recovery-type pumping tests to determine the hydraulic characteristics of the Seymour Formation during their ground-water investigation of Knox and Haskell Counties. The tests in Knox County indicated that the calculated coefficients of transmissibility ranged from 23,000 to 177,000 gallons per day per foot and the field permeabilities ranged from 1,000 to 14,000 gallons per day per square foot. However, the authors concluded that the calculated values "...are subject to considerable error...." and that "...the true values may be considerably smaller."

In the Rhineland area the depth to water in the Seymour Formation ranges from about 10 to 30 feet, depending on the surface elevation. The saturated thickness of the formation ranges between about 10 and 20 feet, thickening to the south. Plate 2, a map showing the altitude of the water table at Rhineland, indicates that the water table slopes toward the northeast and that the hydraulic gradient flattens considerably in the northern part of the townsite. The decrease in gradient is possibly the result of an increase in the permeability of the aquifer in this area although data are not available to substantiate this hypothesis. Since aquifer tests were not performed during this investigation, the precise hydraulic characteristics of the Seymour Formation in the Rhineland area are not known. The overall average rate of ground-water movement is probably on the order of several inches per day, although locally the water may move as much as several feet per day. In general, the hydrologic characteristics of the Seymour Formation in the Rhineland area are believed to be comparable to the conditions in the aquifer in other parts of the county.

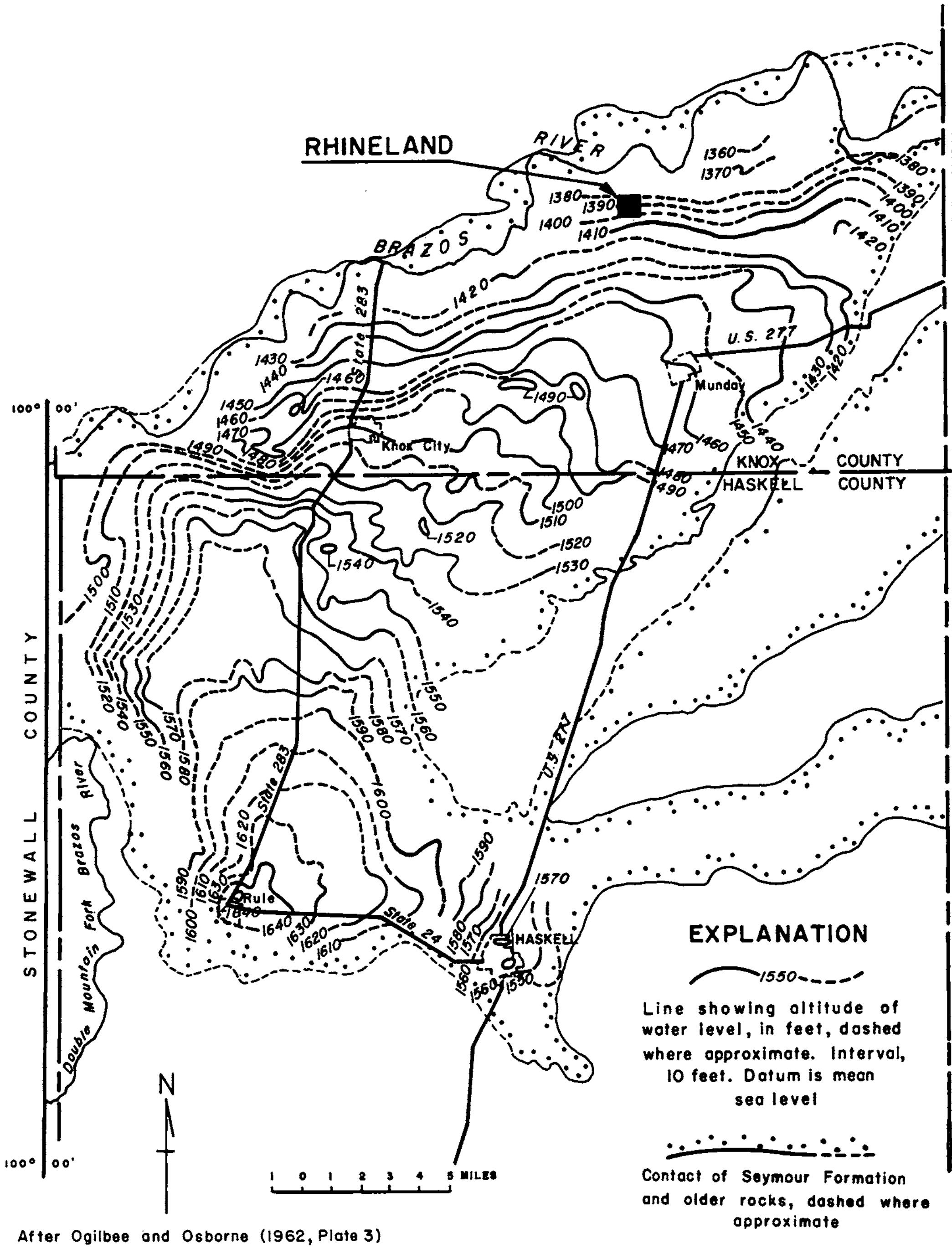

Figure 2
Altitude of Water Level in Wells in the Seymour Formation in Haskell and Knox Counties, Winter of 1956-57
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GENERAL DISCUSSION OF QUALITY OF WATER

The chemical and bacteriological suitability of water depends upon the proposed use. The quality of water used for domestic and public supplies is often compared to the standards established by the U.S. Public Health Service (1962) for water used by common carriers in interstate commerce. However, in many areas the availability of water, not the quality, is often the controlling factor in its use for domestic and public supplies.

Chemical Quality

Various criteria have been developed for ascertaining water-quality requirements. For many purposes, the chemical suitability of water is determined by the total dissolved-mineral content of the water. A general classification of water, based on dissolved-solids content, presented by Winslow and Kister (1956, p. 5) is given below:

Description	Dissolved-solids content in parts per million
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Highly saline	10,000 to 35,000
Brine	More than 35,000

The Public Health Service chemical quality standards are designed to protect the traveling public and are usually the standards used to evaluate public water supplies. Some of the limits recommended by the Public Health Service (1962, p. 70) are as follows:

Substance	Concentration (ppm)
Alkyl Benzene Sulfonate (ABS)	0.5
Iron (Fe) and Manganese (Mn) together	.3
Magnesium (Mg)	125
Chloride (Cl)	250
Sulfate (SO_4)	250
Fluoride (must not exceed)	1.5
Nitrate (NO_3)	45
Total dissolved solids	500

ABS is an anionic surfactant contained in most household detergents. The surfactant is a synthetic organic chemical and not a naturally occurring substance. Its presence in ground water is an indication of pollution from sewage or other man-made waste. The Public Health Service recommends that ABS in drinking water should not exceed 0.5 ppm (parts per million) inasmuch as higher concentrations may cause the water to exhibit undesirable taste and foaming.

If the nitrate content of drinking water is in excess of 45 ppm, a potential danger exists. Concentrations of nitrate in excess of 45 ppm in water used for infant feeding have been related to the incidence of infant cyanosis (methemoglobinemia or "blue baby disease"), and water containing such concentrations should be regarded as unsafe (Maxcy, 1950, p. 221). High nitrate concentrations may also be an indication of pollution from organic matter, commonly sewage. However, it has been fairly well established that although pollution may increase the nitrate content of water, a high nitrate content does not necessarily indicate pollution.

Excessive concentrations of iron and manganese in water cause reddish-brown or dark-gray precipitates that stain clothing and plumbing fixtures. A chloride content exceeding 250 ppm may cause salty taste, and sulfate concentrations in excess of 250 ppm may produce a laxative effect. Excessive concentrations of fluoride in water may cause teeth to become mottled.

Calcium and magnesium are the principal constituents in water that cause hardness. Excessive hardness causes increased consumption of soap. The commonly accepted standards and classification of water hardness are as follows:

Hardness range (ppm)	Classification
60 or less	Soft
61 to 120	Moderately hard
121 to 180	Hard
More than 180	Very hard

In rural and urban areas, where ground water is the principal source of water supply and domestic sewage disposal is on an individual basis, many cases of pollution of ground water from sewage effluent have been reported. It is possible to use certain inorganic ions to determine the extent of infiltration of sewage effluent into ground water. Any ions that have a significant concentration differential between the sewage and ground water can be used to determine infiltration. According to McKinney (1962), the inorganic ion concentrations in domestic sewage range from 300 to 3,000 ppm, for an average of 500 ppm. The approximate concentrations of inorganic ions, by weight, in domestic sewage are as shown in the following table.

Inorganic ion	Percent (by weight)
Sodium	25
Potassium	2
Ammonium *	4
Calcium	5
Magnesium	1
Iron	<1
Bicarbonate	40
Sulfate	10
Chloride *	10
Phosphate	1

* A major component of human and animal waste.

Bacteriological Quality

Ground water is generally considered to be bacteriologically sanitary except in areas where it has been polluted by sewage. Standards for the bacteriological quality of water used for public water supplies are generally based on the presence of the coliform group of bacteria in the water.

Coliform organisms are nonpathogenic (not disease-producing) bacteria that are characteristic of human or animal intestinal origin, and are therefore used as indicators of the presence of sewage contaminants. Pathogenic organisms are not easily detected by normal bacteriological laboratory techniques; hence, indicator organisms such as the coliform group, which can be rather easily identified, must be relied upon to detect bacteriological pollution.

The coliform group of bacteria include the genera *Escherichia* and *Aerobacter*, both of which were originally believed to be entirely of fecal origin. It has recently been shown, however, that *Aerobacter* and certain *Escherichia* can grow in soil (McKinney, 1962, p. 153). In some cases a high coliform count in well water can be attributed to the decay of animals that have entered the well and died. Generally, however, the presence of the species *Escherichia coli* indicates fecal origin.

The Texas State Department of Health uses the multiple-tube fermentation technique (presumptive and confirmed tests) in bacteriological analyses as an indication of the sanitary quality of water. This technique consists of ascertaining the incidence of coliform organisms in water samples. Water of satisfactory bacteriological quality should be free from coliform organisms and the Health Department considers a confirmed test of one (1) tube in five (5) on water well samples to be an indication of pollution. The number of positive findings of coliform group organisms (either presumptive or confirmed) is sometimes computed and reported in terms of the MPN ("most probable number"), which is a means of estimating the coliform density in a water and thereby aiding in establishing its sanitary quality (American Public Health Association, 1961, p. 494, 502).

QUALITY OF GROUND WATER IN THE SEYMOUR FORMATION

The chemical quality of ground water in the Seymour Formation differs from place to place; however, generally it is of a quality suitable for most purposes. A review of available chemical analyses of ground water from the Seymour Formation indicates that the water does not meet all of the suggested limits of mineral composition for drinking water.

The water from the Seymour Formation in Haskell and Knox Counties is very hard. In general, the dissolved-solids content of the water ranges from about 500 to 1,000 ppm. The water can be classified primarily as a sodium bicarbonate water. In most places, the chloride and sulfate ions are within the recommended limits for drinking water; however, in some areas where they exceed the recommended limit, it can probably be attributed to commingling of the Seymour water with water of a poorer quality from other rocks or to concentration of the mineral constituents due to evapotranspiration processes.

The nitrate content in 62 samples of ground water from the Seymour Formation in Haskell and Knox Counties, reported by Ogilbee and Osborne (1962, p. 22), ranged from 21 to 183 ppm and averaged 67 ppm. Of these 62 samples, 39 exceeded the recommended limit of 45 ppm for nitrate, and 28 samples exceeded the average nitrate content of the 62 samples. In general, those samples containing comparatively high nitrate concentrations also were correspondingly high in total dissolved solids. These data indicate that high nitrate concentrations are characteristic of ground water in the Seymour Formation. George and Hastings (1951) report that shallow ground waters in many parts of central Texas contain high nitrate; however, a satisfactory explanation for the origin of the high nitrate has not yet been found.

RESULTS OF THE INVESTIGATION AT RHINELAND

Construction of Water Wells at Rhineland

Three types of water wells presently are in use in the Rhineland area, drilled, dug, and punched wells, and the methods of completion of these wells vary. Figure 3 illustrates the types of completion practices of water wells in the Rhineland area.

Irrigation wells generally are drilled by a modified rotary rig equipped with a 24- or 36-inch bucket. The bottom of the bucket has a knifelike cutting edge, and the loosened material enters the bucket as it is rotated. Water or drilling mud is used to condition the hole during the drilling operation. The hole usually is drilled 1 to 3 feet into the red beds, cased to the bottom with slotted casing, and gravel packed to the surface. Only the lower section of the casing opposite the water-saturated basal gravel deposits is slotted.

The drilling procedure for domestic wells is similar to that for irrigation wells except that a conventional bit is used to drill a smaller diameter

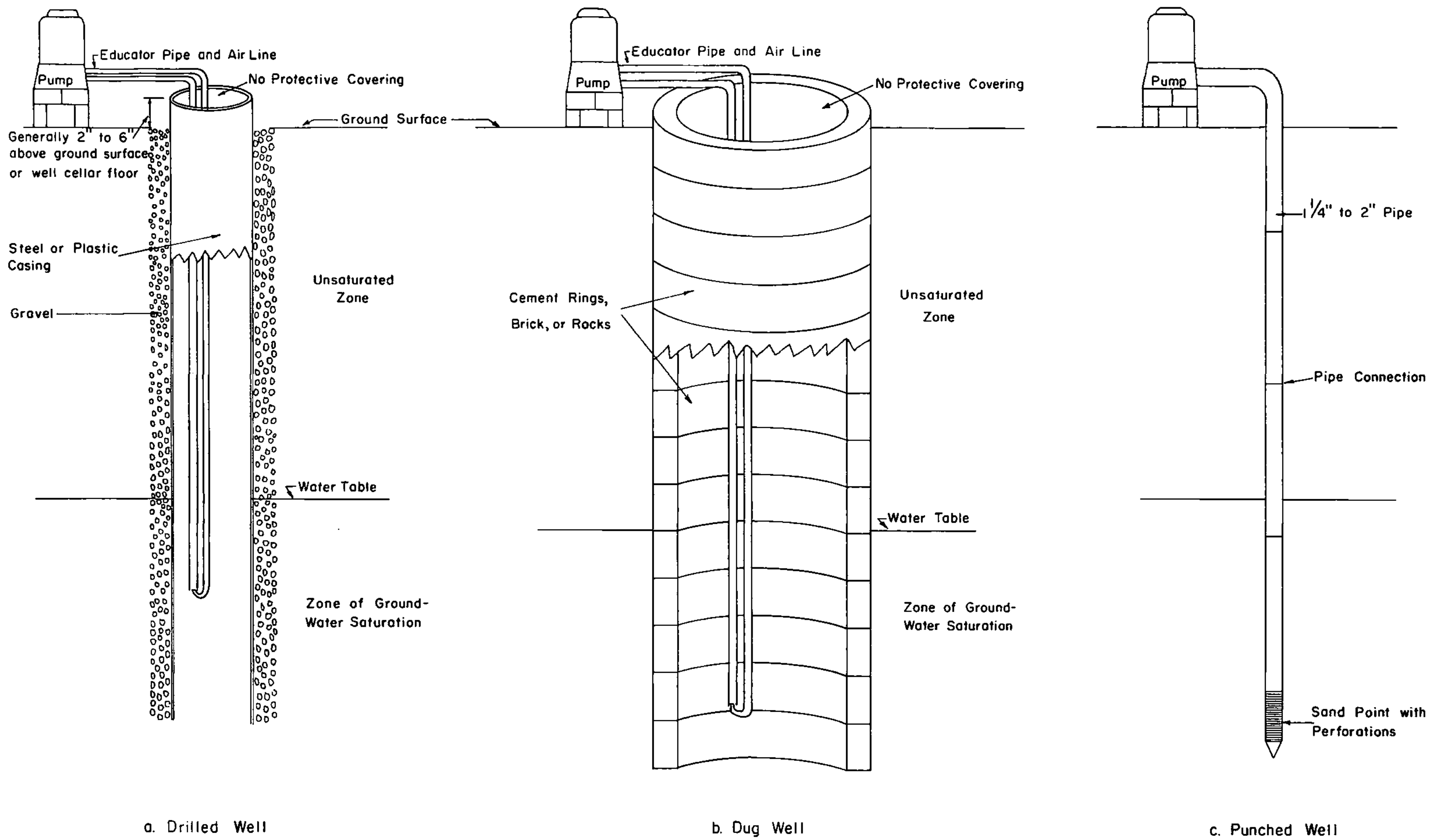

Figure 3
Diagrammatic Sketch Showing Methods of Water Well Construction at Rhineland

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hole. Slotted casing is set 1 to 3 feet into the red beds and the well is gravel packed to the surface (Figure 3a).

The hand-dug wells are usually completed to a depth of 1 to 5 feet below the water table. These wells are generally cased from top to bottom with 30-inch-diameter, culvert-type cement rings; however, some of the wells are lined with brick or rock (Figure 3b).

The punched well is constructed by using a perforated sand point fitted to the end of tightly connected sections of pipe (Figure 3c). The pipe and sand point are usually 1-1/4 inch to 2 inches in diameter. As the sand point is driven below the ground surface, sections of pipe are connected until the point is driven below the water table. The pipe string then serves as the casing and production string for the completed well.

Many of the domestic wells in the Rhineland community have well cellars which are 3 to 5 feet deep. The cellars are usually walled with brick or concrete blocks and have dirt floors. The top of the well casing generally is 2 to 6 inches above the floor of the cellar, and in most cases there is not adequate protection to exclude foreign material from entering the well.

The location of a water well and the well-completion method are of uppermost importance in protecting a ground-water supply from possible contamination. Figure 4 illustrates a typical situation in which a domestic water-supply well is located near sources of potential contamination. The Texas State Department of Health recommends that the well be located a minimum of 150 feet upslope (slope of the land surface) from livestock pens, outdoor privies, septic tanks, and other sources of contamination. If local conditions will not permit this distance between the well and the entire septic tank system, a water-tight septic tank should be installed at least 50 feet from the well and an effluent line of tight joints should be laid so that no part of an open-jointed absorption field will be located within 150 feet of the well (Texas State Department of Health, 1961, p. 9). These recommendations are intended primarily to minimize the possibility of contaminants reaching the ground water in the immediate vicinity of the well and are also founded on the presumption (based on experimental and field data) that contaminants are filtered out or absorbed by aquifer material during this distance of travel. In areas where the water table is near the surface, however, of equal significance is the direction of the hydraulic gradient and the operating capacity of the well. A well should be located up gradient from sources of contamination so that contaminants which have reached the water table will move away from the well in the direction of natural ground-water movement.

A dug water well is the most difficult type of well to maintain so as to assure a sanitary water supply. To be protected from surface contamination, the dug well should be completed with a water-tight casing and cover. The casing or curbing for a dug well can be cement tile, brick, or rock. Regardless of the material used, the inside of the material should be mortared and the outside should be reinforced from the water-bearing strata to the surface, preferably with cement several inches in thickness (Figure 5a).

The drilled well is not as difficult to complete and maintain for a sanitary water supply. Preferably, the well should be drilled through the water-bearing strata, and slotted casing, made of steel or plastic, should be set from about 18 inches above the ground surface to the bottom of the well. The well should be gravel packed through the water-bearing interval and the annular

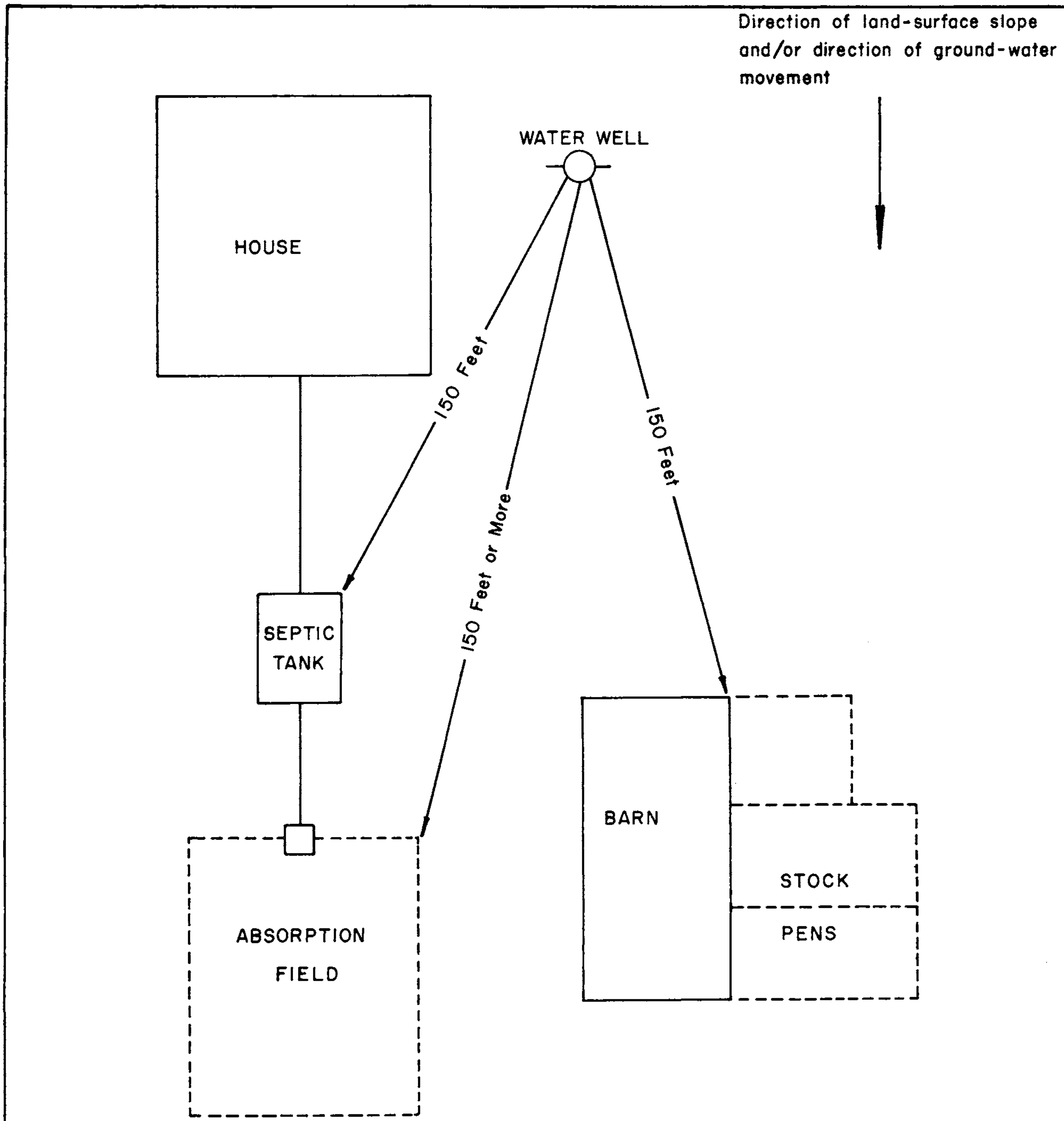

Figure 4

Sketch Showing Recommended Location of Water Well With Reference to Possible Sources of Contamination

(After Texas State Department of Health, 1961, Figure 1)

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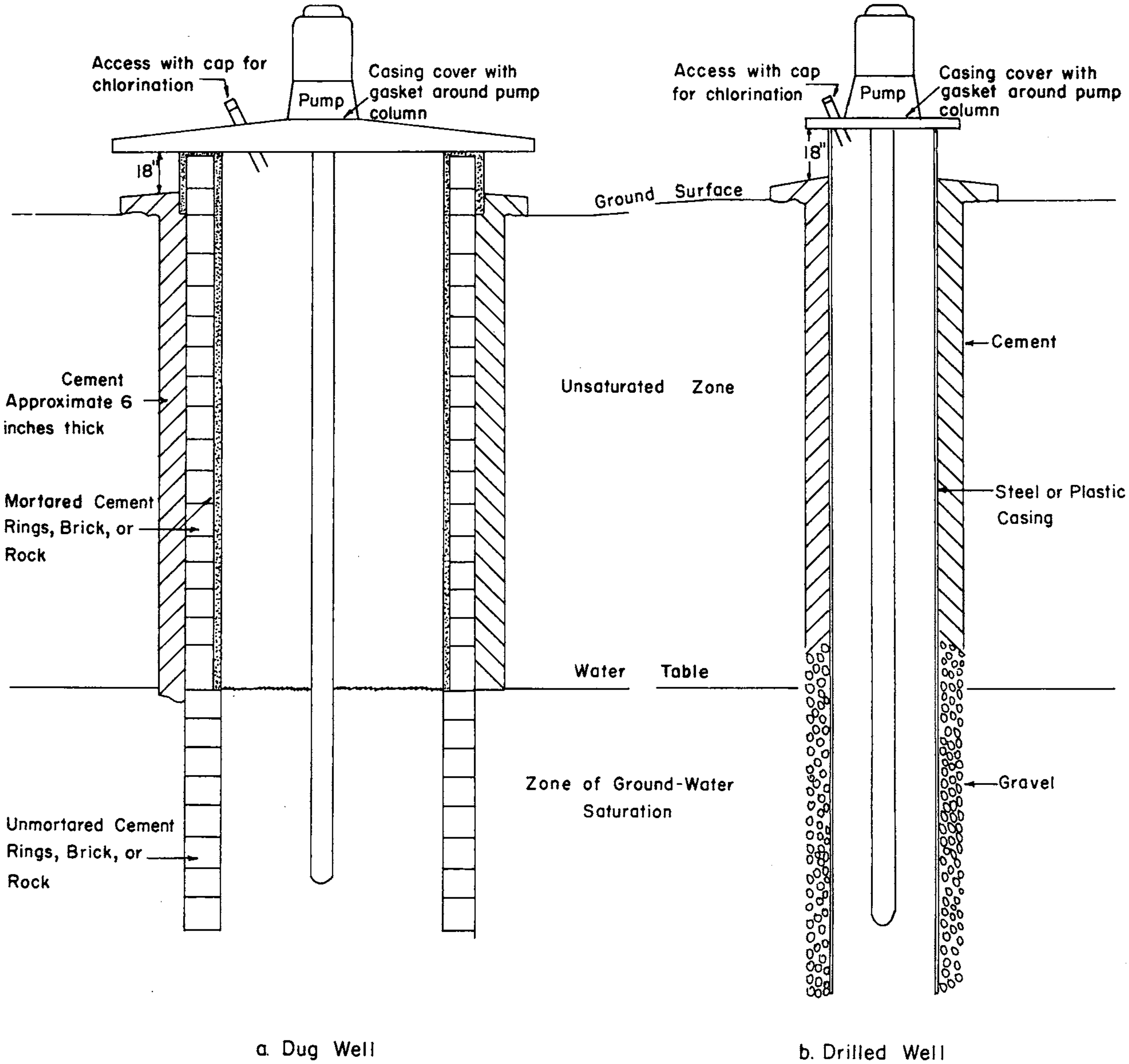

Figure 5

Diagrammatic Sketch Showing Recommended Water Well Construction Methods for Drilled and Dug Wells

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space between the casing and the well bore should be cemented from the top of the gravel to the surface (Figure 5b).

In all types of well completion the well casing or curbing should be a sufficient height above the ground surface or well cellar floor to exclude surface drainage. The casing should have a water-tight, impervious cover to exclude pump leakage, dust, insects, small animals, and other foreign material from the well bore. The covering should have a capped access pipe for periodic chlorination of the well. The pump piping should be tightly sealed where it enters the well cover, and the pump and pipe connections should be fitted tightly to prevent leakage.

Methods of Sewage Disposal at Rhineland

Sewage disposal in the Rhineland community is on an individual basis. Each house has a septic tank or cesspool for its sewage effluent. The various types of facilities and locations of the disposal facilities in the community are indicated on Plate 2. In many cases the construction of the disposal facility could not be determined.

Generally, the septic tanks are constructed of steel, concrete, or cement rings. The steel or concrete tank is the preferred type of septic tank facility. Reportedly, the cement-ring type is constructed of cement rings that are approximately 2 inches thick, 18 inches wide, and 30 inches in diameter. In some cases the rings are mortared on the inside and have concrete bottoms although in others only the bottom of the tank is cemented.

At most of the residences kitchen wastes and washing-machine effluent are discharged into shallow unlined holes or onto the ground surface. At several residences, it was reported that this type of effluent is disposed of into cesspools which are 4 to 6 feet deep, rock filled, and covered with soil.

The septic tank and cesspool are both designed to produce anaerobic digestion of the waste, although the septic tank utilizes a larger leaching or absorption field than does the cesspool. The leaching field of a cesspool is confined to the area of the facility, whereas the field for the septic tank can cover a considerable area dependent upon the characteristics of the material in which the effluent discharge lines are laid.

Evidence of Contamination

Chemical analyses of water samples collected from 26 wells during this investigation indicate that the quality of ground water in the Seymour Formation in the Rhineland area is comparable to the quality of water from the formation in other areas of Knox and Haskell Counties. The nitrate content of the 26 samples ranged from 13 to 86 ppm and averaged 51 ppm. Seventeen samples exceeded the recommended limits of 45 ppm for nitrate and 11 of the samples exceeded the average for the 26 samples. Determinations for free ammonia, nitrogen, and nitrite were not performed on the samples. Such determinations would perhaps have better indicated the magnitude of organic pollution in the wells.

Twenty-nine water samples were analyzed for ABS. The analyses indicate that the ABS content of all of the water samples was less than 0.2 ppm. However, previous analyses of water from Well 22 indicated ABS concentrations of 0.2 and 0.3 ppm, and from Well 57 a concentration of 0.08 ppm was determined. Although the 29 samples did not contain ABS in concentrations greater than 0.2 ppm, it is possible that ABS was present in the water in lower concentrations.

Numerous water samples from wells in the area of investigation have been collected for bacteriological analysis. The samples were collected by individual well owners, the State Department of Health, and the Texas Water Commission. A tabulation of the available analyses is given in Table 3. The water samples were analyzed for the presence of the coliform group of bacteria using the multiple tube fermentation technique. The results are reported by the presumptive test, confirmed test, or in terms of the "most probable number."

During the present investigation, water samples were collected for bacteriological analysis from 40 wells within the Rhineland townsite and the results expressed in MPN (Plate 2). Water from 70 percent (28) of the wells contained coliform organisms. Four additional samples were collected from wells located outside of the townsite, and three of these samples were reported to contain coliform organisms. The MPN in the 31 samples containing coliform organisms ranged from 3.6 to 11,000 per 100 millileters of sample. Escherichia organisms were isolated in the samples taken from Wells 3, 6, 39, 55, and 62. A sample from Well 22, previously collected by the Department of Health, contained Aerobacter aerogenes organisms. Escherichia was found in previously obtained samples from Wells 20 and 33. No significant correlation could be determined between the incidence of coliform bacteria and the dissolved-solids content of the various water samples.

Of the 44 wells sampled for bacteriological analysis, 13 were drilled wells, 5 were punched wells, and 26 were dug wells. The samples from the 5 punched wells were free of coliform organisms. Seven of the 13 samples from drilled wells and 24 of the 26 samples from dug wells contained coliform organisms. The statistical relationship between the incidence of coliform bacteria and the methods of water well construction is illustrated graphically in Figure 6. From this it would appear that the drilled and dug wells are more susceptible to contamination than the punched wells, and this in turn can apparently be related primarily to well completion methods.

The method of drilling and completing the punched well is such that the system is essentially closed from the water-bearing material to the distribution system. There is little opportunity for a contaminant to enter the system unless it has entered the ground water. The pump is connected to the casing, which prevents the entrance of contaminants into the well from the surface.

In most instances casing in the drilled and dug wells is open from the surface to the water table. This condition offers an excellent avenue for the entrance of contaminants into the well. Drilled wells in which the casing is gravel packed to the surface are also susceptible to contaminated fluids moving downward to the water table through the gravel behind the casing. Dug wells, cased only with cement rings, brick, or rock, can be polluted by contaminating fluids moving laterally through the unsaturated part of the formation and seeping into the well bore above the water table.

In many instances the waste-disposal facilities are closer to the water wells than the minimum distance of 150 feet recommended by the State Department of Health. The reported methods of construction of some of these facilities and the permeable nature of the surface and subsurface material would suggest that domestic sewage effluent is seeping downward to the water table. Also,

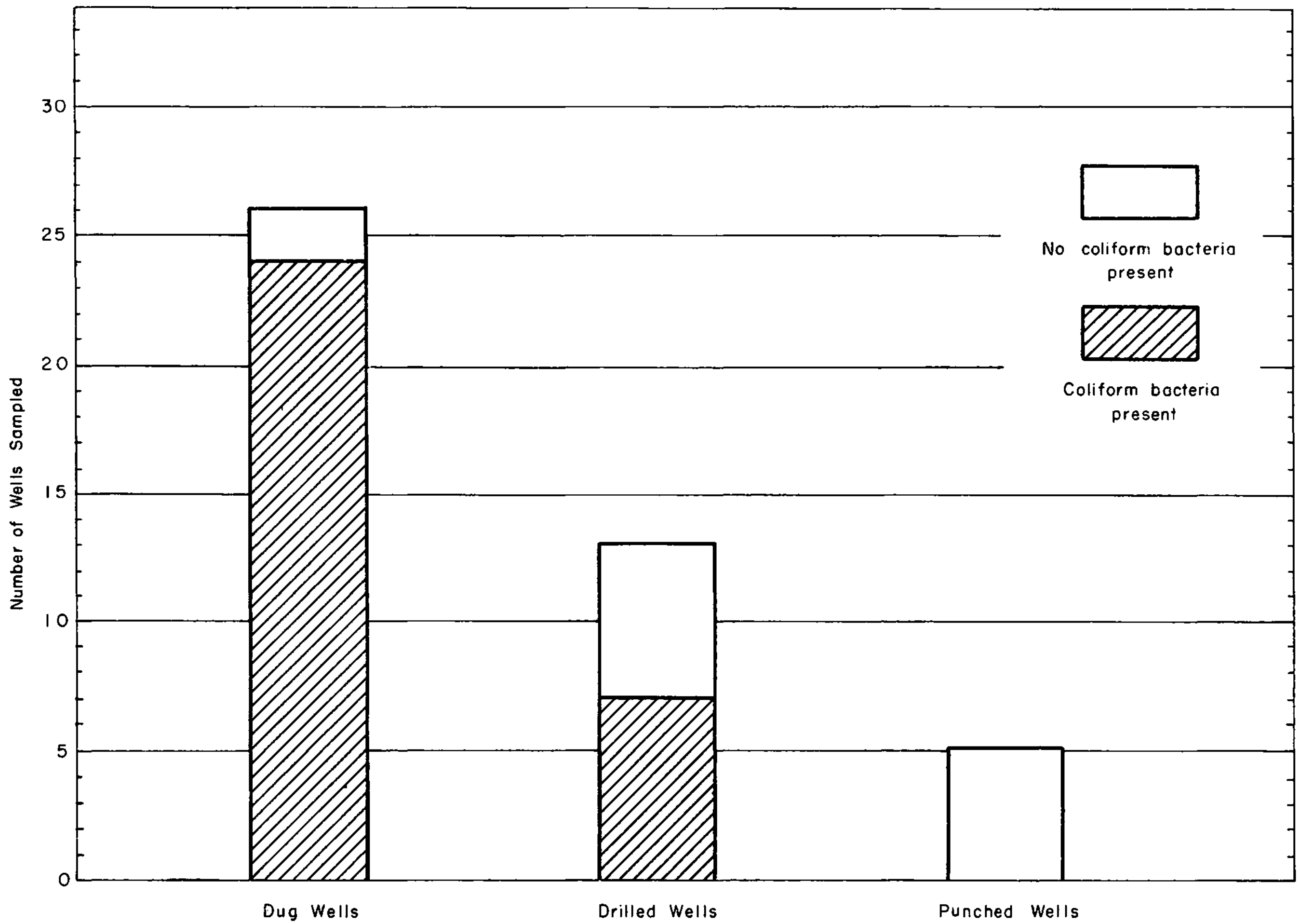

Figure 6

Diagram Illustrating Relationship Between Method of Water Well Construction and Incidence of Bacteriological Contamination at Rhineland

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Plate 2 indicates that in some places the septic tank or cesspool is located upslope and up the hydraulic gradient from the water well, putting the well in the path of contaminated fluids that may be moving either within the unsaturated zone or with the ground water.

The incidence of water-borne enteric disorders among the people in the Rhineland community is not known. One family is reported to have had infectious hepatitis, but no evidence is available that would connect the virus with the drinking-water supply.

SUMMARY OF CONCLUSIONS

The presence of coliform organisms in approximately 70 percent of the 44 shallow water wells sampled in the area of Rhineland indicates the existence of a general contamination problem. The principal source of the bacteria is considered to be domestic sewage which is discharged into individual cesspools and septic tanks in the community.

Statistics suggest that the incidence of coliform organisms in samples collected from the water wells also appears to be directly related to the type of well construction and sanitary conditions at the well head. The fact that none of the samples collected from the punched wells contained coliform organisms seems to emphasize the importance of proper well completion in minimizing contamination from outside sources, although these limited data should not be construed to imply that properly constructed wells eliminate such problems regardless of methods of sewage disposal. It is obvious, however, that dug wells in areas of concentrated septic tank and cesspool sewage disposal are particularly susceptible to bacteriological contamination, one of the major problems in the use of dug wells at Rhineland also being the lack of sanitary precautions at the well head. The casing or curb on a majority of the dug wells extends only a few inches above the ground surface or the well cellar floor, and it is not properly sealed to eliminate the entrance of contaminants from the surface.

Drilled wells that are gravel packed to the surface are also vulnerable to contamination from fluids moving down the well bore behind the casing. However, in some cases concrete bases were poured around the top of the casing, which retards direct surface runoff from seeping downward around the casing and therefore minimizes this problem. Similar to the dug wells, most of the drilled wells in Rhineland are not properly sealed at the surface.

In many cases where the water wells are in well cellars, the cellars are constructed in such a manner that proper sanitary conditions cannot be maintained. Leaking pumps and pipe connections keep dirt floors continuously damp or muddy and in some instances leakage runs directly into uncovered well casings. The covers or roofs on some of the cellars are not properly constructed to exclude the entrance of dust, precipitation, or other foreign material.

The confirmed presence of ABS in significant concentrations (greater than 0.2 ppm) in several water samples collected prior to this investigation, together with the high incidence of coliform organisms, indicate that domestic sewage effluent is reaching the water table. Septic tanks and cesspools are the primary source of the effluent, which seeps downward through the permeable subsurface material until it reaches the water table. The sewage fluid may move laterally during its downward migration if it encounters lenses of clay or other less permeable material. Upon reaching the water table, the effluent moves in the direction of the prevailing hydraulic gradient. Dispersion of the effluent in the aquifer is dependent upon the volume of effluent introduced, the permeability of the water-bearing material, and the rate of movement of the ground water.

Figure 7 is an idealized cross section showing seepage from a cesspool or poorly constructed septic tank in the vicinity of a pumping water well. The hydraulic gradient created by the pumping well illustrated may be opposite to the natural hydraulic gradient in the aquifer; thus, both the capacity of wells and their proximity to sources of ground-water contaminants obviously have a very significant effect upon the direction and rate of movement and the degree of dispersion of the contaminants.

Studies have indicated that degradation of ABS in ground water is a very slow process. Biochemical processes, physical adsorption, and chemical reaction with aquifer material all have some effect on the removal of ABS from the water (Walton, 1960, p. 1360), which may in part be responsible for the lack of ABS in concentrations above 0.2 ppm in the samples. However, ABS concentration in ground water is probably reduced primarily by dilution due to the distance traveled and rates of movement through the aquifer and by dispersion during travel through material of varying permeability. A more precise ABS determination, beyond the standard routine reporting limit of 0.2 ppm, of the samples collected during this investigation would perhaps reveal concentrations below 0.2 ppm which might be of significance in an analysis of the contamination problem at Rhineland.

Numerous studies have been made on the movement of bacterial contaminants in the subsurface as they relate to the pollution of ground water. These studies have been in the form of controlled laboratory experiments, planned field tests, and case studies of actual ground-water pollution. From these, it is apparent that health hazards exist particularly in suburban and rural areas where water supply and sewage disposal are on an individual basis. In the Rhineland area, the data indicate that because of the permeable nature of the Seymour Formation and the relatively shallow depth to water, sewage effluent can readily percolate downward to the water table.

RECOMMENDATIONS

1. One solution to the problem at Rhineland would be to develop a public ground-water supply with the source remote from the individual sewage-disposal facilities now in use. Preferably, the supply should be developed south of the community. This would place the source up the hydraulic gradient and out of the path of contaminated ground water. Also, the increase in saturated thickness of the Seymour Formation south of Rhineland would help assure the development of larger capacity wells. The well or wells should be properly cased and cemented and provisions should also be made for filtration and treatment of the water.

2. If individual water-supply systems are to be continued, it is suggested that all dug wells be abandoned, properly plugged, and replaced by punched wells or drilled wells that are properly cased and cemented. New wells should be properly located with respect to disposal facilities so as to minimize contamination from such sources. In all wells, proper sanitary precautions

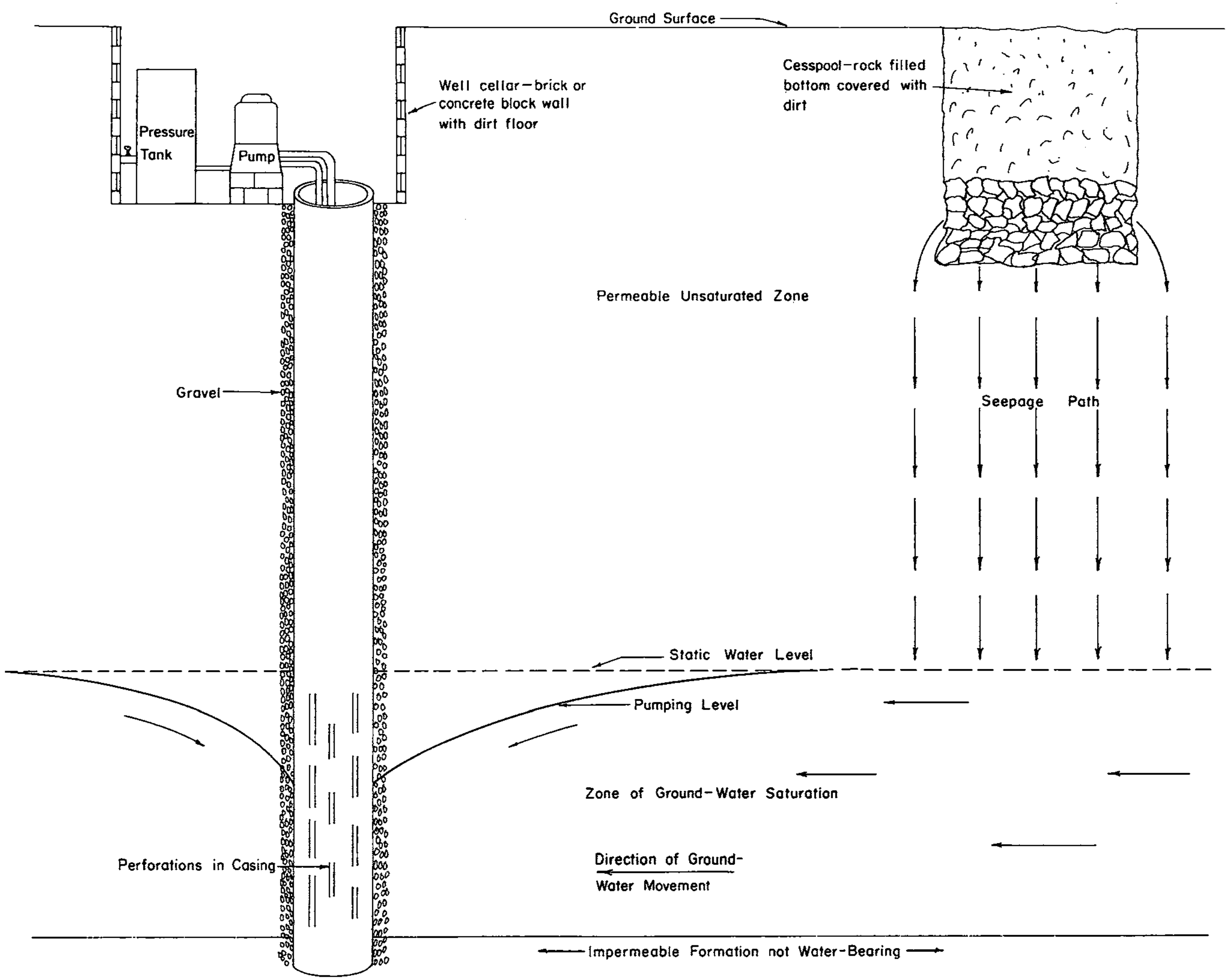

Figure 7

Idealized Cross Section Showing Seepage From a Cesspool and Contamination of a Nearby Well

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should be taken at the well head to eliminate entrance of contaminants from the surface.

In plugging a dug well, the bottom of the well should be filled with gravel or rock through the water-bearing section and covered with a layer of cement. The curbing should be removed and the hole filled to the surface with material similar to that in the well bore. As the filler material settles in the well bore, material should be added at the surface until compaction is complete. Under no circumstances should an abandoned well be used for the disposal of sewage, septic tank effluent, or other waste.

3. The citizens of Rhineland should be encouraged to provide sewage disposal facilities that will minimize the possibility of sewage contamination of ground water. This would necessitate the elimination of cesspool-type facilities and replacement of these facilities with properly constructed septic tanks with sufficient discharge lines to develop large leaching fields.

SELECTED REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Association, 1961, Standard methods for the examination of water and waste water, eleventh edition: Am. Public Health Assoc., Inc., p. 494-508.

California State Water Pollution Control Board, 1954, Report on the investigation of travel of pollution: Pub. no 11.

Clark, N. A., and Chang, S. L., 1959, Enteric viruses in water: Jour. Am. Water Works Assoc., v. 51, no. 6, p. 1299-1317.

Cummins, W. F., 1890, The Permian of Texas and its overlying beds: Texas Geol. Survey 1st Ann. Rept., p. 183-197.

______1893, Notes on the geology of northwest Texas: Texas Geol. Survey 4th Ann. Rept., p. 177-238.

Cronin, J. G., Follett, C. R., Shafer, G. H., and Rettman, P. L., 1963, Reconnaissance investigation of the ground-water resources of the Brazos River Basin, Texas: Texas Water Comm. Bull. 6310.

Draper, D. C., 1960, Investigation of contamination complaint in south-central Knox County, Texas: Texas Board Water Engineers Contamination Rept. no. 7.

Farquhar, J. D., Stokes, Joseph, Jr., and Schrack, W. D., Jr., 1952, Epidemic of viral hepatitis apparently spread by drinking water: Jour. Am. Medical Assoc., v. 149, no. 11, p. 991-993.

Follett, C. R., 1955, Records of water-level measurements in Haskell and Knox Counties, Texas: Texas Board Water Engineers Bull. 5503.

Follett, C. R., and Dante, J. H., 1945, Ground water in the vicinity of Benjamin, Texas: U.S. Geol. Survey open-file rept., 2 p.

George, W. O., and Hastings, W. W., 1951, Nitrate in the ground water of Texas: Trans. Am. Geophys. Union, v. 32, no. 3, p. 450-456.

Gordon, C. H., 1913, Geology and underground waters of the Wichita region, north-central Texas: U.S. Geol. Survey Water-Supply Paper 317.

Huggins, L. P., and Turner, S. F., 1937, [records of wells] Knox County, Texas: Texas Board Water Engineers duplicated rept.

Mallman, W. L., and Mack, W. N., 1961, Biological contamination of ground water, in Proceedings of 1961 Symposium, Ground Water Contamination: Robert A. Taft Sanitary Eng. Center Tech. Rept. W61-5.

Maxcy, K. F., 1950, Report on the relation of nitrate concentration in well waters to the occurrence of methemoglobinemia in infants: Natl. Research Council Bull. Sanitary Eng. and Environment, App. D., p. 265-271.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria: Resources Agency of California, State Water Quality Control Board Pub. no. 3-A.

McKinney, R. E., 1962, Microbiology for sanitary engineers: New York, McGraw-Hill Book Co., Inc.

Mosley, J. W., and Smither, W. W., 1957, Infectious hepatitis - report of an outbreak probably caused by drinking water: New England Jour. Medicine, v. 257, no. 13, p. 590-595.

Neefe, J. R., and Stokes, Joseph, Jr., 1945, An epidemic of infectious hepatitis apparently due to a waterborne agent: Jour. Am. Medical Assoc., v. 128, no. 15, p. 1063-1075.

North Texas Geological Society, 1959, A guide to the upper Permian and Quaternary of North Central Texas: North Texas Geol. Soc. duplicated rept.

Ogilbee, William, and Osborne, F. L., Jr., 1962, Ground water resources of Haskell and Knox Counties, Texas: Texas Water Comm. Bull. 6209.

Sundstrom, R. W., Broadhurst, W. L., and Dwyer, B. C., 1949, Public water supplies in central and north-central Texas: U.S. Geol. Survey Water-Supply Paper 1069.

Texas State Department of Health, 1961a, Protection of small water supplies: Texas State Dept. Health duplicated rept.

_______1961b, A guide to the disposal of household sewage: Texas State Dept. Health duplicated rept.

Tucker, C. B., Owen, W. H., and Farrell, R. P., 1954, An outbreak of infectious hepatitis apparently transmitted through water: Southern Medical Jour., v. 47, no. 8, p. 732-740.

U.S. Public Health Service, 1961, Ground water contamination, Proceedings of the 1961 Symposium: Robert A. Taft Sanitary Eng. Center Tech. Rept. W61-5.

_______1962, Drinking water standards: Public Health Service Pub. no. 956.

Walton, Graham, 1960, ABS contamination: Jour. Am. Water Works Assoc., v. 52, no. 11, p. 1354-1362.

Winslow, A. G., and Kister, L. R., Jr., 1956, The saline water resources of Texas: U.S. Geol. Survey Water-Supply Paper 1365.

Table 1.--Records of wells in the Rhineland area, Knox County

All wells are in the Seymour Formation.
Method of lift and type of power: B, bucket; C, cylinder; Cf, centrifugal; E, electric; G, gasoline, butane, or diesel; H, hand; J, jet; N, none; T, turbine; W, windmill.
Use of water : D, domestic; Ind, industrial; Irr, irrigation; N, none; P, public supply; S, stock.

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)	Below land-surface datum (ft)	Date of measurement			
1	V. Redder	--	--	Spring	--	--	--	--		N	
2	J. Farber	Les Jameson	1962	17	8	17	9.23	Jan. 11, 1964	Cf,E	D	Drilled well.
3	John Brown	--	1926	24	30	24	18.70	do	Cf,E	D	Dug well.
4	A. Schumacher	--	1897	16	30	16	10.50 9.57	Dec. 21, 1936 Jan. 11, 1964	Cf,E	D	Dug well. Well 330 in Huggins and Turner (1937).
5	Mrs. A. F. Homer	--	--	12	30	12	8.84	Jan. 11, 1964	Cf,E	N	Dug well.
6	John Albus	--	--	21	30	21	17.50 18.47	Dec. 22, 1936 Jan. 11, 1964	Cf,E	D,S	Dug well. Well 328 in Huggins and Turner (1937).
7	do	--	--	Spring	--	--	--	--	--	N	
8	Louis Homer	--	--	26	13	26	23.36	Jan. 11, 1964	Cf,E	D	Dug well with casing set and gravel packed.
9	H. P. Decker	--	--	23	30	23	19.90	Dec. 19, 1963	Cf,E	S	Dug well.
10	do	--	1955	24	4	24	19.38	do	Cf,E	D	Drilled well.
11	A. C. Loran	--	--	--	1	--	--	--	Cf,E	D	Punched well.
12	Rhineland Co-op Gin	--	--	24	30	24	22.43	Dec. 19, 1963	C,W	N	Dug well.
13	do	Les Jameson	--	26	8	26	21.62	Jan. 12, 1964	Cf,E	P	Drilled well.
14	H. N. Claus	--	1921	22	30	22	18.37	Dec. 19, 1963	Cf,E	D	Dug well.
15	Rhineland Co-op Gin	Les Jameson	--	28	10	28	19.42	do	J,E	Ind	Drilled well.
16	Bischel Estate	--	--	30	24	30	27.00 28.15	Dec. 22, 1936 Dec. 6, 1963	N	N	Dug well. Well 329 in Huggins and Turner (1937).

Table 1.--Records of wells in the Rhineland area, Knox County--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing Diameter (in.)	Casing Depth (ft)	Water level Below land-surface datum (ft)	Water level Date of measurement	Method of lift	Use of water	Remarks
17	Knights of Columbus Club	--	--	23	30	23	19.33	Dec. 19, 1963	J,E	P	Dug well.
18	D. J. Brown Groc.	Les Jameson	1962	28	8	28	19.44	do	Cf,E	D	Drilled well.
19	Joe A. Brown	--	--	24	30	24	19.84	do	J,E	D	Dug well.
20	St. Joseph Church	Les Jameson	1963	28	7	28	23.68	Dec. 6, 1963	J,E	P	Drilled well.
21	do	--	--	25	30	25	22.37	do	N	N	Dug well.
22	St. Joseph School	--	--	24	30	24	16.97	do	J,E	P	Do.
23	E. Krisks	--	--	24	30	24	14.72	Dec. 5, 1963	J,E	D	Do.
24	A. J. Loran	--	1940	--	--	--	--	--	Cf,E	D	Punched well.
25	do	--	1940	--	--	--	--	--	Cf,E	D	Do.
26	A. Wilde	--	--	18	30, 8	13, 14	15.43	Dec. 18, 1963	Cf,E	D	Dug well.
27	do	--	1963	22	8	22	15.55	Jan. 15, 1963	Cf,E	Irr	Drilled well.
28	Mrs. A. F. Homer	--	1896	18	24	18	15.60	Dec. 5, 1963	J,E	D	Dug well.
29	H. L. Edrington	--	1925	20	--	--	--	--	Cf,E	D	
30	Birkenfeld Humble Service Station	M. Birkenfeld	--	20	1-3/4	20	--	--	Cf,E	D	Punched well.
31	M. Redder	Les Jameson	1961	19	7	19	14.40	Dec. 18, 1963	Cf,E	D	Drilled well.
32	F. J. Loran	--	--	21	5	21	14.75	Dec. 15, 1963	Cf,E	D	Do.
33	Rhineland High School	--	--	21	30	21	15.48	Dec. 5, 1963	Cf,E	P	Dug well.
34	W. C. Hertel	--	--	23	14	23	15.85	Dec. 18, 1963	Cf,E	Irr	Drilled well.

Table 1.--Records of wells in the Rhineland area, Knox County--Continued

Well	Owner	Driller	Date com-plet-ed	Depth of well (ft)	Casing		Water level		Method of lift	Use of water	Remarks
					Diam-eter (in.)	Depth (ft)	Below land-surface datum (ft)	Date of measurement			
35	W. C. Hertel	--	--	25	14	25	16.25	Dec. 12, 1963	Cf,E	Irr	Drilled well.
36	do	--	1955	28	14	28	19.13 17.33	Dec. 20, 1956 Dec. 12, 1963	T,E	Irr	Do.
37	do	--	--	18	--	--	16.65	Dec. 18, 1963	Cf,E	D	Dug well.
38	Joseph Decker	--	--	19	30	19	17.00	Dec. 6, 1963	J,E	D	Do.
39	B. J. Myers	--	1956	26	12	26	17.35	do	J,E	D	Drilled well.
40	Joseph Decker	--	1954	17	30	17	15.97	do	J,E	D	Dug well.
41	C. Kuehler	--	--	21	30	21	17.02	Dec. 18, 1963	Cf,E	D	Do.
42	J. Ayala	--	--	20	30	20	17.32	do	J,E	D	Do.
43	M. Sanchez	--	--	20	30	20	17.39	do	B,H	D	Do.
44	P. Gonzales	--	--	22	30	22	17.60	do	J,E	D	Do.
45	J. A. Albus	--	--	--	--	--	--	--	--	N	Do.
46	do	--	1930	25	--	--	--	--	Cf,E	D	Punched well.
47	F. J. Redder	--	--	--	--	--	--	--	C,W	N	Do.
48	do	--	--	22	30	22	19.22	Dec. 19, 1963	J,E	D	Dug well.
49	S. E. Williamson	--	1959	25	5	25	19.69	do	Cf,E	D	Drilled well.
50	W. Herring	--	--	--	--	--	--	--	--	N	Dug well.
51	F. Fetsch	--	--	24	36	24	19.94	Dec. 19, 1963	Cf,E	D	Do.
52	W. Herring	--	--	22	30	22	19.97	do	Cf,E	N	Do.
53	John Decker	--	--	25	30	25	20.92	do	J,E	D	Do.
54	Anna Kuehler	--	--	25	7	25	22.38	do	Cf,E	D	Drilled well.

Table 1.--Records of wells in the Rhineland area, Knox County--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing: Diameter (in.)	Casing: Depth (ft)	Water level: Below land-surface datum (ft)	Water level: Date of measurement	Method of lift	Use of water	Remarks
55	M. Krietz	--	--	19	30	19	12.63	Dec. 19, 1963	Cf,E	D	Dug well.
56	L. Holub	--	1956	22	10	22	15.38	do	J,E	D	Drilled well.
57	Phillip Homer	J. M. Rae	1963	25	8	25	19.25	Dec. 18, 1963	Cf,E	D	Do.
58	do	do	1963	30	14	30	21.18	Dec. 12, 1963	Cf,E	Irr	Do.
59	F. Herring	Les Jameson	1962	29	7	29	19.10	Dec. 18, 1963	J,E	D	Do.
60	Anna Kuehler	--	--	32	30	32	26.40	do	J,E	D	Dug well.
61	L. Albus	--	1923	23	36	23	18.36	do	J,E	D	Do.
62	A. J. Kuehler	--	--	23	36	23	18.19	do	J,E	D	Do.
63	H. Herring	--	--	21	36	21	19.25	do	N	N	Do.
64	M. C. Kuehler	--	--	22	30	22	17.69	do	Cf,E	D	Do.
65	do	--	1932	25	--	--	--	--	J,E	D	Do.
66	Anna Kuehler	--	--	26	--	26	14.69	Dec. 18, 1963	Cf,E	Irr	Drilled well.
67	Phillip Homer	--	--	25	7	25	16.34	Dec. 12, 1963	N	N	Do.
68	--	--	--	25	30	25	23.85	Jan. 10, 1964	N	N	Dug well.
69	V. S. Moore	--	--	--	--	--	--	--	T,G	Irr	Drilled well.
70	do	--	--	29	30	29	25.53	Dec. 17, 1963	N	N	Dug well.
71	A. O. Tomlinson	D. Dickerson	1956	40	14	40	26.45 25.47	Dec. 20, 1956 Dec. 12, 1963	T,E	Irr	Drilled well. Well F-45 in Ogilbee and Osborne (1962).
72	do	J. Kale	1955	37	14	37	22.02 20.50	Dec. 20, 1956 Dec. 12, 1963	T,G	Irr	Drilled well. Well F-44 in Ogilbee and Osborne (1962).
73	do	--	--	--	--	--	--	--	N	N	Dug well. Apparently plugged at 15 ft.

Table 1.--Records of wells in the Rhineland area, Knox County--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)	Below land-surface datum (ft)	Date of measurement			
74	A. O. Tomlinson	--	--	24	36	24	16.40	Jan. 10, 1964	C,H	N	Dug well.
75	Anna Kuehler	--	--	26	18	26	14.94	Dec. 19, 1963	Cf,E	Irr	Drilled well.
76	do	--	--	21	30	21	16.60	Dec. 12, 1963	--	D	Dug well.
77	do	D. Dickerson	1955	34	12	34	19.62 17.80	Dec. 20, 1956 Dec. 19, 1963	T,E	Irr	Drilled well. Well F-41 in Ogilbee and Osborne (1962).
78	do	do	1956	34	12	34	--	--	T,E	Irr	Drilled well. Well F-42 in Ogilbee and Osborne (1962).
79	do	do	1956	34	12	34	--	--	T,E	Irr	Drilled well. Well F-43 in Ogilbee and Osborne (1962).
80	C. J. Smajstrala	--	--	35	30	35	31.32	Dec. 17, 1963	Cf,E	D	Dug well.
81	do	Les Jameson	1963	49	12	49	31.44	do	N	N	Drilled well.
82	do	--	--	23	30	23	12.45	do	N	N	Dug well.
83	F. Cervany Estate	--	--	24	30	24	14.52	do	C,W	S	Do.
84	J. C. Baty	--	--	23	30	23	16.22	Dec. 15, 1959	N	N	Dug well. Plugged.
85	do	J. M. Rae	1960	31	8	31	13.20	Dec. 17, 1963	Cf,E	D	Drilled well.
86	--	--	--	11	30	11	6.10	do	N	N	Dug well.
87	--	--	--	14	30	14	11.68	do	N	N	Do.
88	Phillip Homer	--	--	22	30	22	11.80	do	Cf,E	S	Do.
89	Leo Fetsch	--	--	20	30	20	12.30	do	C,W	D	Do.
90	do	--	--	24	30, 18	15, 24	14.83	do	Cf,E	Irr	
91	do	--	--	25	30, 18	13, 25	15.45	do	Cf,E	Irr	

Table 1.--Records of wells in the Rhineland area, Knox County--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)	Below land-surface datum (ft)	Date of measurement			
92	Leo Fetsch	--	--	24	30, 7	7, 24	16.07	Dec. 17, 1963	Cf,E	Irr	
93	do	--	--	25	30, 5	8, 25	14.85	do	Cf,E	Irr	

Table 2.--Chemical analyses of water from wells in the Rhineland area, Knox County

(Analyses are in parts per million except specific conductance, pH, percent sodium, and SAR)

Samples analyzed by the Texas State Department of Health except where indicated otherwise by footnote.

Well	Depth of well (ft)	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium	Specific conductance (micromhos at 25°C)	pH	SAR
1	Spring	Jan. 14, 1964	10	42	55	293	670	187	154	3.0	13	1,098	330	--	1,840	8.4	--
* 2	17	do	20	37	74	187	510	125	164	1.8	30	890	396	--	1,540	7.8	--
* 3	24	do	20	27	48	95	405	45	46	2.4	37	524	265	--	886	8.0	--
4	16	do	30	61	87	283	560	240	266	1.5	49	1,294	510	--	2,110	7.6	--
* 6	21	Dec. 22, 1936	--	49	60	139	488	76	135	--	--	699	367	--	--	--	--
a/		Jan. 14, 1964	20	39	63	147	466	92	133	1.4	38	742	354	--	1,280	7.8	--
7	Spring	do	20	43	62	147	467	91	117	1.2	37	752	361	--	1,300	8.2	--
* 8	26	do	23	41	41	113	395	77	59	2.1	49	599	272	--	993	8.3	--
* 10	24	Jan. 12, 1964	33	56	61	190	610	100	104	1.2	55	899	392	--	1,510	7.6	--
* 13	26	Jan. 13, 1964	28	47	38	160	438	107	83	1.8	64	970	272	--	1,185	7.8	--
* 14	22	Jan. 12, 1964	30	65	61	138	530	89	92	1.4	75	810	415	--	1,360	7.9	--
* 15	28	Jan. 13, 1964	28	57	52	182	530	108	126	1.8	50	870	357	--	1,450	7.7	--
* 20	28	Jan. 15, 1964	30	52	56	168	494	113	123	1.8	65	848	361	--	1,420	8.1	--
* 28	18	Jan. 7, 1964	30	63	54	98	383	78	114	1.2	50	675	381	--	1,159	7.8	--
31	19	do	28	65	51	148	400	99	158	1.5	48	796	372	--	1,380	7.6	--
* 33	21	do	30	66	61	160	460	123	147	1.5	60	875	413	--	1,480	8.1	--
36	28	Jan. 18, 1964	36	95	74	201	429	209	274	1.1	62	1,161	540	--	1,950	7.9	--
* 51	24	Jan. 13, 1964	28	51	40	120	415	71	65	1.2	76	658	292	--	1,082	8.0	--

See footnotes at end of table.

Table 2.--Chemical analyses of water from wells in the Rhineland area, Knox County--Continued

Well	Depth of well (ft)	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium	Specific conductance (micromhos at 25°C)	pH	SAR
54	25	Jan. 13, 1964	28	54	40	153	464	84	85	1.7	62	733	300	--	1,230	7.9	--
* 56	22	Jan. 12, 1964	26	54	35	123	423	73	73	1.4	41	634	278	--	1,072	7.9	--
58	30	Jan. 15, 1964	28	52	47	137	421	78	97	1.4	50	694	326	--	1,165	8.2	--
* 64	22	Jan. 8, 1964	33	49	74	145	484	98	117	2.1	86	853	426	--	1,440	7.8	--
b/ 70	29	Dec. 15, 1959	24	54	25	108	316	72	46	1.3	86	571	238	50	897	7.3	3.0
71	40	Jan. 15, 1964	23	59	27	105	346	62	73	1.1	39	564	257	--	962	7.8	--
b/ 72	37	Aug. 29, 1956	24	46	25	136	364	80	62	2.0	41	598	218	57	971	7.6	4.0
80	35	Jan. 18, 1964	23	42	20	137	387	62	43	1.5	67	583	188	--	967	8.1	--
b/ 83	24	Dec. 15, 1959	26	102	149	702	522	948	605	--	155	2,940	867	64	4,210	7.8	10.0
b/ 84	23	do	28	225	322	1,000	481	1,620	1,300	3.5	180	4,920	1,890	54	6,730	7.7	10.0
85	31	Jan. 16, 1964	28	64	79	454	474	500	362	3.2	29	1,748	484	--	2,850	7.9	--
88	22	do	26	270	363	900	393	1,470	1,540	4.4	68	4,801	2,170	--	7,150	7.9	--
90	24	Jan. 18, 1964	23	20	18	192	500	51	40	4.2	35	625	124	--	1,085	8.3	--

* Presence of coliform organisms determined by bacteriological analysis (Table 3).
a/ Analysis from Huggins and Turner (1937).
b/ Sample analyzed by U.S. Geological Survey.

Table 3.--Bacteriological analyses of water from wells in the Rhineland area, Knox County

Samples analyzed by the Texas State Department of Health

Well	Date sampled	Presumptive test		Confirmed test*	MPN per 100 ml	Coliform organisms	Remarks
		24-hr*	48-hr*				
2	Jan. 1964	--	--	--	3	Yes	
3	do	--	--	--	1,100	Yes	_Escherichia_ _coli_ isolated.
4	July 1963	0	0	0	--	No	
	Jan. 1964	--	--	--	0	No	
6	Aug. 1963	0	0	0	--	No	
	Jan. 1964	--	--	--	460	Yes	_Escherichia_ _coli_ isolated.
8	July 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	0	No	
10	July 1963	5	5	5	--	Yes	
	do	5	5	5	--	Yes	
	Aug. 1963	0	0	0	--	No	Sample probably taken after well treated with Clorox.
	Jan. 1964	--	--	--	0	No	
11	July 1963	5	5	5	--	Yes	
	do	0	0	0	--	No	
	do	5	5	5	--	Yes	
	do	0	0	0	--	No	
	do	0	0	0	--	No	
	Jan. 1964	--	--	--	0	No	
13	do	--	--	--	43	Yes	
14	July 1963	5	5	5	--	Yes	
	do	5	5	5	--	Yes	
	do	5	5	5	--	Yes	
	Aug. 1963	0	0	0	--	No	Sample probably taken after well treated with Clorox.
	Sept. 1963	5	5	5	--	Yes	
	Nov. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	240	Yes	
15	do	--	--	--	23	Yes	
17	do	--	--	--	43	Yes	
18	July 1963	5	5	5	--	Yes	
19	do	0	5	5	--	Yes	
	Aug. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	240	Yes	
20	Oct. 1963	--	--	--	7	Yes	_Escherichia_ _coli_ isolated.
	Jan. 1964	--	--	--	0	No	Sample collected from plastic pipe after pumping well 10 minutes.
	do	--	--	--	0	No	Sample collected from plastic pipe after treating pipe with Clorox solution and pumping well 1 hr.
22	Mar. 1963	5	5	5	--	Yes	
	do	5	5	5	--	Yes	
	Apr. 1963	5	5	5	--	Yes	

* Number of tubes showing coliform organisms.

Table 3.--Bacteriological analyses of water from wells in the Rhineland area, Knox County--Continued

Well	Date sampled	Presumptive test		Confirmed test*	MPN per 100 ml	Coliform organisms	Remarks
		24-hr*	48-hr*				
22	Oct. 1963	--	--	--	22	Yes	Aerobacter aerogenes isolated.
	Jan. 1964	--	--	--	240	Yes	
	do	--	--	--	9.1	Yes	
23	do	--	--	--	>11,000	Yes	
	do	--	--	--	240	Yes	
24	July 1963	0	0	0	--	No	
	Jan. 1964	--	--	--	0	No	
25	do	--	--	--	0	No	
26	do	--	--	--	23	Yes	
28	do	--	--	--	9.1	Yes	
29	Aug. 1963	0	0	0	--	No	
	do	0	1	1	--	Yes	Sample collected Aug. 8, 1963, and analysis not made until Aug. 21, 1963.
	do	0	0	0	--	No	
	Jan. 1964	--	--	--	0	No	
30	Oct. 1964	--	--	--	0	No	
	Jan. 1964	--	--	--	0	No	
31	Aug. 1963	0	0	0	--	No	
	Jan. 1964	--	--	--	0	No	
32	Aug. 1963	1	2	2	--	Yes	
	Jan. 1964	--	--	--	23	Yes	
33	Oct. 1963	--	--	--	17	Yes	Escherichia coli isolated.
	Jan. 1964	--	--	--	3.6	Yes	
37	do	--	--	--	0	No	
38	Apr. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	9.1	Yes	
39	Aug. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	>11,000	Yes	
	do	--	--	--	1,100	Yes	Escherichia coli isolated.
40	Apr. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	240	Yes	
41	Apr. 1963	5	5	5	--	Yes	
	Aug. 1963	3	3	3	--	Yes	
	Jan. 1964	--	--	--	240	Yes	
44	do	--	--	--	>11,000	Yes	
	do	--	--	--	150	Yes	Tap treated with Clorox solution before sample collected.
46	do	--	--	--	0	No	
48	do	--	--	--	23	Yes	

* Number of tubes showing coliform organisms.

Table 3.--Bacteriological analyses of water from wells in the Rhineland area, Knox County--Continued

Well	Date sampled	Presumptive test		Confirmed test*	MPN per 100 ml	Coliform organisms	Remarks
		24-hr*	48-hr*				
49	Aug. 1963	5	5	5	--	Yes	
	Jan. 1964	--	--	--	3.6	Yes	
51	do	--	--	--	150	Yes	
53	do	--	--	--	>11,000	Yes	
54	do	--	--	--	0	No	
55	do	--	--	--	1,100	Yes	*Escherichia coli* isolated.
56	do	--	--	--	93	Yes	
57	Oct. 1963	--	--	--	0	No	
	Jan. 1964	--	--	--	0	No	
59	do	--	--	--	0	No	
60	do	--	--	--	7.3	Yes	
61	Aug. 1963	0	0	0	--	No	
	Jan. 1964	--	--	--	20	Yes	
62	do	--	--	--	>11,000	Yes	
	do	--	--	--	>1,100	Yes	*Escherichia coli* isolated.
64	do	--	--	--	39	Yes	
65	do	--	--	--	23	Yes	

* Number of tubes showing coliform organisms.

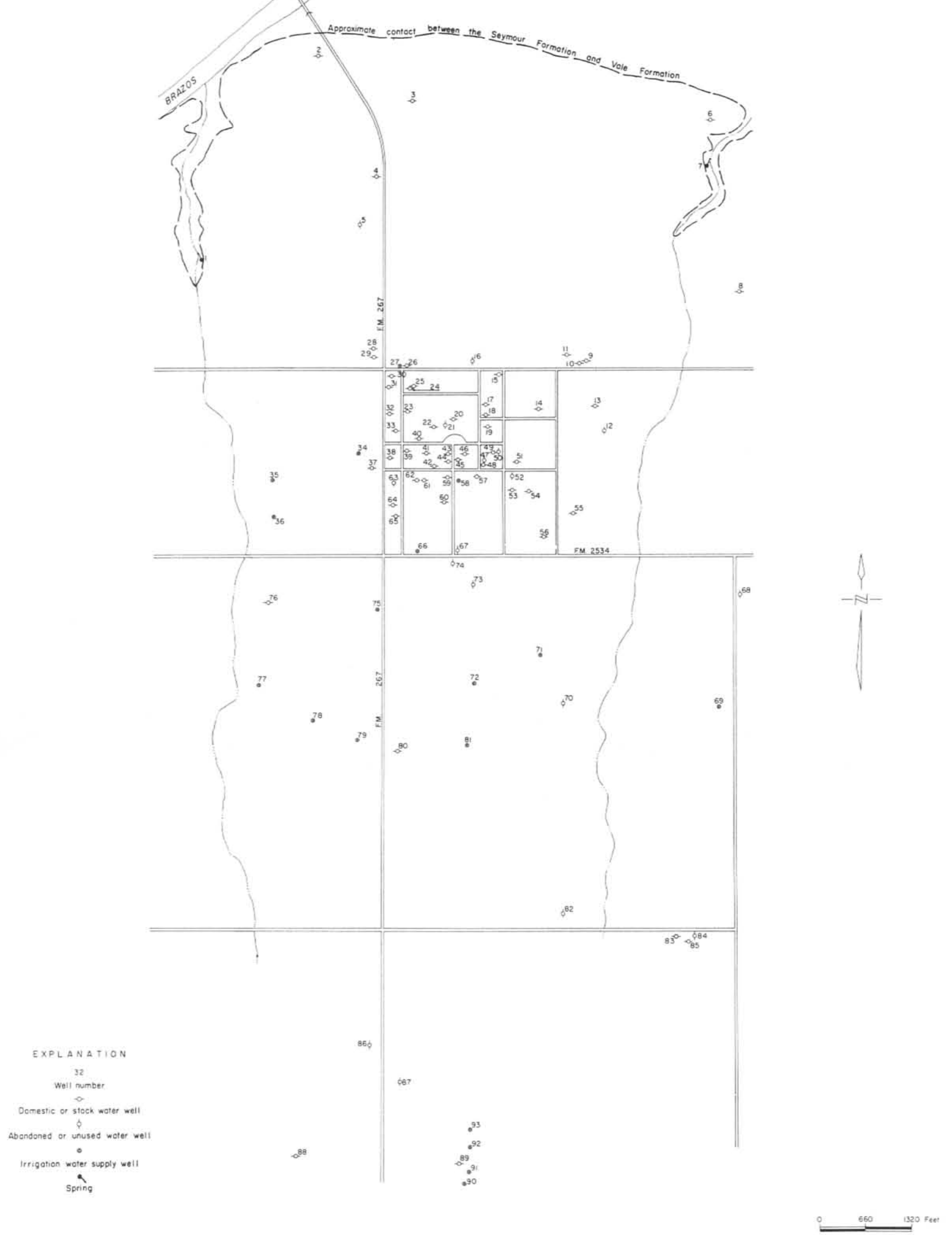

Plate 1

Map of Rhineland Area Showing Location of Water Wells

Texas Water Commission

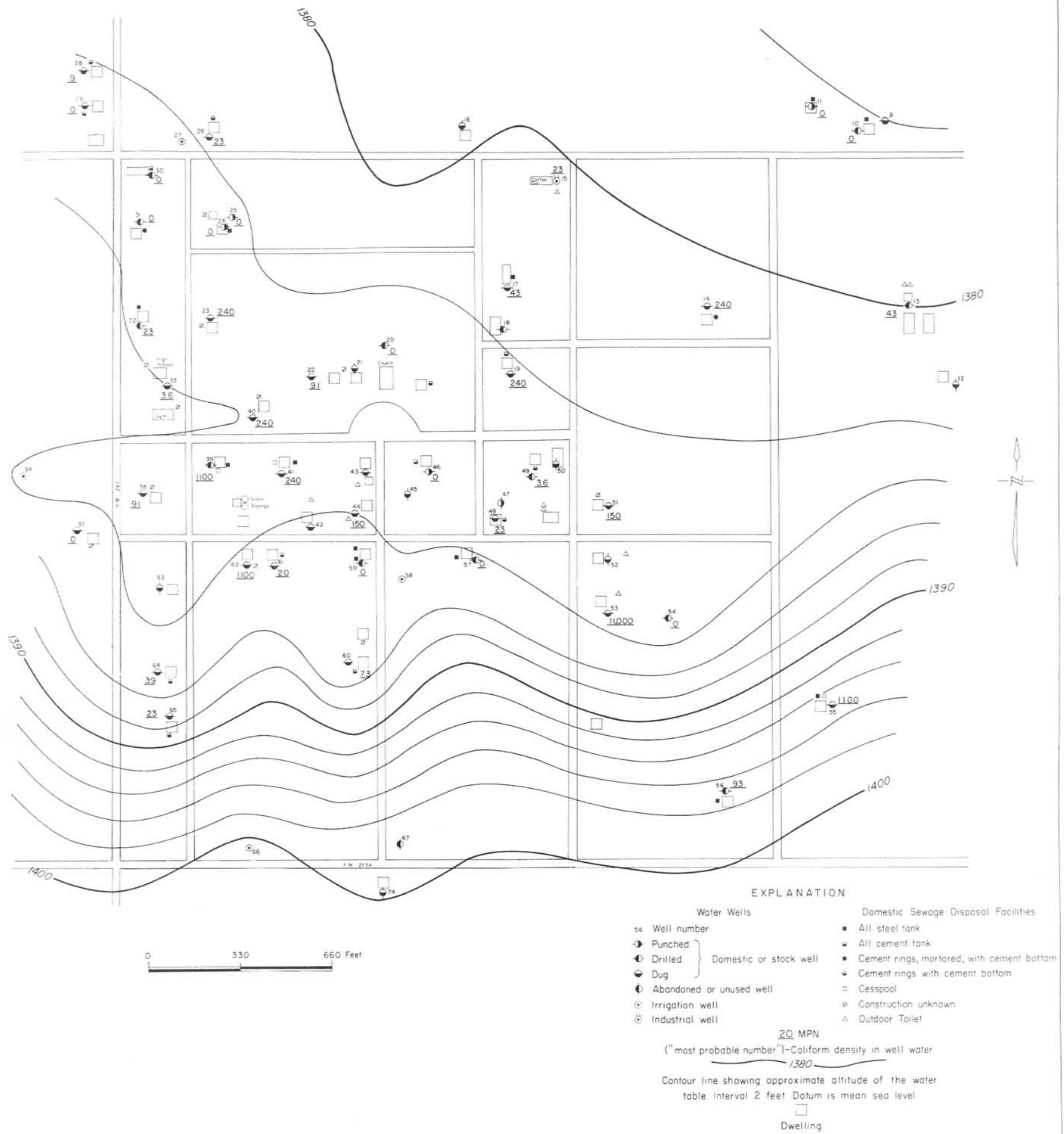

Plate 2

Map of Rhineland Townsite Showing Location of Water Wells, Domestic Sewage Disposal Facilities, Incidence of Coliform Organisms in Water Samples, and Altitude of the Water Table in the Seymour Formation, Winter of 1963-64

Texas Water Commission