CIRCULAR 80

A Preliminary Report on New Mexico's Geothermal Energy Resources

by W. K. SUMMERS

Prepared for the Mineral Element of the New Mexico Resources Development Plan of the State Planning Office, this material was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 107 of the Housing Act of 1954, as amended.

1965

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

For sale by the New Mexico Bureau of Mines and Mineral Resources
Campus Station, Socorro, N. Mex.—Price $0.75

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Geothermal power could become a potent economic force in New Mexico. The state has all the geologic characteristics associated with steam fields around the world, so it seems likely that several steam fields will be discovered in the state when ever the economic factors involved justify the exploration that is required.

Much remains to be learned about geothermal energy and its development. Research into various aspects of geothermal energy NOW is a must, if the resource is to be used to the best advantage of the state!

Introduction

As an aid to those interested in geothermal power in New Mexico, this circular summarizes the information available on geothermal energy and geothermal power as they apply to this state. Considered are not only the sources of heat in the state, including a summary of the locations and characteristics of warm and hot springs and wells and what has been published about them, but also the pertinent background information on geothermal energy gleaned from world-wide experiences.

In addition, information that needs to be gathered and the research that should be undertaken if we are to make the best possible use of the geothermal resources are reviewed.

Finally, a comprehensive; but not exhaustive, bibliography lists the published sources of information relating to geothermal energy in New Mexico.

A word of caution is in order: Although much has been written about the heat of the earth in its various forms, very little is known about geothermal energy or how to develop it.

BACKGROUND

Geothermal energy is the heat generated in the interior of the earth and conducted to the earth's surface where it is radiated into space. The small, daily radiation of heat from the earth's surface goes unnoticed, because the rate at which the earth radiates heat is low, averaging about 10^{-6} cal/cm^2. Only where volcanoes, hot springs, or geysers show the impact of extraordinary heat are we aware of the earth as a tremendous reservoir of heat.

If the heat from the earth's interior, which now dissipates into space when it reaches the surface, can be converted into electrical power, it can be transmitted to those places where it is needed.

In practice, the development of geothermal power is the development of natural steam, and the extent to which geothermal energy is available depends upon the quality and quantity of the available natural steam.

The term *geothermal power* has been coined to describe the electrical energy generated by the utilization of natural steam. According to McNitt (1963, p. 8), "This power is harnessed by releasing steam from natural thermal areas through bore holes and conducting it through a system of pipes to a turbine-generator unit." Natural steam heats homes and other buildings in Iceland, Idaho, Montana, and Alaska. Health spas take advantage of the "medicinal" properties of the hot, mineral waters.

Until 1904, uses of geothermal energy were, at best, token. At Larderello, Italy, for example, Francesco Larderel in 1818 used steam as a source of heat to concentrate acid solutions. In 1904, Prince Conti first used geothermal energy (steam) at Larderello to generate power—enough electricity to light five electric lamps. By 1913, a single 250-kilowatt turbine generator was active there. Now, the town has eight stations generating more than 300,000 kilowatts. In addition to power, the noncondensable gases contained in the steam yield boric acid, borax, carbon dioxide, and sulfur, which are processed from the steam and sold.

From 1921 to 1925, eight wells were drilled at The Geysers in California, but they were not developed as power sources. Development of geothermal energy at Wairakei, New Zealand, began in 1950. Plans there call for the ultimate development of 280,000 kilowatts.

The success of the Italian and New Zealand installations has prompted exploration for and development of other steam sources. A new 12,500-kilowatt plant at The Geysers and a 3500-kilowatt plant at Hidalgo, Mexico, are operating. Development of steam fields is under way in Iceland, Chile, Mexico, El Salvador, Japan, Russia, Nevada, Oregon, Hawaii, and in the Salton Sea and Casa Diablo fields in California.

New Mexico's first steam well was an oil test drilled in 1960 at the Baca Location about twelve miles north of Jemez Springs on Jemez Mountain. Two more wells were drilled in 1963 and a fourth in 1964. Until this program was initiated, New Mexico's heat resource was used only in spas, where the discharging waters of hot springs or the deposits they build attract tourists. Some small use is also made of hot springs as water supplies for irrigation, livestock, or communities, but

these uses do not take advantage of thermal properties of the water. In some instances, the temperature of the water detracts from its use.

Tapping the geothermal energy in steam to drive turbines should substantially increase its dollar value and its demand.

ACKNOWLEDGMENTS

Many people around the world contributed to the content of this report, but even though each deserves special thanks, recognition of all individuals would fill several pages.

William E. Bertholf, II, of the Bureau staff initiated this study to add to the information about the state's energy resources as a part of the State Resource Development Plan.

Francis R. Hall of the Institute staff and the graduate students under his direction previewed the available data, made a number of chemical analyses of thermal water, and collected water chemistry data from several other sources. Roy W. Foster of the Bureau staff gathered the information on the northern counties.

The U.S. Soil Conservation Service, Work Unit Conservationists; the U.S. Forest Service, District Foresters; and Fred A. Thompson, New Mexico Department of Game and Fish, deserve special mention, for they took time out of their busy schedules to note the locations of hot springs and warm-water wells that they knew about, thereby contributing greatly to this preliminary inventory.

Henry J. Birdseye and M. Howard Milligan, consulting geologists, opened their files and permitted the use of their information on geothermal steam resources in New Mexico. C. J. Robinove, U.S. Geological Survey, and E. T. Anderson, of Joseph I. O'Neill, Jr., Oil Properties, reviewed technical parts of the text.

Barney Popkin, graduate assistant, helped assemble, organize, and type Tables 2 and 3. Without his help, the project would have been much more difficult.

Mrs. Helen Waxier of the Bureau staff also contributed greatly with her typings of the manuscript from rough drafts.

SPRING AND WELL NUMBERING

The spring and well numbering system employed herein is that used by the U.S. Geological Survey, Ground-Water Branch in New Mexico, which is based on the common units of the township-range system.

The location number consists of four segments separated by periods, as 4S.13W.27.314. The first segment on the left designates the township and the next the range, with the letters indicating direction; the third segment designates the section; and the fourth, or right-hand segment, locates the well or spring within the section, as follows: Each section is divided into quarters numbered from left to right. The northwest quarter is number 1; the northeast quarter, number 2; the southwest quarter, number 3; and the southeast quarter, number 4. Each quarter section is again divided into quarters and numbered in the same order. Each quarter-quarter section is similarly divided and numbered, thus locating a spring or well to the nearest 10-acre tract. Therefore, the first digit (of the fourth segment) locates the quarter section; the second digit, the quarter-quarter section; and the last digit, the 10-acre tract. For a location that cannot be established to a 10-acre plot, the indefinite subdivisions are indicated by zeros; for example, a spring that is known to be in the northwest quarter section but which cannot be located with reference to smaller subdivisions is shown as ".100."

So the location number above, 4S.13W.27.314, places the well in the southeast quarter of the northwest quarter of the southwest quarter of section 27, township 4 south, range 13 west.

In unsurveyed areas, the locations were estimated by superimposing a township grid on the best map available.

Sources of Heat

The earth radiates heat. Measurements made in deep wells and mines show that even in areas where there are no unusual manifestations of heat, the temperature of the earth increases between 0.5° and 1.5°F per 100 feet of depth. In areas of volcanic activity, where the rocks are still warm or even molten, temperatures increase downward at a much greater rate.

In general, the sources of heat can be divided into three broad, overlapping classes that fit the New Mexico situation fairly well:

1. "Normal" heat of the earth as it appears in nonthermal areas that are reflected by the slow rate of temperature increase that occurs with depth.
2. Heat associated with deep-seated bodies of hot rock that cause anomalies in the heat flow pattern but give no other specific indication at the surface of their presence.
3. Heat associated with magma or volcanic rocks that appear at or near the surface.

THE "NORMAL" HEAT OF THE E A R T H

Darton (1920) reported on temperatures measured in 1905 in a water well at the Sandia siding of the Atchison, Topeka, and Santa Fe Railroad, eleven and a half miles southwest of Isleta:

> The water stood at a depth of 445 feet in the boring which was 845 feet deep and penetrated Cretaceous shale and sandstone, overlain by sand of the Tertiary Santa Fe formation at the head sheet of recent lava which covers the plateau to the north and east.

He then gives the observed temperatures as follows:

Feet	*Degrees F*
443	*71.7*
543	*72.1*
643	*75.6*
743	*76.7*
843	*78.1*

These figures indicate a thermal gradient of about 1.6°F per 100 feet.

Temperature logs of a few oil well test holes (table 1) indicate that the gradient is somewhat less than this in southeastern New Mexico. This is also the conclusion of Lang (1929, 1930, 1937). Only two temperature logs of wells in other parts of New Mexico were located. One, from Harding County, gives a thermal gradient of 1.8°F per 100 feet; the other, from San Juan County, gives a thermal gradient of 2.6°F per 100 feet.

Such sparse data are hardly conclusive, but they would seem to suggest that the thermal gradient increases from the southeast to the northwest across the state.

TABLE 1. THERMAL GRADIENTS OBSERVED IN SELECTED OIL TESTS IN NEW MEXICO
(Based on temperature logs)

COUNTY	INTERVAL FROM (FEET)	LOGGED TO (FEET)	GRADIENT (DEGREES F PER 100 FEET)
Chaves	1300	2250	0.6
	1800	2100	1.0
Eddy	100	1745	0.9
	1850	2400	1.1
Harding	1958	2158	1.8
Lea	2000	2755	0.5
	1000	1800	0.6
	300	1400	0.9
	9000	11000	0.4
Roosevelt	7040	8800	0.6
San Juan	1200	4205	2.6

At this state of the development of geothermal power, the deep drill hole to take advantage of the "normal" geothermal gradient is beyond the practical limits of economy. The suitability of such deep holes has been considered by the Office of Saline Water (Bell et al., 1959) as a possible source of energy for converting salt water to fresh. That study indicates that a 20,000-foot hole in granite could be used to tap geothermal energy, but the expense of drilling such a hole and providing generating equipment would run the cost of electricity up to 66 cents a kilowatt hour, whereas the cost of geothermal power from existing facilities ranges from 0.004 to 0.008 cent a kilowatt hour.

DEEP-SEATED HOT ROCKS

Wells 1000 to 2000 feet deep at Larderello, Italy, have been drilled into sedimentary rocks of Tertiary and Mesozoic ages. These wells cross fault zones of Tertiary age that carry water with temperatures ranging from 266° to 446°F. This water is believed to be warmed by deep-seated hot rocks which are a source of extraordinary geothermal energy.

In New Mexico, three lines of evidence suggest that similar sources of heat may exist.

(1) Two oil tests have encountered anomalous temperatures that suggest a deep-seated source of heat:

(a) in Hidalgo County, an oil test (Humble No. 1 State BA) in sec. 25, T. 32 S., R. 16 W., which was drilled to a depth of

14,578 feet, reported the following bottom-hole temperatures from electric logs:

Feet	*Degrees F*
1600	106
5340	115
10875	155
14578	320

(b) in Sierra County, an oil test (15S.2W. 23) 9774 feet deep in dolomite reported the following bottom-hole temperatures from electric logs:

Feet	*Degrees F*
3497	104
6212	160
9774	236

(2) Two wells in T. 10 S., R. 1 W. showed a somewhat different anomaly. One drilled in sec. 25 showed a bottom-hole temperature on electric logs of 122°F at a depth of 6059 feet, whereas the other in sec. 27, less than two miles away, showed a bottom-hole temperature of 170°F at a depth of 6352 feet. Here, there is a temperature difference of 50 degrees at a common depth within a comparatively short distance.

(3) Theis, Taylor, and Murray (1941) believe that the warm waters of the Truth or Consequences area are the product of deeply circulating ground waters being brought to the surface along faults and fractures in Magdalena Limestone.

We may, therefore, conclude that deep masses of warm rock exist in New Mexico. Although those deep hot rocks may ultimately serve as sources of heat energy, for our present needs and with our present technical knowledge, they are, for the most part, *not* economical sources of heat.

HEAT OF VOLCANIC AND SHALLOW IGNEOUS ROCKS

The source of heat for most of the commercial geothermal power stations in the world can be traced to fairly recent igneous activity associated with fault zones.

In New Mexico, warm and hot springs are for the most part in areas of obvious volcanism. Plate 1 shows where igneous rocks of Tertiary and Quaternary ages crop out in the state. Many volcanic cones dot the state's landscape. The preliminary state geologic maps (Dane and Bachman, 1957, 1958, 19'61; Bachman and Dane, 1962) show the location of these cones in considerably more detail than is possible here. Because New Mexico has so many fairly recent volcanoes, the prospects of finding and developing geothermal steam, while not so promising as in California, are still very good. Geothermal steam could become the major energy used to generate power in the state.

Geologic Occurrence of Steam

McNitt (1963, p. 37) summarized the basic characteristics of known steam fields so well that his remarks are quoted here as a sound background for the discussion of New Mexico's steam resource:

> All the thermal areas being developed throughout the world are located in regions of Cenozoic volcanism. It appears, therefore, that the source of heat for the thermal areas is related in some manner to the processes of volcanism and magmatic intrusion. If this is true, then it is reasonable to assume that thermal areas derive their heat either from buried flows of volcanic rock, or from still cooling intrusive bodies, which may be wholly or partially crystallized. Although it is difficult to evaluate the relative importance of extrusive rock as compared to intrusive bodies as heat sources, the latter would seem to be the more significant. Certainly at Larderello and The Geysers, where late Cenozoic volcanic flows do not underlie the steam fields, heat must be derived from an intrusive source. Cenozoic lava flows found in the region of these steam fields testify to youthful volcanic activity, and therefore to the probable presence of magmatic activity at depth.
>
> In the thermal areas now under investigation throughout the world, the fissures which conduct thermal fluid to the surface are steeply dipping normal faults. These faults, however, have originated in two distinctly different structural environments. The Geysers and the Italian steam fields are in highland regions which have undergone recent orogenic uplift. These regions are characterized by complex horst and graben structures, which control the location of the thermal areas. Although located in volcanic belts, the thermal fluids do not rise in volcanic rock, but rather in the older, pre-volcanic rocks, which are brought to the surface on structural highs. On the other hand, geophysical evidence in New Zealand, Casa Diablo, and the Salton Sea indicate that these thermal areas are located within large structural depressions, rather than in areas of recent uplift. Even in this environment, however, there is evidence that some of the thermal areas are located near local, structural highs within the depression. These depressions are all closely associated with late Tertiary or Quaternary volcanism and may have a common origin as volcano-tectonic depressions. The geologic processes which relate magma movements to uplift and subsidence structures, volcanism, and thermal activity are not known.
>
> In considering problems of exploration and development, it is important to distinguish between two types of steam fields: (a) the thermal area which yields dry or slightly superheated steam, and (b) the thermal area which produces saturated steam and hot water. The Geysers steam field and the two Italian fields of Larderello and Bagnore are of the dry steam type, while all the other thermal areas drilled thus far yield saturated steam and hot water. The principal factors which give rise to these two types of steam fields are: (a) the initial enthalpy or heat content of the thermal fluid, which is determined by the temperature of the heat source as well as by the thermodynamic and mechanical equilibrium conditions existing between the heat source and the thermal fluid in an open system, and (b) the amount by which the thermal fluid is diluted by cold, near-surface ground water.
>
> This second factor is controlled principally by the structure and permeability of the rocks underlying the thermal area. If the conducting fissures are located in a structural depression filled with porous sediments and volcanic debris, the ascending thermal fluid will mix with the cold ground water which saturates the porous surface rocks. These conditions result in a thermal area which yields only saturated steam and hot water. If the conducting fissures intersect only impermeable rocks, as at The Geysers, or if they are covered by an impermeable layer which protects them from the downward percolation of near-surface ground water, as in Italy, the thermal fluid will be only slightly diluted by surface water, and the field may yield dry or perhaps superheated steam, depending on its initial enthalpy.
>
> By the above remarks it is not meant to imply that the thermal fluid is entirely of magmatic origin. Whether the fluid is primarily meteoric or magmatic water is a separate problem. . . . When considering the problems of evaluating and developing a steam field, it is more important to distinguish between thermal fluid and cold, locally derived ground water. This is because the problems encountered in producing natural steam are more closely related to the thermal and dynamic equilibriums existing between the thermal fluid and the local, near surface ground water, than to the equilibrium conditions existing between the thermal fluid and the heat source.

New Mexico has geologic features similar to those associated with known steam fields. Moreover, many of the state's warm and hot springs are associated with these features.

The Rio Grande trough is the largest feature. Joesting, Case, and Cordell (1961) describe it as a series of complexly faulted troughs or basins, arranged en echelon, extending from the northern end of the San Luis Valley in Colorado, southward 450 miles along the course of the Rio Grande in New Mexico, to El Paso, Texas.

The trough is bounded both on the east and west by discontinuous fault zones. Small volcanoes and fissure flows mark the boundaries at several localities. Warm and hot springs are found along the faults which

border the trough. Most, but not all, of these springs are on the west side of the trough. Apparently, ground water circulates into zones of hot rock and then finds a convenient conduit to the surface along the faults.

The Animas Valley (Spiegel, 1957) and the Tularosa Basin (Schmidt and Craddock, 1964) are smaller, similar structures. Doubtlessly, others exist as well.

According to Richard D. Holt, exploration staff geologist for Humble Oil and Refining Company (personal communication, May 1965), "The location (of the Humble No. 1 State BA oil test) is close to the zone of faulting between the upthrown Big Hatchet Range and the down-dropped Playas Valley bolson. Also, igneous rocks, probably sills, were drilled at 11,180' to 11,198' and 14,192' to 14,218'."

The Valles Caldera (Ross, Smith, and Bailey, 1961; Conover, Theis, and Griggs, 1963) northeast of Jemez Springs and west of Los Alamos is one of the world's largest volcanic calderas. It came into existence fairly recently in geologic time. This caldera is ringed by warm and hot springs, which also appear to be discharging ground water that has circulated down to hot rock and then found a convenient conduit in a fault or fracture zone.

New Mexico's first steam wells are drilled on the caldera to depths ranging from 2600 to 3700 feet. These wells discharge steam at temperatures up to 500°F. This steam may contain juvenile water released by the cooling magma.

West of the Rio Grande trough are numerous small volcanic cones, many of which are associated with faults. A large caldera has been postulated as occurring in the southwest part of the state south of the San Agustin Plains, but whether this is really the case will have to be decided by field exploration.

Plate 1 shows the volcanic and intrusive igneous rocks of Quaternary and Tertiary ages as they were mapped by the New Mexico Geological Society (1961). The major faults, which it also shows, are those shown by the New Mexico Geological Survey plus those inferred by Frank Kottlowski on the basis of his field work in the state (personal communication, April 1965).

On the plate, the extrusive igneous rocks are grouped together, except for the basalts which are shown separately.

The basalts were distinguished from the other extrusive igneous rocks because they cool rapidly. Many basalt flows, are comparatively thin. The lava spreads out over a large surface area. They are, therefore, subject to rapid cooling. Moreover, basalts elsewhere in the world are more permeable than other igneous rocks. In areas where precipitation is abundant, they are excellent aquifers and even thick, relatively recent, flows yield cool water. (Hawaii, with all its volcanoes, is underlain by basalt whose permeability is so great that the passage of recharging ground water has cooled it, and sources of steam seem to be comparatively rare.)

In New Mexico, apparently the basalts are equally permeable, but the aridity of the region has delayed their cooling by circulating ground water. Consequently, many warm springs are associated with the basalts. However, few of these springs are "hot," suggesting that though the basalts are still warm, they are less likely to generate steam than other volcanic rocks.

Prospecting for Steam in New Mexico

The problem in locating sources of steam is to locate suitably hot ground-water reservoirs.

As the demand makes it economically feasible, the search for steam will in all probability start in those areas where there are hot springs and warm-water wells. Next, those areas which show as hot spots in the infra-red aerial surveys will be examined. Third, those areas where conditions are right geologically but no evidence of heat exists at the surface will be explored. Finally, those areas which are located by means of sophisticated subsurface exploration techniques will be investigated.

Figure 1 shows the temperature to be expected in

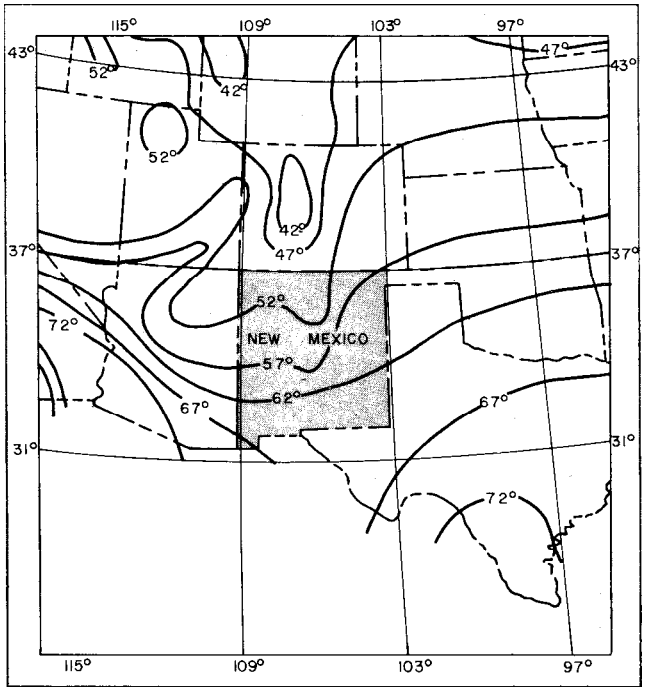

Figure 1
APPROXIMATE TEMPERATURE OF WATER FROM NONTHERMAL WELLS AT DEPTHS OF 30 TO 60 FEET (after Collins, 1925)

a well tapping ground water in an aquifer 30 to 60 feet below the surface. Temperatures of water from deeper sources can be estimated using this map and adding one degree for every 100 feet of depth. Certainly water discharging at temperatures warmer than those we would predict using Figure 1 reflects an extraordinary source of heat.

Plate 1 shows the locations of the warm and hot springs in New Mexico, as well as those water wells known to yield warm or hot water. Whether the sources of heat of the wells or springs shown here are warm enough to generate steam is a question that is unanswerable with our present knowledge.

The classification of discharging water according to temperature (as was required for this map) is an arbitrary matter. As we can see from Figure 1, water with a temperature of 52°F is normal for Santa Fe, whereas water with a temperature of 65°F is normal at Columbus. Clearly, the distinction among "cold," "warm," and "hot" must be approximate. Moreover, hot water that could reflect a source of heat suitable for steam may be masked by mixing with cool ground water before it discharges at the land surface.

The springs shown on the map and listed in Tables 2 and 3 are those which have temperatures of 65 degrees or more. The wells have somewhat higher minimum temperatures (75°F), but wherever there was doubt about the inclusion of a particular well or spring, it was included. If it is not significant, the user can disregard it, but at least the data are available.

The springs and wells are located according to the best information available, short of a personal inspection in the field. The locations of individual springs may be subject to considerable correction when they are field-checked.

Most steam wells tap water in a ground-water reservoir, which has come into contact with extraordinarily hot rock and has been heated to an extraordinary degree. But in some places, the steam may be partly or totally juvenile; that is, it may be composed of water released from the cooling rock. These waters are chemically distinct from the circulating ground water. Hence, geochemical evidence (variations in chemistry especially) may be used to locate potential steam fields. Table 3 gives the chemical analyses available for warm and hot water in the state. The bibliography lists several references that will be of interest to anyone attempting to search for steam by geochemical methods.

Infrared photography and imagery have been used to map Hawaiian volcanoes and the thermal areas of Yellowstone National Park (Fischer et al., 1964). These efforts have shown that it is feasible to separate hot springs and other warm terrestrial features using infra-red techniques.

C. J. Robinove makes several pertinent points about infrared imagery (in the July 1965 issue of the *Journal of the American Waterworks Association)*:

1. The value of infrared imagery in water resources research and in geologic and engineering studies has not yet been fully exploited. Collection of data is quite feasible and some interpretive studies have been conducted. Much effort will have to be expended in learning how to interpret infrared imagery, however, before it can obtain its maximum usefulness in hydrology.

2. Infrared imagery is beginning to be used in water resources studies for the identification of surface and subsurface thermal anomalies as expressed at the surface and the measurement of apparent water surface temperatures. It will attain its maximum usefulness only when interpretation criteria for infrared imagery are fully developed.

3. Although it is possible at this time to identify many features of importance to hydrology by the use of infrared imagery the task remaining is to develop criteria to show the hydrologic significance of the features.

For those interested in the applications of infrared photography and imagery, the bibliography contains a special section on this subject.

Paul Kintzinger (1956) made a geothermal study of a small area southwest of Lordsburg in Hidalgo County, where a well 95 feet deep discharges water of about 210°F. Kintzinger showed the probable extent of the geothermal field there by measuring the soil temperatures at a depth of one meter using resistance thermometers. Subsequent inspection of the aerial photographs showed that the area was also outlined by vegetation changes.

Presumably, the method used by Kintzinger could be used to define and delimit other geothermal areas.

Electrical resistivity is a tool that has not been used in New Mexico to explore for potential steam fields; yet, resistivity is a function of temperature, and warm or hot areas should appear as anomalous areas of low resistivity.

The search for steam fields must also include a study of regional geology, particularly structure and stratigraphy. Steam, in nearly every case where it has been studied, is found in association with fairly recent (geologically speaking) faults and igneous activity. The mapping of known faults and fault zones is a must. Geologically young igneous rocks, particularly young intrusives, are possible sources of heat and should be investigated accordingly.

Steam is frequently confined below rocks with very low permeability, so that only token indications of its pressure appear at the surface.

Geohydraulics of Steam

Information on the rate and direction of movement of steam in a field is limited. The New Zealanders have studied the subject because field pressures are declining; others have considered various aspects of the problem. Jaeger (1964) gives a series of mathematical models to describe the temperature around intrusions of different shapes. Heat exchanges between the fluid in a well bore and the country rock are discussed by Melikov (1964) for circulating mud and by Boldizar (1958) for artesian flow. Facca and Tonani (1964) discuss the relationship between ". . . the heat source, the permeable payzone, and the impermeable cap rock."

Several points should be made with respect to the dynamics of steam-well behavior:

1. Steam wells have pressures that range up to a maximum of about 500 pounds a square inch but usually are much less, 60 to 100 pounds a square inch being the usual range of operating pressure.
2. Steam-well discharge is measured in pounds of steam an hour. There is about 1/450th gallon of water in a pound of steam. The discharge rate varies according to the pressure of the steam and the available heat, porosity and permeability of the steam reservoirs, and the degree of interaction between steam wells. At The Geysers, the several wells deliver 250,000 pounds an hour of steam to the turbine at about 100 pounds pressure. This is a water discharge of about 550 gal-ions a minute. The used steam is cooled and discharged as surface water.
3. Lowering the pressure at the well head generally increases the flow of steam to a limit, then further reductions in pressure have no effect. At The Geysers, the lower limit of pressure is about 35 pounds a square inch.
4. Steam wells have been drilled as close together as 150 feet.
5. The yield of the wells at The Geysers has fallen off some since the first wells were drilled in 1922 and shows only minor interaction of pressure or steam flow. In 1964, the New Zealand field, however, has shown a pressure loss. The loss has been interpreted to mean that the hot steam is being replaced by cold water that is not being heated to the same degree as the original steam, possibly because the rate at which the new water moves in is so much faster under conditions of artificial discharge than it was when the warmed water was discharging naturally to springs. Another explanation that has been put forth is that there is an inflowing volume of water from a second reservoir during the production of steam.

Apparently, the best steam reservoirs will have a balance between the amount of heat available to convert water to steam and the amount of water available. On the one hand, where there is too much water, each unit of water is warmed only slightly. On the other, hand, sufficient water must be available for conversion to steam in sufficient quantity to turn turbines.

Problems that Arise in the Use of Steam

Using natural steam for power may seem to be a panacea. It is not. Steam in many cases carries with it corrosive gases that are difficult to dispose of and that cause excessive corrosion of the turbines and steam lines. If the steam is not chemically suited, it may be impossible to develop it economically.

On the other side of the coin is the steam that carries with it gases or solids that may be processed out and sold independently.

Drilling steam wells is made difficult in several ways. There is the additional care necessary to prevent blow-outs. The loss of drilling fluid and its immediate re-placement by steam can lead to costly blowouts as well as serious injury to men on the rig.

High temperature of the rock requires special, generally more expensive, alloys in the tools.

The mineral content of many steam wells is partly deposited as the steam escapes into the borehole. This has led to a build-up of mineral matter in some wells that has finally shut them off completely.

Thermal expansion at the higher temperatures can cause a casing to elongate as much as 3 feet per 1000 feet. Drilling muds must be put together so that they do not break down or bake. In addition, provision has to be made to cool the mud before it recirculates and water has to be added, as water losses are high. A sodium surfactant mud was used to drill the Sportsman No. 1 well at the Salton Sea steam field. The deepest (8100 feet) and the hottest (800°F) steam well ever drilled was also drilled in the Salton Sea steam field, using compressed air.

The cost of steam wells ranges from $15,000 or $20,000 for the wells drilled at The Geysers to more than $120,000 for deep wells such as those drilled at Salton Sea. E. T. Anderson (personal communication) believes the cost of steam wells around the world ranges between 35 and 50 dollars per foot of depth.

Steam wells are noisy. Working around a discharging steam well requires ear caps or plugs, and all communication is by written message.

The average life of a steam well at Larderello, Italy —the only geothermal power station that has been in operation for a sufficiently long period to arrive at an average—is about 20 years. The New Zealand wells are depreciated over a ten-year period, whereas the Icelandic wells are depreciated over a five-year period. Presumably, the life of the wells in the New Zealand and Iceland fields will be much longer than these depreciation periods.

Recommendations

In reviewing the available literature and surveying the available information on geothermal energy in New Mexico, several omissions, ambiguities, and unknown factors came to light. To make the best use of the resource, we need more information. The following recommendations are offered:

1. The need for a field inventory of springs is acute. The hot springs in the state have never been adequately inventoried, and the little work that has been done is generally frustrating to use because locations are all too often inadequate. The tables of springs given here are at best a preview of what might be obtained.
2. The chemistry of the springs has been studied by different investigators who chose to measure particular ionic or physical properties of the water and not others. Each spring or group of springs should be sampled and detailed chemical analyses of the water should be made with the idea that water chemistry is a tool to be used to locate other steam fields. Such a chemical study could lead to a much better understanding of hydrothermal phenomena in general, particularly the mechanism of ore emplacement. Steam is a gas. Associated with it are other gases, notably hydrogen sulfide, carbon dioxide, methane, ammonia, and hydrogen. To date, little attention has been given to the gases emitted at the warm and hot springs in New Mexico except to note that the air around some springs has the distinctive smell of hydrogen sulfide. Field studies should include analyses for these gases.
3. There are on file some 10,000 electric logs of oil wells drilled in the state which frequently give bottom-hole temperatures of the wells logged. There are also on file temperature and sample logs. A study of these logs should lead to a greater understanding of the geothermal characteristics of the state.
4. The need for a comprehensive bibliography embracing all the aspects of geothermal energy is acute. The literature can be divided into several classes, and the workers in one class do not seem to cross very often into the fields of the others. Hot springs, hydrothermal deposits, ground water, geochemistry, volcanism, heat flow, geothermal gradients, and geothermal power are studied by men of different background. The least difficult (but much needed) and convenient way to bring the disciplines together is with a comprehensive bibliography. Also, the questions that developers of geothermal power raise are questions that demand a knowledge of the world's literature, not only on steam but on geothermal energy in all its ramifications.
5. Despite the huge amount of literature on ground water in general and on hot springs in particular, there is no detailed study of the movement of water, either hot or cold, through and along a fault. Yet much of the movement of the thermal water is speculated to be along or through fault zones. There is, then, a need for a detailed investigation of the dynamic characteristics of water in a fractured area.

   Such a study must investigate the geologic framework about a fault and the differences in piezometric head in the fluid as it moves in and around the fault. This would involve the installation of several piezometer groups.
6. The data on geothermal characteristics and the data on wells plus various sorts of other data are found in publications, in files of the various state agencies, and in the files of individual workers. These data collectively are of great value, but it takes many hours to obtain and to process them to the point where they can be useful. In most cases, researchers who go to the trouble of digging out specific material bury the raw data in their own files and publish only their interpretations. The result is that the "raw" data are lost to subsequent researchers unless they, too, wish to dig them out. The answer to this problem is a central processing center where data of all kinds are filed and cross-referenced in such a way that a researcher locking for all the information on a particular subject can have the data read out to him in a short time.
7. The data on the fluctuation of temperature and the chemical quality of hot springs are sparse. At least a few of these springs should be monitored for changes in flow, temperature, and water quality.
8. The mechanics of the movement of steam and hot water in a ground-water reservoir has not been reduced to a suitable mathematical model. As a result, much work needs to be done on the mechanics of ground-water movement in terms of optimum well spacings and well yields under various hydrodynamic and geological conditions.,
9. Infrared photography and imagery promises to be a useful tool in the investigation for steam. Some attention should be given to the calibration of images in areas where the heat flow to the surface is known. In New Mexico, this would mean that heat flows would have to be determined.

TABLE 2. INFORMATION ABOUT THERMAL SPRINGS AND WELLS FOR WHICH NO CHEMICAL ANALYSES ARE AVAILABLE

COUNTY	SOURCE	LOCATION	TEMP. (°F)	DISCHARGE (GPM)	DISCHARGE FROM (AQUIFER)	DEPTH (FEET)	REMARKS (*see* FOOTNOTES AT END OF TABLE)
Bernalillo	well	10N.2W.21.343	90	—	—	1180	U
	spring	11N.2W.32	68	3	Mancos Shale	—	S
Catron	spring	11S.12W.30.100	80	50	lava agglomerate	—	S
	spring	11S.14W.25	160	900	—	—	T
	spring	12S.13W.7	—	—	—	—	F
	spring	12S.13W.11	151	30	lava	—	S
	spring	12S.13W.14	100	—	—	—	P
	spring	12S.13W.24	—	—	—	—	F
Dona Ana	well	19S.2W.9.120	120	100	—	110	Sc
	Agua Caliente	23S.1E.7	—	—	—	—	P
	Kilbourne Hole	27S.1W.8	100	—	—	100	LRe
Grant	spring	12S.20W.26	—	—	—	—	U
	spring	13S.13W.20	—	30	lava	—	S
	spring	14S.16W.3	—	20	lava	—	S
	spring	14S.16W.16	—	20	lava	—	S
	hot spring area	15S.17W.9&10	—	—	—	—	U
	flowing well	15S.17W.29.442	68.5	2	—	410	U; cased to 40 ft
	warm spring	16S.12W.22	150	—	—	—	P
	well	16S.17W.9.223	85	—	—	22	U
	well	16S.17W.10.433	90	—	—	—	U
	well	16S.17W.19.213	67	—	—	180	U
	spring	17S.17W.34	—	30	Gila Conglomerate	—	Sc
	Hudson's Hot Spring	18S.10W.4.100	142	—	lava	—	S
	Apache Tejo Warm Spring	19S.12W.19.300	89, 97	2000	—	—	SPPa
	warm spring	20S.11W.18.300	—	dry	near rhyolite plug	—	PaU
	well	20S.19W.15.400	—	—	—	—	U
	Fuller's Ranch well	20S.19W.15.400	81	—	—	361	U
Guadalupe	Rock Lake	8N.21E.14	65	2700	—	—	T
Hidalgo	well	20S.19W.19.321	81	—	—	361	R
	well	21S.18W.18.180	83	—	—	—	R
	well	21S.20W.1.410	82	—	—	—	R
	well	22S.19W.23.130	85	—	—	—	R
	well	24S.18W.32	—	—	—	—	well used to heat greenhouse
	well	25S.19W.7.143	98	—	—	—	R
	well	25S.19W.7.134	84.5	—	—	74	R
	well	30S.19W.7	—	—	—	—	Sc; hot stock well
	spring	30S.19W.7	—	—	—	—	Sc; thermal pipe by road
	Humble Oil and Refining Co. No. 1	32S.16W.25	—	—	—	14588	BH 320°F
McKinley	spring	16N.18W.35	—	—	—	—	P
	Togay Spring	19N.15W.33	65	20	—	—	S
Sandoval	Spense Hot Springs	14N.3E.28	110	100	—	—	F
	spring	18N.1E.24	—	—	—	—	T
	San Antonio Spring	20N.3E.29	130	150	—	—	SBaSc
	Westates Petroleum No. 1	20N.3E.35	—	—	—	3675	BH 400+°F
San Juan	spring	24N.18W.3	—	—	—	—	PJo
	spring	25N.18W.34	65	3	—	—	S
	spring	25N.18W.	67	7	—	—	S

TABLE 2. INFORMATION ABOUT THERMAL SPRINGS AND WELLS FOR WHICH NO CHEMICAL ANALYSE

COUNTY	SOURCE	LOCATION	TEMP. (°F)	DISCHARGE (GPM)	DISCHARGE FROM (AQUIFER)
	spring	28N.18W.10	68	3	—
San Miguel	well	16N.16E.5.211	—	—	granite
Sierra	Victoria Land and Cattle Co. No. 2	10S.1W.25	—	—	—
	Victoria Land and Cattle Co. No. 1	10S.1W.27	—	—	—
	16 wells	13S.4W.33	98.6-112.5	—	Magdalena Limestone
	spring	13S.4W.33	—	—	—
	Ojo Caliente	14S.1W.28	—	—	—
	8 wells	14S.4W.4	107-116	—	Magdalena Limestone
	springs	14S.4W.4	94-110.8	—	—
	Cabello Springs	14S.5W.12.4	136	—	—
	Barney Iorio No. 1 fee	14S.5W.25	90	30	—
	Sunray–Midcontinent No. 1	15S.2W.23	—	—	—
Socorro	Ojo Caliente	8S.7W.30	89	1350	—
	Crater well	9S.1E.18.320	—	—	basalt
Taos	Warm Sulphur Springs	—	68	—	—
	Glen–Woody Camp Springs	24N.11E.28	—	—	—
	Ponce de Leon Hot Spring	24N.13E.7	98	100	—
	Mamby's Hot Spring	26N.11E.1	100	—	—
	Warmsley Hot Spring	27N.12E.31	—	—	—
	Arsenic Springs	28N.12E.8.100	—	—	—
	springs	29N.12E.12	—	—	—
Valencia	warm spring	5N.1W.16	64-82	—	Rio Puerco fault
	spring	7N.2W.8	65	3	—
	spring	7N.2W.16	67	7	sandstone and shale intruded by porphyry
	Quelities Mineral Spring	8N.2W.17	80	3	—

B = open-file data of the N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res.
Ba = Bailey, 1961
BH = bottom-hole temperature
F = personal communications April 1965 from District Rangers, U.S. Forest Service
G = Gilbert, 1875
H = Herron, 1915, plate IV
J = Jemez Springs quadrangle, 1948
Jo = Jones, 1904
K = Kelley and Silver, 1956
L = Lee, 1907b
P = Peale, 1886
Pa = Paige, 1916
R = Reeder, 1957
Re = Reiche, 1940
S = Stearns, 1937
Sc = Personal communications May 1965 from the Work Unit Conservationists, U.S. Soil Conserva. Serv.
T = Personal communication April 1965 from Fred A. Thompson, N. Mex. Dept. Game and Fish
Th = Theis et al., 1941
U = Unpub. data in the files of the Ground-Water Branch, U.S. Geol. Surv.
V = Valverde quadrangle, 1958
W = Weber, 1963
Wi = Winograd, 1959

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Bernalillo
Source: Spring ("Clear Water Spring") Location: 9N.4E.24.1															
Remarks: About 50 yards north of Iron Spring															
—	69	7-25-45	—	—	—	—	—	—	218	48	—	234		890	0
															Catron
Source: Spring Location: 2S.14W.17.410															
Remarks: Across road from old church and near court house upper end of Mangas															
450	72	7-17-63	—	—	—	—	—	—	<1		—	62		115	22
Source: Aragon Springs Location: 5S.16W.3.300															
Remarks: "a" taken upstream from springs; "b" taken several hundred yards downstream from springs. Numerous springs in meadow															
2000	70	11-20-52	44	—	—	—	—	—	—	—	—	20		138	0
1000	68	11- 8-54	42	0.1	0.05	0.00	—	—	21	6.6	—	19	3.3	139	0
1500	70	7-16-63		—	—	—	—	—	22	6	—	13		124	0
"a" small	—	7-16-63		—	—	—	—	—	22	6	—	24		154	0
"b" —	70	7-16-63		—	—	—	—	—	28	6	—	14		146	0
Source: Frisco Hot Springs (upper) Location: 5S.19W.34.200															
Remarks: Discharge from alluvium collected at old bath house (FRH); runs out of Gila Conglomerate about 100 ft above floor of San															
—	98	5-22-58	58	—	—	—	0.00	0.01	—	—	2.2	66	0.5	57	55
Source: Frisco Hot Springs (lower) Location: 12S.20W.23.100															
Remarks: Discharges from lava of late Tertiary age, at temperatures ranging from 80°-124°F (S); temperature=130°F (P)															
20+	117.0	5-16-53	85	—	—	—	—	—	—	—	—	333		130	0
—	109	6-13-58	76	—	—	—	0.00	0.00	—	—	0	280	16	132	0
—	115	7- 6-59	—	—	—	—	—	—	49	40	—	289	—	127	0
															Dona Ana
Source: Well Location: 19S.5E.5.100															
Remarks: Two dug wells 65 ft deep															
—	69	—	—	—	—	—	—	—	120	106	—	858		171	104
Source: Radium Springs (Radium Hot Springs) Location: 21S.1W.10.213															
Remarks: Springs issue at base of rhyolite hill on east border of lowland of the Rio Grande; temperatures = 168°, 185°F (S); rhyolite															
—	—	5-17-48	71	—	—	—	—	—	142	23	—	1160		427	—
—	128	11-17-54	75	0.1	0.15	0.40	—	—	126	12	—	1100	161	417	0
10	120+	4-14-58	66	—	—	—	0.0	0.25	—	—	0.0	1100	155	424	0
—	—	5- 4-62	—	—	0.0	0.1	—	—	131	15	—	1100	163	416	—
—	—	8-31-22	60	—	1.2	—	—	—	138	17	—	1164	111	429	0
Source: Well Location: 21S.1W.20.200															
Remarks: (3 miles SW of Radium Springs) Drilled well, 2½ inches in diameter, 250 ft deep, cased to 150 ft, water-bearing formation =															
8-9	"hot"	5-25-58	46	—	—	—	0.01	0.18	—	—	0.0	227	6.0	534	0
Source: Cleofas Spring Location: 21S.1E.23.200															
Remarks: Discharges from andesite tuff															
0.5	65	4-24-58	39	—	—	—	0.02	0.00	—	—	0.0	66	5.5	216	0
Source: Well Location: 21S.1W.31.200															
Remarks: Drilled well 2½ inches in diameter, 51 ft deep, cased to 24 ft, water level 24 ft below land surface, water-bearing formation 20-															
4	68	4-24-58	56	—	—	—	—	—	—	—	—	95	6.6	310	0
Source: Well Location: 23S.1W.31.400															
Remarks: Drilled well 1200 ft deep, water level at 597 ft below land surface, water sample from 1030-1200 ft															
13.2	90	2-19-55	19	0.02	—	—	—	—	110	1.1	—	928		55	—
Source: Wildcat oil well Location: 28S.2W.24.213															
Remarks: Water was struck at 675 ft; sample from waste water pumped by well during drilling; contains detergent and possibly other															
500	113	11-25-61	—	—	—	—	—	—	—	—	—	1380	—	934	0
															Grant
Source: Gila Hot Springs Location: 13S.13W.5.241															
Remarks: Discharge from lava (S)															
25	147	6-23-57	33	—	0.00	—	—	—	11	0.2	—	129		109	0
100	147	7-25-62	68	0.31	0.00	0.00	—	—	12	0	—	121	3.6	106	0
Source: Hot Spring Location: 13S.13W.10.121															
10	126	6-23-57	—	—	—	—	—	—	—	—	—	—	—	108	0

AND WELLS INCLUDING CHEMICAL ANALYSES
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County																	
93	300	—	—	—	—		1330		742	—	232	—	—	—	—	—	4086
County																	
2	1	—	—	—	—				0.0	—	304	9.3	—		—	—	FRH
along east edge of canyon floor (B); issues from lake beds—sand, gravel, clay—of extinct Lake San Agustin (S&B)																	
7.0	5	0.4	0.5	—	—			—	86	0	236	—	—	—	—	—	21145
2.9	4.5	0.6	1.5	—	0.04			175	80	—	234	8.2	—	<7	<0.1	1.1	S&B
2	3	—	—	—	—			—	78	—	235	7.6	—	—	—	—	FRH
2	3	—	—	—	—			—	80	—	267	7.4	—	—	—	—	FRH
2	3	—	—	—	—			—	94	—	264	7.9	—	—	—	—	FRH
Francisco River bed, 130°F at 30 gpm (Sc)																	
6.6	5.0	1.0	0.8	—	0.04				10	0	284	9.7	—	—	—	—	38851
45	512	1.6	1.5	—	—				157	50	1930	—	—	—	—	—	22690
41	434	1.8	1.3	—	0.32				142	34	1660	7.6	—	—	—	—	38864
—	460	—	—	—	—			1020	286	182	1780	7.8	—	—	—	—	42605
County																	
241	1541	—	—	—	—	3019			174	—	—	—	—	—	—	—	M&H
dikes intruded into latitic tuffs overlain by alluvium (S&B)																	
265	1680	4.6	2.0	—	—			3540	449	—	6060	—	—	—	—	—	C
255	1650	4.8	1.1	—	—			3620	364	—	6100	7.2	—	170	0.6	18	S&B
277	1660	5.7	1.4	—	0.32			—	380	32	5540	7.2	—	—	—	—	38867
269	1677	5.3	0.26	—	—	3660			390	—	6100	7.2	—	—	—	—	NMPHL
253	1752	—	—	—	—	3738	3707		352	—	—	—	—	—	—	—	2058
andesite breccia																	
126	32	2.2	28	—	0.13				142	0	1130	8.2	—	—	—	—	38863
100	42	1.0	0.3	—	0.04				188	11	627	7.8	—	—	—	—	38862
51 ft = latite tuff																	
49	10	5.2	16	—	.17				126	—	612	7.8	—	—	—	—	38847
927	910	—	3.3	—	—	2930			279		4640	8.6	—	—	—	—	H&K
drilling chemical contaminants; lime of Cretaceous age																	
856	1610	—	—	—	—				736	0	7380	7.3	—	—	—	—	48858
County																	
40	104	12	0.5	—	0.07	369			28	—	653	8.2	—	—	—	—	36105
45	102	9	0.07	0.00	—		414	421	30	0	638	7.5	—	—	—	—	4897
22	59	—	—	—	—				15	0	432	8.1	—	—	—	—	36104

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Grant
Source: Drilled well Location: 15S.17W.27.111															
Remarks: Gila Conglomerate; water level 17.5 ft below surface; well 300 ft deep; producing from 75-85 ft and 170-180 ft															
10	92	7-14-62	48	—	0.00	—	—	—	3.0	0.1	—	150		130	24
Source: Spring Location: 15S.17W.30.224															
Remarks: Gila Conglomerate															
30	77	9-14-55	—	—	—	—	—	—	—	—	—	—	—	123	14
Source: Allen Springs Location: 16S.15W.26.412															
Remarks: Issues from fault zone in limestone															
80	77.5	4- 2-54	18	—	—	—	—	—	78	39	—	18		387	0
Source: Drilled well Location: 16S.17W.9.242															
Remarks: 36 ft deep, diameter 8″, cased to 36 ft; water level 19 ft below surface															
—	86	6- 8-55	40	—	0.09	—	—	—	7.5	1.0	—	126		241	0
Source: Well Location: 16S.17W.34.212															
Remarks: Pipe in orifice; volcanic rock (latite ?); water level +60 ft below surface															
90	84	4-26-55	32	—	0.04	—	—	—	18	3.0	—	92		232	0
Source: Spring Location: 16S.18W.34.314															
Remarks: Volcanic tuff of Tertiary age and sandstone															
0.75	68	7-28-55	—	—	—	—	—	—	—	—	—	—	—	212	0
Source: Spring Location: 16S.21W.20.300 (?)															
Remarks: Spring in bed of Bitter Creek															
1	69	9-20-41	—	—	—	—	—	—	536	67	—	62	—	164	0
Source: Ash Spring Location: 17S.15W.20.222															
Remarks: Granite of Precambrian age															
0.25	72	8- -54	15	—	—	—	—	—	71	21	—	11		200	0
Source: Spring Location: 17S.21W.18.200 (?)															
Remarks: Spring at fault															
1	69	9-17-41	—	—	—	—	—	—	56	93	—	83	—	415	12
Source: Spring Location: 18S.9W.31.340															
5	71.5	6-10-52	—	—	—	—	—	—	—	—	—	—	—	160	0
Source: Goat Spring Location: 18S.9W.34.124															
Remarks: Mimbres conglomerate; water issues from joints in conglomerate striking N. 45 W., dipping 30° S															
20	66	3-21-57	—	—	—	—	—	—	—	—	—	—	—	210	0
Source: Mimbres Hot Springs Location: 18S.10W.18.100															
Remarks: "a" spring upstream from Mimbres spring; "b," Green Horse Spring; "c," Mimbres Hot Spring. Discharge 100 gpm at 135° and															
"a"															
10	79	6- 5-52	—	—	—	—	—	—	—	—	—	—	—	83	14
"b"															
10	135.5	6- 5-52	—	—	—	—	—	—	—	—	—	—	—	75	20
"c"															
20	137	6- 5-52	53	—	—	—	—	—	12	2.6	—	86		113	—
Source: Faywood Hot Springs Location: 20S.11W.20.243															
Remarks: Several springs discharging 120 gpm @ 142°F from base of lava slope; issues from top of travertine mound 20 ft high (S); (see															
15-20	129.2	6- 5-52	—	—	—	—	—	—	—	—	—	91		282	0
50	128	4-19-57	43	0.0	0.1	0.00	—	—	38	7.3	—	85	7.8	278	0
Include with data below: Pb = 0.00															
50	128	11- 9-54	—	—	—	—	0.0	0.0	37	8.5	—	—	—	282	0
Source: Well Location: 23S.15W.31.110															
Remarks: Drilled well 470 ft deep, water level 443 ft below surface															
—	82	5-16-55	34	—	0.15	—	—	—	44	13	—	123		229	0
															Guadalupe
Source: Spring Location: 8N.21E.1.333															
Remarks: Blue Hole at outlet to U.S. Fish Hatchery at Santa Rosa; yield of 500-1000 gpm at 65.5°F (B)															
500-1000	65.5	5- 6-59	16	—	—	—	—	—	620	62	—	33		181	0
															Hidalgo
Source: "Blowing" well Location: 22S.21W.3.312															
Remarks: Well of unknown depth with water level 446 ft below the land surface, discharges water from the Santa Fe formation (H&K);															
5	88	7- 8-55	—	—	—	—	—	—	—	—	—	—	—	431	—

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
103	18	21	0.1	—	—		431	435	8	0	665	9.0	—	—	—	—	50019
—	5.2	—	—	—	—				72	0	256	8.7	—	—	—	—	31368
20	38	0.8	2.4	—	—		404		355	38	621	—	—	—	—	—	26035
51	16	8.0	1.6	—	—	363	370		22	0	551	7.9	—	—	—	—	29790
38	8.5	6.0	0.1	—	—	311	312		58	0	472	7.9	—	—	—	—	29750
—	8.8	—	—	—	—				158	0	389	7.2	—	—	—	—	31374
1519	21	1.1	0.8	—	—	2288			1613	—	255	—	—	—	—	—	1559
110	4	1.2	1.2	—	—		332		264	100	526	—	—	—	—	—	27635
283	21	0.9	20	—	—		773		522	—	118	—	—	—	—	—	1569
—	9.0	5.2	—	—	—				66	—	347	—	—	—	—	—	19655
—	9.0	—	—	—	—				132	0	353	7.4	—	—	—	—	38212
137°F from Mimbres fault zone (S); about 30 springs with a combined flow of 100+ gpm from latite and rhyolite at the surface (EBu)																	
—	17	16	—	—	—				11	—	451	—	—	—	—	—	19647
—	16	16	—	—	—				9	—	450	—	—	—	—	—	19645
65	17	16	0	—	—		308		40	0	457	—	—	—	—	—	19646
also JoEBu)																	
50	18	7.0	0.1	—	—			—	129	0	606	—	—	—	—	—	19824
52	16	6.8	0.2	0.00	—			384	125	—	605	7.4	—	19	29	0.1	S&B
—	17	—	—	—	—				128	0	600	—	—	—	—	—	27917
193	23	2.8	3.5	—	—		549	553	164		820	8.0	—	—	—	—	29797
County																	
1590	48	0.5	0.1	—	—		2460		1800	1650	2620	7.3	—	—	—	—	42376
County																	
temperature is 95°F, depth is 449 ft (R)																	
—	102	—	—	—	—				128		1590	7.8	—	—	—	—	H&K

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Hidalgo
Source: Wells Location: 25S.19W.7.234															
Remarks: A group of three irrigation wells in alluvium, ranging from 83 to 106 ft deep with casings perforated 42-90, ?, & 50-82 ft, drilled															
—	—	2- 1-49	—	—	—	—	—	—	24	1.5	—	324		146	0
—	240	4-28-49	141	—	—	—	—	—	19	1.2	—	329		181	0
—	—	7-30-51	—	—	—	—	—	—	—	—	—	—	—	163	7
—	—	3-28-52	—	—	—	—	—	—	—	—	—	—	—	163	7
—	210	4-27-54	138	0.1	0.07	0.00	—	—	21	0.7	—	324	21	145	6
—	—	4-10-55	135	—	—	—	—	—	22	1.5	—	319		157	0
															Rio Arriba
Source: Springs at Ojo Caliente Location: 24N.8E.															
Soda Spring															
15	95	10- 1-47	60	—	—	—	—	—	23	8.7	—	1040		2200	0
Soda Spring															
—	—	10- 6-49	66	—	—	—	—	—	25	9.0	—	997	29	2180	0
Sodium Sulfate Spring															
0.25	90	10- 1-47	56	—	—	—	—	—	25	8.7	—	1040		2210	0
Soda Spring															
—	115	10- 6-49	60	0.3	1.2	—	—	—	23	9.5	Trace	996	31	2230	—
Bath House															
10	105	10- 6-49	63	—	0.02	—	—	—	24	7.6	—	933	34	2160	0
Arsenic Spring															
—	113	10- 6-49	63	—	0.01	—	—	—	25	8.9	—	928	30	2160	0
Source: Spring Location: 25N.8E.25															
Remarks: Three almost contingent springs; from Dakota Sandstone (?)															
Field 1															
—	97	9- 5-52	—	—	—	—	—	—	—	—	—	—	—	692	0
Field 2															
—	97	9- 5-52	—	—	—	—	—	—	—	—	—	—	—	698	0
Field 3															
—	97	9- 5-52	—	—	—	—	—	—	—	—	—	—	—	694	0
Field 4															
—	97	9- 5-52	22	—	—	—	—	—	145	59	—	187		698	0
Field 5															
—	65	9-15-52	15	—	0.01	—	—	—	44	11	—	11		73	0
															Sandoval
Source: Spring Location: 13N.4E.36.323															
Remarks: Seep in arroyo bottom at fault															
0.5	68	8- 9-62	—	—	—	—	—	—	—	—	—	10	1.2	291	0
Source: San Ysidro Warm Springs Location: 15N.1E.3, 9, and 10															
Remarks: A group of several springs north of Rio Salado, deposits of calcareous tufa around spring (Ri); several springs issuing from															
—	68	9-15-24	15	—	3.0	—	—	—	368	85	—	2219		1757	—
—	—	3- 6-45	—	—	—	—	—	—	322	84	—	1830		1780	0
—	—	3- 6-45	—	—	—	—	—	—	306	73	—	2080		2000	0
—	—	3- 2-45	—	—	0.48	—	—	—	324	85	—	1850		1820	0
5-10	72	9-29-48	16	—	—	—	—	—	300	74	—	2100		2020	0
Source: San Ysidro Hot Springs Location: 15N.1E.8.400															
Remarks: Issues from faulted beds of Triassic age (S); calcareous tufa around spring (Ri)															
—	86	9-15-24	15	—	2.0	—	—	—	497	91	—	3310		1969	—
Source: "Hot well" Location: 16N.1W.1 (unsurveyed)															
Remarks: Drilled well 12" in diameter, 550 ft deep (Ri), 2008 ft deep [Aqua Zarca, 600 ft; San Andres, 870 ft; Abo, 1535 ft; Magdalena,															
—	115	9-29-26	18	—	2.3	—	—	—	400	73	—	3450		1498	—
Include with data below: Mo = 0.00; Pb = 0.6; Li = 6.9; As = 0.60; Br = 0.3; I = 4.6; Se = 0.00															
1500	130	3-14-64	31	2.6	3.9	0.01	0.04	1.5	345	56	—	3550	87	1450	0
Source: Spring and oil test well Location: 16N.1W.1.410															
Remarks: The flowing abandoned well is an oil test, rich in H_2S and other gases; the oil test is 2000 ft deep															
—	180	4- 3-56	35	—	—	—	—	—	328	76	—	3500		1470	0
—	—	7-29-58	31	—	0.00	—	—	—	301	67	—	3590		1410	0
Well															
—	140	9-29-48	27	—	—	—	—	—	368	73	—	3640		1470	0
Source: Swimming pool spring Location: 16N.1E.20 (unsurveyed)															
—	70	9-14-24	30	—	0.60	—	—	—	260	70	—	2400		1301	—
Source: Indian Spring Location: 16N.2E.29.142															
2	95	8-30-62	48	—	0.03	—	—	—	100	8.6	—	1240		1280	0

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
into "hard rock" and "solid rock, very hot" (R)																	
509	85	—	6	—	—			1020	66	0	1650	—	—	—	—	—	R
460	78	11	0.9	—	0.45			1130	52	0	1540	—	—	—	—	—	12284
—	81	—	—	—	—			—	—	0	1660	—	—	—	—	—	R
—	82	—	0.4	—	—			—	55	—	1600	8.2	—	—	—	—	R
474	83	9.9	0.3	—	—			1160	56	—	1580	8.4	—	12	0.3	0.2	S&B
459	80	13	0.2	—	—			1110	61	0	1510	7.6	—	—	—	—	R
County																	
168	238	16	1.6	—	1.7		2640		106	0	3890	—	—	—	—	—	8977
162	240	16	0.9	—	—		2620		100	0	3910	7.2	—	—	—	—	13378
165	245	16	1.7	—	4.6		2650		106	0	3890	—	—	—	—	—	8978
151	231	0.84	0.9	0.2	1.2				—	—	—	7.2	—	—	—	—	WH&W
156	238	16	0.5	—	1.7		2540		91	0	3920	6.9	—	—	—	—	13192
156	238	16	0.8	—	1.6		2530		99	0	3930	7.1	—	—	—	—	13193
—	107	—	—	—	—				—	—	1730	—	—	—	—	—	20032
—	111	—	—	—	—				—	—	1760	—	—	—	—	—	20033
—	108	—	—	—	—				—	—	1740	—	—	—	—	—	20034
270	110	1.4	0.2	—	—		1140		604	32	1740	—	—	—	—	—	20035
110	2.5	0.2	0.2	—	—		230		115	95	347	7.0	—	—	—	—	20119
County																	
57	6.4	—	0.6	—	—				294	56	563	7.4	—	—	—	—	50288
faulted crest of anticline (S)																	
1712	1940	—	Trace	—	—	7320			—	—	—	—	—	—	—	—	Ri
1200	1710	—	—	—	BO_3=60		6020		1150	0	903	—	—	—	—	—	3478
1200	1920	—	—	—	BO_3=60		6560		1060	0	980	—	—	—	—	—	3479
1240	1700	—	—	—	—		6100		1160	0	896	—	—	—	—	—	3548
1240	1880	3.8	5.1	—	10.3		6610		1050	0	9750	6.5	—	—	—	—	10983
3401	2500	—	Trace	—	50	10960			1608	—	—	—	—	—	—	—	Ri
1890 ft] (B)																	
3645	2660	—	0	—	—			11120	1299	—	—	—	—	—	—	—	Ri
3260	2990	2.8	0.2	—	4.8		11000		1090	0	15300	7.3	—	—	—	—	54144
3320	2900	—	—	—	—		10900		1130	0	15000	6.6	—	—	—	—	32740
3340	2970	4.5	8.1	—	6.6		11000		1030	0	14900	7.2	—	—	—	—	39231
3540	3010	2.6	—	—	6.6		11400		1220	14	15400	6.8	—	—	—	—	10984
1728	2330	—	Trace	—	—			7510	—	937	—	—	—	—	—	—	Ri
286	1140	7.3	0.3	—	6.1		3470		285	0	5680	8.0	—	—	—	—	50248

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Sandoval
Source: Spring at Ojo del Espiritu ranch house (CCC camp on San Ysidro quadrangle) Location: 17N.1W.15 (unsurveyed)															
—	60	9-22-24	30	—	0.30	—	—	—	90	12	12		12	259	
Source: Soda Dam springs (The Sulphurs) Location: 18N.2E.14 (unsurveyed)															
Remarks: Large tufa deposit in channel of Jemez River from flow of about 10 gpm at 75°-105°F (S); at contact of granite of Precambrian															
—	104	8-21-24	48	—	0.10	—	—	—	328	23	—		1000	1440	—
40	96	6-28-49	47	—	—	—	—	—	327	27	—		830	1400	0
Sulphur Pool															
—	100	8- 2-49	—	—	—	—	—	—	—	—	—	—	—	1500	0
Sulphur Pool															
10	102	6-24-49	47	—	—	—	—	—	330	29	—		1170	1540	0
Sulphur Pool															
1	—	1-20-50	42	—	—	—	—	—	221	29	—	1020	197	1200	0
Sulphur Pool															
—	—	12-20-49	—	—	—	—	—	—	—	—	—	—	—	1520	0
Geyser Spring															
—	—	10-10-50	—	—	—	—	—	—	—	—	—	—	—	1550	0
Geyser Spring															
—	—	6-20-50	—	—	—	—	—	—	—	—	—	—	—	1550	0
Geyser Spring															
—	110	8- 2-49	—	—	—	—	—	—	—	—	—	—	—	1580	0
Geyser Spring															
5	—	6-28-49	47	—	—	—	—	—	344	29	—		1140	1580	0
Geyser Spring															
—	—	12-20-49	—	—	—	—	—	—	—	—	—	—	—	1590	0
—	—	8-31-46	—	—	—	—	—	—	—	—	—	—	—	883	0
Hole-in-Rock Spring															
—	—	6-14-49	35	—	—	—	—	—	304	32	—		932	1560	0
Sulphur Pool															
—	—	8-31-49	48	—	0.04	—	—	—	332	33	—	1000	183	1530	0
—	104	8-21-24	48	—	0.10	—	—	—	328	23	—		1000	1440	0
2	81	6-26-49	43	—	—	—	—	—	326	30	—		1200	1550	0
25	95	8- 2-49	44	—	—	—	—	—	326	27	—		986	1440	0
—	—	8-31-46	—	—	—	—	—	—	346	33	—		1230	1530	0
—	—	8-31-46	—	—	—	—	—	—	314	32	—		989	1560	0
0.5	102	6-14-49	47	—	—	—	—	—	340	31	—		1170	1590	0
Well															
12.5	—	12-13-57	—	—	—	—	—	—	—	—	—	—	—	338	5
Dug Pit															
40	96	6-28-49	47	—	—	—	—	—	327	27	—		830	1400	0
Source: Jemez Hot Springs Location: 18N.2E.23 (unsurveyed)															
Remarks: About 10 springs flowing 200 gpm with temperatures ranging from 94° to 168°F from faults in redbeds of Permian age (S)															
Bath House															
—	125	8-21-24	91	—	1.2	—	—	—	166	9.0	—		645	791	—
—	160	4- 3-56	86	—	—	—	—	—	136	10	—	618	70	716	0
Main Spring No. 1															
—	—	4-15-47	47	—	0.04	—	—	—	18	6.2	—	12	3.6	94	0
Main Spring No. 2															
—	—	4-15-47	60	—	0.01	—	—	—	47	14	—	14	3.0	228	0
No. 3															
—	—	4-15-47	51	—	0.01	—	—	—	34	10	—	39	3.8	232	0
—	164	8- 1-47	64	—	0.0	—	—	—	137	4.4	—		701	750	0
25	—	6-14-49	91	—	—	—	—	—	137	9.0	—		677	740	0
Behind Bath House															
10	150	6-14-49	92	—	—	—	—	—	140	9.4	—		680	758	0
10	150	8-31-49	93	—	0.03	—	—	—	138	6.6	—	572	70	735	0
Behind Bath House															
20	152	10-24-51	—	—	—	—	—	—	—	—	—	—	—	727	0
Source: Hot spring (McCauley Spring) Location: 18N.3E.4															
Remarks: Issues at base of recent volcanic flow on contact with red beds of Permian age; no obvious mineralization															
110	98	8- 1-47	53	—	0	—	—	—	11	4.2	—		23	87	0
Source: Sulphur Springs on Sulphur Creek Location: 19N.3E.4 (unsurveyed)															
Remarks: Thermal waters issue from volcanics of late Tertiary age (Ri); about 8 springs discharging 500 gpm at 86°-167°F from andesites															
Ladies Bath House; Acidity as SO_4 = 2304															
—	110	8-31-24	276	195	369	—	Trace	—	321	24	—		304	0	0
Alum Spring; Acidity as SO_4 = 2328															
—	76	8-31-24	146	421	72	—	—	—	316	51	—		127	0	0
Alum Spring; Acidity as SO_4 = 2570															
—	61	8-13-47	170	501	2.8	—	—	—	256	35	—	—	—	0	0
Laxative Spring; Acidity as SO_4 = —															
—	—	8-31-49	42	—	0.64	—	—	—	168	23	—	14	—	0	0

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
99	4	—	0.25	—	—	396			274	—	—	—	—	—	—	—	Ri
and Magdalena Group (Ri) (see Jo)																	
40	1320	—	Trace	—	—	3458			914	—	—	—	—	—	—	—	Ri
51	1080	2.4	1.3	—	8.7		3060		927	—	5160	6.8	—	—	—	—	12208
39	1540	—	—	—	—				—	—	6610	—	—	—	—	—	12529
42	1540	3.2	1.0	—	14		3920		942	0	6600	6.9	—	—	—	—	12210
39	1510	3.3	4.3	—	—		3660		670	0	6150	—	—	—	—	—	13845
—	1530	—	—	—	—				—	—	6530	—	—	—	—	—	13484
—	1550	—	—	—	—				—	—	6620	—	—	—	—	—	15097
—	1550	—	—	—	—				—	—	6590	—	—	—	—	—	15096
40	1510	—	—	—	—				—	—	6590	—	—	—	—	—	12530
42	1500	3.2	1.3	—	13		3880		978	0	6520	6.9	—	—	—	—	12211
—	1520	—	—	—	—				—	—	6530	—	—	—	—	—	13485
912	1570	—	—	—	—				—	—	5970	—	—	—	—	—	7124
60	1110	3.2	1.6	—	9.8		3250		890	0	5410	6.9	—	—	—	—	12146
41	1550	3.6	1.4	—	12		3950		964	0	6570	6.9	—	—	—	—	13080
40	1320	—	Trace	—	BO_3=2.5		3471		914	—	3458	—	0	—	—	—	3227
40	1580	3.6	1.2	—	12		3990		937	0	6720	7.0	—	—	—	—	12209
45	1300	2.8	1.7	—	9.1		3440		924	0	5860	—	—	—	—	—	12531
263	1520	3.5	1.5	—	—		4150		999	0	651	—	—	—	—	—	7125
53	1220	2.8	1.4	—	—		3380		915	0	563	—	—	—	—	—	7126
37	1540	4.0	2.0	—	12.5		3950		976	0	6620	6.7	—	—	—	—	12147
—	9.0	—	—	—	—				266	0	563	8.3	—	—	—	—	—
51	1080	2.4	1.3	—	8.7		3060		927	0	5160	6.8	—	—	—	—	12208
(see also RiJoP)																	
42	820	—	5.0	—	2.5	2184			452	—	—	—	—	—	—	—	Ri, 3226
44	870	5.2	0.5	—	—		2190		380	0	3860	6.7	—	—	—	—	32741
15	4	0.8	0.4	—	0.0		153		70	0	1840	—	—	—	—	—	8252
15	4	0.8	0.3	—	0.0		270		175	0	3510	—	—	—	—	—	8253
17	4	0.8	0.3	—	BO_3=0.0		274		126	0	3640	—	—	—	—	—	8254
44	855	7.1	0.4	—	6.33		2180		360	0	3700	7.2	—	—	—	—	8928
51	835	4.9	1.7	—	—		2170		379	0	3640	7.6	—	—	—	—	12139
51	835	4.9	1.5	—	—		2190		388	0	3670	7.7	—	—	—	—	12140
49	795	5.2	0.8	—	11	2150	2090		372	0	3560	7.2	—	—	—	—	13079
—	—	—	—	—	—				—	—	3680	—	—	—	—	—	17772
8.0	8.0	1.6	0.4	—	BO_3=0		152		45	0	19.8	8.1	—	—	—	—	8929
and rhyolites of Tertiary age (S) (see also GPH)																	
3560	294	—	0	77	—	6270	5420		—	—	—	—	8.2	—	—	—	3224
3159	1.0	—	Trace	41	—	4344	4344		—	—	—	—	2.1	—	—	—	3221
4030	170	0.7	0.4	—	—				—	—	826	1.8	—	—	—	—	8937
614	8.0	0.0	0.4	—	—	967			514	514	1270	3.1	—	—	—	—	13257

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Sandoval
Source: Sulphur Springs on Sulphur Creek (cont)															
Lemonade Spring															
—	150	8-31-49	216	56	33	3.3	—	—	185	52	—	6.7	24	0	0
Men's Bath House															
—	110+	8-31-49	219	205	217	—	—	—	66	17	—		42	0	0
Bath House; As = 0.05; Li = 0.07; Pb = 0.12 Se = 0.03															
—	188	11- 4-63	190	36	115	0.33	—	—	6.9	9.7	—	24	31	0	0
Foot Bath															
—	99	8-31-24	259	90	252	—	—	—	41	16	—		52	0	—
Lemonade Spring															
—	115	8-13-47	162	—	1.8	—	—	—	150	73	—		—	0	0
Lemonade Spring															
1	130	7-28-49	—	—	—	—	—	—	—	—	—	—	—	—	—
Lemonade Spring; Se = 0.00															
—	—	1-20-50	—	—	—	—	—	—	—	—	—	—	—	—	—
Lemonade Spring															
—	—	10-24-51	—	—	—	—	—	—	—	—	—	—	—	—	—
Men's Bath House; Acidity as SO_4=5400															
—	—	8-31-24	324	303	1250	—	—	—	303	33	—		157	0	0
Ladies' Bath House															
—	—	8-31-49	237	172	93	—	—	—	110	11	—	24	—	0	0
Mud Bath															
—	99	7-28-49	—	—	—	—	—	—	—	—	—	—	—	—	—
Hot Sulphur Mud Bath															
—	80-98	8-13-47	—	694	22	1.1	—	—	154	42	—	—	12	—	—
Mud Foot Bath															
—	97	8-13-47	122	469	12	—	—	—	7.2	19	—	—	—	0	0
Footbath Spring															
—	72	7-28-49	—	—	—	—	—	—	—	—	—	—	—	—	—
Mud Bath															
—	105	8-31-49	174	104	92	—	—	—	45	12	—	13	—	0	0
Electric Spring															
—	97	8-13-47	166	—	3.4	—	—	—	140	161	—	—	—	0	0
Electric Spring															
15	102	7-28-49	—	—	—	—	—	—	—	—	—	—	—	—	—
Electric Spring															
1	—	8-31-49	206	194	81	—	—	—	101	23	—	9.6	42	0	0
Alum and Boric Spring															
—	72	8-13-47	—	364	17	—	—	—	372	43	—	—	47	—	—
Sulphur Creek below Sulphur Springs															
—	—	10-22-49	83	76	40	—	—	—	164	24	—	16	—	0	0
Source: Hot spring (Natural Bath-Tub) Location: 19N.3E.28.310															
Remarks: Issues at base of recent volcanic flow on contact with red beds of Permian age; no observable mineralization; elevation 7350 ft															
—	100	8- 1-47	71	—	0	—	—	—	7.5	2.2	—		56	139	0
Source: Steam well Location: 20N.3E.35 (unsurveyed)															
Remarks: Analyses reported to be of steam condensate which would enter stream as runoff															
—	—	6-13-63	—	—	12.6	0.5	—	—	28	0	—	83	27	623	—
—	—	6-18-63	—	—	1.05	0.03	—	—	2	1.2	—	83	31	854	—
Source: Alamo Canyon Spring Location: 20N.3E.35															
Remarks: Over area approximately 50 × 100 ft are numerous points evolving gas, some sulfurous gas but largely CO_2; elevation 8700 ft;															
—	—	8- 1-47	87	—	0.41	—	—	—	32	22	—	—	—	0	0
Source: Spring on Rio Antonio (warm spring) Location: 20N.4E.7 (unsurveyed)															
Remarks: Issues from rhyolite of Tertiary age (He); 50 gpm at 120°F (S) (see also P)															
25	101	8- 1-47	103	—	0	—	—	—	6.5	1.1	—		40	77	0
															San Miguel
Source: Spring Location: 16N.16E.6															
1	106	3-11-52	68	—	0.02	—	—	—	4.5	1.0	—		179	77	16
5	123	3-11-52	59	—	0.03	—	—	—	4.5	1.1	—		179	66	22
Source: Montezuma Hot Springs Location: 16N.16E.6															
—	—	5-16-39	—	—	—	—	—	—	14	8.3	—		141	—	—
—	130	7- 2-40	—	—	—	—	—	—	8.5	0.7	—		173	92	11
—	—	8-20-40	—	—	—	—	—	—	—	—	—	—	—	82	13
—	—	8-20-40	—	—	—	—	—	—	—	—	—	—	—	80	15
															Sierra
Source: Oil test, Victoria Land and Cattle Company No. 2 Location: 10S.2W.25.100															
Remarks: Flow from 1328 to 1347 ft from San Andres Limestone (H&K)															
900	94	—	—	—	—	—	—	—	—	—	—	—	—	636	—

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
1570	3.5	1.1	0	—	—	1950			676	0	4570	1.9	—	—	—	—	He, 13260
4250	45	0.9	0.5	—	—		3630		234	234	13900	1.4	—	—	—	—	13253
35100	24	1.2	0.0	2.4	—				57	57	13800	2.0	—	—	—	—	5300
2337	20	—	0	154	—	2562	3221		168	—	—	—	1.6	—	—	—	Ri, 3225
1190	65	1.0	0.3	—	—				—	—	—	2.0	—	—	—	—	8935
1590	—	—	—	—	—				—	—	4570	2.2	—	—	—	—	12524
—	—	—	—	—	—				—	—	3560	2.2	—	—	—	—	13558
—	—	—	—	—	—				—	—	2710	2.3	—	—	—	—	17774
6156	54	—	Trace	37	—	7887	8617		—	—	—	—	—	—	—	—	3223
2740	20	0.5	0.6	—	—	2690			320	320	8510	1.6	—	—	—	—	13254
1550	—	—	—	—	—				—	—	6100	1.9	—	—	—	—	12520
5430	241	—	—	—	—				—	—	1410	1.9	—	—	—	—	9171
5190	649	—	0.3	—	—				—	—	1660	1.5	—	—	—	—	8934
5230	—	—	—	—	—				—	—	13900	1.7	—	—	—	—	12519
1440	—	—	0.7	—	—	1730			162	162	4370	1.9	—	—	—	—	13258
3520	410	1.5	0.3	—	—				—	—	1170	1.5	—	—	—	—	8936
3880	—	—	—	—	—				—	—	12500	1.7	—	—	—	—	12522
3820	2.5	1.0	0.0	—	—	3160			346	346	12700	1.4	—	—	—	—	13259
3560	74	—	—	—	—		364		—	—	794	2.9	—	—	—	—	9172
1160	4.0	0.3	0.0	—	—	1600			508	508	2270	2.5	—	—	—	—	13262
17	11	0.8	0.2	—	0.8		234		28	0	28.3	7.3	—	—	—	—	8933
335	121	24	0.00	—	—	2970			70	—	2225	8.0	—	—	—	—	NMPHL
177	114	24	0.00	—	—	1700			10	—	2070	8.3	—	—	—	—	NMPHL
acidity as H_2SO_4 = 153																	
242	3.0	0.3	0.6	—	BO_3=0.2				—	—	72.1	2.9	—	—	—	—	8930
15	17	1.6	0.4	—	0		222	230	20	0	16.7	6.7	—	—	—	—	He
County																	
42	155	20	0.1	—	—	528	524		15	0	876	8.8	—	—	—	—	18610
42	155	20	0.1	—	—	530	515		16	0	876	9.0	—	—	—	—	18609
66	154	—	—	—	—	554			—	—	878	—	—	—	—	—	2083
49	158	—	0.2	—	—	537			—	—	870	—	—	—	—	—	4801
—	160	—	—	—	—	531			—	—	878	—	—	—	—	—	5233
—	159	—	—	—	—	523			—	—	872	—	—	—	—	—	5233
County																	
1660	22	—	—	—	—				1850	—	1850	7.2	—	—	—	—	H&K

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Sierra
Source: Warm spring Location: 12S.5W.28															
Remarks: In Cuchillo Canyon, 10 miles NW of T or C and 15 miles W of Cuchillo (Th)															
—	85.6	2-9/10-39	37	—	0.00	—	—	—	109	10	—	386	26	212	0
Source: Drilled wells at Truth or Consequences Location: 13S.4W.33															
Remarks: (for detailed location, see Th) Magdalena Limestone (Th); "discharge," respectively, from 27 ft, 105 ft, and 100 ft deep															
—	112.3	2-9/10-39	38	—	0.10	—	—	—	150	16	—	692	45	218	—
—	114	2-9/10-39	—	—	0.07	—	—	—	152	18	—	740	—	210	—
—	111.2	2-9/10-39	—	—	0.42	—	—	—	155	17	—	772	—	214	—
Source: Springs at Truth or Consequences Location: 13S.4W.33															
Remarks: Discharge from alluvium (for detailed description, see Th)															
1.3	103-106	9-9/10-39	36	—	0.1	—	—	—	154	14	—	731	39	215	0
1	99-103	2-9/10-39	37	—	0.08	—	—	—	148	16	—	678	36	212	0
Old Gov't Spring															
—	106	7-23-38	—	—	—	—	—	—	168	36	—	687	53	217	0
Source: Drilled well in Truth or Consequences Location: 13S.4W.34.310															
Remarks: Valley fill; well 120 ft deep (Th)															
—	70	2-9/10-39	18	—	3.30	—	—	—	460	76	—	661	21	152	—
Source: Palomas Spring Location: 13S.5W.31.130															
Remarks: Santa Fe Formation															
—	—	6-12-58	—	—	—	—	—	—	—	—	—	—	—	171	0
Source: Wells of Truth or Consequences Location: 14S.4W.4															
Remarks: (for detailed location, see Th) Magdalena Limestone (Th); "discharge," respectively, from 212 ft and 208 ft deep															
—	—	2-9/10-39	—	—	0.08	—	—	—	154	16	—	730	—	121	—
—	—	2-9/10-39	32	—	0.53	—	—	—	153	15	—	714	43	219	—
Source: Yucca Baths at Truth or Consequences (Ponce de Leon Spring) Location 14S.4W.4															
Remarks: (for detailed location, see Th) Alluvium samples from 14 ft deep drive point into spring head (Th)															
—	110	2-9/10-39	—	—	0.08	—	—	—	154	19	—	751	—	218	—
2	110	3-31-52	39	—	0.01	—	—	—	174	25	—	692		221	—
1.1	109	5-28-54	41	0.1	0.02	0.19	—	—	154	21	—	735	61	216	0
Well 14 ft deep															
—	109.4	4-28-43	—	—	—	—	—	—	—	—	—	—	—	—	—
0.5	—	7-12-54	—	—	—	—	—	—	156	20	—	749		220	0
0.75	110	8- 2-55	—	—	—	—	—	—	—	—	—	—	—	221	0
0.75	110.5	9-17-56	—	—	—	—	—	—	—	—	—	—	—	216	0
Flowing Well															
8.5	108	8- 5-57	—	—	—	—	—	—	—	—	—	—	—	228	0
Bath House Spring															
—	104	4-15-58	—	—	—	—	—	—	—	—	—	—	—	227	0
North Spring															
—	107	8- 3-59	—	—	—	—	—	—	—	—	—	—	—	221	0
—	104	4- 4-60	—	—	—	—	—	—	—	—	—	—	—	220	0
—	107.5	8-13-62	—	—	—	—	—	—	—	—	—	—	—	220	0
Source: City well No. 2 at Truth or Consequences Location: 14S.4W.6															
Remarks: (for detailed location, see Th) Alluvium; well 200 ft deep (Th)															
—	77	2-9/10-39	21	—	2.20	—	—	—	58	5	—	131	9	125	—
Source: Drilled well Location: 15S.6W.31.34															
Remarks: 193 ft deep, diameter 6"; alluvium; water level at 100 ft															
15	70.2	8-20-46	—	—	—	—	—	—	63	21	—	36		242	0
Source: Drilled well at Hot Springs Location: 16S.5W.22															
40	75	6-14-46	—	—	—	—	—	—	21	4.4	—	59		169	0
Source: Derry Warm Springs Location: 17S.4W.29.340															
Remarks: Issues from limestone bluff on east side of Rincon Valley (C); small dpeosits of travertine; flows approximately 50 gpm from 2															
50	93	4-17-48	—	—	—	—	—	—	52	19	—	303		370	0
5-10	93.2	5- 7-52	32	—	—	—	—	—	48	20	—	293		372	0
10-15	93	4-30-57	—	—	—	—	—	—	—	—	—	—	—	368	0
															Socorro
Source: Springs Location: 1N.1E.31.320															
Remarks: Sand and gravel; flow in area may be as much as 100 gpm; (a) pipe from side of hill at pond on railroad near San Acacia; (b)															
(a) 25	70	7- 9-63	—	—	—	—	—	—	368	143	—	900		178	0
(b) <1	68	7- 9-63	—	—	—	—	—	—	320	118	—	900		163	0

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
79	650	2.4	25.0	—	0.5	1428	1429		314	—	—	—	—	—	—	—	Th
102	1230	3.4	2	—	—	2486			441	—	—	—	—	—	—	—	Th
74	1280	2.6	—	—	—				—	—	—	—	—	—	—	—	Th
73	1330	3.2	—	—	—				457	—	—	—	—	—	—	—	Th
79	1300	3	10	—	—	2560	2472		442	—	452	—	—	—	—	—	Th
81	1210	3	5	—	—	2418	2318		236	—	429	—	—	—	—	—	Th
95	1314	—	—	—	—				—	—	459	—	—	—	—	—	684
1193	1120	1.6	4	—	—	3720			1462	—	—	—	—	—	—	—	Th
23	114	—	—	—	—				158	18	664	7.7	—	—	—	—	38787
75	1250	2.8	—	—	—				451	—	—	—	—	—	—	—	Th
105	1240	3.2	6.2	—	—	2437			444	—	—	—	—	—	—	—	Th
86	1290	3.2	—	—	—				463	—	—	—	—	—	—	—	Th
98	1240	2.8	2.7	—	—		2380	2640	537	—	4430	7.2	—	—	—	—	S&B
93	1290	3.3	2.0	—	—			2670	470	—	4510	7.3	—	100	0.7	3.3	S&B
—	1285	—	—	—	—				—	—	438	—	—	—	—	—	653
95	1290	—	—	—	—		2420		471	290	4420	—	—	—	—	—	27039
91	1300	—	—	—	—				490	309	4450	7.4	—	—	—	—	31082
91	1290	—	—	—	—				525	348	4450	7.4	—	—	—	—	33929
—	1280	—	—	—	—				470	283	4400	7.2	—	—	—	—	38827
—	1280	—	—	—	—				475	289	4460	7.2	—	—	—	—	38930
—	1290	—	—	—	—				—	—	4450	7.2	—	—	—	—	43037
96	1300	—	—	—	—				470	290	4450	7.5	—	—	—	—	44734
—	1310	—	—	—	—				510	330	4480	7.2	—	—	—	—	50301
52	212	0.6	1	—	—	556			166	—	—	—	—	—	—	—	Th
80	26	1.2	1.2	—	—		348		244	45	60.9	—	—	—	—	—	6870
36	13	1.2	0.8	—	0.0		219		70	0	36.0	—	—	—	—	—	6135
levels: (1) 5 ft above floor at 92°F, (2) 6 ft above at 66°F from alluvial material above Derry fault block																	
309	160	5.8	2.0	—	—		1030		208	—	1650	—	—	—	—	—	C
306	141	6	1.3	—	—		1030		207	0	1660	—	—	—	—	—	18725
303	158	—	—	—	—				192	0	1660	7.4	—	—	—	—	35977
County																	
in bank of railroad just north of (a)																	
1016	1816	—	—	—	—				1510	—	6970	7.4	—	—	—	—	FRH
920	1526	—	—	—	—				1284	—	6080	7.6	—	—	—	—	FRH

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Socorro
Source: Spring Location: 1N.2W.7.100															
Remarks: Madera Limestone (see H&K)															
500	70	11-30-49	—	—	—	—	—	—	138	59	—	887		420	0
Source: Artesian spring Location: 1N.2W.7.132															
Remarks: (mouth of box on Rio Salado) Madera Limestone															
—	72	11-19-61	—	—	—	—	—	—	—	—	—	—	—	398	0
Source: Well Location: 1N.2E.34.130															
Remarks: 33 ft deep															
—	65	—	21	—	—	—	—	—	562	130	—	21		142	—
Source: Ojitos Springs Location: 2S.1W.19.431 and 2S.1W.19.414															
Remarks: A group of springs discharging from rhyolite breccia fault zone															
106	—	1952	—	—	—	—	—	—	50	12	—	67		308	—
—	68	7- 9-63	—	—	—	—	—	—	29	11	—	38		195	0
—	—	7- 9-63	—	—	—	—	—	—	40	14	—	76		332	0
Source: Cook Spring Location: 3S.1W.15.313; temperature in pond															
10-15	66	3-20-58	28	—	—	—	0.00	0.00	—	—	—	66	3.0	175	0
Include with data below: Li = 0.33															
—	70	9-24-64	26	—	0.58	—	—	—	13	4	—	68	3.4	158	3
Source: Well (Blue Canyon) Location: 3S.1W.16.323															
Remarks: Drilled well 300 ft deep, water level 210 ft below surface in rhyolite breccia															
20	90.4	7-24-56	26	—	—	—	—	—	—	—	—	53		145	8
—	88	12-20-61	—	—	—	—	—	—	18	5	—	55		166	0
—	89	4-10-65	27	—	—	—	—	—	20	4.6	—	56	3	163	0
Source: Socorro warm springs Location: 3S.1W.22.113															
Remarks: (S) Several springs flowing from lake beds of Tertiary age lying against lava hills flowing 500 gpm at 91°F (S&B); flow from															
—	—	2-17-36	—	—	—	—	—	—	19	4	—	55	5	168	—
—	—	12- 4-36	—	—	—	—	—	—	18	5	—	53		156	—
—	91	1952	—	—	—	—	—	—	19	5	—	53		163	—
353	90	1-24-57	27	0.00	0.00	0.00	—	—	18	3.9	—	52	2.8	154	0
220	90	3-20-58	39	—	—	—	0.00	0.04	—	—	1.6	55	3.0	160	5
—	91	12-12-61	—	—	—	—	—	—	18	5	—	50		163	0
—	91	2- 5-63	—	—	—	—	—	—	13	5	—	—	—	156	0
—	92	4-10-65	—	—	—	—	—	—	18	4.4	—	—	—	155	0
Source: Sedillo Spring Location: 3S.1W.22.131															
Remarks: Issues from rhyolite breccia															
240	90	3-20-58	27	—	—	—	0.00	0.04	—	—	0.00	54	2.9	159	0
—	88	12-12-61	—	—	—	—	—	—	18	5	—	50		154	5
Source: Ojo de las Cañas, east of Rio Grande Location: 3S.2E.19.323															
Remarks: Controlled by prominent east-dipping sandstone bed in Yeso Formation, with fault control downstream (FRH)															
—	79	6-13-62	—	—	—	—	—	—	552	141	—	38		193	0
10	—	3-15-63	—	—	—	—	—	—	488	141	—	—	—	142	0
Source: Well Location: 4N.2E.35.220															
Remarks: 187 ft deep															
—	73	2-24-50	32	—	—	—	—	—	24	6.3	—	34		115	—
Source: Well Location: 4N.3E.23.430															
Remarks: 370 ft deep															
—	72	3-29-50	17	—	—	—	—	—	20	6.0	—	28		98	—
Source: Well Location: 5S.1E.36.440															
Remarks: Alluvium															
—	80	10- 5-62	—	—	—	—	—	—	—	—	—	—	—	258	0
Source: Sawmill Spring Location: 5S.3W.4.231															
Remarks: Sawmill Canyon above Birris Ranch															
—	66	8- 7-63	—	—	—	—	—	—	33	3.9	—	6		124	0
Source: Spring Location: 6S.1W.6.440															
Remarks: (Diamond A Ranch) Volcanics in fault zone (?)															
25	70	6-18-63	—	—	—	—	—	—	22	2.4	—	22		112	0
Source: Springs Location: 8S.7W.31.300															
Remarks: Issues from Gila Conglomerate (?); (a) from developed spring area, below ruins, east of Alamosa River at Ojo Caliente; (b) from															
(a) 4-5	82	12-13-63	—	—	—	—	—	—	44.8	1.4	—	—	—	117.1	0.
(b) —	—	—	—	—	—	—	—	—	37.6	1.9	—	—	—	122	0.

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County (Continued)																	
611	1160	—	4.9	—	—		3110		714	—	5023	—	—	—	—	—	13430
—	1080	—	—	—	—				—	—	4750	7.6	—	—	—	—	48607
1770	10	0.6	10	—	—	2590			1940	—	2760	—	—	—	—	—	SP
38	20	—	—	—	—				174	—	—	—	—	—	—	—	—
20	14	—	—	—	—				118	—	499	7.7	—	—	—	—	FRH
20	22	—	—	—	—				158	—	703	8.2	—	—	—	—	FRH
44	14	1.0	1.1	—	0.08				62	0	393	8.1	—	—	—	—	38856
42	14	0.8	0.8	—	0.13		254	250	49	0	391	8.4	—	—	—	—	55434
37	14	0.6	1.0	—	0.76				78	—	380	—	—	—	—	—	33772
32	17	—	—	—	—				68	—	390	8.0	—	—	—	—	FRH
36	14	—	1.1	—	—				69	0	375	7.6	—	—	—	—	56677
rhyolite agglomerate (Sp, Sd, Ho, FRH, Jo)																	
30	14	—	1.3	—	—				63	—	340	—	—	—	—	—	Sd
30	13	1.0	0.6	—	—				64	—	348	—	—	—	—	—	Sd
30	13	—	—	—	—	234			70	—	—	8.2	—	—	—	—	
28	15	0.6	1.2	0.15	—			224	61	—	348	7.8	—	<11	0.2	1.8	S&B
33	16	0.7	1.1	—	0.06				74	0	362	8.4	—	—	—	—	38854
28	8	—	—	—	—				64	—	370	8.1	—	—	—	—	FRH
20	12	—	—	—	—				52	—	356	7.8	—	—	—	—	FRH
—	—	—	—	—	—				63	0	346	7.8	—	—	—	—	56678
33	14	0.8	1.3	—	0.05				63	0	318	8.2	—	—	—	—	38853
24	10	—	—	—	—				64	—	370	8.4	—	—	—	—	FRH
1776	24	—	—	—	—				1960	—	3030	7.6	—	—	—	—	FRH
1568	20	—	—	—	—				1800	—	2800	—	—	—	—	—	FRH
49	9	0.8	1.6	—	—	214			86	—	310	—	—	—	—	—	Sp
40	7	0.6	1.6	—	—	168			74	—	263	—	—	—	—	—	Sp
2170	1060	—	—	—	—				1700	1490	6740	7.0	—	—	—	—	50501
4	4	—	—	—	—				98	—	246	7.0	—	—	—	—	FRH
12	4	—	2.2	—	—				66	—	244	7.9	—	—	—	—	FRH
up side ravine, east of Alamosa River at Ojo Caliente																	
80	154.0	—	—	—	—				112	—	910	7.9	—	—	—	—	FRH
76.0	108.0	—	—	—	—				94	—	772	8.1	—	—	—	—	FRH

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Valencia
Source: Coyote Spring Location: 5N.3W.29.441															
Remarks: Issues from limestone at wide gap in hogback upstream from fault; precipitate covers estimated 30 acres of arroyo flow (Ti)															
3	64	1941	59	—	0.80	—	—	—	284	245	—	10000		2700	—
Source: Spring Location: 6N.2W.6.340															
Remarks: Issues from Magdalena Limestone; a Lucero fault zone spring (Wr)															
0.1	78	—	21	—	0.02	—	—	—	534	448	—	3650	38	1385	—
Source: Spring Location: 6N.3W.35.340															
Remarks: Issues from Magdalena Limestone; a Lucero fault zone spring (Wr); issues from limestone at gap in hogback upstream from															
—	71	1941	15	—	0.57	—	—	—	704	356	—	4570	79	2049	—
—	58	5- 1-57	16	—	—	—	—	—	823	460	—	5830		2990	0
10	15.3	11-30-63	18	—	0.01	—	—	—	809	419	—	5730	99	2420	0
Source: Laguna Pueblo springs Location: 7N.2W.6.210 & .444															
Remarks: .444 issues from limestone in gap in hogback upstream from fault; precipitate covers arroyo floor (Ti)															
(.210) 0.3	—	1941	—	—	—	—	—	—	227	185	—	11400		2050	—
(.444) —	68	4-30-57	25	—	—	—	—	—	681	314	—	7450		2440	—
Source: Springs Location: 7N.2W.6.400															
Remarks: Two springs with large travertine deposits issue from sandstone in fault zone															
0.5	80	1941	—	—	—	—	—	—	312	133	—	9460		2100	—
3	58	2-20-56	—	—	—	—	—	—	92	126	—	9670		2440	—
Source: Springs Location: 7N.2W.7.100 and .340															
Remarks: Issue from sandstone and shale along fault zone (Wr)															
(.100) 0.5	76	—	37	—	0.08	—	—	—	108	138	—	9760	283	1713	—
(.340) 0.05	—	—	—	—	—	—	—	—	324	152	—	—	—	2214	—
Source: Springs Location: 7N.2W.7.124 and .320															
Remarks: Issue from shale and sandstone at fault zone (Ti)															
(.320) 0.1	—	1941	—	—	—	—	—	—	324	152	—	9250		2210	—
(.124) 3	76	8-25-41	37	—	0.08	—	—	—	108	138	—	10000		1710	—
Source: Laguna Pueblo Seeps Location: 7N.2W.18.140, .312, and .313															
Remarks: Issue from sandstone and shale in fault zone (Ti)															
(.313) 0.02	82	1941	—	—	—	—	—	—	560	188	—	—	—	2030	—
(.312) 0.05	—	1941	—	—	—	—	—	—	560	188	—	—	—	2030	—
(.140) 0.2	—	1941	—	—	—	—	—	—	418	187	—	10700		1610	—
Source: Unnamed springs and seeps, Laguna Pueblo Location: 7N.2W.30															
Remarks: (see Wr and Ti for exact locations) A series of springs along the Lucero fault zone issuing from limestone, sandstone, and															
0.05	86	—	—	—	—	—	—	—	297	224	—	—	—	1374	—
0.35	75	1941	32	—	15	—	—	—	702	214	—	6470	165	2174	—
0.02	82	—	34	—	1.8	—	—	—	918	220	—	10950	283	2840	—
5	72	1941	20	—	0.09	—	—	—	516	163	—	6820		1340	—
Source: Spring Location: 7N.2W.31.140															
Remarks: Issues from sandstone in Abo Formation along fault zone (Wr; see also H&K)															
0.05	80	1941	20	—	0.18	—	—	—	603	271	—	5230	118	1615	—
Source: Spring Location: 7N.4W.3.430															
Remarks: Issues from shale and sandstone (Wr)															
0.01	65	—	—	—	—	—	—	—	606	150	—	—	—	408	—
Source: Spring Location: 7N.5W.20.340															
Remarks: Issues from sandstone and shale (Wr)															
3	68	—	—	—	—	—	—	—	604	130	—	—	—	428	—
Source: Ojo Escondido Spring Location: 8N.2W.19.421															
Remarks: Issues from sandstone along fault zone (Ti)															
20	73	9- 8-41	12	—	0.02	—	—	—	33	20	—	23	5.6	220	—

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/1)	Ra ($\mu\mu$c/1)	U (μg/1)	Ref.
County																	
4510	12500	1.6	—	—	—	29500			1720	0	—	—	—	—	—	—	Ti
2640	5160	1.0	—	—	—	13540			3170	—	—	—	—	—	—	—	Wr
fault; water cascades through dams built by precipitates (Ti)																	
2660	6240	—	—	—	—	15630			3220	1540	—	—	—	—	—	—	Wr-Ti
3250	7900	1.8	—	—	—	19700			3940	1860	26700	6.5	—	—	—	—	Ti
3210	7790	1.1	1.3	—	3.2		19300		3740	1760	26800	6.4	—	—	—	—	53068
7800	11600	—	—	—	—	32400			1330	—	—	—	—	—	—	—	Ti
3490	9610	—	—	—	—	22700			2990	990	31000	7	—	—	—	—	Ti
6380	9600	—	—	—	—	—	27100		1330	—	—	—	—	—	—	—	Ti
6300	9400	—	—	—	—	—			748	—	35200	7.7	—	—	—	—	Ti
6710	9940	5.8	—	—	—	29500			1716	—	—	—	—	—	—	—	Wr
6670	9070	—	—	—	—	26700			—	—	—	—	—	—	—	—	Wr
8870	9070	—	—	—	—	26700			1430	—	—	—	—	—	—	—	Ti
6710	9940	5.8	—	—	—	27900			837	—	—	—	—	—	—	—	Ti
7390	9210	—	—	—	—	27800			2180	521	—	—	—	—	—	—	Ti
7390	9210	—	—	—	—	27800			2180	521	—	—	—	—	—	—	Ti
8040	10200	—	—	—	—	30000			1810	492	—	—	—	—	—	—	Ti
gypsum (Ti)																	
6710	8880	—	—	—	—	25700			1660	540	—	—	—	—	—	—	Wr-Ti
5640	6560	2.8	—	—	—	20920			2630	853	—	—	—	—	—	—	Wr-Ti
8910	11120	3.4	—	—	—	33900			3200	—	—	—	—	—	—	—	Wr-Ti
6540	8170	4.3	—	—	—	20900			1960	860	—	—	—	—	—	—	Wr-Ti
5380	5120	1.2	—	—	—	17540			2620	—	—	—	—	—	—	—	Wr
1969	146	—	—	—	—	3440			—	—	—	—	—	—	—	—	Wr
2010	113	—	—	—	—	3500			—	—	—	—	—	—	—	—	Wr
32	5.6	0.7	0.1	—	—	239			164	—	—	—	—	—	—	—	Ti, Wr

TABLE 3. INFORMATION ABOUT THERMAL SPRINGS
(All constituents in parts

gpm	°F	Date	SiO_2	Al	Fe	Mn	Cu	Zn	Ca	Mg	Ba	Na	K	HCO_3	CO_3
															Valencia
Source: Spring Location: 8N.2W.30.340															
Remarks: Issues from fault zone (Wr)															
0.03	73	—	—	—	—	—	—	—	227	185	—	—	—	2047	—
0.3	72	9- 3-41	20	—	0.09	—	—	—	516	163	—	6630	194	1340	—
Source: Suwanee Spring (Laguna Pueblo) Location: 8N.3W.10.224															
Remarks: Issues from alluvium and lava-filled shallow valley (Ti)															
30	62	4- 2-58	29	—	—	—	—	—	258	99	—	558		224	—
Source: Dipping Vat Spring Location: 8N.3W.12.342															
Remarks: Issues from sandstone (Ti)															
400	60	4- 2-58	30	—	0.26	—	—	—	270	109	—	609		222	—
Source: Spring near Mesa Redondo Location: 8N.3W.15.413															
25	68.2	11-29-63	11	—	0.05	—	—	—	676	174	—	3500	116	2370	0
Source: Springs Location: 8N.3W.35.100															
Remarks: Issue from shale, sandstone, and basalt slump blocks (Ti)															
1	65	—	28	—	0.09	—	—	—	516	163	—	6630	194	1345	—
1	65	9- 3-41	28	—	0.02	—	—	—	65	18	—	43	3.9	377	0
Source: Ojo Caliente Spring Location: 8N.20W.21.140															
—	80	12-20-33	—	—	—	—	—	—	145	44	—	50		342	0
450	71	11-25-57	19	—	—	—	—	—	143	37	—	66		344	0
—	—	10-19-61	16	—	0.01	—	—	—	224	21	—	3.3	—	419	0
Source: Spring Location: 10N.3W.26.330 (?)															
Remarks: From uncontaminated Todilto gypsum (?)															
1/16	72	6-30-58	18	—	—	—	—	—	174	15	—	9.4		599	0

12345=U.S. Geol. Surv. laboratory number; analyses probably previously unpublished
B=unpublished data in the files of the N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res.
Bu=Bushman, 1955
C = Conover, 1954
E=Elston, 1957
FRH=unpublished data from the files of Francis R. Hall (*or* Hall, 1963)
He=Hem, 1959
H&K-=Hood and Kister, 1962

AND WELLS INCLUDING CHEMICAL ANALYSES (cont)
per million unless noted)

SO_4	Cl	F	NO_3	PO_4	B	Total solids	Total solids (sum)	Total solids (evap)	Hardness as $CaCO_3$	Noncarb. hardness as $CaCO_3$	Sp. Cond. (μmhos at 25°C)	pH	H_2S	Total β-γ activity ($\mu\mu$c/l)	Ra ($\mu\mu$c/l)	U (μg/l)	Ref.
County (Continued)																	
7800	11560	—	—	—	—	32400			—	—	—	—	—	—	—	—	Wr
6540	6170	4.3	—	—	—	20900			1960	—	—	—	—	—			H&K
1530	344	—	3.6	—	—	3020			1090	807	3790	7.7	—	—	—	—	Ti
1640	384	0.7	4.7	—	0.85	3270			1120	940	4030	7.7	—	—	—	—	Ti
4220	2740	2.3	0.7	—	6.3		12600		2400	458	15800	7.3	—	—	—	—	53069
6540	6170	4.3	—	—	—	20900			1958	—	—	—	—	—	—	—	Wr
13	3.1	0.2	0.83	—	—	355	361		236	—	—	—	—	—	—	—	Ti
310	34	0.0	0.10	—	—		752		543	—	—	—	—	—	—	—	12573
303	37	0.7	0.0	—	—	809	775		509	227	1120	7.1	—	—	—	—	38875
463	54	0.5	11	—	0.23		1120		644	—	1560	7.2	—	—	—	—	48325
13	5.5	0.6	2.3	—	—		533		496	4	906	7.7	—	—	—	—	40498

Jo Jones, 1904
K&S=Kelley and Silver, 1952
M&H=Meinzer and Hall, 1915
NMPHL=N. Mex. Pub. Health Lab. P=Peale, 1886
R=Reeder, 1957
Ri=Renick, 1931
S=Stearns et al., 1937
Sc=Personal communication from the Work Unit Conservationists, U.S. Soil Conserv. Serv.
Sd=Schofield, 1938
Sp=Spiegel, 1957
S&B=Scott and Barker, 1962
Ti=Titus, 1963
Wr=Wright, 1946
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Appendix A

Below is a breakdown of the cost of drilling a 2000-foot-deep steam well in 1963, prepared by W. M. Middleton, chief engineer, Thermal Power Company, San Francisco, California.

Site preparation, including water tank, pump, and piping rental	$2,000
Rig transportation, six truckloads	8,000
Loading and unloading rig at the Big Geysers	1,450
Permit fees, trip costs ($182, included in costs above)	
Rig rental during transport	300
Casing transportation, three truckloads	1,000
Casing 10'-20" at $5/ft; 100'-13-3/8" at $606/100 ft; 1000'-10-3/4" at $392/100 ft; 1000'-8-5/8" slotted at $295 + $121/100 ft	8,536
Centralizers at $37.20 each	223
Three RBOP stripper rubbers at $210 each	630
Cement plug and shoe 13-3/8", estimated	110
One 8-5/8" guide shoe	52
Ten 8-5/8" baffle collars at $85 each	856
Labor, supervision, running supplies, fuel, rig, drill string and blowout equipment, 12 days at $1250 a day	15,000
Bits, five at $300 each	1,500
Cementing	3,500
Mud	1,500
Geothermograph rental	100
One l0"—300# WKM gate valve	1,500
One 2"—300# gate valve	50
Two 10"--300# R. J. flanges	300
Two 2"—300# R. J. flanges	50
Bolts	50
Welder	600
Casing tools	500
Under-reamers and reamers:	
14" rotary oil tool under-reamer	500
Used 13-3/8" reamers	205
6-point 12-1/4" reamer	528
6-point 9-7/8" reamer	412
11" rotary oil tool under-reamer	500
2 per cent sales tax on purchased items	350
SUBTOTAL	$48,752
10 per cent contingency	4,872
TOTAL	$53,627

Appendix B

ECONOMICS OF GEOTHERMAL STEAM

(taken from Kaufman, 1964 a, b, and Facca and Ten Dam, 1963)

A. Geothermal well drilling costs

	depth (feet)		cost (dollars per foot)	
Area	low	high	low	high
The Geysers, Calif.	525	984	39	60
Iceland	984	7216	12	17
Larderello, Italy	984	5248	22	40
Wairakei, New Zealand	1476	2952	—	48*

*average

B. Cost of drilling materials, Imperial Valley, California

	0-2696 feet	2690-4729 feet	0-4729 feet
Cost per day	$173.00	$925.00	$565.00
Cost per foot drilled	0.70	5.46	2.74

C. Cost of producing geothermal power

area	total capacity (megawatts)	total capital cost (million dollars)	capital cost (dollars per kw)	total cost (mills per kwh)
The Geysers, Calif.	12.5	1.9	152	5.0
Iceland	15.0	5.5	364	7.9
Larderello, Italy	3.5 to 300	0.7 to 36.2	121 to 280	3.0 to 7.0
Pathe, Mexico	3.5	0.2	53	6.0
Wairakei, New Zealand	192.2	44.0	230	4.6

D. Distribution of capital costs

	per cent	
process	Larderello, Italy	Wairakei, New Zealand
Steam winning	34 to 70	23
Steam transmission	3 to 4	27
Powerhouse and plant	—	42
Cooling-water systems	25 to 61	—
and cooling towers	—	7
Electric substation	21	21

E. Comparative costs with other sources of energy

	total cost of electric power at 60.0 megawatt plants (dollars per net kwh)
Coal	31.32
Oil	30.33
Gas	31.15
Geothermal	30.15, to 33.44

F. Generating cost per kilowatt hour net output for various types of power plants

	mills	
	minimum	maximum
Geothermal	2.55	4.90
Conventional thermal	5.47	7.75
Nuclear power (average)	5.42	11.56
Hydroelectric	5.00	11.36

G'. Pessimistic estimated cost of exploration to discover a commercial geothermal field

	one zone		three zones	
	minimum	maximum	minimum	maximum
		general reconnaissance		
Preliminary survey	$ 40,000	$ 50,000	$ 120,000	$ 150,000
Economic survey	10,000	10,000	30,000	30,000
Study surface shows	30,000	30,000	90,000	90,000
Vulcanological study	3,000	6,000	9,000	18,000
Survey of zone of interest	30,000	30,000	90,000	90,000
Subtotals	113,000	126,000	339,000	378,000
		detailed exploration		
Gravity survey	29,000	65,000	87,000	195,000
Geothermal gradient survey	100,000	100,000	300,000	300,000
Seismic survey	30,000	60,000	90,000	180,000
Drilling	600,000	700,000	1,800,000	2,100,000
Subtotals	$759,000	$ 925,000	$2,277,000	$2,775,000
Totals	$872,000	$1,051,000	$2,616,000	$3,153,000

Appendix C

Summary of information about steam wells drilled near Sulphur Springs (T. 20 N., R. 3 E., sec. 35, unsurveyed), Sandoval County, New Mexico

Author's note: No factual statement of the facts about these steam wells has been published. The following information was compiled from various sources and is believed to express the facts with reasonable accuracy.

A. Bond et al. No. 1 (a wildcat oil test drilled by Westates Petroleum Co.)

Spudded: 5/19/60, D & A 7/12/60
Total depth: 3675 feet drilled with mud to 3670
drilled with air to 3675
Casing: 13-3/8" to 404 feet
9-5/8" to 1217 feet
Yield: Discharge est. 5 MMCF steam at 275°F at 3650 feet
Discharge est. 25 MMCF steam at 3675 feet
Elevation: 8697 feet

B. Steam Well No. 1 (James P. Dunigan and Associates No. 1 Baca)

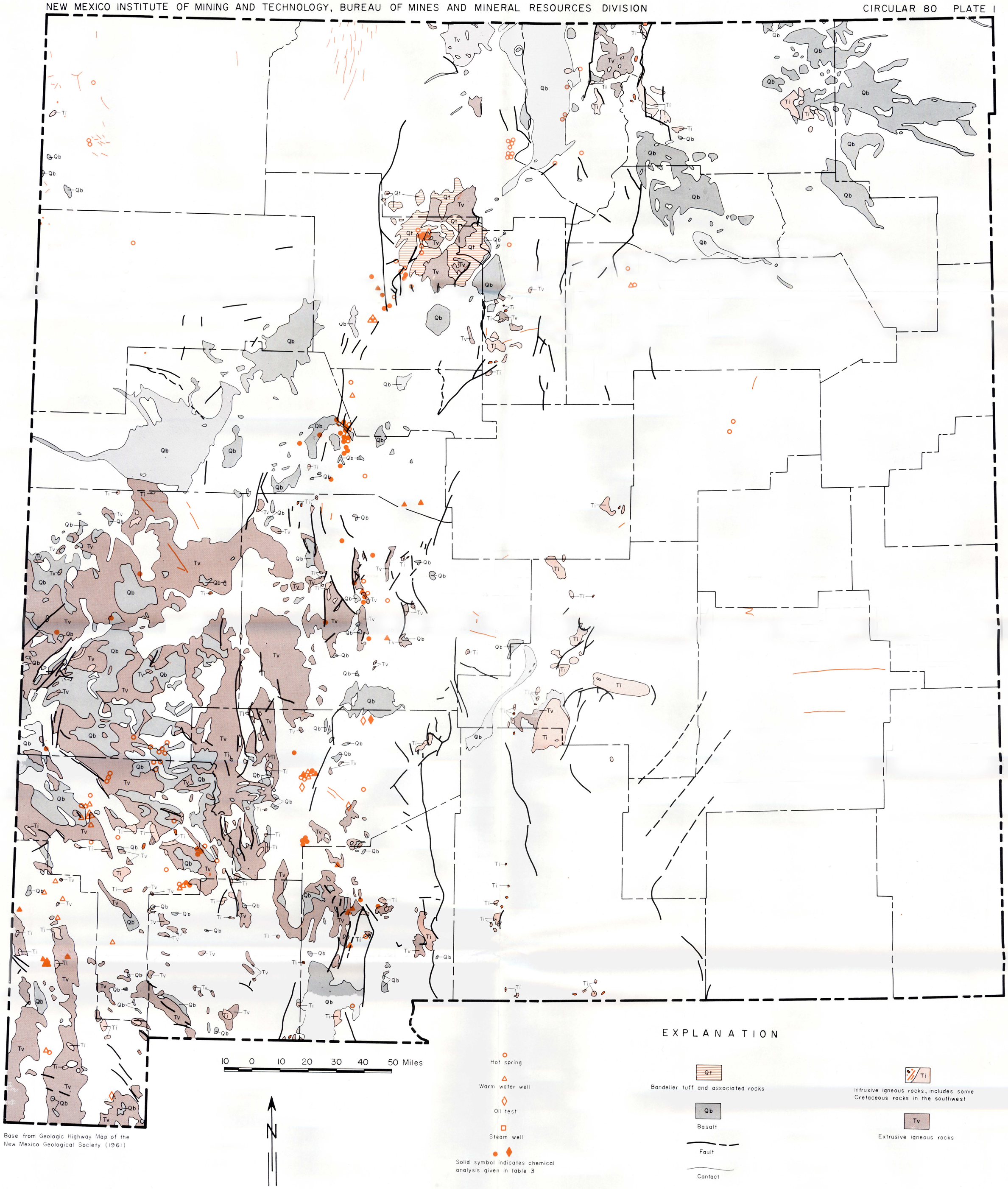
Owned by: Dunigan Tool and Supply Co., Abilene, Texas, and Baca Land and Cattle Company
Drilled by: Moran Bros., Inc., Farmington, New Mexico
Spudded:
Total depth: 2560 feet
Casing:
Yield: Steam discharged from depths of less than 1000 feet
Tested from 1300-1350 feet at 85,000 lbs of steam an hour
Temperatures reported up to 500°F
Bottom-hole temperature: 310° to 320°F, according to Baker Engineering Co.
Remarks: Well abandoned because of "sloughing problems"

C. Steam Well No. 2

Owned by: Dunigan Tool and Supply, Abilene, Texas, and Baca Land and Cattle Co.
Drilled by:
Spudded: July 1963
Total depth: 5600 feet
Casing: ? to 3460 feet
Yield: Casing perforated 2400 to 3100 feet, well discharged 100 barrels hot water an hour at 400+°F
Casing perforated 1750-2300 feet, well discharged 120 barrels hot water an hour at 400+°F
Remarks: Drilled with air below casing

D. Steam Well No. 3 (located 100 feet east of steam well No. 1)

Owned by: Dunigan Tool and Supply Co., Abilene, Texas, and Baca Land and Cattle Co.
Drilled by:
Spudded: 6/16/64
Total depth: ±2600 feet
Casing:
Yield: With casing perforated 1880 to 1936 feet, well discharged both steam and water
With casing perforated 1780-1840 feet, well discharged both steam and water



Base from Geologic Highway Map of the New Mexico Geological Society (1961)

THERMAL SPRINGS AND WELLS IN QUATERNARY AND TERTIARY IGNEOUS ROCKS IN NEW MEXICO