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THOMAS M. McCLURE
*State Engineer*
SANTA FE, NEW MEXICO

# THERMAL WATERS OF THE HOT SPRINGS ARTESIAN BASIN
# SIERRA COUNTY, NEW MEXICO

By
CHARLES V. THEIS, GEORGE C. TAYLOR, JR.,
AND
C. RICHARD MURRAY

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Charles V. Theis, George C. Taylor, Jr., and C. Richard Murray
Geological Survey, United States Department of the Interior

## ABSTRACT

Hot Springs, a health resort located on the Rio Grande in Sierra County, N. Mex., is the site of a number of hot mineral-water springs. The water rises in the alluvial material of the river's flood plain. Artesian wells drilled to the Magdalena limestone underlying the town also yield water of this kind. The purpose of the present investigation was to determine the amount of development that can take place at Hot Springs without adversely affecting either the temperature or supply of thermal water.

The geologic formations in the Hot Springs area range from Pre-Cambrian to Recent, in age. Pre-Cambrian rocks crop out half a mile south of the town, in the Sierra Caballos, and in the Mud Springs Mountains. Overlying the Pre-Cambrian rocks in the Sierra Caballos and Mud Springs Mountains are Paleozoic strata. Upper Cretaceous rocks crop out in the vicinity of Elephant Butte Reservoir, about 5 miles northeast of the area. Tertiary and Quaternary rocks form most of the surface of the Hot Springs area.

Great thicknesses of Tertiary and Quaternary volcanic rocks occur in the nearby San Mateo Mountains and the Black Range. Volcanic flows of Pleistocene age occur within a few miles of Hot Springs.

The geologic structure at Hot Springs is complex. The rocks in the nearby mountains are broken and contorted by faults and folds of great magnitude. Pre-Cambrian rocks are faulted against limestone of probable Magdalena age immediately south of the thermal water area, and the fault probably extends under cover westward past the Mud Springs Mountains.

Although the alluvium at Hot Springs conceals most of the details of the geologic structure, it is probable that the thermal water enters the Magdalena limestone along the fault zone south of its area of occurrence and moves up the dip of the Magdalena limestone, or perhaps through fractures in it, to discharge into the overlying alluvium. The basal part of the alluvium appears from well logs to be less permeable than the upper part. Movement upward into the alluvium is comparatively difficult so that the water in the Magdalena limestone is confined under artesian pressure. The thermal water moves laterally through the alluvium to the Rio Grande. The quantity of thermal water discharging, largely by natural means in this area, was determined to be about 3.5 second feet or about 2,260,000 gallons a day. About 130,000 gallons a day are discharged from artesian wells.

The chemical character of the thermal water is nearly the same throughout the area in which it occurs whether it is drawn from the Magdalena limestone or the overlying alluvium. In 8 samples calcium ranged from 148 to 155 parts per million, magnesium from 14 to 18, sodium and potassium from 714 to 772, bicarbonate from 210 to 219, sulphate from 73 to 105 and chloride from 1210 to 1330. The thermal water is distinctly different in chemical composition from the other ground water in the neighborhood. It is apparent that the thermal water has an entirely different source than the other ground water of the vicinity and does not mingle with the other water to any appreciable degree. The temperature of the thermal water ranges between 98 and 114°F.

A drawdown of water level in artesian wells of as much as 0.4 foot is produced daily by the pumping of nearby wells. In addition to this daily fluctuation of artesian pressure, there is a seasonal change produced by the stage of the water in the Rio Grande channel. A three-foot rise in the water level of the river produces an increase of approximately 0.7 foot in artesian head in the wells. The river is the ultimate discharge area of the hot water, and the piezometric surface indicates that the discharge from the artesian aquifer is somewhat localized along a line of easier escape. The water table in the thermal-water area has a similar seasonal fluctuation.

Pumping tests were conducted to determine the hydrologic characteristics of the Magdalena limestone aquifer. The wells that were tested yielded from 10 to 37 gallons of thermal water per foot of drawdown. Most of the pumps discharge about 50 gallons a minute, drawdowns varying from about 4¼ to 1¼ feet. The aquifer was found to be inelastic and anisotropic, with a higher transmissibility in the direction of the strike of the Magdalena strata.

The discharge of heat by the thermal water amounts to about 180 million calories a minute. To heat the water artificially would require the combustion of about 40 tons of coal a day. The heat is probably yielded by some means by a late igneous intrusion in the area. The heat could be furnished by conduction from such a body, but the chemical character of the water, particularly its high content of sodium chloride, suggests that both its heat and its locally unusual chemical character are derived from superheated steam and magmatic vapors rising from such an intrusion.

The present discharge of thermal water from artesian wells is only a small fraction of the discharge by natural means. Water level records show there has been no lowering of the piezometric surface because of over development. It is concluded that additional development of the water by artesian wells can take place without adverse effects. Periodic water-level and temperature measurements should be continued to detect any tendency toward cooling, dilution, or depletion of the thermal water.

# INTRODUCTION

## NATURE OF THE PROBLEM

The purpose of the present investigation has been to determine the amount of development of hot mineral water in Hot Springs that can take place without lowering the temperature or depleting the supply of water. In order to ascertain this it is obviously necessary to have as thorough an understanding as possible of the origin of the water, its movement, the location and amount of natural discharge, and the location and amount of artificial withdrawal. Furthermore, as the present study deals with a supply of hot water, the question regarding the nature of the source of heat becomes important. The Hot Springs area is in a region of greatly disturbed rocks, and the geologic processes that have occurred here are responsible both for the character of movement through the aquifer carrying the water and for the presence of the excess heat of the water. The present report, therefore, assembles all the evidence that could be obtained from geology and hydrology as to the nature of the movement of the water, the character of the aquifer, and the origin of the heat.

## SCOPE OF THE INVESTIGATION

The investigation of the Hot Springs artesian basin was carried on by the Division of Ground Water of the United States Geological Survey upon the request of and in cooperation with Mr. T. M. McClure, State Engineer of New Mexico. The work was carried on under the general supervision of O. E. Meinzer, Geologist in Charge of the Division of Ground Water, and under the immediate supervision of Charles V. Theis, Geologist in Charge of Ground Water Investigations in New Mexico, who outlined the field work to be undertaken, wrote certain sections of the report, and checked the complete report.

Four months in the first part of 1939 were spent in the field in collecting data relating to these problems by George C. Taylor, Jr., and some time was spent by C. R. Murray in the later part of 1939 and in the early part of 1940 in continuing observations and measurements. C. S. Conover, of the Geological Survey, ran levels to a number of the wells, assisted in pumping tests, made measurements of chloride content in waters of the area, and otherwise helped in the field and office work. Vincent C. Kelley, Assistant Professor of Geology at the University of New Mexico, was in the field with Mr. Taylor four days in the latter part of January 1939, during which time the general geology of the Hot Springs region was examined.

A brief investigation of the thermal waters of the Hot Springs area had previously been made in February 1929 by W. Carlos Powell[1], of the State Engineer's Office. In October 1937 Frank W. Robinson, also of the State Engineer's Office, visited the area and prepared a short memorandum for the State Engineer in which data on the hot springs and wells were tabulated.

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[1] Powell, W. Carlos, Report of An Investigation of the Hot Springs Artesian Basin; N. Mex. State Eng., 9th Bienn. Rept., pp. 123-127, 1930.

## GEOGRAPHIC FEATURES OF THE AREA

### LOCATION

The Hot Springs Artesian Basin is located along the flood plain of the Rio Grande, in the central part of Sierra County, in south-central New Mexico. Hot Springs is on U. S. Highway 85, 150 miles south of Albuquerque, and 120 miles north of El Paso.

The nearest railroad point to Hot Springs is Engle, a station on the Albuquerque-El Paso line of the Atchison, Topeka, and Santa Fe Railway, located 26 miles northeast of the town.

### TOPOGRAPHY

The southern part of the town of Hot Springs (fig. 1) is situated on a semicircular flat, about one-half to three-quarters of a mile wide, which is part of an old cut-off meander of the Rio Grande. Elephant Butte Dam, on the Rio Grande, is about 5 miles northeast of Hot Springs. Below the dam the river flows westward through a narrow canyon cut in Cretaceous rocks. About 2 miles northeast of Hot Springs the Rio Grande has been diverted to the north by an extensive alluvial fan formed by Cuchillo creek; a large northward loop is thus formed where the river cuts back to the south through the fan deposits and resumes its natural course.

Below Hot Springs the Rio Grande enters a narrow canyon cut in pre-Cambrian granite, through which it flows for about three-quarters of a mile. Beyond this canyon the valley widens and the river flows almost straight west. At the mouth of Mud Springs Wash, 3 miles southwest of Hot Springs, the river bends sharply to the south and enters the Rincon Valley, through which it passes in a series of wide meanders to the south line of Sierra County.

In the center of the town of Hot Springs there is a prominent ridge (pl. 1) rising about 150 feet above the river level. This ridge has a northwest-southeast trend and is formed by tilted Magdalena limestone strata having a steep dip to the southwest. The northern part of the town is situated on a terrace approximately 100 feet higher than the river level.

The most prominent mountain mass in the vicinity of Hot Springs is the Sierra Caballos, whose northern terminus is on the east side of the Rio Grande just below Elephant Butte reservoir. From this point the range trends southward, parallel to the course of the Rio Grande. The southern end of the Sierra Caballos is near Hatch in the northern part of Dona Ana County, 25 miles south of Hot Springs. Just west of Hot Springs are the Mud Springs Mountains, a range of low hills about 6 miles long, trending northwest. The south end of the San Mateo Mountains is about 20 miles north of Hot Springs. About 20 miles west of Hot Springs are the Animas Hills and the Sierra Cuchillo, which

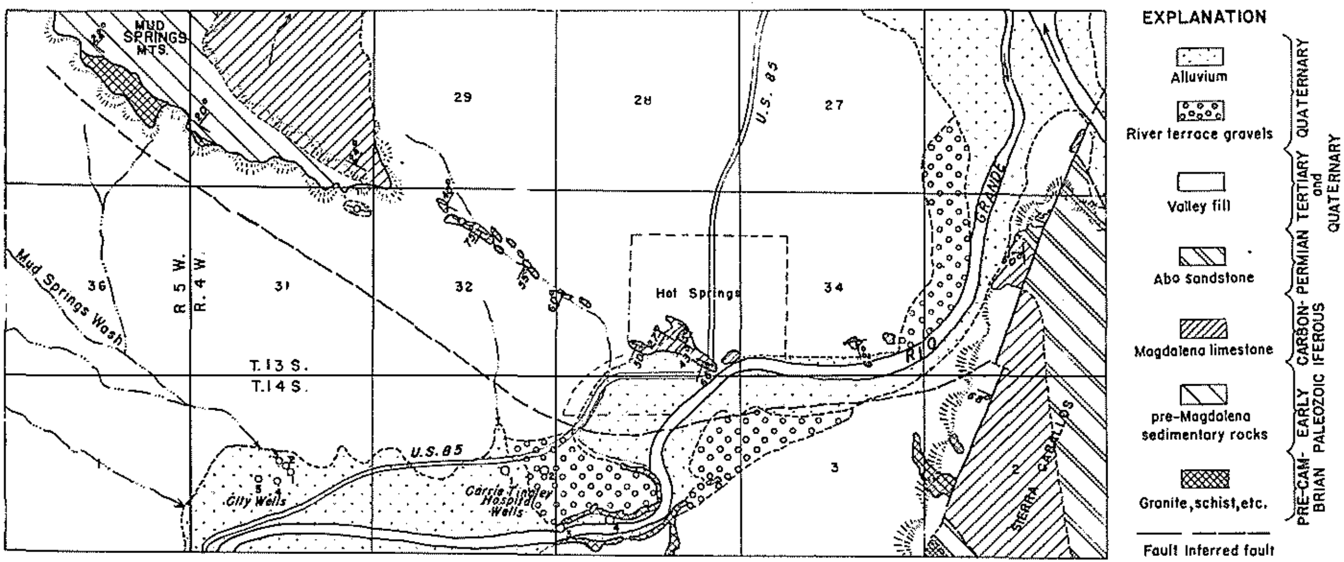

Fig. 1. Map showing geology in vicinity of Hot Springs, Sierra County, N. M.

trend north and south. Still farther west is the Black Range in which rise most of the larger eastward-flowing tributaries which enter the Rio Grande near Hot Springs.

Hot Springs lies in the Mexican Highland section of the Basin and Range Province[2]. The characteristic land forms of this physiographic section are isolated mountain ranges separted by aggraded desert plains. According to Gordon[3] there are three types of structure represented in the mountains of the Hot Springs region. The first of these types is the tilted mountain due to the displacement of a crustal block, often more or less modified by accumulations of volcanic material and by intrusions. In this classification are the Mud Springs Mountains, Sierra Caballos, and Sierra Cuchillo. A second type represented by the Black Range is due to the upthrust of a granitic core. The third type is due almost entirely to the accumulation of volcanic material and is represented by the San Mateo Mountains.

West of the town of Hot Springs is an extensive sloping plain or pediment. This surface is cut largely on the relatively soft beds of the Tertiary and Quaternary valley fill, but the same slope is maintained over areas of more resistant material. The gravel-covered surface of this pediment slopes gently eastward toward the Rio Grande and is trenched by steep-walled arroyos having almost parallel courses. Along the base of the mountains bordering the pediment, alluvial material in small fans and sheets has been deposited.

## CLIMATE AND VEGETATION

The climate of Hot Springs lies near the border line between the classifications for arid and semi-arid conditions. The greater part of the annual precipitation comes in the form of summer showers in July, August, and September. Light snows which rarely lie on the ground more than a day occur in the winter months. Temperatures on summer days range from 90° to over 100°F., but the heat is made more bearable by the dryness of the air. Climatological data for Elephant Butte Dam, which is located about 5 miles northeast of Hot Springs and at about the same elevation, are shown in the following summary:

*Summary of Climatological Data for Elephant Butte Dam Station Near Hot Springs, New Mexico*
(From United States Weather Bureau Reports)

| | |
|---|---|
| Elevation (feet) | 4,265 |
| Mean annual precipitation (inches) | 9.66 |
| Average annual snowfall (inches) | 5.00 |
| Mean annual temperature (degrees F.) | 59.8 |

On the flood plain of the Rio Grande and in small tributary arroyos near the river the native vegetation is typically an assemblage of cot-

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[2] Fenneman, N. M., Physical Divisions of the United States, Scale 1:7,000,000; U.S. Geol. Survey, 1930.

[3] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The Ore Deposits of New Mexico; U. S. Geol. Survey Prof. Paper 68, p. 220, 1910.

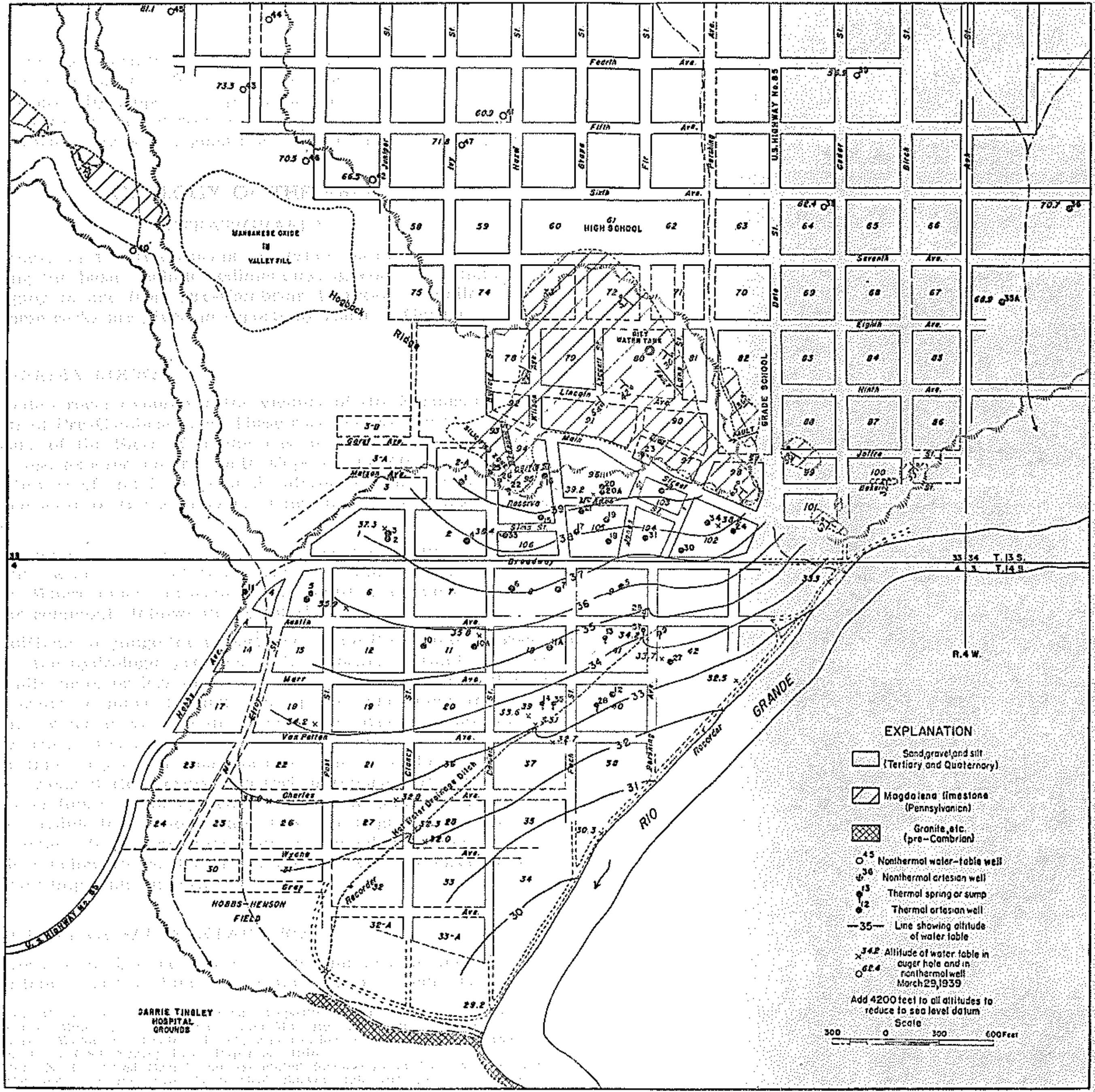

**Plate 1.** Map of Hot Springs, Sierra County, N. M., showing geological features, location of wells and springs, and altitude of water table in thermal water area on March 29, 1939.

tonwoods, willows, tornillo mesquite, tamarisk, and salt grass. These plants flourish in places where the water table is at shallow depth. The higher gravelly slopes and plains in the vicinity of Hot Springs support a sparse growth of creosote bush, mesquite, and cactus; and in small areas where the soil is good there are reaches of range grass.

## GEOLOGY OF THE AREA

### STRATIGRAPHY

The rocks in the Hot Springs Artesian Basin and in the region surrounding the basin include sedimentary, igneous, and metamorphic rocks ranging in age from Pre-Cambrian to recent. Detailed descriptions of these rocks are given in reports by Harley[4], Gordon[5], and Darton[6].

### *PRE-CAMBRIAN ROCKS*

The oldest rocks exposed in the vicinity of Hot Springs are granite and schists of Pre-Cambrian age. These rocks outcrop in the westward-facing scarp of the Sierra Caballos east of the river at Hot Springs. They are also exposed on the south slope of the Mud Springs Mountains, northwest of Hot Springs, and outcrop around and underlie the low terrace south of Hot Springs on which the Carrie Tingley Hospital is located.

The dominant Pre-Cambrian rock is a coarse-textured red-to-pink granite with which dikes of finer grained granite and pegmatite are associated. Where older mica-amphibole schist is intruded by granite, the granite commonly follows the schistosity.

It is difficult to judge the importance of the Pre-Cambrian rocks in relation to the hydrologic problem at Hot Springs. Granite and schist are generally more or less impermeable to water. However, it is possible for water to move through joint planes and other fractures in these rocks, which in view of the intense late structural movements in the Hot Springs area are probably more numerous and better developed here than they are in most localities. In the driller's logs of several of the wells at Hot Springs red rock is reported. It is thought that in most cases this is probably red jasperized Magdalena limestone, but it is quite possible that in some cases this rock is granite. On the whole, it would appear that these underlying basement rocks most probably form a floor below which it is impossible for water to circulate downward in any important quantity.

### *PRE-MAGDALENA SEDIMENTARY ROCKS*

The rocks lying between the Pre-Cambrian granite and the Magdalena limestone consist of limestone, sandstone, and shale. They seem to

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[4] Harley, G. T., The Geology and Ore Deposits of Sierra County, N. Mex.; New Mexico School of Mines, State Bur. Mines and Min. Resources, Bull. 10, 1934.

[5] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The Ore Deposits of New Mexico; U. S. Geol. Survey Prof. Paper 68, 1910.

[6] Darton, N. H., "Red Beds" and associated formations of New Mexico, with an outline of the geology of the State; U. S. Geol. Survey Bull. 794, 1928.

be of minor importance in the ground-water problem at Hot Springs. They are exposed in the southern part of the Sierra Caballos and in the Mud Springs Mountains. In the northern part of the Sierra Caballos the Magdalena limestone is in fault contact with Pre-Cambrian granite, and the Pre-Magdalena sedimentary rocks have been cut out. It is quite possible that the Pre-Magdalena strata are also absent because of faulting at the town of Hot Springs.

The lowest of the Pre-Magdalena sedimentary rocks is the Bliss sandstone which lies unconformably on the Pre-Cambrian rocks. It consists of quartzite with subordinate shales. It is reported by Darton[7] to have an average thickness of 100 feet in the Sierra Caballos. An Upper Cambrian age has formerly been assigned to the Bliss, but P. B. King[8] of the Geological Survey has lately secured evidence in support of an Ordovician age for it. The Bliss sandstone, like the granite below, can probably transmit water only along joint planes and fractures.

The El Paso limestone rests on the Bliss sandstone with apparent conformity, the contact frequently being gradational. The El Paso limestone is Lower Ordovician in age and consists of massive-beded gray dolomitic limestone whose weathered surface is usually covered with a fine network of brown chert. In outcrops in the Sierra Caballos it is reported by Darton[9] to be about 300 to 400 feet thick. In the Mud Springs Mountains the El Paso limestone has a thickness of approximately 300 feet.

The Montoya limestone, of Upper Ordovician age, rests disconformably on the El Paso limestone. The Montoya is a dark gray limestone somewhat more massively bedded than the El Paso limestone below. It has a thickness of 200 to 300 feet in this area.

The Fusselman limestone, of Lower Silurian age, rests unconformably on the Montoya limestone. It consists of two members, a lower one of compact gray limestone and an upper one of hard dark limestone containing fossils.

The Percha shale, of late Devonian age, rests disconformably on the Fusselman limestone. In most localities the lower beds are black fissile shales and the upper beds are chiefly gray and tan shale with nodular limestone. In the Sierra Caballos the Percha is about 250 feet thick, but in the Mud Springs Mountains only the upper beds are present and attain a thickness of approximately 70 feet.

A species of brachiopod which occurs in great abundance in the gray shale assigned to the Percha was identified by M. A. Stainbrook of Texas Technological College as "near, if not quite conspecific with *Atrypa devoniana.*" Another less abundant species of brachiopod from the same zone was identified by S. A. Northrop of the University of New Mexico as *Schizophoria striatula var. australis* Kindle. A species of brachiopod of the genus *Pugnax* is also fairly common in the Percha

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[7] Darton, N. H., op. cit., p. 10.

[8] King, P. B., Older Rocks of Van Horn Region, Texas; Am. Assoc. Petroleum Geologists Bull., vol. 24, No. 1, p. 153, 1940.

[9] Darton, N. H., op. cit., p. 11.

of this area. Within the lower three feet of the limestone overlying the shale a species of spirifer identified by C. E. Needham of the New Mexico School of Mines as *Spirifer occidentalis* is very abundant. This fossil indicates that the stratum is lowermost Magdalena in age, and that the Lake Valley limestone is absent in the Mud Springs Mountains.

In the Sierra Caballos to the south of Hot Springs the Lake Valley limestone, of early Mississippian age, rests disconformably on the Percha shale. It consists of bluish gray, massive or slabby coarse-grained limestone.

It is possible that some ground water moves through fractures and solution passages in the limestones in this lower section of stratified rocks, and that such conduits carry water from places of outcrop to the Magdalena limestone underlying Hot Springs where the main supply of hot water is found. However, because these rocks are nowhere exposed in the vicinity of Hot Springs except in the mountainous areas and because no wells have penetrated them in that vicinity, their hydrologic characteristics cannot be definitely ascertained.

### *MAGDALENA LIMESTONE*

The Magdalena limestone, of Pennsylvanian age, is apparently the chief aquifer yielding thermal water in the Hot Springs area; its characteristics were therefore studied in some detail in connection with this investigation. In most of southern New Mexico the Magdalena limestone generally rests on the Lake Valley limestone with no apparent discordance, although the two formations are separated by a break representing late Mississippian time. However, in the Mud Springs Mountains the Magdalena appears to rest directly on the Percha shale.

The Magdalena consists of thin-bedded to massive-bedded gray cherty limestone with dark gray and red shale in subordinate amounts. Sandstone, conglomerate, and limestone-pebble conglomerate are locally present. The formation is reported by Darton[10] to attain a thickness of 600 feet in the Sierra Caballos.

The following section of 361 feet of Magdalena strata measured in the Mud Springs Mountains in the SE¼ sec. 24, T. 13 S., R. 5 W., about 3½ miles northwest of Hot Springs, beginning with the uppermost strata, indicates the general character of the rocks:

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[10] Darton, N. H., op. cit., p. 322.

*Section of Magdalena Limestone in the Mud Springs Mountains, N. Mex. in the SE¼ sec. 24, T. 13 S., R. 5 W.*

| Strata | Thickness Feet |
|---|---|
| Gray limestone forming the north or dip slope of the mountains | 5 |
| Slabby gray limestone, weathers brown, contains many brachiopods | 10 |
| Limestone with shaly nodular partings, weathered surface having a distinct brown color because of included brown chert | 64 |
| Hard gray limestone | 5 |
| Thin-bedded limestone with some shale | 20 |
| Dark gray thick-bedded limestone | 11 |
| Alternating limestones and shales with a coarse-grained, light brown sandstone at the top | 104 |
| Dense black platy limestone, weathered outcrop appears brown because of included brown chert | 6 |
| Shale and limestone | 75 |
| Felsite sill | 35 |
| Dark gray cherty limestone (base of Magdalena) | 26 |
| | 361 |
| Gray and buff shale containing limestone nodules at top (Percha) | 72 |
| | 433 |

Dense light gray very thick-bedded limestone (Fusselman?) not measured.

The felsite sill occurring near the base of the Magdalena limestone weathers on its outcropping surfaces to a sandy or granular material which from a distance resembles a weathering shale bank. This sill where unweathered would tend to form an impermeable mass through which ground water could move only with difficulty. However, it lenses out before reaching the southeast end of the Mud Springs Mountains and therefore is probably not important in directing movement of the hot water in Hot Springs.

In the hill in the northwest part of Hot Springs the following section of Magdalena limestone, beginning with the uppermost strata, crops out from southwest to northeast. (See pl. 1.)

*Section of the Magdalena Limestone at Hot Springs, N. Mex., SE¼ sec. 33, T. 13 S., R. 4 W.*

| Strata | Approximate thickness Feet |
|---|---|
| Brown limestone largely replaced by red or dark gray chert and containing large cavities filled with calcite crystals along fault planes | 40 |
| Buff colored altered rock which appears to have been an argillaceous-to-sandy limestone from which calcium carbonate has been removed leaving a porous siliceous or argillaceous skeleton. Clay or ash-like material is locally present as are also large blocks of chert. Thick-bedded strata of bluish gray limestone occur near the top | 200 |
| Dense red limestone with subordinate amounts of gray limestone | 100 |
| Covered zone with no outcrops | 235 |
| Red nodular limestone | 25 |
| Black argillaceous shale | 12 |
| Red limestone with shale partings | 30 |
| Gray limestone | 40 |
| | 682 |

Wells in the southern part of the town of Hot Springs find hot water in seams and apparently in porous zones in the upper few feet of a limestone that appears from inadequate well logs to be similar throughout the developed area and is probably in the Magdalena limestone. The following well logs indicate its character so far as known:

Mrs. M. J. Scarborough, Well 31 in Block 104, SE¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W., Hot Springs Townsite
Temperature of water 112°F.

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand | 60 | 60 | Alluvium | Warm water |
| Conglomeration of clay and rock | 46 | 106 | Magdalena limestone and shale | First flow at 108 ft. |
| Seam rock | 11 | 117 | Probably Magdalena limestone | Some water at 115 ft. |
| Rock and clay | 135 | 252 | Magdalena limestones and shales | Open seam at 252 ft. |
| Caprock | 6 | 258 | Magdalena limestone | Good flow at 255 ft. |

### Bill Green, Well 19 in Block 105, SW¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
### Temperature of water 112°F.

Log by Bill Green, owner

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Owner's remarks |
|---|---|---|---|---|
| Blue clay mud | 2 | 2 | Alluvium | Warm water |
| Quicksand | 15 | 17 | Alluvium | Warm water |
| Clay with gravel | 7 | 24 | Alluvium | |
| Red rock | 3 | 27 | Jasperized Magdalena limestone | Water in crevice |

### G. L. Egbert, Well 11A in Block 10, NW¼NW¼NE¼, sec. 4, T. 14 S., R. 4 W. Hot Springs Townsite
### Temperature of water 113°F.

Log by Geo. Cook, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Coarse river sand and quicksand | 45 | 45 | Alluvium. Warm water | |
| Clay with some gravel | 56 | 101 | Alluvium. Water at 85 ft., 113°F. Pebbles of limestone and quartz. Coarse grit 1/16 inch in diameter with jasper and quartz grains. Light brown clay mixed with grit. | |
| Hard red rock with white rock in stalactitic pocket | 45 | 146 | Probably jasperized Magdalena limestone with secondary calcite filling cavities | |
| Gray rock with seams | 40 | 186 | Magdalena limestone | Water in crevice |

### E. L. Morris, Well 10A in Block 11, NE¼NE¼NW¼, Sec. 4, T. 14 S., R. 4 W. Hot Springs Townsite
### Temperature of water 108°F.

Log by Geo. Cook, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Sand | 58 | 58 | Alluvium | |
| Red clay | 34 | 92 | Alluvium | |
| Gray caprock | 98 | 190 | Magdalena limestone | |
| Granite | 15 | 205 | This may be jasperized Magdalena limestone | |

### C. E. James, Well 4 in Block 2, SE¼SE¼SW¼, Sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
### Temperature of water 114°F.

Log by Geo. Cook, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand and clay | 60 | 60 | Alluvium | |
| Red rock | 45 | 105 | Jasperized Magdalena limestone | Water in crevice |

### C. E. James, Well 6 in Block 8, NW¼NW¼NE¼, sec. 4, T. 14 S., R. 4 W. Hot Springs Townsite
### Reported temperature of water 116°F.

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand | 61 | 61 | Alluvium | |
| Red concrete and rock | 37 | 98 | Jasperized Magdalena limestone | |
| Gray caprock | 7 | 105 | Magdalena limestone | Water in crevice at 105 feet |

### Gregorio Alamendoz, Well 17 in Block 105, SW¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
### Temperature of water 112°F

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand | 42 | 42 | Alluvium | |
| Gray Caprock | 19 | 61 | Magdalena limestone | |

### Joe Joerger, Well 18 in Block 105, SW¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
### Temperature of water 111°F.

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand and clay | 22 | 22 | Alluvium | |
| Caprock | 33 | 55 | Magdalena limestone | Water in big seam |

Mrs. G. L. Mills, Well 20 in Block 96, SW¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
Reported temperature of water 106°F.

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Conglomeration of clay and sand | 128 | 128 | Probably largely Magdalena Magdalena limestone | Strong flow at 139 feet, 102°F. |
| Gray seam rock | 16 | 144 | | |
| Clay and boulders | 14 | 158 | Slumped blocks of Magdalena limestone in shales | Main flow at 144 feet, 106°F. |

G. L. Mills, Well 30 in Block 102, SE¼SW¼SE¼, sec. 33, T. 13 S., R. 4 W. Hot Springs Townsite
Temperature of water 111°F.

Log by L. A. Gordon, driller

| Log | Thickness (feet) | Depth (feet) | Writer's remarks | Driller's remarks |
|---|---|---|---|---|
| Quicksand | 63 | 63 | Alluvium | |
| Yellow clay and sand | 27 | 90 | Alluvium | |
| Quicksand | 15 | 105 | Alluvium | |
| Caprock | 17 | 122 | Magdalena limestone | Water in seam at 122 ft. |

## *PRE-TERTIARY STRATA OVERLYING THE MAGDALENA LIMESTONE*

The Abo sandstone, the basal formation of the Permian system rests on the Magdalena limestone. Darton[11] states that the contact of these two formations may possibly be unconformable in the Sierra Caballos. In the valleys of Cuchillo Creek and its tributaries near the northwest end of the Mud Springs Mountains, red limestones, sandstones, and shales are exposed; these strata may be uppermost Magdalena or basal Abo. Here the contact is gradational.

At the north end of the Sierra Caballos (fig. 1) the Abo consists chiefly of hard slabby reddish-brown sandstone interbedded with red shales and sandy shales. The basal member of the formation as observed in outcrops to the east of Hot Springs on the east side of the Rio Grande consists of 150 feet of red sandy shale with a few thin beds of gray limestone and red sandstone. The formation has an approximate thickness of about 800 feet in the Sierra Caballos[12].

Above the Abo sandstone are the beds called by Darton the Chupadera formation which form a considerable part of the eastern or dip slope of the Sierra Caballos. This formation does not outcrop in the vicinity of Hot Springs, but the occurrence of water containing an un-

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[11] Darton, N. H., op. cit., p. 322.
[12] Harley, G. T., op. cit.

usually large amount of calcium sulphate in the Howard well (No. 35A, pl. 1) in the northeast part of Hot Springs suggests the possibility that the gypsiferous Yeso formation may be present under cover in the region.

### *CRETACEOUS SYSTEM*

Rocks of Triassic, Jurassic, and Lower Cretaceous age are not known to be present in Sierra County, and Upper Cretaceous rocks rest directly on the Permian rocks. The lowest formation in the Upper Cretaceous is the Dakota (?) sandstone, which outcrops on the east flank of the Sierra Caballos. The Dakota (?) usually consists of a gray to buff hard massive sandstone from 80 to 100 feet thick. Above the Dakota (?) sandstone are the Mancos shale and the Mesaverde formation also of Upper Cretaceous age. These formations outcrop to the east of the north end of the Sierra Caballos in the vicinity of Elephant Butte Dam. The Mancos consists of gray marine shale with some sandstone and is 900 to 1,300 feet thick. Above the Mancos is the Mesaverde formation consisting of about equal amounts of white, brown, and red sandstone and shale. So far as is known, these rocks have no relation to the occurrence of the thermal water at Hot Springs.

### *TERTIARY AND QUATERNARY DEPOSITS*

Except in the mountains and in small areas elsewhere, the surface materials in the vicinity of Hot Springs consist largely of a valley fill of unconsolidated or poorly consolidated sand, gravel, and clay. These materials extend in places to great depths, probably to as much as 2,000 feet[13]. The valley-fill deposits, exclusive of obviously later terrace materials along the river, were named the Palomas gravel by Gordon[14] and were assigned to the Pleistocene because of their resemblance to and apparent continuity with the Gila conglomerate of Arizona, then regarded as most probably Pleistocene in age. The Gila is now known to be at least in part of Pliocene age. Bryan[15] considers the major part of the valley-fill deposits in the Rio Grande Valley in southern New Mexico to be contemporaneous with the Santa Fe formation which, as applied to Sierra County, is also the view of Harley[16]. Both named formations in their type areas are valley-fill deposits and they are certainly in part contemporaneous. The distinction between the two is largely based on early interpretations of the age of small and incomplete assemblages of vertebrate faunas, and in the absence of fossils the valley fill in a particular locality cannot be definitely assigned to either formation. In this report the deposits will be referred to as the valley fill. It is believed because of the relationship of the basin near Hot Springs to those farther north in the Rio Grande valley that probably most of the fill here is of Tertiary (Santa Fe) age although some of the later and higher deposits may quite probably be of Quaternary age.

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[13] Harley, G. T., op. cit., p. 30.

[14] Gordon, C. H., op. cit., p. 237.

[15] Bryan, Kirk, Geology and Ground-Water Conditions of the Rio Grande Depressions in Colorado and New Mexico; Regional Planning, Part VI, the Rio Grande Joint Inv. in the Upper Rio Grande Basin, vol. 1, p. 205, Nat. Resources Comm., 1938.

[16] Harley, G. T., op. cit., p. 29.

The valley fill underlies the broad pediments or slopes from the mountains west of Hot Springs to the Rio Grande. It is well exposed in bluffs bordering the Rio Grande near Hot Springs, in ravines leading into the Sierra Caballos on the east side of the Rio Grande, and in the canyon slopes of large tributaries entering the Rio Grande from the west. At the mouth of Mud Springs Wash, about 3 miles southwest of Hot Springs, these rocks are horizontal or nearly horizontal beds of soft sandstone, siltstone, clay, and conglomerate having an exposed thickness of from 150 to 200 feet. The bedding of the sediments at this point is quite regular, but in other localities there is a considerable horizontal gradation in the texture of the sediments from place to place. In bluffs along the Rio Grande the sediments are made up for the most part of about equal amounts of medium-to-fine grained soft sandstone and soft clay shale. Occasional beds of coarse-textured conglomeratic sandstone and grit also occur. The clay shales are usually light red or pink in color, and the sandstones are usually yellowish gray or light brown in color. In most of the outcrops along this bluff, weathering is concentrated on the bedding planes of the sediments giving the rocks a banded appearance due to the removal of the softer material before the hard.

On the western slopes of the Sierra Caballos, underlying younger alluvial fan deposits, there is a well-cemented fanglomerate containing angular and sub-angular cobbles and boulders as much as two feet in diameter imbedded in a heterogeneous, poorly assorted matrix of smaller pebbles, sand, and clay. The character of the fanglomerate is apparently largely dependent upon the nature of the adjacent bedrock from which the material was derived. Thus, adjacent to the Abo sandstone in outcrops east of Hot Springs the fanglomerate has a dark red color, and the pebbles and cobbles are chiefly reddish brown sandstone. At other points the pebbles are of limestone derived from the neighboring Magdalena limestone. In small ravines leading from the Sierra Caballos into the Rio Grande the gradation in texture from the poorly assorted fanglomeratic deposits along the base of the mountains to the well-assorted evenly bedded sandstones and clays which outcrop along the Rio Grande can be followed continuously through several intermediate textural phases.

In plate 1, an area is indicated in which manganese oxide forms the cementing material for sands of the valley fill. Manganese oxide is common in the vicinity of Hot Springs and was found in the Pre-Cambrian, lower Paleozoic, Magdalena, Tertiary, and Quaternary rocks. In many of these occurrences, it appears to have been deposited by hydrothermal solution, but in certain occurrences it may be detrital in origin.

The wells furnishing the municipal water supply of the town of Hot Springs derive their water from the valley fill. The logs of these wells, given below, indicate the general character of the upper part of these rocks in this region. The upper part of the sediments shown by these logs is of Quaternary age, but just where the line should be drawn between Quaternary and Tertiary sediments is doubtful.

Hot Springs city supply Well No. 4 in the NE¼SW¼ sec. 6, T. 14 S., R. 4 W.

20+ feet artesian head above ground level
Temperature 79°F.

Flow, April 28, 1939, was 200 gallons a minute

Log by A. D. Turner, driller

| Log | Thickness (feet) | Depth (feet) | Driller's remarks |
|---|---|---|---|
| Surface silt | 5 | 5 | |
| Clay | 10 | 15 | |
| Sand and gravel | 10 | 25 | Shallow unconfined water at 25 feet |
| Gravel | 5 | 30 | |
| Blue Shale | 5 | 35 | |
| Sand | 12 | 47 | |
| Gravel | 5 | 52 | |
| Sandy clay | 8 | 60 | |
| Gravel | 10 | 70 | |
| Red shale | 20 | 90 | |
| Adobe | 22 | 112 | |
| Sandstone | 8 | 120 | |
| Adobe | 17 | 137 | |
| Gravel | 6 | 143 | |
| Adobe | 7 | 150 | |
| Gravel | 3 | 153 | |
| Adobe | 11 | 164 | |
| Sandstone | 6 | 170 | |
| Adobe | 4 | 174 | |
| Gravel | 4 | 178 | |
| Adobe | 30 | 208 | |
| Gravel | 7 | 215 | Water-bearing |
| Adobe | 5 | 220 | First flow at 220 feet |
| Sand | 5 | 225 | Water-bearing |
| Adobe | 3 | 228 | |
| Sand | 10 | 238 | Water-bearing |
| Sandy adobe | 9 | 247 | |
| Sand | 4 | 251 | Water-bearing |
| Hard adobe | 19 | 270 | |
| Sand | 5 | 275 | Water-bearing, strong flow |
| Adobe (?) | 5 | 280 | |
| Sandstone | 5 | 285 | |

Note: Adobe according to the driller is a soft light-textured clay or clay shale.

Hot Springs city supply well No. 5 in the NE¼SW¼ sec. 6, T. 14 S., R. 4 W. 700 feet west of No. 4
20+ feet artesian head above ground level
Temperature 80°F.
Flow, June 15, 1939, was 250-300 gallons a minute
Log by A. D. Turner, driller

| Log | Thickness (feet) | Depth (feet) | Driller's remarks |
|---|---|---|---|
| Gravel | 8 | 8 | |
| Sandy adobe | 12 | 20 | Shallow water (cased off) |
| Sand and gravel | 10 | 30 | |
| Sandy adobe | 5 | 35 | |
| Sand and gravel | 58 | 93 | |
| Adobe | 22 | 115 | |
| Gravel | 2 | 117 | |
| Adobe | 23 | 140 | |
| Sand | 3 | 143 | Nonflowing artesian water rose to within 6 feet of ground level |
| Adobe | 50 | 193 | Main confining bed |
| Sand | 5 | 198 | Water flowed at surface |
| Adobe | 21 | 219 | Secondary confining bed |
| Sand | 7 | 226 | Flow increased |
| Adobe | 9 | 235 | |
| Sand | 5 | 240 | Flow increased |
| Adobe | 10 | 250 | |
| Sand | 5 | 255 | Flow |
| Adobe | 5 | 260 | |
| Sand | 8 | 268 | Strong flow |
| Gravel with sand | 7 | 275 | |

Note: Adobe according to the driller is a soft light-textured clay or clay shale.

Younger than these deposits are the unconsolidated sands and gravels forming the terraces along the Rio Grande near Hot Springs. Some of this material has been brought in by the river from a considerable distance, and some is probably reworked material derived from older Quaternary and Tertiary deposits. The thickness of these terrace deposits is quite variable. Along the north and west side of the Rio Grande just east of Hot Springs there is a terrace level averaging 1,200 feet in width and standing approximately 60 feet above the present river level. The gravel deposits forming this terrace are about 15 to 45 feet in thickness and rest upon the uneven surface of older sediments of the valley fill. Remnants of terraces at about the same level above the river are found on the south and east side of the Rio Grande at several points between Hot Springs and the mouth of Palomas Creek. Just south of Hot Springs there is a thin mantle of these terrace gravels resting on a surface of Pre-Cambrian granite. In Hot Springs a similar gravel deposit partially covers the ridge of Magdalena limestone and adjacent older Quaternary and Tertiary deposits.

Still younger than the terrace gravels are the sediments underlying the present flood plain of the Rio Grande. The size of this material ranges from fine silt and clay to pebbles the size of which is dependent on the carrying power of the Rio Grande at the time of deposition. At Hot Springs and vicinity these deposits are relatively thin in comparison with their thickness in other parts of the Rio Grande Valley. Logs of wells drilled in Hot Springs indicate that the thickness of the flood-plain deposits at this point ranges from about 20 to 100 feet. At this location the flood-plain deposits are essentially clay and fine to coarse sand with occasional stringers of fine gravel.

About one mile southwest of Hot Springs, just below the lower end of the canyon cut by the Rio Grande in the Pre-Cambrian granite, the thickness of the flood-plain deposits is indicated by the log of well No. 1, Carrie Tingley Hospital, to be about 50 feet. The sediments comprising the flood-plain deposits at this point are clay, gravel and fine-textured sand. In the granite canyon just south and east of this point two test wells were drilled (Carrie Tingley Hospital Wells Nos. 3 and 4, fig. 1). One encountered Pre-Cambrian bedrock at 25 feet after going through sand, clay, and gravel; the other well went down 55 feet in sand and gravel in which the well ended.

## *TERTIARY AND QUATERNARY IGNEOUS ROCKS*

Considerable igneous activity took place in the region around Hot Springs in Tertiary and Quaternary time. Great thicknesses of lavas and tuffs of probable Tertiary age form the San Mateo Mountains to the north and the Black Range to the west of Hot Springs. Basalt flows of Quaternary age cover a large area northeast of the Fra Cristobal Range and smaller areas near Elephant Butte and in Palomas Creek, about 15 miles west of Hot Springs. Bryan[17] considers the San Marcial flow, northeast of the Fra Cristobal Mountains, to be of approximately the same age as the broad Ortiz pediment, and the flows near Elephant Butte to be of even later age. Hence, it appears that volcanic activity in the area extended well into the Pleistocene.

Nearer to Hot Springs intrusive igneous rocks are found in the Mud Springs Mountains and in the Sierra Caballos. Their age is not definitely known, but they are probably related genetically to either the Tertiary or Quaternary igneous rocks of the surrounding area. A felsite sill is intruded into the Magdalena strata in the Mud Springs Mountains a few feet above the base of this formation. This sill is about 35 feet thick, and it is exposed along the strike of the Magdalena for more than a mile. The rock of the sill is badly weathered on its outcropping surfaces and is light gray in color. Needlelike crystals of a black mineral resembling hornblende are abundant in the rock. Near the northwest end of the Mud Springs Mountains a dike of gray porphyry cuts the lower Magdalena strata along a fault zone. This rock has large pink feldspar phenocrysts and somewhat smaller white phen-

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[17] Bryan, Kirk, op. cit., pp. 218-219, 1938.

ocrysts of plagioclase feldspar. Small colorless glassy crystals of quartz are also rather abundant. Biotite mica in flakes and hexagonal-shaped crystals forms black phenocrysts. Another sill was observed in the small area of Abo sandstone on the western side of the transverse fault at the north end of the Sierra Caballos. This rock is dark gray in color and is probably of andesitic or basaltic composition. The presence of such igneous intrusions in the vicinity of Hot Springs is of significance with regard to the origin and heat of the waters of the area. They are of particular significance with regard to the possibility that there may be a deep-seated igneous intrusion without surface expression at Hot Springs. Such an intrusion would perhaps account both for the chemical character and temperature of the thermal water at Hot Springs.

## STRUCTURAL FEATURES

### *GENERAL FEATURES*

The larger structural features of the general area of Hot Springs are shown on the geologic map of New Mexico[18]. Some revisions in the areal geology as shown on this map for the immediate vicinity of Hot Springs are indicated on the more detailed map accompanying this report (fig. 1). The geology of the area shown on the map was plotted on aerial photographs on a scale of 2 inches to one mile.

The major structural lines in the region around the Hot Springs Artesian Basin appear to have been formed principally during the period of early Tertiary igneous activity during which time the great thicknesses of rhyolite, andesite, and latite forming the greater part of the Black Range and the San Mateo Mountains were extruded. Harley[19] believes that probably most of this activity occurred in Oligocene time.

The Black Range west of Hot Springs has an anticlinal structure caused by the upthrust of a granitic core. The Sierra Caballos, which lies east of the Rio Grande, is a fault block tilted to the east. The Fra Cristobal Range also lies east of the Rio Grande and extends from a point about 6 miles north of Hot Springs to a point about 25 miles north. It also is a fault block tilted to the east, offset from the Sierra Caballos fault block about 10 miles to the east. Between the two ranges is an area of Cretaceous and early Tertiary strata depressed relative to the ranges to the north and south.

The main elements of the structure as shown east of the river near Hot Springs therefore appear to be north-south faulting along the river tilting the strata to the east, on the one hand, and on the other a contrary and interfering depression of the strata along a northwest axis between the two ranges in the neighborhood of Elephant Butte Dam.

Immediately west of the river near Hot Springs the bedded rocks are largely concealed beneath the valley fill. The Magdalena limestone appears in several small outcrops and in the prominent hill in Hot Springs, where the strike of the beds is dominantly west-northwest. This structural trend is continued in a series of small hogback ridges of

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[18] Darton, N. H., Geologic map of New Mexico, op. cit.
[19] Harley, G. T., op. cit., p. 31.

Magdalena limestone extending west-northwest from Hot Springs to the Mud Springs Mountains. Here again the strike is west-northwest, although a reversal in dip has occurred between Hot Springs and the Mud Springs Mountains. The Mud Springs Mountain Range is a small faulted block in which the fault line is on the south side and the dip of the beds is to the northeast.

## *STRUCTURE OF THE SIERRA CABALLOS*

The Sierra Caballos, which lies east of the Rio Grande and extends from a few miles north of Hot Springs to about 25 miles south, is a faulted block with a steep escarpment on the west side facing the Rio Grande and a low dip slope to the east. Pre-Cambrian rocks overlain by lower Paleozoic strata and Magdalena limestone make up the west facing scarp, and the Permian and Cretaceous strata outcrop on the dip slope. North-south faults are apparent on the dip slope, the blocks to the east being depressed relative to those to the west. As shown on the State map, the most prominent of these faults bears northwestward near the north end of the mountains, where it is also shown on figure 1. The fault here intersects the northeastward trending fault described below. As suggested by Darton [20], it may extend under cover past the northeast side of the Mud Springs Mountains (Cerro Cuchillo of Darton), west of Hot Springs.

Near Hot Springs a prominent fault striking about N. 20° E. and dipping 70° W. cuts across the north end of the Sierra Caballos. (See fig. 1.) This fault is the southward continuation of the fault mapped by Lee[21] passing under Elephant Butte reservoir. To the south this diagonal fault dies out, and a normal depositional sequence of Pre-Cambrian, lower Paleosoic, and Magdalena limestone is present at the southwest corner of sec. 2, T. 14 S., R. 4 W., or about 3 miles north of where the geological map of New Mexico[22] shows lower Paleozoic strata.

The resultant of the movements which have occurred along this fault has been such that the rocks on the west or hanging wall side are raised with respect to those on the east; thus, in sec. 2, T. 14 S., R. 4 W., Pre-Cambrian rocks exposed by erosion of the overlying valley fill on the west side of the fault line are in fault contact with Magdalena limestone which occurs on the east side of the fault. Farther north the fault is bordered on the east by the Abo sandstone and on the west by the valley fill, Magdalena limestone, and Abo sandstone. Near the north end of the fault, as shown in figure 1, there is a small area of dune sand which partially covers what is believed to be Cretaceous shale. This fault is marked by a conspicuous sheared and brecciated zone which has a width in some places of over 100 feet. This zone has been mineralized chiefly by quartz, jasper, calcite, and barite. Along a considerable part of the length of the fault the rocks on the east side have a domed appearance, that is, at a distance of a few hundred feet east of the fault the rocks have a normal eastward dip whereas near

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[20] Darton, N. H., op. cit. (Bull. 794), pp. 323-324.

[21] Lee, W. T., Water Resources of the Rio Grande Valley in New Mexico and Their Development; U. S. Geol. Survey Water-Supply Paper 188, pl. 8, 1907.

[22] Darton, N. H., Geologic Map of New Mexico, op. cit.

the fault they dip to the northwest or, in other words, into the fault. Immediately adjacent to the fault this dip becomes very steep having the appearance of being either down drag or secondary stratification caused by severe crushing and re-cementation along the fault.

Probably at least two periods of movement took place along this fault: one movement previous to the deposition of the valley fill in which the Magdalena and Abo strata along the fault were badly broken, and a second less important movement after the deposition of the valley fill. Evidence that the valley fill has been faulted is shown by sheeting in this material near the fault.

## *STRUCTURE OF THE MUD SPRINGS MOUNTAINS*

The Mud Springs Mountains, called the Cerro Cuchillo by Darton[23] and Lee[24], lie a few miles northwest of Hot Springs. The mountains are a comparatively small faulted block, with a steep scarp to the southwest and dip slopes to the northeast.

The maximum elevation and greatest width of the Mud Springs Mountains are attained near their center. At this point the trend of the mountains changes from northwest to more nearly north. Pre-Cambrian granite occurs at the southern base of the mountains. The slope of the mountains rises gently on the granite, but the overlying Bliss, El Paso, and Montoya strata give rise to precipitious southward facing cliffs. Approximately a mile farther north the Magdalena limestone forms another escarpment and the dip slope of the mountains. Between the two crests a strike valley approximately follows the contact of the Fusselman limestone and the Percha shale. The sequence of strata outcropping on the north side of this valley was given earlier.

The dip of the Paleozoic beds throughout most of the uplift is close to 20° to the northeast. At the extreme southeast end the Ordovician strata have extremely high dips to the northeast and at the most southerly exposure are vertical. The Tertiary and later alluvial materials overlap the Paleozoic strata with little or no distortion.

## *STRUCTURE OF THE MAGDALENA LIMESTONE IN THE VICINITY OF HOT SPRINGS*

The geologic structure of the area near Hot Springs is complicated, and the thick cover of Tertiary and later alluvial deposits over the bed rock makes it impossible to determine many of the details.

A narrow band of Magdalena limestone forms a wide arc of discontinuous outcrops extending from the southeast tip of the Mud Springs Mountains to outcrops abutting the west side of the diagonal fault across the north end of the Sierra Caballos (fig. 1). The strike of the beds is more or less parallel to the band of outcrops. Thus, a short distance northwest of Hot Springs the beds are striking northwest, and just east of Hot Springs they are striking northeast. In the

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[23] Darton, N. H., "Red Beds" and associated formations in New Mexico with an outline of the geology of the State; U. S. Geol. Survey Bull. 794, p. 319, 1928.

[24] Lee, W. T., op. cit., pl. 1.

Mud Springs Mountains, the north or dip slope of which is capped by Magdalena limestone, the dip of the beds is to the northeast ranging in amount from about 20° to 25°. About one quarter mile southeast of the eastern end of the Mud Springs Mountains there is a sharp reversal of dip shown in the Magdalena limestone in two small outcrops (fig. 1). In the westernmost outcrop the strike is approximately northwest and the dip is about 40° to the northeast or in about the same direction as the general dip of the rocks in the Mud Springs Mountains. In the next outcrop, about 300 feet south and east and separated from the first by a cover of sand and gravel, the beds also strike northwest, but the dip is vertical. On following the Magdalena outcrops toward Hot Springs, the dip changes from vertical to southwest as in Hot Springs. The amount of this southwest dip is quite variable in Hot Springs (pl. 1) ranging from over 60° near the intersection of Date and Main Streets to 5° northwest of the city water tank, where there is a sudden flattening in the dip of the strata at least in part caused by local faulting.

Just west of where the reversal in dip occurs, the following sequence comprising about 50 feet of beds was observed from north to south: brown limestone composed largely of cup corals, 15 feet of gray limestone, red banded limestone containing numerous corals, blotchy brown and gray limestone, and light gray crystalline limestone, the weathered surface of which is covered with brown chert. The northeast dip of 40° is easily discernible in the brown coral limestone, and the northeast dip can be seen as far down in the section as the red banded limestone. In the remaining lower beds to the south the limestone is intensely jointed, bedding planes are not detectible, and the direction of dip cannot be determined.

The sequence of strata exposed poorly in Hot Springs could not be matched elsewhere, no well-developed ripple marks are present in the bedding planes, and no other criteria were found which would indicate whether or not these beds are overturned.

The interpretation of the structural features in the vicinity of Hot Springs is difficult because of the cover of valley fill over most of the area. Undoubtedly there is a fault trending more or less east-west between the southernmost of the hot-water wells in the city tapping limestones of probable Magdalena age and the exposures of Pre-Cambrian rocks in the terrace underlying the Carrie Tingley Hospital, for these limestones where seen in outcrop are dipping southerly into the granite. The presence of the half-exhumed ridge of steeply dipping Magdalena beds passing from the area both to the east and west indicate the structural trend in the vicinity and because of their considerable distortion suggest strongly that the line or zone of faulting in Hot Springs is continued as shown on figure 1 from the southern base of the Mud Springs Mountains to the western edge of the Caballos. This fracturing is probably complicated and probably comprises a zone of faulting rather than a single fault. All available direct evidence indicated that the upthrown side is on the south—obviously so in Hot Springs and apparently so in the Mud Springs Mountains, where the northeasterly dip increases toward the south to become vertical at the southern end of the mountains near the presumed fault, suggesting drag on a down-thrown block. There is some suggestion, however, that this apparent drag may be connected with subsidiary faulting, in that the strike of the beds here intersects the area of crushing and reversal of dip in the western part of the line of discontinuous Magdalena outcrops between the Mud Springs Mountains and Hot Springs.

The gross features of the geological structure suggest thrusting of a southwestern block over one to the northeast accompanied by the crumpling of the sediments in the northeastern block shown in the connecting ridge of Magdalena outcrops between the Mud Springs Mountains and Hot Springs. However, so much of the structure is concealed by the valley fill that some of the visible features may be incidental distortions of a number of individual blocks not to be correlated with the major structure. A complete elucidation of the structure must await more detailed geological work throughout the area and is apparently not necessary to the hydrologic problem.

## GEOLOGIC HISTORY

The oldest rocks in the Hot Springs area are in the Pre-Cambrian granites and schists which underlie all of the younger rocks. Resting upon the eroded surface of the Pre-Cambrian rocks is a thick succession of Paleozoic limestones, sandstones, and shales and Upper Cretaceous sandstones and shales, separated from each other by periods of non-deposition and erosion.

During late Cretaceous and early Tertiary time[25], folding, such as gave rise to the anticline of the Black Range, took place. Later in conjunction with igneous activity major faults having a north-south trend gave rise to the present structural features.

Tertiary igneous activity probably began during Oligocene[26] time with the extrusion of andesite flows along fault zones previously established. Faulting continued during this period, and possibly as a result of the removal of lava from below and accumulation on the surface, fault blocks settled unequally and became tilted. In further igneous activity magmas of monzonite and granodiorite intruded the Paleozoic rocks as stocks, sills, and dikes, finding easiest access in zones of faulting. Then followed a period of erosion during which time a considerable part of the Tertiary volcanics were removed. Subsequently another period of igneous activity occurred, great thicknesses of rhyolitic lavas were extruded, and the older rocks were completely covered in places. Following this period of igneous activity there was another period of erosion during Miocene and Pliocene time. Throughout this interval the highlands were being eroded, and the material derived from this erosion was accumulating in the Rio Grande trough and building up the sands, gravels, and silts of the valley fill. Small movements principally along old faults occurred at this time but not in the magnitude of the earlier faulting. There was movement at this time or possibly later along the diagonal fault cutting the north end of the Sierra Caballos where conglomerate, believed to be of Tertiary age, is

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[25] Harley, G. T., op. cit., p. 38.
[26] Idem. p. 38.

now in fault contact with Magdalena and Abo rocks. The conglomerate is considerably sheared and sheeted along this fault zone. The movement along the conjectured fault to the south of the Mud Springs Mountains and through the town of Hot Springs took place before deposition of the valley fill, since the valley fill lies horizontally and without break around the tilted block of the Mud Springs Mountains and across the Magdalena limestone ridge passing through Hot Springs.

Quaternary time was marked by continued erosion during which old fault blocks were planed down and the Tertiary intrusive rocks of the highlands were deeply eroded. The debris from this erosion was laid down principally on the earlier valley fill deposits. Later, basalt flows were extruded at several points near Hot Springs, notably near Elephant Butte Dam and near the hills about 20 miles west of Hot Springs. Most of these flows were extruded along old fault zones, showing that the faults are of a deep-seated type. A basalt flow near the north end of the Fra Cristobal Range was believed by Lee[27] to have diverted the Rio Grande from an old course through the Jornada del Muerto lying on the east side of the Fra Cristobal Range to its present course on the west side of this range and the Sierra Caballos. Subsequently the Rio Grande in establishing a new grade began to cut into the deposits of valley fill. Side tributaries heading in the Black Range in adjusting themselves to this new grade cut the broad eastward sloping plain lying to the west of the Rio Grande and to the east of the foothills of the Black Range. The Rio Grande apparently remained at this grade for a considerable length of time before again beginning its cycle of downcutting in which terraces were formed along the main stream. The side tributaries, notably Cuchillo Creek and Palomas Creek, in adjusting their courses to the changing grade of the Rio Grande also developed corresponding terraces.

Of geologically recent time are the flood-plain deposits underlying the present Rio Grande, the alluvial fans forming along the bases of the highlands, and wind-blown sand now accumulating along lee slopes.

## HYDROLOGIC FEATURES OF THE AREA

### OCCURRENCE OF GROUND WATER

Ground water in the vicinity of Hot Springs has a three fold occurrence: namely, in the Magdalena limestone of Pennsylvanian age, in Tertiary and Quaternary valley fill, and in the recent deposits underlying the flood plain of the Rio Grande. This report is primarily concerned with the thermal water occurring in recent alluvium and in the Magdalena limestone in the town of Hot Springs, but nonthermal ground water occurring in the neighboring Tertiary and Quaternary valley fill and in flood-plain deposits of the Rio Grande is also considered, since it is part of the general ground-water system in the Hot Springs area. The information available on wells and springs yielding hot water is given in table 1 and on wells yielding water of nearly normal temperature in table 2.

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[27] Lee, W. T., op. cit., p. 23.

*THERMAL WATER*

According to one method of classification, waters having temperatures above the mean annual air temperature for the region under consideration are classed as thermal. The mean annual air temperature at Elephant Butte Dam, about 5 miles from Hot Springs, is 59.8°F. Under this classification practically all of the ground water in the Hot Springs area could be classed as thermal, with the possible exception of the ground water constituting the underflow of the river. Other methods class as thermal only those waters having a temperature appreciably above the mean annual temperature. Gilbert[28] in his report on the hot springs of the United States placed only those waters having temperatures exceeding the mean annual air temperature by 15°F. in the hot springs class. In general only those waters which are recognized as being appreciably warmer than usual in a region are now classed as thermal[29]. In studying the Hot Springs area, it was found that there is a large area around the town itself in which the waters have temperatures ranging up to 80°F. There is then a gap of 18° to the lowest temperatures of the waters considered "hot" in the area, for which temperatures range from 98°F. to 114°F. Because of this gap and for purposes of discussion in this report only those waters having temperatures above 90°F. are called thermal, while those waters below this temperature are called nonthermal. This separation is also justified on mineral content as the water with the higher temperatures also has a much higher mineral content than the typical water with the lower temperatures.

The hot waters of the Hot Springs Artesian Basin are confined to a relatively small area in the N½ sec. 4., T. 14 S., R. 4 W., and the S½ sec. 33, T. 13 S., R. 4 W., lying within the limits of the town of Hot Springs. (See pl. 1.) Practically all of the developed area is within a radius of a quarter of a mile from the south quarter corner of sec. 33, T. 13 S., R. 4 W. This area is south of the ridge of Magdalena limestone passing through the center of the town of Hot Springs and north of the granite outcrop on the south side of the small semicircular alluvial flat which is part of the Rio Grande flood plain. The wells and springs in this area are shown in plate 1. Hot water with temperatures ranging from 98°F. to 114°F. is obtained principally from the Magdalena limestone in joint and bedding planes, solution cavities, and fractures near the fault zone between the Magdalena limestone and the Pre-Cambrian granite (see fig. 1), but also occurs in the alluvium overlying the Magdalena.

As indicated by the hydrologic and geologic features of the area, the circulation of the water appears to be as follows: The hot water apparently rises in the fault zone between the developed area and the Pre-Cambrian ridge on which the Carrie Tingley Hospital is situated. It apparently migrates up the dip of the Magdalena beds, which are dipping into the fault at this point. The water that is not intercepted

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[28] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 144, 1875.

[29] Stearns, Norah D., Stearns, Harold T., and Waring, Gerald A., Thermal springs in the United States; U. S. Geol. Survey Water-Supply Paper 679-B, p. 61, 1937.

by wells in the Magdalena limestone escapes into the overlying alluvium. The permeability of the alluvium in the vertical direction is such that the hot water can move up through it but can do so only very slowly and with considerable difficulty; hence it acts as an imperfect confining bed for water in the Magdalena limestone. The hot water escapes by slow upward penetration into the alluvium and by migration up the dip of the Magdalena beds to the point where the alluvium pinches out by overlap against the hill of Magdalena limestone in the center of the town of Hot Springs. At the edge of the alluvium and base of the hill hot water moves around the end of the confining bed out of the Magdalena and into the upper part of the alluvium, which appears to be somewhat more permeable than the lower part. The springs, State spring 22 and Government spring 23, occurring near the contact of the alluvium and the Magdalena limestone, represent the overflow from the Magdalena along this zone. The larger part of the water in the alluvium discharges into the river or the hot water drain. The character of the rocks from which the hot water is derived is shown by the well logs.

As discussed more fully later, there is no outstanding variation in temperature or quality of the water in this area. Water obtained from the alluvium in areas where circulation is rapid because of pumping or natural flow has a temperature near that of the hotter wells in the Magdalena limestone, and the chemical character and concentration of the water is also the same in the two aquifers.

### *NONTHERMAL WATER*

Nonthermal ground water in the vicinity of Hot Springs occurs in the sands and gravel of the valley fill and in Recent alluvium in the flood plain of the Rio Grande outside the hot-water area in the town of Hot Springs. Numerous shallow dug and drilled wells near Hot Springs obtain domestic supplies from the flood-plain materials. The water table in this material usually lies within 20 feet of the surface.

On the north side of the ridge of Magdalena limestone in Hot Springs ground water is obtained from sands and gravels in the Tertiary and Quaternary deposits at depths ranging from 50 to 200 feet. Water is found under artesian conditions in three domestic wells located in the SW¼ sec. 34, T. 13 S., R. 4 W. In only one of these wells, No. 35A, plate 1, is the artesian pressure sufficient to cause the water to flow at the surface; in the other two the water rises to within a few feet of the surface. Shallow unconfined ground water was encountered above the artesian horizons in all of the wells but was cased off. Artesian water was encountered in the Swingle well, No. 36, plate 1, in the NW¼ SW¼ sec. 34, at 135 feet and again at 155 feet and 185 feet in soft sandstone. The water from the lowest aquifer is reported slightly warm. From the elevation of the water table as shown by measurements in a few wells in this area (see pl. 1), the water in the valley fill appears to move in a northeasterly direction away from the limestone ridge in the town. The ultimate point of discharge of this water is the Rio Grande, but measurements indicating the shape of the water table here are too few to determine the exact path of movement. A part of the water moving down this gradient is probably trapped in gravel beds between more impervious clay beds, thus giving rise to artesian conditions in the SW¼ sec. 34.

Five flowing artesian wells, three of which supply water to the municipal water-supply system of Hot Springs, have been drilled on the edge of the flood plain of the Rio Grande near the center of sec. 6, T. 14 S., R. 4 W., near the mouth of Mud Springs Wash. All of these wells encountered ground water under artesian pressure in three or more sand and gravel beds in the valley fill within depths of 300 feet of the surface. The combined flow of the three wells supplying the Hot Springs city system is about 550 gallons a minute. The temperature of the water from these wells ranges from 78°F. to 80°F.

Another flowing artesian well in the same area was recently completed by Dr. T. B. Williams of Hot Springs. The water from this well is being used for domestic and irrigation purposes in the west suburban addition to Hot Springs.

This well is said by the owner to flow approximately 500 gallons a minute. No measurements of the flow could be made during the investigation. It is believed that ground water in the aquifer supplying these wells occurs under conditions similar to those discussed for the north side of Hot Springs. The detailed character of the aquifers supplying these wells is shown in the well logs.

The temperature of the water from the city wells is about 80°F., which is about 20° above the mean annual air temperature. The high temperature of the water in these wells, as also in those on the north side of town, which range from 75°F. to 80°F., is probably genetically related to the heat in the thermal water area.

## QUALITY OF WATER

### *MINERAL CONTENT OF THE GROUND WATERS*

The chemical character of water from several wells in the Hot Springs area is shown in the following table:

## ANALYSES OF WATER FROM WELLS AND SPRINGS AT HOT SPRINGS, SIERRA COUNTY, N. MEX.

(Collected Feb. 9 and 10, 1939)

Analyses Nos. 1-11 by C. S. Howard; Analysis No. 12 by W. M. Noble

Quantities in Parts per Million

| Analysis No. | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate ($HCO_3$) | Sulphate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Total dissolved solids | Total hardness as $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ---- | 0.07 | 152 | 18 | 740 | ---- | 210 | 74 | 1,280 | 2.6 | ---- | ---- | 454 |
| 2 | ---- | 0.42 | 155 | 17 | 772 | ---- | 214 | 73 | 1,330 | 3.2 | ---- | ---- | 457 |
| 3 | 38 | 0.10 | 150 | 16 | 692 | 45 | 218 | 102 | 1,230 | 3.4 | 2.0 | 2,486 | 441 |
| 4 | 32 | 0.53 | 153 | 15 | 714 | 43 | 219 | 105 | 1,240 | 3.2 | 6.2 | 2,437 | 444 |
| 5 | ---- | 0.08 | 154 | 16 | 730 | ---- | 212 | 75 | 1,250 | 2.8 | ---- | ---- | 451 |
| 6 | ---- | 0.08 | 154 | 19 | 751 | ---- | 218 | 86 | 1,290 | 3.2 | ---- | ---- | 463 |
| 7 | 37 | 0.08 | 148 | 16 | 678 | 36 | 212 | 81 | 1,210 | 3.0 | 5.0 | 2,418 | 436 |
| 8 | 36 | 0.10 | 154 | 14 | 731 | 39 | 215 | 79 | 1,300 | 3.0 | 10.0 | 2,560 | 442 |
| 9 | 18 | 3.30 | 460 | 76 | 661 | 21 | 152 | 1,193 | 1,120 | 1.6 | 4.0 | 3,720 | 1,462 |
| 10 | 26 | 0.76 | 85 | 17 | 91 | 11 | 272 | 156 | 74 | 0.0 | 0.2 | 610 | 282 |
| 11 | 21 | 2.20 | 58 | 5 | 131 | 9 | 125 | 52 | 212 | 0.6 | 1.0 | 556 | 166 |
| 12 | 37 | 0.00 | 109 | 10 | 386 | 26 | 212 | 79 | 650 | 2.4 | 25.0 | 1,428 | 314 |

1. Drilled well, 105 ft. deep 6¾ in. diam.; owned by C. E. James. Temp. 114°F. Well 4 of maps and tables.
2. Nonflowing artesian well, drilled, 100 ft. deep, 4 in. diam.; owned by Bill Anderson. Temp. 111.2°F. Well 24 of maps and tables.
3. Nonflowing artesian well, 27 ft. deep, 4 in. diam.; owned by Bill Green. Temp. 112.3°F. Well 19 of maps and tables.
4. Flowing well, 208 ft. deep, 12 in. diam.; owned by Mr. Graham. Temp. 102°F. Well 27 of maps and tables.
5. Drilled well, 212 ft. deep, 6¾ in. diam.; Carrie Tingley Hospital well. Temp. reported 113°F. Well 8 of maps and tables.
6. Drive point 14 ft. deep into spring head; owned by J. J. Jaeger. Temp. 110°F. Ponce de Leon Spring. Well 13 of maps and tables.
7. Spring; owned by town of Hot Springs. Temp. 99°-103°F. Spring 22 of maps and tables.
8. Spring; owned by U. S. A., managed by town of Hot Springs. Temp. 103°-105°F. Spring 23 of maps and tables.
9. Drilled well, flowing artesian, 120 ft. deep, 6 in. diam.; owned by Mrs. Howard. Temp. 70°F. Well 35A of maps and tables.
10. Driven well, 4 ft. deep, 2 in. diam.; owned by E. M. Van Sant. Temp. 54°F. On Rio Grande bank above Hot Springs.
11. Flowing artesian well, 200 ft. (Approx) deep, 6 in. diam.; owned by George Cook. Temp. 77°F. City Supply well No. 2.
12. Warm spring, 10 miles northwest of Hot Springs in Cuchillo Canyon, 15 miles west of Cuchillo, N. Mex. Temp. 85.6°F.

The first 8 analyses represent hot water drawn from various sources at Hot Springs. The first 5 analyses represent waters from wells drilled into the Magdalena limestone underlying the alluvium; analysis 6 is for water from a well 14 feet deep in the alluvium near the head of the hot water drain ditch; and analyses 7 and 8 represent water from springs near the contact between the alluvium and Magdalena limestone at the base of the limestone ridge. Analysis 9 is for water from the Howard well (No. 35A) in the northeast part of Hot Springs. Analysis 10 is for water from a well 4 feet deep close to the river above the area of hot water. Analysis 11 is for water from one of the wells furnishing the municipal water supply of Hot Springs. This well is located in the mouth of Mud Springs Wash, about 3 miles southwest of the hot water area, and draws water from the valley fill. Analysis 12 is for water from a warm spring rising along a fault zone in the Magdalena limestone approximately 10 miles northwest of Hot Springs. This water is similar to, but less concentrated than the typical Hot Springs mineral water.

In order to supplement the available analyses, field tests for chloride content were made on April 8, 1940, on water from many wells in the thermal water area at Hot Springs. The results of these tests are given in the following table:

*Field Measurements of the Chloride Content of Thermal Waters, Hot Springs Artesian Basin, April 8, 1940*

| Well (No.) | Chloride (Cl) (parts per million) | Spring or sump (No.) | Chloride (Cl) (parts per million) |
|---|---|---|---|
| 1 | 1,370 | 9 | 1,380 |
| 4 | 1,400 | 13 | 1,370 |
| 5 | 1,380 | 14 | 1,350 |
| 8 | 1,400 | 22 | 1,330 |
| 10 | 1,370 | 23 | 1,400 |
| 11A | 1,370 | | |
| 12 | 1,400 | 29 | 1,380 |
| 15 | 1,320 | 37 | 1,370 |
| 18 | 1,350 | | |
| 19 | 1,330 | | |
| 20A | 1,400 | Hot water drain | 1,370 |
| 24 | 1,370 | | 1,400 |
| 27 | 1,340 | | |
| 30 | 1,370 | | |
| 31 | 1,380 | | |
| 32 | 1,380 | | |

In making these field chloride determinations, the water was titrated with a silver nitrate solution from a dropping bottle. The silver nitrate was of such strength that one drop of the solution equaled 10 parts of chloride per million when a 25 cc. sample of the water was titrated. Because of the high chloride content of the thermal water it was necessary to dilute 7.5 cc. of the water with 17.5 cc. of distilled water, thus making each drop of the silver nitrate solution equivalent to 33.3 parts chloride per million. Successive determinations of any sample checked within one drop of silver nitrate solution or 33 parts of chloride. All the waters except that of well 15 gave chloride values within 33 parts of the mean value. The values obtained by these field tests appear to be uniformly about 100 parts per million higher than the laboratory determinations given in the first table of this subsection. This variance may have been caused by a slight decomposition of the standard silver nitrate solution before the field tests were run, the need for applying a correction factor for passing the true end point, or perhaps the size of drops of silver nitrate solution used in the titration.

Much greater variation in chloride content than that found in the above analysis is indicated for the nonthermal waters of the Hot Springs area. Some of these determinations are given below:

*Field Measurements of Chloride Content of Nonthermal Waters, Hot Springs Artesian Basin, April 8, 1940*

| Well (No.) | Chloride (Cl) | Well (No.) | Chloride (Cl) |
|---|---|---|---|
| 35A | 1,200 | City water supply | 215 |
| 36 | 1,250 | Rio Grande water | 70 |
| 46 | 440 | | |
| 44 | 670 | | |
| 40 | 1,710 | | |

The high chloride value measured in well 40, half a mile northwest of the center of the town of Hot Springs but penetrating the Magdalena, indicates water similar in composition to that of the Hot Springs thermal water area but concentrated somewhat, perhaps by evaporation or by lack of circulation. The well had not been used for some time before sampling.

The water carried by the hot water drain (pl. 1) was also tested for chloride content. The chloride content of the water of the drain throughout its extent was very nearly 1,370 parts per million, indicating little if any addition of nonmineral water. All the ground water in the area where thermal water occurs appears, therefore, to be essentially of the same composition as the water found in the limestone and in the overlying alluvium.

The character of the water from the valley fill in the extreme northeastern part of the area shown in plate 1, in wells 35A (analysis 9) and 36 is exceptional. It has only a slightly lower content of sodium chloride than typical thermal water but contains a much greater proportion of calcium sulphate and has a relatively low temperature (70°F.). It appears to be essentially the thermal water only slightly diluted with the normal water of the area. The higher concentration of calcium, magnesium, and sulphate ions may indicate that the water has come in contact with gypsum horizons in red beds of Carboniferous and Permiam age. The Abo sandstone crops out in Cuchillo Creek north of the Mud Springs Mountains, that is, northwest of Hot Springs and also to the east of Hot Springs on the west side of the fault at the base of the Sierra Caballos (fig. 1). It is conceivable that water moving through Abo rocks or possibly the overlying Permian beds of this region may enter the valley fill at Hot Springs and produce the type of water in wells 35A and 36. Faulting to the north of the Magdalena ridge in Hot Springs may have elevated the Carboniferous and Permian formations into a position such that ground waters can come into contact with them.

It should be observed that all the analyses of the hot water show high concentrations of fluoride. Fluoride in excessive amounts causes mottling of teeth while they are in process of development in children. The hot water therefore should not be drunk by children in large amounts nor consistently.

From the data available the following generalizations concerning the quality of the water in Hot Springs and its vicinity can be made:

(1) Within the area in which hot water is developed, that is, in an area of about 160 acres within the town of Hot Springs the water is remarkably uniform in composition whether it comes from the Magdalena or from the sands and gravels overlying the Magdalena. The sodium and potassium content of 8 samples of thermal water varied only from 714 to 772 parts per million and the chloride content from 1,210 to 1,330. The sodium-potassium ratio is uniform. Calcium varied only from 148 to 155 parts per million, magnesium from 14 to 19 parts, and bicarbonate from 210 to 219 parts.

(2) There is no apparent areal pattern of variation of chemical content within the small ranges in chemical content noted.

(3) The thermal water is entirely different in chemical character from any of the nonthermal water near Hot Springs and from typical ground water elsewhere in the Rio Grande Valley. The water from the city well (analysis 11) is more or less typical of water from the valley fill elsewhere in the Rio Grande Valley, although somewhat higher in sodium chloride[30], and is much less highly mineralized than the thermal water. Water from the flood-plain deposits about Hot Springs (analysis 10) is a calcium sulphate and calcium bicarbonate water much less highly mineralized than the thermal water.

The fact that the thermal water is uniform in composition and distinctly different from other ground water in the vicinity indicates that the water has a common source different from that of the remainder. The origin of the water will be more thoroughly discussed later after other factors have been considered. The variation in chloride content of the nonthermal water suggests that there may be some admixture of thermal water to typical ground water in the outlying areas in the vicinity of Hot Springs.

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[30] Lee, W. T., op. cit. pp. 53-54.

## TEMPERATURE

Many measurements of temperature of water from various sources in the Hot Springs area were made in the period February 1939-June 1940. The earlier measurements were made with a thermometer graduated to two Fahrenheit degrees and are probably accurate to within one degree. Some of the temperatures given in the table of well records were taken with a thermometer graduated to one-fifth of a Centigrade degree and are probably accurate to within one-half of a Fahrenheit degree. All temperatures of water from wells were read after vigorous pumping and after the reading of the thermometer remained constant with continued pumping.

Temperature readings throughout a year indicate that the temperature of the water from any individual deep well is practically constant. The temperature of water issuing from the thermal springs at the base of the limestone ridge (State spring 22 and Government spring 23) varies seasonally, being lower in winter than in summer, but these variations are doubtless caused by cooling in the artificial pools in which the spring water collects before it discharges.

There is little evidence that wells tapping different horizons in the Magdalena rocks encounter water with different temperatures. This is seen in the case of wells 19 and 31, which are only about 200 feet apart. Well 19 taps thermal water in a crevice in Magdalena limestone at 27 feet, and well 31 obtains its water from horizons in the Magdalena to depths below 250 feet; yet there is less than a degree difference in temperature of the water obtained from these wells. (See fig. 2.) Further, it appears that the cooler areas are not produced by the infiltration of cool nonmineral water into the area, inasmuch as the water is remarkably uniform in chemical character.

The areal distribution of water temperatures in the wells of the hot-water area, most of which were measured on April 26, 1940, is shown in figure 2. Differences in temperatures between wells are indicated by means of isothermal lines drawn between points of equal temperature at intervals of 1 degree. It will be observed from inspection of this illustration that the hottest water was found in wells 4 and 6, where temperatures of about 114°F. were recorded or reported. From this locus of high temperature a long temperature "ridge" projects in a northeasterly direction, passing through wells 17 and 19, and thence somewhat more easterly through well 34 to well 24. Along this trend relatively high temperatures are maintained with only very gradual decreases toward the eastern end. A similar but less prominent projection extends southeastward from the high temperature locus through wells 11A and 12. The decline of temperature along this trend is apparently somewhat greater than along the northeast projection described above.

Centering around well 18 and opening to the southeast is a temperature "trough" indicating a rapid decline in temperature in this direction. The spacing of the isothermal lines also indicates that the tem-

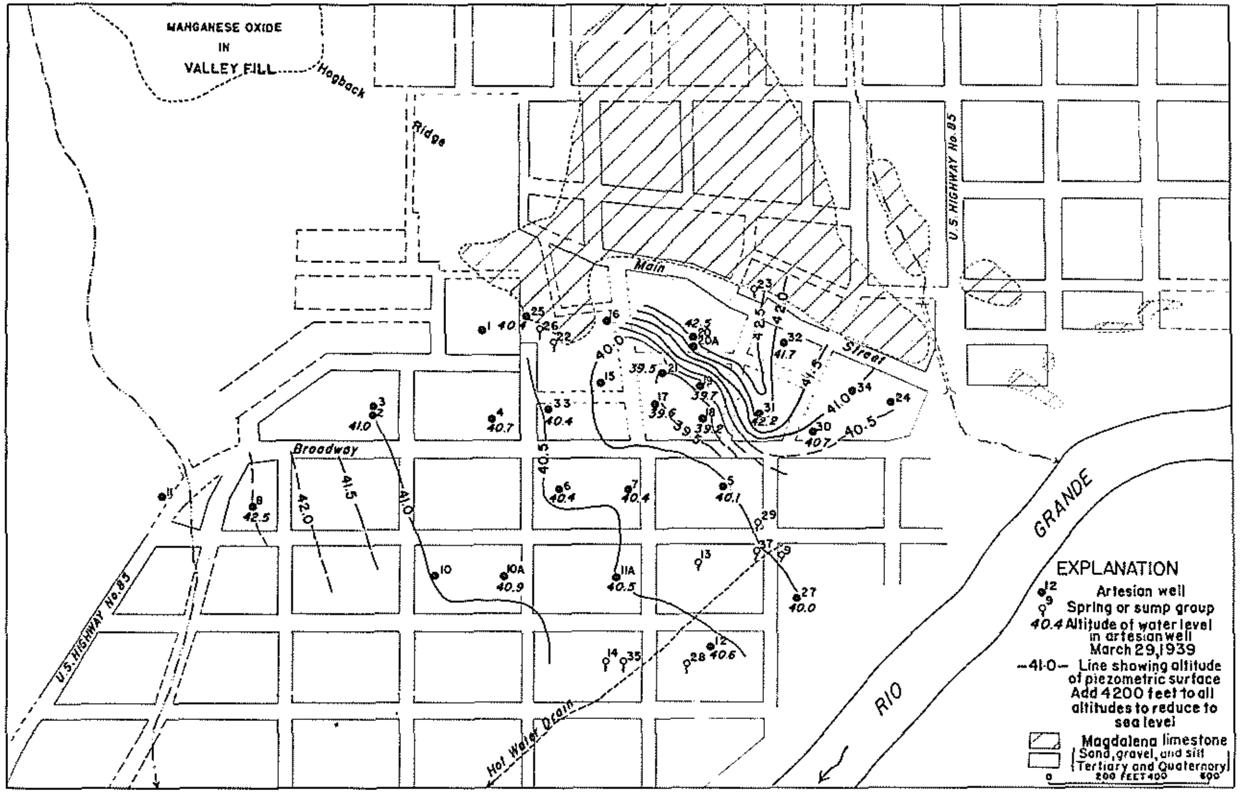

FIG. 2. Map of a part of Hot Springs, N. M., showing distribution of temperatures of thermal water from artesian wells, April 26, 1940.

peratures fall off rapidly in a northerly direction away from the high temperature area.

The causes for the differences in temperature in wells are not yet completely understood, but the known facts concerning the geologic and hydrologic conditions at Hot Springs indicate the general cause.

The temperature pattern indicated by the isothermal lines is evidently connected with the structure or distribution of the Magdalena rocks in which the hot water is found. Minor faults occur in a number of places in the area of outcrop of Magdalena rocks in the center of Hot Springs, notably in blocks 82 and 93. (pl. 1). It seems probable, therefore, that the pattern shown on the temperature map is related to a pattern in the Magdalena rocks concealed beneath the alluvium. The locus of high temperature possibly occurs at the point of convergence or intersection of two or more minor faults. The shattered zone produced at the intersection of such faults would allow more rapid circulation of the thermal water than in adjacent areas of unbroken rock. By rapid circulation in the shattered zone sufficient quantities of heat would be imported to maintain the high temperature. In adjacent unbroken rock slower circulation would take place because the thermal water would have to follow more devious paths. The water would therefore have a lower temperature because of the greater time allowed for cooling.

The high temperature maintained in the "ridge" may also represent a linear zone of greater permeability and rapid circulation along a fault zone, or perhaps a bedding plane or major joint plane. The southeastward temperature projection though less definite in outline may have been produced by similar causes.

## DEVELOPMENT OF THE THERMAL WATER

All of the development of thermal water at Hot Springs is concentrated in a rather small area within approximately a quarter of a mile radius of the south quarter-corner of sec. 33, T. 13 S., R. 4 W. The thermal water has been developed by wells drilled into the deeper hot-water horizons and by sumps constructed in the alluvium to intercept the shallow thermal waters moving upward from the deeper horizons in the Magdalena limestone toward the point of discharge in the Rio Grande.

In July 1940, there were 28 drilled wells; 18 of these wells were in operation, and 10 were capped, abandoned, or otherwise unused. Fifteen of the operating wells are equipped with small 1-inch or 1½-inch centrifugal pumps with electric motors of less than 2 horsepower. Most of these pumping wells are also equipped with small quarter-inch pipes tapping the side of the casing from which hot water is withdrawn for drinking purposes. Hot water flows from these side taps whenever the water level in the well rises to the necessary height. The remaining three of the operating wells are not equipped with pumps because the artesian flow is sufficiently great to meet the requirements of the users. A tabulated list of the hot water wells, springs, and sumps in Hot

Springs is given near the end of this report. Their areal distribution is shown in plate 1.

Artificial discharge of the thermal water at Hot Springs by pumping and flowing wells takes place throughout the year. There is no particular bathing season at Hot Springs, but there is usually a general increase during the summer months in the number of baths given. With a few exceptions, the pumps are not run for long or continuous periods, and pumping occurs sporadically from 6 a. m. until midnight. In general the pumps are run only four or five minutes, the time usually required to fill a large bath tub. Some of the bath houses are equipped with swimming pools, the larger ones of which take a considerably longer time to fill. The heaviest withdrawals of the thermal water through artesian wells usually take place from about 6 a. m. to 11 a. m. There is then a slack period until about 2 p. m., and from this time until about 8 or 9 p. m. pumping occurs sporadically with the largest withdrawals in the afternoon period at about 5 p. m.

In addition to the development of the deeper artesian water by drilled wells, there is a considerable amount of shallow unconfined thermal water used for bathing purposes. Most of this water has been developed by shallow sumps constructed in flood-plain sands and gravels through which the hot water rises. The hot water rises in the sumps, circulates through them, and discharges into the river by way of an open drain ditch which runs diagonally southwest across the south side of the town of Hot Springs. There are also a few shallow driven wells obtaining thermal water from the alluvium. The water from these wells is used principally for drinking purposes. The largest development of shallow water is in blocks 39, 40, and 41 of the Hot Springs Townsite. (See pl. 1). In block 41 there are 20 sump baths supplied by shallow thermal water with temperatures ranging from 110°F. to 111°F. The sumps are generally two or three feet in depth. The sides of the sumps are usually lined with concrete or with wooden planking, and the sumps range in size from circular pools 15 feet in diameter to small rectangular pools two or three feet in width. In all there are about 30 sump baths in the three blocks mentioned above. Supplementing the sump baths in block 41 are two driven wells less than 15 feet in depth and equipped with 1-inch pumps and small electric motors.

## *QUANTITY OF THERMAL WATER USED*

As all of the pumped wells in the thermal water area use electrical power, it was possible to make a computation of the amount of hot water pumped on the basis of power records furnished by the New Mexico Public Service Company of Hot Springs. Four pumping plants were rated according to the amount of water pumped in gallons per kilowatt hour consumed, and an average rating was computed. The pumping plants rated were those at wells 17, 18, 19, and 31. (See pl. 1). Well 17 was rated at 3,200 gallons pumped per kilowatt hour, and wells 18, 19, and 31 were rated at 3,100, 2,100 and 2,600 gallons pumped per kilowatt hour, respectively. On the basis of these data and a general consideration of the condition, size, and capacity of the pumps and motors on wells at Hot Springs a figure of 3,000 gallons per kilowatt hour consumed is believed to represent a good approximation to the actual pumpage per kilowatt hour. As has been mentioned previously, the pumped artesian wells in Hot Springs are equipped with 1-inch to 1½-inch pumps and 1 to 2-horsepower electric motors. The one exception to this is well 8 used by the Carrie Tingley Hospital, which has a 2-inch pump and a 10-horsepower motor. This plant was not included in the calculation of the figure for pumpage in gallons per kilowatt hour consumed because of the larger capacity of the pump. Because the pumps are all small and the water is pumped through a considerable length of small pipe to the baths, the plant efficiency is small, as indicated by the figure obtained. The power-plant records used in computing the pumpage figures given below extended through the year from May 1938 to April 1939. The records obtained from the power company were tabulated on a monthly basis. For the purpose of this report a yearly figure was obtained by totaling the monthly records. By multiplying this figure by 3,000 the yearly pumpage was computed. The average daily pumpage was obtained by dividing the yearly pumpage by 365. The daily pumpage for well 8 was computed separately.

From the figure of 3,000 gallons per kilowatt hour and the power records it was computed that the average daily withdrawal of hot water through pumped artesian wells is approximately 128,000 gallons. Of this amount about 38,000 gallons a day is pumped by the Carrie Tingley Hospital from well 8, in block 5 of the Hot Springs Townsite. This well is pumped an average of 5 hours a day, with the exception of Sundays, at the rate of about 125 gallons a minute. The total daily pumpage of the other 14 pumping plants in the hot water area amounts to approximately 90,000 gallons a day, or an average of about 6,400 gallons a day for each well. In addition to the hot water pumped, the artesian flow during the initial period of this investigation has amounted to about 8,500 gallons a day from October 1 to March 31, and about 15,000 gallons a day from April 1 to September 30. The greater flow in the months from April to October has been due largely to the higher stage of the river at that time, which affects the artesian head of the wells. The total production of hot water from wells was therefore about 136,500 gallons a day from October to April and 143,000 gallons a day from April to the next October.

Since December 1940 the discharge from Elephant Butte Reservoir has been largely determined by the water requirements of the hydroelectric plant which began operating there at that time. During most of the 1941 releases from Elephant Butte Reservoir were rather uniform and artesian pressures intermediate in magnitude; however, during the last quarter of the year and during 1942 discharges from the reservoir increased materially as a result of exceptional stream flow resulting from abnormal precipitation and artesian pressures rose accordingly, reaching a maximum in May and June 1942. With this increased artesian head it is believed that the total production of water from wells is now somewhat greater than that during the former high April to October period.

The development of water by sumps is in one sense a considerably more wasteful method of utilizing the thermal water than withdrawal through wells in which the flow of water is more readily controlled. A large part of the thermal water rising in the sump baths is unavoidably wasted, because in order to maintain circulation, both for heat and sanitation, thermal water must flow through the bathing pools continuously, even when the pools are not in use. However, inasmuch as the sumps merely divert water in process of natural discharge, they cause no additional drain on the ground-water system. Inasmuch as the discharge of the sumps enters the drain along with more general seepage and the waste from baths served by artesian wells, it is not possible to ascertain the amount of thermal water that is actually discharged from the sumps. As discussed on a later page, the flow of the drain is about 2 second-feet, that is, about 900 gallons a minute or 1,296,000 gallons a day.

## PIEZOMETRIC SURFACE AND WATER TABLE IN THE AREA OF THERMAL WATER

### SHAPE OF THE PIEZOMETRIC SURFACE

In figure 3 is shown a map of the piezometric surface of the thermal water confined in the artesian aquifer of the Magdalena limestone. The piezometric surface represents the level to which the water in an artesian well would rise if the casing were produced sufficiently high above the ground level to stop the flow of water. In many wells in the thermal water area of the Hot Springs Artesian Basin the piezometric surface lies below ground level, and hence the wells do not flow. In all cases the artesian head of the thermal artesian wells is quite small, the maximum observed head being about 4 feet above ground level. The shape of the piezometric surface is shown by means of contour lines at one-half foot intervals. The direction of the movement of the ground water is approximately at right angles to these lines. As can be observed from inspection of this map, the most prominent feature of the piezometric surface is a trough which trends northwest-southeast and centers around well 18 in block 105. Bordering this trough are two areas of high presssure: one of these is in the vicinity of Government spring 23 and well 20, the other is at the extreme west end of the developed hot water area in the vicinity of well 8. From the high pressure area near well 8 the slope of the piezometric surface and consequently the movement is in an easterly to northeasterly direction toward the area of greatest discharge represented by the trough. The trough trends more or less parallel to the strike of the Magdalena limestone.

This trough may be due to one or more of several causes. It may be in part due to the fact that wells tapping different strata strike artesian water having different pressures. Thus well 31 which is 258 feet deep and considerably deeper than neighboring wells appears to have an unusually high artesian head. Wells 20 and 32, having depths of 160

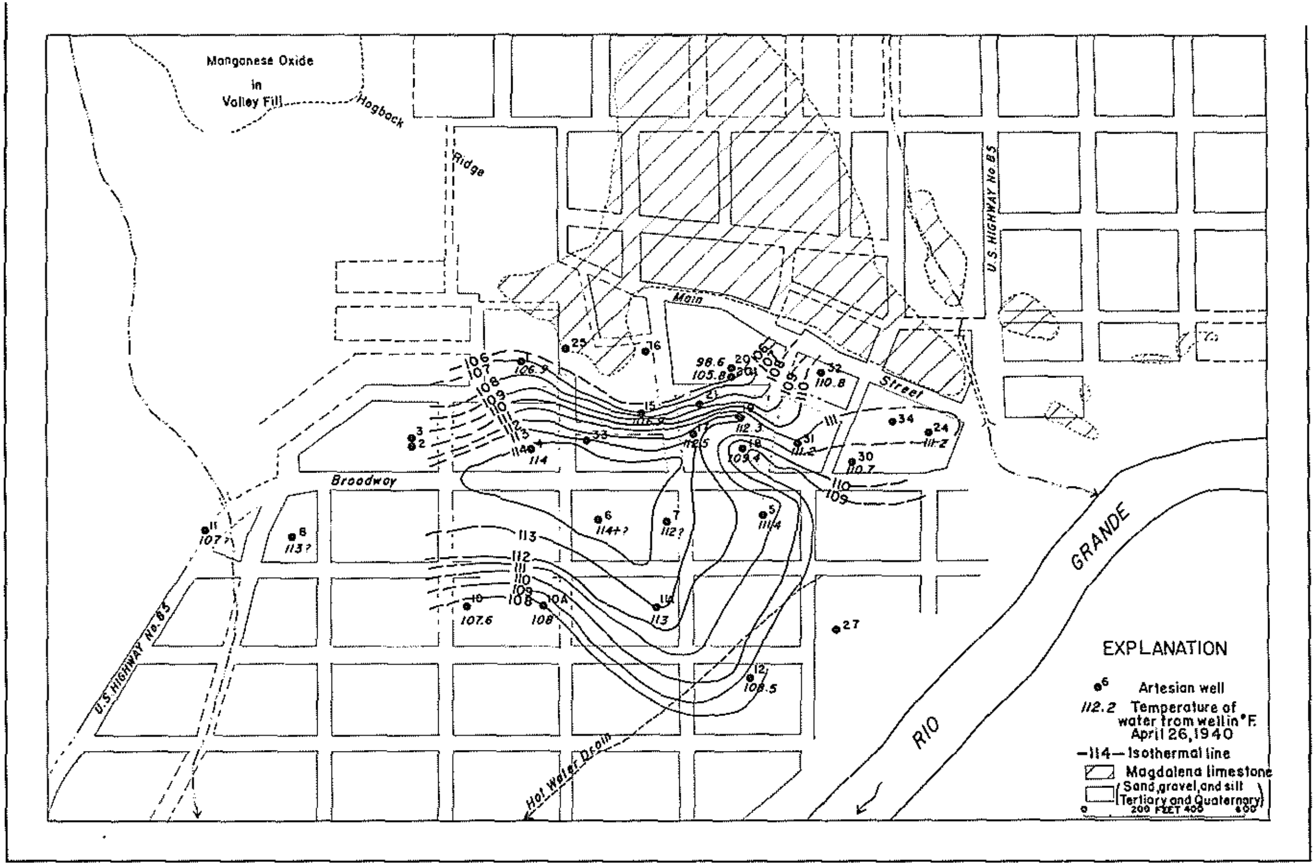

FIG. 3. Map of a part of Hot Springs, N. M., showing the altitude of the piezometric surface in artesian wells in the thermal water area, March 29, 1939.

and 239 feet, respectively, also have comparatively high artesian heads. By comparison, wells 17, 18, and 19 with depths of only 101, 55, and 27 feet, respectively, are located in the head of the piezometric trough. It, therefore, appears that the deeper beds in the Magdalena rocks carry water under greater pressure than the more shallow beds and that the piezometric trough indicated in figure 4 might not be so pronounced if all of the wells tapped the same water-bearing horizon in the Magdalena. Because complete well data are not available, it is impossible to exactly evaluate the importance of the depth of the wells on the magnitude of artesian pressures.

The trough may be also partly caused by development of a cone of depression due to the concentrated pumping of hot water in the area centering around the head of the trough, though this does not seem likely in view of the extremely high coefficients of transmissibility and rapid recovery of wells after pumping.

Another factor in the formation of the trough is suggested by the well logs available and the projection of the Magdalena limestone ridge in the direction of the trough. Apparently a bedrock ridge underlies the trough, and as a consequence the confining bed is thinner here than elsewhere. If this is so, a higher rate of percolation would be induced through the confining bed in the area of the trough, and its discharge would therefore be greater. The fact that the trough is an area of discharge is also indicated by the presence of springs 22 and 23 (fig. 3) and that before the hot water drain was constructed the area near its head was marsh into which the hot water discharged naturally.

## SHAPE OF THE WATER TABLE

The configuration and elevation of the water table above sea level on March 29, 1939, is shown in plate 1 by means of contour lines at 1-foot intervals. The water table at Hot Springs represents the upper surface of the ground water moving through the upper and more permeable part of the alluvium. As shown on the map, the water table slopes from an elevation of 4,239 feet at the base of the limestone hill, where the water table in the alluvium coincides with the piezometric surface in the artesian aquifer, to 4,230 feet at the base of the granite bluff where the alluvium pinches out. Thus the water table drops approximately 9 feet in a distance of slightly more than half a mile. In general the ground water in the alluvium moves south and southeast from the base of the limestone hill to the river. A part of the water moving down this slope is intercepted by the drain and sumps, but a large part passes on to discharge into the river.

The water table lies within two feet of the surface in a considerable area in the southern part of Hot Springs. Over much of this area ground-water is discharged by transpiration. Evaporation is evidenced by a thin salt crust which lies in small patches over a large part of the land surface where the depth to the water table is small.

## FLUCTUATIONS OF THE PIEZOMETRIC SURFACE AND THE WATER TABLE

The fact that in the hot-water area the temperature and chemical character of the water in the alluvium and in the underlying Magdalena limestone are alike indicates a common source, and the difference in head between the water in the alluvium and that in the limestone indicates that the water discharges from the limestone into the alluvium. Further evidence of the intimate connection between the two bodies of ground water is found in some of the fluctuations of the water levels in wells in the two formations.

The most prominent fluctuations both of artesian pressure and water table are caused by pumping from the respective aquifers. During the day pumping is at a maximum, and the water level falls. During the night pumping slackens and finally stops, and the water level rises. This type of fluctuation is illustrated in figure 4, which shows the typical daily fluctuations of water level in well 25. Figure 4a shows the fluctuations during a 24-hour period on June 22 and 23, 1939. The highest water stage was reached at 4:30 a. m. and the lowest stage at 10:40 a. m. The time of low stage corresponds with the period of greatest pumping, and the time of high stage corresponds with the time of maximum recovery from the previous day's pumping. Figure 4b shows the fluctuations of well 25 over the period June 30 to July 5, 1939. This graph indicates small secondary peaks occurring from 2 to 3 p. m., which approximately coincides with the slack period of pumping during the day. The large drawdown of the water level Sunday night July 2 was caused by the pumping of well 8 to fill the Carrie Tingley Hospital swimming pool. Figure 5 shows the fluctuations in artesian pressure in well 10A, located in block 11 of the Hot Springs Townsite, for the 24-hour period, November 27 and 28, 1939. As will be observed from this graph, the greatest daily change in artesian pressure from the highest to the lowest point amounts to about 0.4 foot. The greatest part of this daily change is caused by pumping well 8, owned by the Carrie Tingley Hospital, about 960 feet northwest of well 10A. This well is usually pumped from about 7:30 a. m. to 1:00 p. m. at the rate of about 125 gallons a minute.

Both the artesian pressure and the water table fluctuate seasonally and in response to weather conditions in an interrelated manner. Seasonal fluctuations of artesian wells 25 and 10A and of the shallow water-table well 13 are shown in figure 6. This chart also shows the daily stage of Elephant Butte Reservoir, releases from the reservoir, and the average of the daily rainfall at Elephant Butte and Caballo Dams.

The response of both the water table and the artesian pressure to releases from Elephant Butte Reservoir is at once apparent from the graphs. The Rio Grande is the point of discharge for the thermal water moving laterally through the upper part of the alluvium, which in turn is fed by thermal water moving slowly upward through the confining

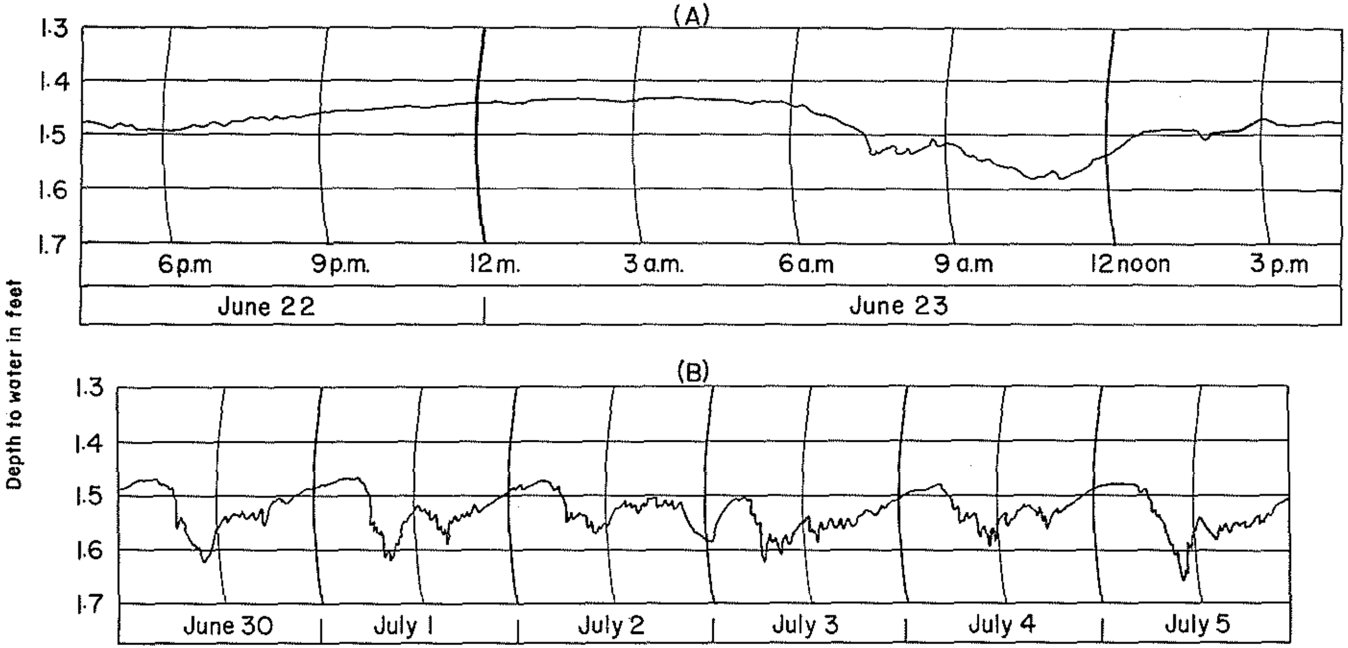

FIG. 4. Fluctuations in water level in well 25.

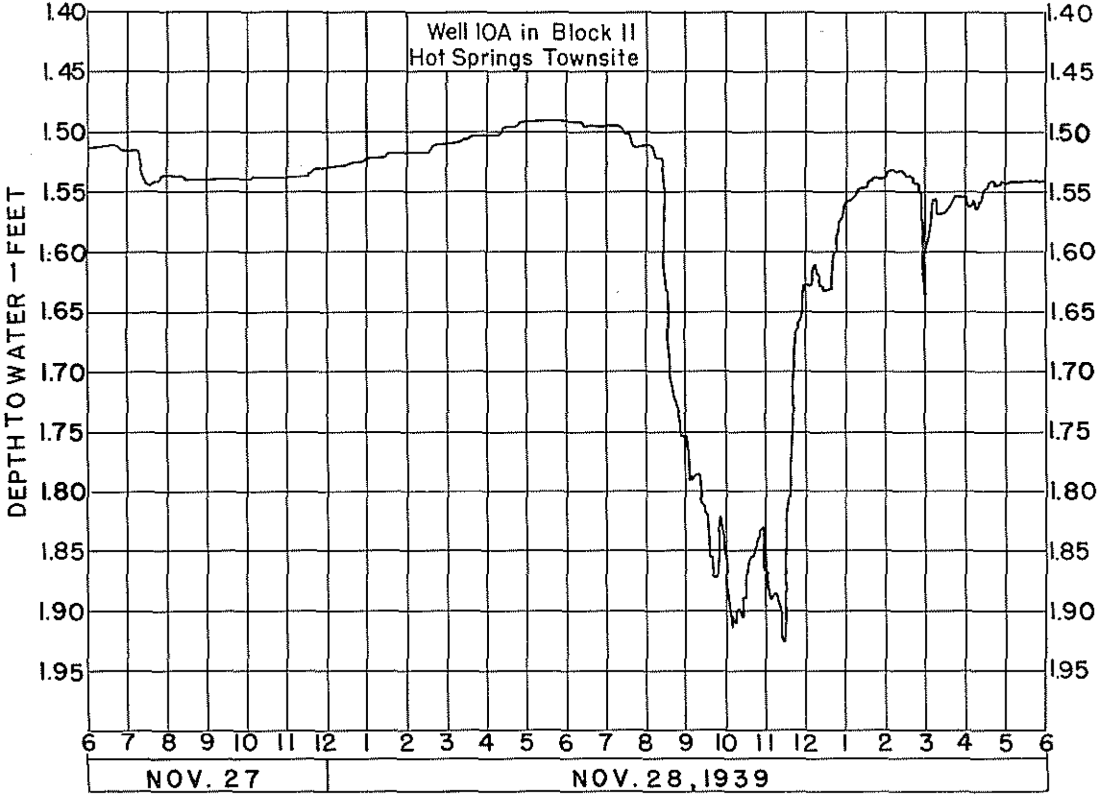

FIG. 5. Fluctuations in water level in well 10A.

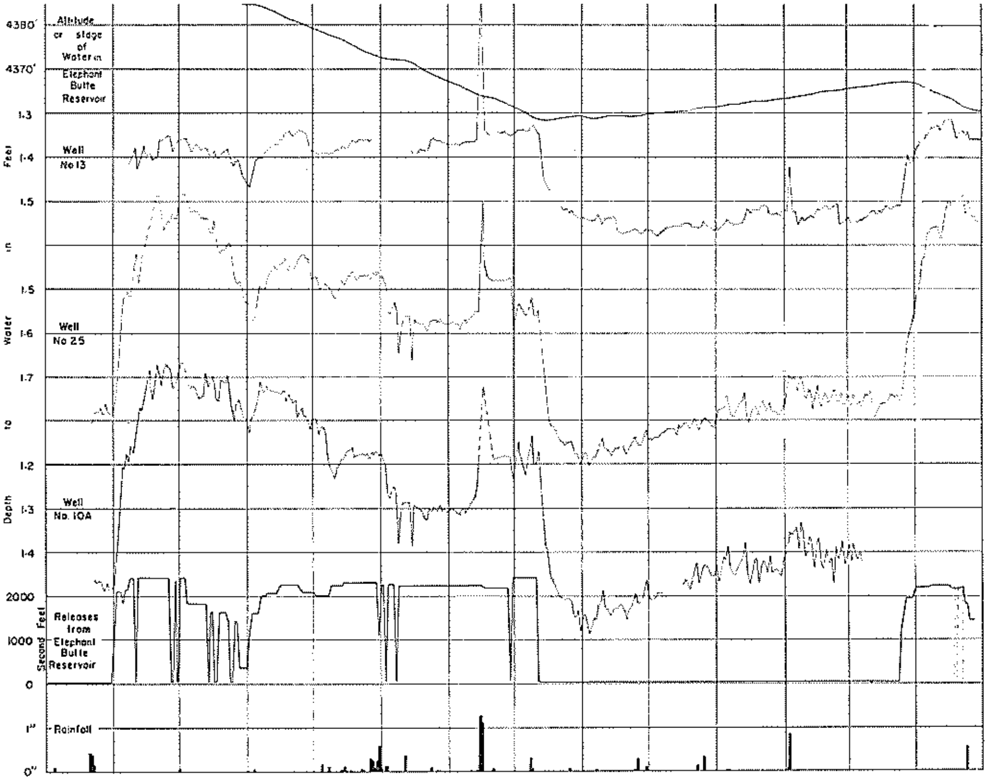

FIG. 6. Hydrograph of artesian wells 25, 10A and water-table well 13, and related hydrologic phenomena.

ed from the artesian aquifer. When water is released from Elephant Butte Dam, the alluvium above the water table near the river becomes aturated by inflow of water from the river. The stage of the river was measured by a water-stage recorder, the location of which is shown on plate 1. The rise in the river and in ground-water level, measured near he river is approximately 3 feet at the beginning of the irrigation seaon, but the amount of rise diminishes rapidly toward the hot water drain. Above the drain there is a progressive rise in the water table more or less paralleling its previous position. The amount of this rise s approximately 0.4 foot near the contact of the alluvium and the Magdalena limestone. The amplitude of the fluctuations in well 13 is damped by the presence of Ponce de Leon spring about 10 feet south of the well and by other discharging sumps in block 41.

The higher level of the water table increases the head against which the water in the artesian aquifer discharges, and as a consequence the artesian pressure increases. Two sets of measurements of artesian pressures, one before and the other after water was let out of Elephant Butte Reservoir at the beginning of the irrigation season on April 1, 1939, indicated that the increases in artesian pressure caused by the change in the stage of the river varied from 0.28 to 0.44 foot in the 12 artesian wells measured; that is, about the same as the rise in the water table northwest of the drain.

If the artesian aquifers discharged directly into the river, the increase in artesian pressure would be approximately equal to the increase in the water level of the river. However, the water level in the river rises commonly about 3 feet, whereas the greatest seasonal rise in artesian pressure noted amounted only to about 0.7 foot of water. Hence it is indicated that all or nearly all the natural discharge from the limestone aquifers is into the alluvium and thence into the river.

The rise in the stage of the river also tends to decrease the effectiveness of the Hot Springs water drain by backing up the lower part of the drain. This effect appears to be of minor importance as there is sufficient fall in the drain to prevent this rise from reaching the area where most of the shallow thermal water emerges.

A rapid increase in artesian pressure accompanied heavy regional rains on September 13, 14, and 15, 1939. This marked peak is indicated on all of the graphs in figure 6. It might be expected that a rise in artesian pressure due to back pressure caused by raising the water table in the alluvium would be accompanied by a rapid decline as soon as flash floods in the river were over. However, considerable time is apparently necessary for the water to drain into the river channel for the artesian pressure remained approximately 0.10 foot high for about two weeks after the heavy rainfalls. A similar though less marked increase in artesian pressure followed the rainfall of February 2, 1940. It thus appears that heavy rainfalls produce a pressure adjustment within the hydrologic system, the effects of which are maintained for some time.

As indicated in figure 6, artesian pressures reach a maximum in the latter half of April after which there is a rather steady decrease of pressure although the river remains at a high stage; conversely, artesian pressures reach a minimum about November 1 and then increase gradually although the river remains at a low stage. This action appears to be another example of the interrelation of the artesian pressure and the water level in the alluvium. In the summer the effects of transpiration and soil evaporation progressively lower the water table and consequently reduce the artesian pressure; whereas in the winter season the water table builds up slowly during the season of reduced growth of vegetation and as a consequence the artesian pressure increases.

However, there is an ostensible correlation of this fluctuation of the artesian pressure with the rise and fall of Elephant Butte Reservoir, as shown in figure 6. For instance, in the period between April 13 and October 11, 1939, the water level in the reservoir fell rather gradually about 30 feet and in the same period the artesian pressure gradually fell 0.3 foot while the stage of the river was about stationary. There is a possibility of movement of water from the reservoir to Hot Springs along the transverse fault at the north end of the Sierra Caballos which connects the two localities. Inasmuch as the discharge of the thermal water occurs at Hot Springs, any pressure imposed at the reservoir would have a greatly reduced effect at Hot Springs. Moreover, if movement existed it would have been accelerated by the construction of Elephant Butte Reservoir and, as ground water generally moves very slowly, the full effect of this accelerated movement might not yet be felt. However, no correlation of stage of Elephant Butte Reservoir and artesian pressures can be traced over extended periods. Thus the yearly high stage in the reservoir on April 13, 1939, was 4,378.4 feet and in the next year on March 24, 1940, it was 4,357.0 feet, a difference of 21.4 feet; whereas the highest artesian pressure in well 25 was about exactly the same in the two years, the stage of the river at Hot Springs being practically the same. Undoubtedly both the fluctuation of the reservoir and of the artesian pressure are effects of the same cause, that is, fluctuations in the demand of vegetation for water, in one case crops served by the irrigation water of Elephant Butte and in the other native vegetation drawing on the ground water of Hot Springs.

The artesian pressures of wells in the hot water area of the Hot Springs Artesian Basin are not appreciably affected by changes in barometric pressure. This condition was demonstrated by comparing the continuous record of barometric pressure as recorded on a micro-barograph maintained at Hot Springs with the record of water-level fluctuations in two artesian wells. In general barometric fluctuations in artesian wells in limestone aquifers are quite pronounced. Such aquifers are rigid. None or little of the varying pressure of the atmosphere is transmitted to the water underground and as a consequence the varying load of the atmosphere raises or depresses the water column in the well, causing the water level to rise when the barometric pressure decreases and to lower when the barometric pressure increases. The lack of barometric effects in the limestone aquifer at Hot Springs is another evidence of the intimate connection between the water in that aquifer and the alluvium. The varying barometric loads are imposed directly on the water table and in turn the loads are transmitted to the water the limestone aquifer nullifying the effects of the loads imposed by e atmosphere on the water columns in the wells.

Of minor importance, but of large amplitude are sudden rises and lls of the water columns in the artesian wells as a result of earth-uake shocks. Rises of as much as 0.5 foot with corresponding falls ave been recorded by water-stage recorders on these wells even when e earthquakes have occurred at very great distances from the area.

## NATURAL DISCHARGE OF THE THERMAL WATER

Before the existence of the town of Hot Springs and the develop-ent of the thermal water by means of artesian wells and shallow umps, the greater part of the thermal water rising to the surface was ischarged into the Rio Grande by way of seeps and springs. Accord-ng to the reports of old settlers the thermal waters discharging at the urface gave rise to marshy areas supporting dense growths of cat-tails, lags, and tules. Apparently the point of greatest surface discharge was entered in what is now block 41 of the Hot Springs Townsite in the pper part of a slough or old abandoned channel of the Rio Grande. Thermal water rising at this point made its way to the Rio Grande as small stream following the slough to a point near the granite bluff where it entered the river. At the present time the course of the slough is followed by the hot water drain, and since the construction of the drain and the development of the sump baths in and near block 41 the water table has been lowered to about 1 foot or less below the surface in parts of the slough adjacent to the drain and the sumps.

A part of the thermal water which formerly rose to the surface in seeps and springs has been diverted to the wells. However, from the indication of the available data discussed in the section headed "Quantity of Thermal Water Used," the diverted quantity is relatively small in comparison with the quantity discharged by natural processes. Under the present developed condition of the thermal water area, natural discharge takes place through the springs located along the base of the limestone bluff, by general seepage into the sides and bottom of the channel of the Rio Grande, by discharge of the sumps and drain which empties into the Rio Grande, and by transpiration and evaporation. With the exception of the last named type of discharge all of the discharge eventually enters the river. Transpiration and evaporation of the thermal water under water-table conditions take place over most of the small alluvial flat occupied by the south half of the Hot Springs Townsite. Tornillo, mesquite and salt grass grow here in relative abundance. Over all of this area the water table is within 8 feet of the surface and over most of the area it is within 3 or 4 feet of the surface. In many areas it is so shallow that the capillary fringe extends to the surface, and evaporation takes place quite readily, leaving a saline crust composed largely of sodium chloride at the surface.

The small springs along the base of the limestone bluff represent overflow from the artesian aquifer into the alluvium near the point where the alluvium pinches out. The total discharge from all these springs is only about 10 gallons a minute. The general seepage into the river comes from thermal water moving slowly upward from the artesian aquifer into the upper part of the alluvium and thence laterally down the slope of the water table to the river. The discharge of the sumps and drains is intercepted thermal water which would otherwise discharge into the river.

Probably the most feasible way of determining the quantity of thermal water available for bathing and drinking purposes at Hot Springs is to determine the amount of natural discharge. As stated above, the principal point of discharge is the Rio Grande. This discharge takes place in the hot water drain and as general seepage along the sides and bottom of the river channel in the interval between the limestone outcrop near the river and the first granite outcrop on the west side of the river at the south limit of Hot Springs.

In January and February 1936 a seepage run of the Rio Grande from Elephant Butte Dam to El Paso, Texas, was made by John H. Bliss[31], of the Office of the New Mexico State Engineer. In this seepage determination, two measurements of the Rio Grande in the vicinity of Hot Springs were made. The first of these was made about 1.3 miles upstream from Hot Springs, and a second measurement was made about 2.9 miles downstream from Hot Springs just below the mouth of Mud Springs Wash. The invisible gain in the river through this 4.2-mile interval was 3.2 second-feet (1435 gallons a minute) or about 340 gallons a minute per mile of river. If it were assumed that there was equal distribution of the seepage through this stretch, there would be approximately 275 gallons a minute entering the Rio Grande through the discharge belt of the thermal water. However, it is practically certain that the proportionate seepage in this belt is much larger than the average in the section of river measured.

Additional measurements of the pick-up of the river through the hot water belt were made during the course of the present investigation on November 28 and 29, 1939, when there were releases of only 15.5 second-feet from Elephant Butte Reservoir and the river was consequently at a low stage.

During the course of the seepage runs samples were collected at 10-foot intervals across the channel and the chloride content, determined by field methods, was weighted according to the discharge in that interval of the river. In one set of measurements taken just above the hot water area, a flow of 20.5 second-feet was measured and the chloride content of the river water averaged 242 parts per million with no apparent systematic distribution from one bank to the other. In a second set of measurements taken opposite the lower end of the area of hot mineral water, but above the mouth of the hot water drain, the flow of the river was 22.7 second-feet. Here the average chloride content for the main body of the stream was 302 parts per million, but along the west bank there was a small branch flowing about 0.15 second-foot which appeared to be largely water seeping into the river from the Hot Springs flat. The chloride content of this stream was 1,410

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[31] Bliss, John H., Report on investigation of invisible gains and losses in the Rio Grande from Elephant Butte to El Paso, Texas; Memorandum to T. M. McClure, State Engineer, February, 1936.

parts per million and when averaged with the rest of the river at this point gave an average value of 310 parts per million of chloride.

As shown by chemical analyses and field chloride tests, the chloride content of the hot mineral water is quite uniform. Inasmuch as all the ground water on the west side of the river at Hot Springs is this type of water and as the water of the valley fill which might enter the river from the east is generally lower in chloride than the river at the upper section, the increase in chloride content is a rough measure of the seepage of hot water into the river. From the values of chloride content and the flow of 20.5 second-feet as measured at the first station, it would appear that an addition of 1.4 second-feet of water carrying 1,300 parts per million chloride would be sufficient to produce the increased chloride content in the river water observed at the second station. The additional pick-up of 0.8 second-foot in the river measured with a pygmy current meter between the two stations quite possibly represents the dilution of the mineral water by normal ground water from the east. It thus appears that between 1.5 and 2 second-feet, or between 675 and 900 gallons a minute, of thermal water seeps directly into the river from the hot water area, with the balance of evidence favoring the lower figure.

In addition to the thermal water which discharges directly into the river is that carried by the hot-water drain. This drain intercepts a considerable amount of the water moving toward the river and discharges it into the river at the base of the granite bluff below the thermal water area. It is difficult to state to what extent the sump baths have artificially developed thermal water. In general it may be said they they only intercept and divert to the drain thermal water that is already moving toward the river. In this way they act as small subsidiary drains contributing to the flow of the main drain.

On November 29, 1939, the flow of the drain was measured by pygmy current meter at the beginning of the drain and at its mouth, as well as at two intermediate points. These measurements were made early in the morning so as to eliminate as nearly as possible the addition of waste water to the drain from pumped wells. The values obtained were 0.1 second-foot near the upper end of the drain, 1.4 second-feet at Daniels Street, 1.5 second-feet at Wyona Avenue, and 1.45 second-feet or 650 gallons a minute at the mouth of the drain. The stage of the river and water table at this time was low.

On April 9, 1940, at 6:20 p. m., the flow of the hot water drain was again measured by pygmy current meter, and the flow was found to be 2.1 second-feet, or 950 gallons a minute. A water-stage recorder on the drain, whose position is shown in plate 1, indicated that the flow of the drain reached a maximum daily stage at this time. From the 4-month record for the flow of the drain obtained up to July 1, 1940, it appears that this date was also near the time of yearly maximum flow. The measurements were made at times when transpiration by native vegetation was near a minimum and hence when practically all the water was discharging into the river. It thus appears that the total amount of thermal water discharged into the river at Hot Springs is between 3 and 4 second-feet, or between 2 and 2.6 million gallons a day. This amount is greatly in excess of that obtained from wells, 140,000 gallons a day.

## HYDROLOGIC CHARACTER OF THE AQUIFER

The source rock from which the artesian wells at Hot Springs obtain their supply of water is the Magdalena limestone of Pennsylvanian age. From the indications of well logs and from studies of the character of the source rock in surface outcrops it appears that the thermal water is found largely in connected joint and bedding planes chiefly in and near the fractured zone along the fault between the Pre-Cambrian granite and the Magdalena limestone. A considerable amount of thermal water may also occur in pore spaces in the zone of altered limestone from which the calcium carbonate has been removed leaving a porous siliceous to argillaceous skeleton. Thermal water probably also exists in cavernous solution openings in the limestone, although to what extent is not known.

In order to determine the character of the movement of the water in the limestone, pumping tests were made on several wells. These tests consisted of the determination of the specific capacity of four wells and more elaborate observations during the pumping of two wells, during which the drawdown in neighboring wells and the rate of recovery of water levels were measured.

The correspondence between the fluctuations of water levels in the wells in the alluvium and those in the limestone and the similarity in chemical character of the water in the two aquifers, as well as other hydraulic observations, show that the water seeps upward from the limestone into the alluvium. Under these conditions, it appeared doubtful that the quantitative determination of the transmissibility of the formation could be made by the techniques and formulas developed for pumping tests in ordinary aquifers in which there is no movement vertically into or out of the aquifer. However, the two tests were made in accordance with standard techniques on the possibility that the upward leakage might be less than was anticipated, and in any case to test these techniques under the given conditions.

### SPECIFIC CAPACITIES OF WELLS

In order to determine specific capacities for some of the wells in Hot Springs the yield of water during pumping and the drawdown of the water level occasioned thereby were measured for wells 19 and 31 in block 104, and wells 17 and 18 in block 105. In each case, when pumping was stopped, the recovery from the pumping level to the static water level was almost instantaneous or consumed only the time necessary to fill the well casing from the pumping level to the static level. The time required for this process was in all cases less than one minute. The specific capacities of the wells or the amount of water delivered in gallons a minute per foot of drawdown of the water column in the well obtained from these tests are as follows:

*Specific Capacities of Some Hot Springs Thermal Wells*

| Well | Yield of well (gallons a minute) | Draw-down (feet) | Specific capacity (gallons a minute per foot of drawdown) | Duration of test (hours) |
|---|---|---|---|---|
| 17 | 50 | 1.37 | 37 | 1.75 |
| 18 | 52 | 4.91 | 13 | 1 |
| 19 | 68 | 4.66 | 15 | 2 |
| 31 | 43 | 4.25 | 10 | 3 |

The specific capacity of well 17 is comparable to that of wells in good irrigation aquifers elsewhere in New Mexico, and considering the small diameter of the well, indicates an aquifer of high permeability at this locality. The smaller specific capacities of the other wells probably indicate less permeable parts of the aquifer, although inasmuch as the wells are small and that in general there is no necessity to develop these wells to their maximum capacity after drilling, the low specific capacities may be a result of the type of well construction rather than of an aquifer of low transmissibility.

## PUMPING TEST NO. 1

A pumping test was made on May 11, 1939, during the early morning hours when interference from pumping in other wells was at a minimum. Well 18 in block 105 was pumped at a rate of 52 gallons a minute from 5:04 a. m. until 6:04 a. m. and water levels in wells 5, 7, 17, and 19, surrounding the pumped well, were measured at intervals throughout this period to determine to what extent they were affected by the pumping in well 18. The position of these wells is shown in plate 1. Depth to water measurements obtained during this test are given in the following table:

*Drawdowns of Water Levels in Adjacent Wells Caused by Pumping Well* 18, *Block* 105 *on May* 11, 1939

Well 18 pumped at the rate of 52 gallons a minute from 5:04 a. m. to 6:04 a. m.

| WELL 17 | | WELL 19 | | WELL 5 | | WELL 7 | |
|---|---|---|---|---|---|---|---|
| Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) |
| 5:10 | 0.07 | 5:09 | 0.00 | | | 5:10 | 0.01 |
| 5:12 | 0.08 | | | 5:15 | 0.00 | 5:14 | 0.02 |
| 5:16 | 0.08 | 5:17 | 0.06 | | | 5:17 | 0.03 |
| 5:19 | 0.08 | 5:19 | 0.07 | | | 5:21 | 0.03 |
| 5:22 | 0.08 | 5:20 | 0.07 | 5:24 | 0.00 | 5:25 | 0.02 |
| 5:27 | 0.08 | | | 5:28 | 0.00 | 5:28 | 0.03 |
| 5:30 | 0.08 | 5:31 | 0.07 | | | 5:32 | 0.02 |
| 5:34 | 0.08 | | | | | 5:35 | 0.03 |
| 5:37 | 0.08 | | | | | 5:50 | 0.02 |
| 5:52 | 0.08 | 6:03 | | 5:52 | 0.02 | 5:53 | 0.03 |
| 5:56 | 0.08 | | 0.08 | 6:01 | 0.03 | | |
| Pumping stopped at 6:04 | | | | | | | |
| 6:04 | 0.06 | 6:04 | 0.04 | | | | |
| 6:05 | 0.05 | | | | | | |
| 6:06 | 0.04 | 6:06 | 0.03 | | | | |
| 6:07 | 0.03 | | | | | | |
| 6:08 | 0.03 | 6:08 | 0.02 | 6:10 | 0.02 | 6:10 | 0.00 |
| | | 6:14 | 0.02 | | | | |

It is apparent from the drawdown figures in the foregoing table that well 17 in block 105 about 185 feet west and a little north of the pumping well responded most quickly to the pumping, since the lowering of the water level in well 17 began at an earlier time than in any other observation well. Well 19, about 119 feet north and a little west of the pumped well was next in order of time to respond to pumping of well 18. In well 19 the water level did not begin to lower until about 6 or 8 minutes after pumping began. Well 5 in block 9, about 260 feet southeast of the pumped well, was not affected until at least 25 minutes after pumping began, and then only very slightly, and well 7 in block 8, about 385 feet southwest of the pumped well, showed only small irregular and apparently not significant fluctuations during the pumping test. The fact that well 17 was affected more quickly and to a greater degree than any of the other wells indicates a greater transmissibility or ease of movement along a line from well 17 to 18, that is, in a southeasterly direction or along the general direction of the strike of the Magdalena strata. (pl. 1.)

It is also to be observed that all the wells, with the exception of well 5, reached their ultimate drawdowns, or nearly their ultimate, within a few minutes after pumping started, apparently indicating that a state of equilibrium was reached rather quickly. Such a condition could be explained as the effect of pumping in an artesian aquifer of high transmissibility, but it seems more probable in this area that it is the result of the diversion to the pump of the normal upward seepage through the confining bed.

## PUMPING TEST NO. 2

On December 4, 1939, a longer pumping test was made on well 8 belonging to the Carrie Tingley Hospital. This well was pumped continuously for a period of 4 hours at a rate of approximately 120 gallons a minute. Pumping of this well began at 12:56 a. m. and ceased at 4:57 a. m. During this period of pumping and for a time thereafter, measurements of water levels were made in wells 4, 5, 10A, 12, 17, 18, 19, 25, 27, 30, 31 and 35A. Water-level measurements during this test are shown in tabular form on the following pages, and the data are shown graphically on figure 7. On a sketch map on which contour lines were drawn through points of equal maximum drawdown, it was again observed as in pumping test No. 1 that the direction of greatest effect of the pumping was in a southeasterly direction, from well 8 to well 10A and thence to well 12. Well 10A was most strongly affected by the pumping in well 8. At this locality as at that of the first pumping test, the greater transmissibility in a southeasterly direction is doubtless caused by the greater ease of movement in the direction of the strike of the bedding planes of the Magdalena aquifer.

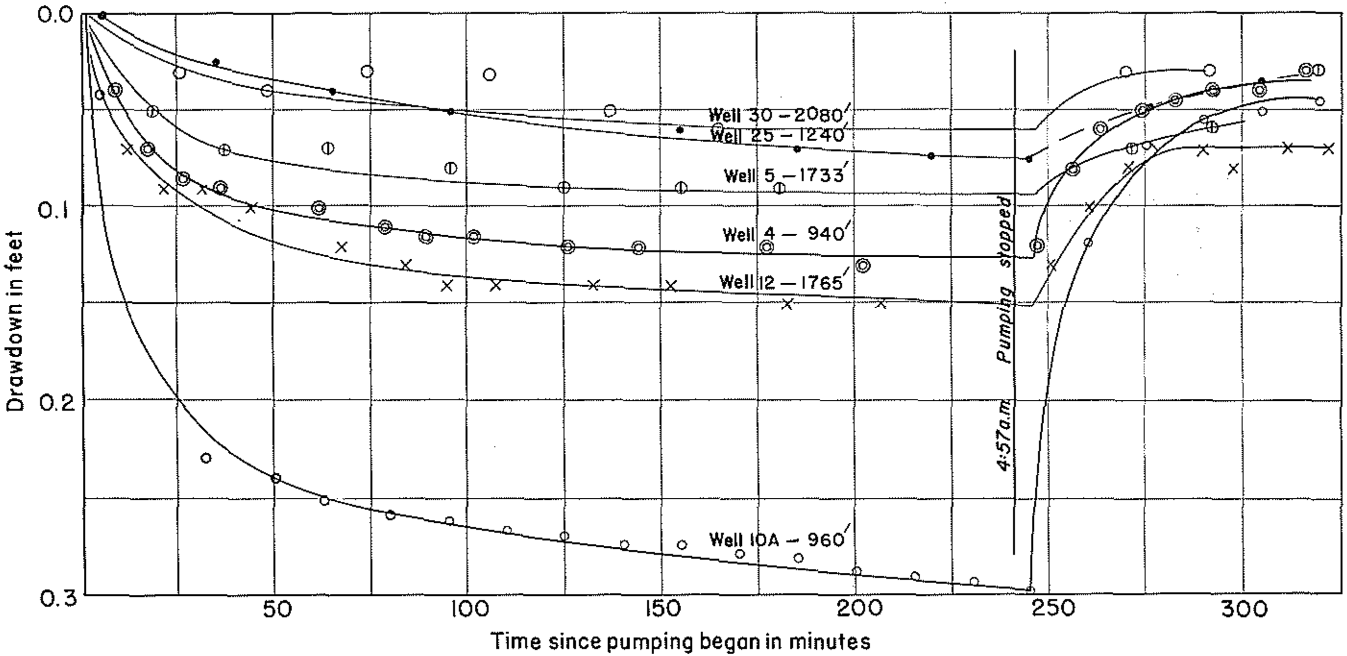

FIG. 7. Drawdown in water level in adjacent wells caused by pumping well 8. Distance from pumped well to each observation well shown in feet.

*Drawdown in Adjacent Wells Caused by Pumping Well 8, December 4, 1939*

Pumping began at 12:56 a. m.; stopped at 4:57 a. m.;
Yield: 120 gallons a minute

| WELL 4 | | WELL 5 | | WELL 10A | | WELL 12 | |
|---|---|---|---|---|---|---|---|
| Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) |
| | | | | 12:56 | .00 | | |
| | | | | 1:00 | .042 | | |
| 1:04 | .04 | | | | | 1:08 | .07 |
| 1:13 | .07 | 1:14 | .05 | 1:15 | .184 | 1:17 | .09 |
| 1:22 | .08 | | | | | 1:27 | .09 |
| | | | | 1:30 | .228 | 1:39 | .10 |
| 1:32 | .09 | 1:33 | .07 | 1:45 | .240 | | |
| 1:57 | .10 | 1:59 | .07 | 2:00 | .251 | 2:03 | .12 |
| 2:14 | .11 | | | 2:15 | .258 | 2:19 | .13 |
| 2:24 | .11 | | | 2:30 | .261 | 2:30 | .14 |
| | | 2:31 | .08 | | | | |
| 2:37 | .11 | | | | | 2:43 | .14 |
| | | | | 2:45 | .267 | | |
| | | 3:00 | .09 | 3:00 | .269 | | |
| 3:01 | .12 | | | 3:15 | .273 | 3:08 | .14 |
| 3:19 | .12 | | | | | 3:28 | .14 |
| | | 3:30 | .09 | 3:30 | .274 | | |
| | | | | 3:45 | .278 | | |
| 3:53 | .12 | 3:56 | .09 | | | 3:58 | .15 |
| | | | | 4:00 | .281 | | |
| | | | | 4:15 | .287 | 4:22 | .15 |
| 4:17 | .13 | | | 4:30 | .290 | | |
| | | | | 4:45 | .293 | | |
| Pumping stopped at 4:57 | | | | | | | |
| | | | | 5:00 | .298 | | |
| 5:02 | .12 | | | | | 5:06 | .13 |
| 5:12 | .08 | | | 5:15 | .118 | 5:16 | .10 |
| | | 5:17 | .07 | | | | |
| 5:21 | .06 | | | | | 5:26 | .08 |
| 5:29 | .05 | | | 5:30 | .068 | 5:33 | .07 |
| 5:38 | .04 | 5:38 | .06 | 5:45 | .055 | 5:45 | .07 |
| 5:48 | .04 | | | | | 5:53 | .08 |
| 5:59 | .04 | | | 6:00 | .051 | | |
| | | 6:05 | .03 | | | 6:07 | .07 |
| 6:12 | .03 | | | 6:15 | .047 | 6:18 | .07 |

*Drawdown in Adjacent Wells Caused by Pumping Well 8, December 4, 1939*
Continued

Pumping began at 12:56 a. m.; stopped at 4:57 a. m.;
Yield: 120 gallons a minute

| WELL 17 | | WELL 18 | | WELL 19 | | WELL 25 | |
|---|---|---|---|---|---|---|---|
| Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) |
| 1:05 | .00 | | | | | | |
| | | 1:11 | .02 | | | | |
| | | | | 1:18 | .03 | | |
| 1:25 | .02 | | | | | 1:30 | .02 |
| | | 1:29 | .04 | | | | |
| | | | | 1:39 | .06 | 2:00 | .04 |
| 1:50 | .04 | 1:55 | .03 | | | | |
| | | | | 2:03 | .06 | | |
| 2:22 | .06 | 2:27 | .04 | | | 2:30 | .05 |
| | | | | 2:35 | .06 | | |
| 2:48 | .05 | 2:55 | .06 | 3:05 | .07 | | |
| 3:19 | .07 | 3:25 | .06 | | | | |
| | | | | | | 3:30 | .06 |
| | | | | 3:34 | .07 | | |
| 3:45 | .06 | 3:52 | .06 | 4:00 | .06 | 4:00 | .07 |
| | | | | | | 4:30 | .07 |
| Pumping stopped at 4:57 | | | | | | | |
| | | | | | | 5:00 | .07 |
| 5:07 | .02 | 5:12 | .03 | | | | |
| | | | | | | 5:15 | .07 |
| | | | | 5:21 | .05 | | |
| | | 5:35 | .02 | | | 5:30 | .05 |
| 5:56 | .03 | | | 5:43 | .04 | | |
| | | 6:01 | .02 | | | 5:45 | .04 |
| | | | | | | 6:00 | .04 |
| | | | | 6:11 | .03 | | |

*Drawdown in Adjacent Wells Caused by Pumping Well* 8, *December* 4, 1939
Continued

Pumping began at 12:56 a. m.; stopped at 4:57 a. m.;
Yield: 120 gallons a minute

| WELL 27 | | WELL 30 | | WELL 31 | |
|---|---|---|---|---|---|
| Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) | Time (a.m.) | Drawdown (feet) |
| 1:05 | .05 | | | 1:10 | .04 |
| 1:15 | .05 | | | | |
| | | | | 1:20 | .03 |
| | | 1:21 | .03 | | |
| 1:25 | .06 | | | 1:29 | .04 |
| 1:37 | .06 | | | | |
| 2:00 | .09 | | | 2:05 | .05 |
| | | 2:09 | .03 | | |
| 2:16 | .08 | | | 2:22 | .04 |
| 2:27 | .09 | | | | |
| | | | | 2:33 | .04 |
| 2:40 | .10 | 2:41 | .03 | 2:47 | .04 |
| 3:05 | .10 | | | 3:11 | .04 |
| | | 3:12 | .05 | | |
| 3:25 | .10 | | | 3:30 | .04 |
| 3:57 | .10 | | | 4:01 | .05 |
| 4:20 | .10 | | | | |
| | | | | 4:27 | .05 |
| Pumping stopped at 4:57 | | | | | |
| 5:04 | .08 | | | 5:08 | .04 |
| 5:15 | .06 | | | 5:18 | .04 |
| 5:24 | .03 | 5:25 | .03 | | |
| 5:32 | .03 | | | 5:36 | .03 |
| 5:43 | .02 | | | | |
| | | 5:47 | .03 | | |
| 5:51 | .04 | | | 5:56 | .03 |
| 6:05 | .04 | | | | |
| 6:17 | .03 | | | 6:22 | .02 |

## INTERPRETATION OF PUMPING TESTS

The data from pumping tests such as those at Hot Springs can usually be interpreted in terms of the coefficient of transmissibility and coefficient of storage of the aquifer when there is no vertical movement of water out of or into the aquifer. The coefficient of transmissibility is the number of gallons of water that moves in one day through each vertical strip of the aquifer one foot wide under a unit hydraulic gradient. It expresses the ease of movement of water through the aquifer. The coefficient of storage is the amount of water in cubic feet derived from storage in each column of the aquifer having a base 1 foot square when the head of the water, as shown by the water level in a well, falls 1 foot. This stored water represents water drained out of the aquifer when the water table is lowered in a non-artesian aquifer, or water derived from compression of an artesian aquifer, including the clayey beds in the aquifer.

These quantities are derived from the data from pumping tests by three techniques, namely (1) Thiem's method[32], in which the lowering of water levels in observation wells near the pumped well is used as base data, (2) the recovery method[33], in which the rate of recovery of the water level in the pumped well after pumping stops is the essential information, and (3) the drawdown method[34], in which the rate of lowering of water level in one or more observation wells is the essential information. The first two methods yield the coefficient of transmissibility, the last both the coefficient of transmissibility and the coefficient of storage. In addition computations based on the data of the first method using a procedure suggested by Meinzer and developed by Wenzel[35], can yield the coefficient of storage.

All these methods were applied to the data from the pumping tests at Hot Springs. The determinations of the coefficients of the aquifer as indicated by pumping test No. 2 are given in the following table:

*Summary of Values Obtained for the Coefficients of Transmissibility and Storage for the Magdalena Limestone Aquifer, in the Hot Springs Artesian Basin*

| Well | Dist. from pumped well (feet) | Direction from pumped well | Graphical drawdown curve method | | Recovery curve method | Thiem's method |
|---|---|---|---|---|---|---|
| | | | Coefficient of transmissibility | Coefficient of storage | Coefficient of transmissibility | Coefficient of transmissibility |
| 4 | 940 | ENE | $5.2 \times 10^5$ | $1.6 \times 10^{-4}$ | $7.2 \times 10^5$ | |
| 5 | 1,733 | E | $5.5 \times 10^5$ | $1.7 \times 10^{-3}$ | | |
| 10A | 960 | ESE | $4.5 \times 10^5$ | $1.8 \times 10^{-6}$ | $5.5 \times 10^5$ | |
| 10A & 12 | | | | | | $1.1 \times 10^5$ |
| 12 | 1,800 | ESE | $3.4 \times 10^5$ | $8.1 \times 10^{-5}$ | $2.6 \times 10^5$ | |
| 17 | 1,530 | ENE | | | $3.8 \times 10^5$ | |
| 25 | 1,240 | NE | $4.3 \times 10^5$ | $1.2 \times 10^{-3}$ | $4.5 \times 10^5$ | |
| 10A & 27 | 2,035 | ESE | | | | $1.0 \times 10^5$ |

It was found that Thiem's equation was in general inapplicable because of the obviously greater ease of movement along the strike of the strata. However, figures were derived using the drawdowns in wells

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[32] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials; U. S. Geol. Survey Water-Supply Paper 679-A, p. 10, 1935.

[33] Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage; Am. Geophys. Union Trans., 16th Ann. Meeting, pp. 519-524, 1935.

[34] Jacob, C. E., On the flow of water in an elastic artesian aquifer; Am. Geophys. Union Trans., 21st Ann. Meeting, pp. 574-586, 1940.

[35] Wenzel, L. K. op. cit. pp. 53-57.

10A and 12, and 10A and 27 which are in an approximately straight line along the strike of the strata. These data gave coefficients of transmissibility of the order of 100,000 as shown in the table. Computations from drawdowns in the adjacent wells and from recovery of adjacent wells gave coefficients varying from 260,000 to 720,000, the computed coefficient diminishing rather regularly with distance from the well. The computed coefficients of storage varied widely and irregularly.

Many of the discrepancies in the computed figures are no doubt to be correlated in part with the lack of homogeneity in the aquifer. However, the much larger values found for the coefficient of transmissibility by the methods using the rate of change in water level than were found by Thiem's method are probably the result very largely of the vertical discharge of water. The methods depend on the rapidity with which the water levels approach an equilibrium or quasi-equilibrium, and it is evident that if changes in the rate of vertical movement help to attain this equilibrium then formulas not taking this movement into consideration will give results that make the other chief factor that controls this rate—the transmissibility—too high. Likewise, if changes in the vertical rate of movement of water account for much of the water discharged by the well, there will be less water moving past the observation wells that were used for the Thiem's test, and it is probable that the figure for transmissibility so derived is also somewhat too high.

In summary, the pumping tests indicate that the movement of the water in the aquifer is easiest in the direction of strike, or along the grain, of the rocks. Quantitative determinations of the characteristics of the aquifer were not possible with existent techniques but seem to bear out the conclusion that the limestone aquifer discharges largely by upward percolation into the alluvium.

## SOURCE OF THE THERMAL WATER

The source of the heat of the hot water and of the water itself at Hot Springs cannot be definitely demonstrated. Similar questions about other areas of hot springs have been discussed in geologic literature for decades without definite and universally accepted answers. However, the evidence available at Hot Springs throws considerable light on the subject.

It has been shown above that about 1,570 gallons of hot water a minute are being discharged at Hot Springs. The temperature of this water may be taken as about 114°F., which is an increase of 54 degrees over the average annual temperature at Hot Springs. This increase in the temperature of 1,570 gallons or 13,200 pounds of water represents the addition of about 180,000,000 calories of heat. Hence, the flow of hot water at Hot Springs represents also the flow of 180,000,000 calories of heat each minute. To heat this water artificially would require the complete combuston of about 40 tons of coal each day. As a comparison, Old Faithful geyser in Yellowstone Park discharges about 12,000 gallons of water each hour at a temperature about 160°F. (88°C.)

above the average annual temperature[36]. The amount of thermal water discharged by Hot Springs is therefore about 8 times that discharged by Old Faithful and the amount of heat brought to the earth's surface by the water at Hot Springs is about 2½ times that brought by Old Faithful. To be added to this amount of heat is that represented by the discharge of slightly warm shallow ground water in the vicinity but outside the town limits of Hot Springs, such as that in the wells that supply the town. It is impossible to estimate the quantity of heat so represented, but it may be a significant part of the total heat discharged from the area. The source of the heat and the source of the water are interrelated questions and cannot well be discussed separately.

That the source of the hot water is distinctly different from that of the other ground water in the neighborhood is shown by its chemical character, its pressure, and its temperature. It is essentially a sodium chloride water, whereas the other ground water in the vicinity of Hot Springs and, in fact, generally in the Rio Grande Valley in New Mexico has a comparatively small content of this salt. The pressure under which it comes to the surface is apparently such that it pushes aside and out of the basin the shallow ground water of the area. Finally, its high temperature must be connected in some way with deep circulation as there are no obvious sources of heat near the surface.

The heat of hot springs has been variously considered to be derived (a) from the natural increase in temperature of the earth with depth, (b) from an underlying body of hot and possibly molten rock, and (c) from zones where there has been faulting with resulting development of heat[37].

Of these the third hypothesis has apparently the least significance to conditions at Hot Springs. Faulting has been profound and widespread at Hot Springs, but the time at which it occurred is sufficiently in the past to indicate that in order to supply the heat now being removed by the Hot Springs the original temperatures would have had to be high enough to bring the rocks involved nearly or quite to the point of fusion. Inasmuch as there is no evidence of extensive dynamic metamorphism, such a source of heat can be eliminated from consideration in the present instance.

The temperature of the earth increases with depth at rates varying in different places from about 1°F. for every 150 feet to about 1°F. for every 40 feet[38]. Rocks conduct heat very slowly. The coefficient of conduction of most solid rocks of the earth's crust approximates .005 calories per square centimeter per second under a thermal gradient of 1°C. in 1 centimeter. The movement of heat to the earth's surface under a thermal gradient of 1°C. for each 30 meters (approximately 1°F. for each 55 feet), a commonly used value for the thermal gradient, would be about $1.67 \times 10^{-6}$ calories per square centimeter per second. If the

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[36] Day, A. L., The Hot-Spring Problem; Geol. Soc. America Bull., vol. 50, No. 3, pp. 328-329, 1939.

[37] Stearns, N. D., Stearns, H. T., and Waring, G. A., Thermal Springs in the United States; U. S. Geol. Survey, Water-Supply Paper 679-B, p. 68, 1937.

[38] Van Orstrand, C. E., in Gutenberg, Beno, Internal Constitution of the Earth, pp. 132-140, McGraw-Hill, 1939.

water discharging at Hot Springs were heated by this slow normal discharge of heat from the interior of the earth, it would be necessary for it to intercept all the heat normally escaping over about 70 square miles of the earth's surface. As a matter of fact, if the 3.5 second-feet of thermal water emerging at Hot Springs is derived from rainfall in the area, it represents a yearly addition to the deep ground water of about 5/8 inch over 70 square miles of area. Considering the small amounts of rainfall added to the ground water in arid regions, and that much of the water which penetrates to the water table in the Hot Springs area helps to maintain the shallow circulation and never descends to low enough levels to be heated by any means, it appears that the hot water at Hot Springs must be derived over an extensive area, and probably drains by deep circulation an area considerably larger than 70 square miles. It therefore appears that there is no incongruity in the concept that the hot water has covered an area under ground of this order.

It is of course impossible for the deep circulating ground water to intercept all the heat normally being radiated from the earth in a particular locality, for if the temperature of the water is raised, its own heat will be partly lost by conduction through the earth's crust to the surface. Hence, heat must rise faster to the level at which water is circulating than it escapes by conduction from that level to the surface; therefore the thermal gradient must in general be steeper below the level of the water than above it. In order for the heat of the hot water at Hot Springs to be obtained in this way, the thermal gradient below the level of the water would have to be of the order of at least twice the gradient used in the above calculation. The lavas at San Marcial and near Elephant Butte furnish evidence of volcanic activity as late as the Pleistocene in the vicinity of Hot Springs, and it therefore appears quite likely that such a high thermal gradient may have been produced in this area by the injection of molten rock in comparatively late geologic time.

In order to attain a temperature of 114°F. as a result of the normal increase of earth's temperature with depth, the water of Hot Springs would have to descend to a distance of from one-half to one mile below the surface. Because of the probable presence of Pre-Cambrian granite comparatively near the surface at Hot Springs and the probable low transmissibility of the granite, it is improbable that the water attains its temperature immediately under Hot Springs. However, in the synclinal area between Hot Springs and Elephant Butte the water could attain this temperature by circulation through the deeply buried Magdalena limestone or in the crushed rock along the fault zone. It therefore appears in the light of all the evidence available that the heat of the Hot Springs water may be obtained from conduction through the rocks if the thermal gradient has been steepened in the region because of the emplacement of molten rock at depth in comparatively late geologic time.

A variation of the above hypothesis involving the residual heat of igneous rocks is that all or part of the water might descend to actual contact with the cooling body of rocks. Such a variant hypothesis implies the emplacement of the igneous rock at shallower depths or the deeper circulation of ground water than the original hypothesis. It also requires a more rapid cooling and earlier loss of heat of the igneous body and, therefore, seems less probably true than the original hypothesis.

Another means by which heat could be added to the water is by the addition of superheated steam and other hot vapors rising from a still molten body of rock at depth. These vapors would condense and join with the normally circulating ground water. Such water derived from the interior of the earth is called juvenile water. It is evident that if this process furnished the heat of the water, it would also be very likely to change the chemical nature of the resulting mixed water.

It is sometimes possible to deduce the course of ground water before it appears at the surface from its chemical composition. The hot water is higher in its content of calcium bicarbonate and sodium chloride than the common ground water of the area. The excess of calcium bicarbonate is most probably to be correlated with its passage through the Magdalena limestone, in which it occurs at Hot Springs. That a large amount of calcium carbonate has been extracted from the Magdalena limestone in the past is shown by the thick zone of porous rock leached of its calcium carbonate exposed in the hill in Hot Springs. The sodium chloride might be expected to have its origin in the Permian rocks of the area, as these rocks in New Mexico commonly contain beds and lenses of salt. However, the Permian rocks of the neighborhood contain even more gypsum than they do salt, and water obtained from them is usually a "gyp" or calcium sulphate water. Hence, if the sodium chloride of the Hot Springs water was derived from the Permian rocks, it would be expected also to contain a large amount of calcium sulphate. The hot water of the Hot Springs area as a matter of fact is rather low in its content of sulphate. Therefore, it does not seem probable that the chemical character of the hot water can be explained by passage through any of the known rocks of the area.

Many hot springs in different parts of the world, irrespective of the rocks from which they issue, yield water high in sodium chloride. Among the best known and best studied of these are those in Yellowstone Park. The geysers and hot springs of the Upper Geyser Basin are characterized by a neutral to alkaline reaction, by the presence of carbonates and chlorides, and by a high content of silica[39]. These hot springs have been ascribed to the mingling of meteoric water with superheated steam and other gases rising from igneous rocks at depth. Day has given the following synopsis of the process by which the water of Yellowstone Park receives its chemical character and heat[40].

"When these emanations leave the magma and begin their percolation upward through the cover, vapors of the alkali halides are swept along in the current of steam and carbon dioxide. At the lower limit of ground water they enter into solution in quantities appropriate to their temperature and solubility, the steam condenses and thereafter is added to the circulating ground water itself."

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[39] Day, A. L., op. cit., p. 325.

[40] Idem., pp. 326-327.

"These hot solutions react with the adjacent rocks in a manner appropriate to the concentration of the participating ingredients. Carbon dioxide, for example, attacks the silicate minerals of the wall rocks and extracts bases. The resulting alkaline solution then removes silica in colloidal solution . . ."

A comparison of the waters of Old Faithful geyser and of Hot Springs is of interest. The water of Old Faithful has somewhat less mineral matter in solution than that of Hot Springs. The mineral constituents of the water of Old Faithful[41] and of the Town Spring at Hot Springs (analysis 7) in terms of percentage of total dissolved salts are as follows:

| Mineral Constituents | Old Faithful Geyser | Town Spring, Hot Springs |
|---|---|---|
| Sodium | 26.42 | 28.1 |
| Potassium | 1.93 | 1.49 |
| Calcium | 0.11 | 6.1 |
| Magnesium | 0.04 | 0.7 |
| Chloride | 31.64 | 50.1 |
| Sulphate | 1.30 | 3.35 |
| Carbonate | 8.78 | 8.77 (Bicarbonate) |
| Silica | 27.58 | 1.49 |

Of these constituents, the silica and part of the sodium of the Old Faithful water are ascribed by Day to removal of material from the rhyolitic rocks through which the water circulates. The chloride and carbonate are considered to have risen from the magma. At Hot Springs the calcium and magnesium and part of the carbonate must also be derived from the rock through which the water circulates, in this case the Magdalena and other limestones. Part of the sodium may have been derived from contact with Pre-Cambrian granite although it could be added by magmatic vapors. The most likely source for the large quantity of chloride appears to be such magmatic vapors.

If the magmatic gases are responsible for the chemical character of the thermal water at Hot Springs, they would also be responsible for most, or all of the heat of the water. The proportion of magmatic water to meteoric water would probably be very small. The condensation of superheated steam would furnish the necessary heat to the water discharged at Hot Springs if the resulting condensed magmatic water amounted to less than 5 per cent of the meteoric water.

If the magmatic gases were solely responsible for the heat of the water there would probably be a correlation between the temperature and the content of significant chemical constituents, except as the temperatures might be modified by local thermal processes at the wells and springs where temperatures can be measured. The thermal water of the wells in the small area in Hot Springs varies so little in chemi-

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[41] Clarke, F. W., The Data of Geochemistry; U. S. Geol. Survey Bull. 770, p. 197, 1924.

cal character and temperature that apparently no correlation can be developed. The temperature-chloride ratio is erratic within the small range represented. It is known that the temperatures of the Town Spring and U. S. Spring vary seasonally because of chilling of the water in the spring pools. Some of the wells which are little used, such as well 27 (analysis 4), may also indicate abnormally low temperatures. However, it may be significant, rather than adventitious, that there is a rough increase of chloride and fluoride content with temperature in the waters whose analyses were given previously. The average temperature of water from wells in the thermal water area in Hot Springs (analyses 1-6) is 109.5°F., the chloride content is 1270 parts per million, and the fluoride content 3.1 parts; the temperature of the water at the Cuchillo spring (analysis 12), which is 25 miles northwest of Hot Springs but discharges water of the same chemical character, is 85.6°, the chloride content 650 parts per million, and the fluoride content 2.4 parts; the temperature of water from the well used for city supply (analysis 11) is 77°, the chloride content 212 parts, and the fluoride content 0.6 parts. Inasmuch as heating of the water by conduction and by absorption of hot vapors are not mutually exclusive, so that a part of the water may have absorbed relatively little hot vapor and a relatively large amount of heat by conduction, and inasmuch as the vapors to which different parts of the water were exposed were not necessarily exactly alike in composition, it may be that a more detailed agreement between temperature and mineral content cannot be expected.

In summary it appears that the most probable source of the heat of the hot water is igneous rock at depth, either acting by conduction of heat through the rock and steepening the geothermal gradient or by yielding steam and hot gases that rise through fractures to mingle with the normally circulating meteoric ground water. The latter alternative seems to be favored by the chemical character of the water. The slightly warm water that lies around the outskirts of the town may derive its heat by conduction through the rocks or perhaps the admixture of a small amount of the thermal water.

Any change in the quantity of heat being yielded to the water will doubtless take place slowly in geological time, so that from the standpoint of human foresight the quantity of heat may be considered constant. The temperature of the water will not become lower unless the quantity of ground water should be increased for some reason.

The ultimate source of at least the larger part of the hot water is doubtless the rainfall in a somewhat extensive area in the neighborhood of Hot Springs. No evidence has appeared during this investigation to indicate that the quantity of water being delivered to the Hot Springs locality varies in any significant degree. The only hydrologic feature that holds a possibility of changing the rate of flow of ground water to the area is apparently Elephant Butte Reservoir. Because of the possible hydrologic connection between the reservoir and Hot Springs through the fault running between the two localities, it is conceivable that the stage of water in Elephant Butte could affect the rate at which water is delivered to the area and, by varying the amount of water taking up a fixed quantity of heat, could also affect the temperature of the water. If this action occurred, it is possible that because of time lag involved in the ground-water flow the full effect of the construction of Elephant Butte Reservoir may not yet have been felt. There seems to be an ostensible correlation between the artesian pressure at Hot Springs and the stage of water in Elephant Butte Reservoir. However, because the correlation does not hold in detail, it appears that the two phenomena—the stage of the reservoir and the artesian pressure—are both seasonal phenomena and have no causal relationship. Hence it appears that the rate at which heat is furnished the water and the rate of flow of the water may be considered constant, and that no significant change in the amount of the hot water or its temperature is to be expected under present climatic conditions.

## CRITERIA FOR THE DEVELOPMENT OF THE THERMAL WATER

It has been shown in the preceding pages that a total of some 1600 gallons a minute or over 2 million gallons a day of thermal water are discharged naturally by seepage through the alluvium into the drains and river at Hot Springs. The quantity of water taking part in the deep ground-water circulation is unlikely to vary appreciably and the quantity of heat yielded to the water is also unlikely to change in the predictable future. This is the ultimate quantity of water available for development at Hot Springs. Compared to this is the average quantity of water discharged by wells at present, about 100 gallons a minute or 140,000 gallons a day.

All of the 2 million gallons a day could be entirely utilized only by wells operated and spaced in an ideal manner. Under practical conditions the entire natural discharge cannot be utilized.

Any development of the artesian water by wells will reduce the artesian pressure to some extent, and with the reduction in artesian pressure the water table in the alluvium will fall. So long as the water table maintains a slope to the river, there will be no important effects of this lowering. The natural discharge of the alluvium will decrease, there will probably be a somewhat smaller flow into the sumps, and the flow of the springs at the upper edge of the city might decrease. However, the sumps and the springs could obtain the water they need from shallow wells. A conservative number of additional wells or a conservative increase in the use of the present wells is therefore not likely to cause any serious effects.

The stage of over-development will be reached when the water table is so much lowered that its present slope to the river is reversed. If this should occur colder and less mineralized river water would move into the alluvium and thence into the limestone to dilute the hot mineral water.

If the use of the thermal water should be increased greatly, steps to achieve the maximum use of water without reversing the slope of the water table locally should be taken. The wells should be spaced as uniformly as possible throughout the area of available hot water, and records of water level should be maintained in order that the static level of artesian wells in any locality is not allowed to fall below river level.

In order to guard against any adverse effects, whether or not intensive development of the thermal water takes place, shallow observation wells should be maintained near the river and drain to obtain a continuous record of the position of the water table with respect to the river. Such a record should be supplemented by periodic checks on the artesian pressure, the temperature and mineral content of the water, and the amount of water withdrawn by wells.

# RECORDS OF THERMAL WELLS, SPRINGS AND SUMPS IN HOT SPRINGS, SIERRA COUNTY, N. MEX.

| Well No. | Location Block No.[1] | Owner or name | Date completed | Altitude of land surface above sea level (feet) | Type | Reported Depth (feet) | Diameter (inches) |
|---|---|---|---|---|---|---|---|
| (A) Thermal water development in Magdalena limestone wells | | | | | | | |
| 1 | 2A | Odell Apartments | 1929 | 4,243.9 | Drilled | 125 | 6 5/8 |
| 2 | 1 | H. L. Lockhart | 1930 | 4,241.5 | “ | 125 | 6 5/8 |
| 3 | 1 | H. L. Lockhart | 1930 | 4,241.5 | “ | 125 | 6 5/8 |
| 4 | 2 | James Apartments | 1924 | 4,240.3 | “ | 105 | 6 3/4 |
| 5 | 9 | Frenchy's Bath House | 1928 | 4,240.9 | “ | 125 | 6 5/8 |
| 6 | 8 | C. E. James | | 4,241.0 | “ | 105 | 6 5/8 |
| 7 | 8 | A. J. Howe | 1923 | 4,240.5 | “ | 125 | 6 3/4 |
| 8 | 5 | Carrie Tingley Hospital | 1929 | -------- | “ | 212 | 6 3/4 |
| 10 | 11 | Virginia Ann Hospital | 1936 | 4,240.6 | “ | 165 | 6 5/8 |
| 10A | 11 | Morris Baths | 1938 | 4,239.0 | “ | 205 | 6 5/8 |
| 11 | 15 | Hotel Buena Vista | 1937 | -------- | “ | 225 | 6 |
| 11A | 10 | Star Apartments | 1939 | 4,240.8 | “ | 186 | 4 7/8 |
| 12 | 40 | Artesian Baths | 1929 | 4,236.9 | “ | 176 | 6 3/4 |
| 15 | Reserve | State Bath House | 1924 | 4,241.3 | “ | 125 | 6 5/8 |
| 16 | 95 | State of New Mexico | 1928 | -------- | “ | 162 | 4 3/4 |
| 17 | 105 | Arizona Hotel | 1928 | 4,241.2 | “ | 101 | 5 5/16 |
| 18 | 105 | Texas Home | 1928 | 4,241.1 | “ | 55 | 5 5/8 |
| 19 | 105 | Central Bath House | 1926 | 4,240.7 | “ | 27 | 4 |
| 20 | 96 | Sanitary Baths | 1928 | | “ | 158 | 4 7/8 |
| 20A | 96 | Sanitary Baths | | | “ | 165 | |
| 21 | 105 | Sunshine Apartments | 1929 | | “ | 125 | 6 5/8 |
| 24 | 102 | Anderson Hotel | 1926 | | “ | 100 | 4 |
| 25 | 93 | Jim Knox | | | Dug | 20 | |

WELL RECORDS (A)—Continued

| Well No. | WATER LEVEL | | Method of lift | YIELD | | Use | Chloride parts per million Field analyses[2] | Temperature °F | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | Altitude (feet) | Date of measurement (1939) | | Rate (gpm) | Date of measurement (1939) | | | | |
| 1 | | | Elec. Pump | | | Bathing-Drinking | 1,370 | 106.9 | |
| 2 | | | None | | | None | | | Capped |
| 3 | | | None | | | None | | | Capped |
| 4 | 4,240.68 | Mar. 29 | Elec. pump | | | Bathing-Drinking | 1,400 | 114 | |
| 5 | 4,240.17 | Mar. 29 | " | | | " " | 1,380 | 111.4 | |
| 6 | 4,240.80 | [3]Apr. 6 | None | | | None | | [4]116 | Recorder well |
| 7 | 4,240.39 | Mar. 28 | | | | | | 112 | |
| 8 | | | Elec. pump | 120 | Dec. 3 | Bathing-Drinking | 1,400 | [4]113 | |
| 10 | | | " | 60 | Mar. 29 | " " | 1,370 | 107.6 | Used by Hoosier Apts. |
| 10A | 4,240.88 | Mar. 29 | Flowing | | | " " | | 108 | Formerly recorder well |
| 11 | | | None | | | None | | [4]107 | Capped |
| 11A | 4,240.46 | Mar. 29 | Hand pump | | | Bathing-Drinking | 1,370 | 113 | |
| 12 | 4,240.59 | Mar. 29 | Flowing | 55 | Mar. 29 | " " | 1,400 | 108.5 | |
| 15 | | | Elec. pump | | | " " | 1,320 | 106.9 | |
| 16 | | | None | | | None | | [4]106 | Well covered |
| 17 | 4,239.61 | Mar. 28 | Elec. pump | 50 | Mar. 22 | Bathing-Drinking | | 112.5 | |
| 18 | 4,239.20 | Mar. 29 | " | 52 | May 11 | " " | 1,350 | 109.4 | |
| 19 | 4,239.74 | Mar. 28 | " | 68 | Feb. 7 | | 1,330 | 112.3 | |
| 20 | | | Flowing | | | Bathing-Drinking | | 98.6 | |
| 20A | | | Elec. pump | | | " " | 1,400 | 105.8 | |
| 21 | | | None | | | None | | | Capped |
| 24 | | | Elec. pump | | | Bathing-Drinking | 1,370 | 111.2 | |
| 25 | | | | | | None | | | Recorder well |

## WELL RECORDS(A)—Continued

| Well No. | Location Block No.[1] | Owner or name | Date completed | Altitude of land surface above sea level (feet) | Type | Reported Depth (feet) | Diameter (inches) |
|---|---|---|---|---|---|---|---|
| 27 | 42 | Mr. Graham | 1921 | 4,238.0 | Drilled | 185 | 12 |
| 30 | 102 | Dr. Geo. L. Mills | 1929 | 4,242.1 | “ | 125 | 6 1/2 |
| 31 | 104 | Scarborough's Baths | 1928 | 4,241.3 | “ | 258 | 6 5/8 |
| 32 | 103 | Jones Bath House | 1926 | 4,241.8 | “ | 239 | 4 |
| 33 | 106 | C. E. James | 1929 | | | 125 | 6 3/4 |
| 34 | 102 | J. C. Gilbert | 1929 | | Drilled | 125 | 6 3/4 |
| (B) Thermal water development in recent alluvium of Rio Grande flood plain, wells, springs, and sumps | | | | | | | |
| 9 | 42 | Langford's Baths | | | Sump | | |
| 13 | 41 | Yucca Lodge | | | “ | | |
| 13a | 41 | Yucca Lodge | | | Driven | 14 | 8 |
| 13b | 41 | Yucca Lodge | | | “ | 6 | 30 |
| 13c | 41 | Yucca Lodge | | | “ | 15 | 2 |
| 14 | 39 | Mrs. May Wiggins | | | Sump | | |
| 22 | Reserve | State Spring | | | Spring | | |
| 23 | 97 | Government Spring | | | “ | | |
| 26 | Reserve | Town of Hot Springs | | | Sump | | |
| 28 | 40 | Mrs. M. D. Hubbard | | | “ | | |
| 29 | 9 | John C. Morgan | | | “ | | |
| 35 | 39 | T. M. Holder | | | Driven | | |
| 37 | 41 | Dr. Geo. L. Mills | | | Sump | | |

## WELL RECORDS (A)—Continued

| Well No. | WATER LEVEL |  | Method of lift | YIELD |  | Use | Chloride parts per million Field analyses[2] | Temperature °F | Remarks |
|---|---|---|---|---|---|---|---|---|---|
|  | Altitude (feet) | Date of measurement (1939) |  | Rate (gpm) | Date of measurement (1939) |  |  |  |  |
| 27 | 4,240.03 | Mar. 23 | Flowing | 205 | Mar. 22 | None | 1,340 | 102 | Oil prospect well |
| 30 | 4,240.71 | Mar. 28 | Elec. pump | 49 | Dec. 19 | Bathing-Drinking | 1,370 | 110.7 |  |
| 31 | 4,242.23 | Mar. 28 | “ | 43 | Feb. 28 | “ “ | 1,380 | 111.2 |  |
| 32 | 4.241.74 | Mar. 30 | “ |  |  | “ “ | 1,380 | 110.8 |  |
| 33 |  |  |  |  |  | None |  |  | Recorder well |
| 34 |  |  |  |  |  | None |  |  | Capped |

## WELL RECORDS (B)—Continued

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| 9 |  |  |  |  |  | Bathing | 1,380 | 102 | Two sump baths |
| 13 |  |  |  |  |  | Bathing | 1,370 | 100-111 | 19 springs and sumps |
| 13a |  |  | Elec. pump | 127 | Mar. 28 | Bathing-Drinking | 1,370 | 109.5 |  |
| 13b |  |  | “ |  |  | “ “ |  | 111 |  |
| 13c |  |  | Flowing | 7 |  | Drinking |  | 110 |  |
| 14 |  |  |  |  | Apr. 5 | Bathing |  |  |  |
| 22 |  |  |  | 2.3 | Mar. 20 | Drinking | 1,330 | 99-103 |  |
| 23 |  |  |  | 1.3 | Mar. 20 | Drinking | 1,400 | 103-106 |  |
| 26 |  |  |  |  |  | Bathing |  |  | Free public bath |
| 28 |  |  |  |  |  | Bathing | 1,340 | 110 |  |
| 29 |  |  |  |  |  | Bathing | 1,380 | 94 |  |
| 35 |  |  |  |  |  | Bathing | 1,370 | 110.8 |  |
| 37 |  |  |  |  |  | None | 1,370 | 106-109 | 7 sump baths |

## RECORDS OF NONTHERMAL WELLS IN VALLEY-FILL DEPOSITS, HOT SPRINGS, SIERRA CO., N. MEX.

| Well No. | Location[1] | Owner or name | Date completed | Altitude of land surface above sea level (feet) | Type | Reported Depth (feet) | Diameter (inches) |
|---|---|---|---|---|---|---|---|
| 35A | NW¼SW¼ Sec. 34 | Mrs. Howard | | 4,262.8 | Drilled | 120 | 6 |
| 36 | NW¼SW¼ Sec. 34 | R. W. Swingle | 1929 | 4,271.7 | " | 182 | 5 3/4 |
| 37A | NW¼SW¼ Sec. 34 | G. W. Stokes | 1929 | -------- | " | 100 | 6 |
| 38 | NE¼SE¼ Sec. 33 | County Courthouse | | 4,291.7 | " | | 6 |
| 39 | NE¼NE¼ Sec. 33 | Max Hill | | 4,305.3 | Dug | 55 | |
| 40 | NW¼SW¼ Sec. 33 | Mr. Brown | | -------- | " | 52 | |
| 41 | NW¼SE¼ Sec. 33 | Dad Jones | | 4,312.3 | Driven | | |
| 42 | NE¼SW¼ Sec. 33 | Maude Copeland | | 4,318.7 | " | | |
| 43 | NW¼SW¼ Sec. 33 | Mr. Wolfe | | 4,369.9 | " | | |
| 45 | SW¼NW¼ Sec. 33 | Mr. Brown | | 4,370.8 | " | | |
| 46 | NE¼SW¼ Sec. 33 | Ned Bergman | | 4,333.8 | " | | |
| 47 | NE¼SW¼ Sec. 33 | Unknown | | 4,316.4 | " | | |

WELL RECORDS—Continued

| | WATER LEVEL | | | YIELD | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Well No. | Altitude (feet) | Date of measurement (1939) | Method of lift | Rate (gpm) | Date of measurement (1939) | Use | Chloride parts per million Field analyses[2] | Temperature °F | Remarks |
| 35A | 4,268.91 | | Flowing | 1.2 | Feb. 10 | Drinking | 1,200 | 70 | Three artesian strata |
| 36 | 4,270.69 | | Windmill | | | Drinking | 1,250 | | Three artesian strata |
| 37A | | | | | | None | | | Well filled |
| 38 | 4,262.45 | Mar. 29 | | | | None | | | |
| 39 | 4,256.86 | Mar. 29 | Windmill | | | Domestic-stock | | | |
| 40 | | | Bucket | | | Drinking | 1,710 | 76 | Well ends in Magdalena |
| 41 | 4,260.77 | Feb. 28 | Windmill | | | Drinking | | | |
| 42 | 4,263.95 | [3]Feb. 28 | Windmill | | | Drinking | | | |
| 43 | 4,274.02 | [3]Feb. 28 | None | | | None | | | |
| 45 | 4,281.40 | Sept. 12 | Windmill | | | Drinking | 380 | | |
| 46 | 4,271.01 | [3]Feb. 28 | None | | | None | 440 | | |
| 47 | 4,271.40 | June 16 | None | | | None | | | |

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[1] The town of Hot Springs is located in Sec. 4, T. 14 S., R. 4 W., and in Secs. 33 and 34, T. 13 S., R. 4 W.
[2] Field analyses apparently about 100 parts per million too high according to laboratory analyses.
[3] 1940.
[4] Reported; accuracy questionable.