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THE THERMAL SPRINGS OF HOT SPRINGS NATIONAL PARK, ARKANSAS--
FACTORS AFFECTING THEIR ENVIRONMENT AND MANAGEMENT

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SUMMARY AND CONCLUSIONS

The Hot Springs of Hot Springs National Park, Ark., issue from an artesian ground-water system. The water is of meteoric origin. The recharge area is the outcrop of the Bigfork Chert in the breached anticline between West Mountain and Sugarloaf Mountain and their northeasterly extensions. Further study is needed to delineate the size of the recharge area; it includes the Bigfork outcrop in Hot Springs Creek basin and part of the Bigfork outcrop in Gulpha Creek basin. A minor part of recharge is to the Arkansas Novaculite within Hot Springs National Park.

The radioactivity, and the dissolved-mineral and radon content of the hot water, are similar to those of the cold water in springs and wells in the area. Dissolved gases in the water reflect the former atmospheric and soil-air environments of the water. The only anomalous quality aspects of the hot water, compared with nearby cold ground waters, are the high temperature, ranging from 52° centigrade (Celsius) to 62°C, and the higher silica content. The high silica content is due to the increased solubility of silica in hot water.

The high temperature of the water is due to deep circulation of the water and contact with rocks heated by an igneous mass. Hydrogen-isotope analyses of a few samples of water from the Hot Springs indicate that the water is a mixture of an unknown but relatively small amount of water less than 20 years old and a preponderance of much older water. However, even though it may take a particular particle of water many years to pass through the spring system, the time response of the artesian flow system to stress--such as decrease in flow as a result of decrease in recharge--is much less than the time of travel of a water particle.

Flow of the Hot Springs has not been accurately determined on a periodic basis. This lack of flow information is the greatest deterrent to understanding the time response of the flow system to stress and interpretations that might be made therefrom, including evaluation of effects of urbanization to date (1970) on the flow of springs. With the flow data on hand, we can only state with some trepidation that there seems to have been no decrease in flow.

Collection of flow records is the highest priority item of data collection in future studies and should be continued indefinitely.

Bathhouse Row is in a narrow valley between West Mountain and Hot Springs Mountain. The runoff from Hot Springs Creek basin is carried underground along Central Avenue. The surface drainage from rainfall is rapid and runoff periodically exceeds the capacity of the storm sewer system, as in July 1963 when Bathhouse Row was flooded.

Hot Springs Creek basin is 26-percent urbanized; Gulpha Creek basin is 12-percent urbanized (commercial and residential area within the city of Hot Springs). Most of the urbanization is sparse (less than 40-percent impermeable cover). A small percentage of the rural area is cleared of the natural forest cover, but most of the forest has been affected by timber operations.

The effect of urbanization and land use on the Hot Springs flow cannot be assessed at this time, because spring flow has not been measured, the hydrology in the recharge area is incompletely known, and criteria have not been developed for assessing the different land-use factors on recharge.

It is estimated that urbanization and land use have moderately increased peak flows in Hot Springs Creek. As urbanization intensifies, the flood hazard on Central Avenue will increase.

Plans for development and renewal of the park are closely tied to water--both ground and surface. Wise and sound planning must be made with full recognition of the water factor in the environment.

INTRODUCTION

The thermal springs of the Hot Springs National Park, Ark., have been a natural resource of international renown since long before the first scientific study was made in 1804 by William Dunbar and George Hunter. Their study marked the beginning of an era of scientific curiosity as to the origin and heat source of the springs, although use of the spring waters for their therapeutic value, and of the area as a center of community life, dates back many centuries.

With the advent of modern-day environmental problems--effects of uncontrolled urbanization and overuse of the natural resources--scientific curiosity as such becomes subordinate to the more critical need to apply scientific principles and knowledge to preservation of the environment and resources for beneficial use by future generations. It is in this context that a study is being made by the U.S. Geological Survey on behalf of the National Park Service to assess the thermal water resources and the geohydrologic framework of the Hot Springs National Park and its capability to provide continuing esthetic, recreational, and balneological benefits to the public.

Objective and Scope of the Study

In recognition of an unprecedented increase in use of National Park facilities, and the certainty of an accelerated use in the future, the National Park Service is engaged in developing long-range plans to accommodate expanding visitation and, at the same time, to conserve the quality of the park environment. To aid in long-range planning, the Geological Survey has been requested to: (1) describe, on the basis of available records and knowledge, the hydrogeologic framework of the spring system and its functioning in terms of existing theories of spring origin and heat source; (2) evaluate, in accordance with the most acceptable hypothesis of spring origin, the probable effects of changed land use and urban development on the discharge, temperature, and chemical content of the spring waters; and (3) recommend an investigational and monitoring program that will insure adequate records on which to base management and operational decisions for optimum use of spring waters and preservation of esthetic values.

The process by which water enters the spring system, becomes heated, and discharges at the Hot Springs has been identified on the basis of updated geologic mapping, modern knowledge of ground-water hydrology, and data on volume, temperature, and chemical quality of the spring discharge. Old records have been examined to determine their applicability to the current problem, and as a basis for assuring adequate data-collection activities for future management of the springs.

Public interest in the Hot Springs has been focused primarily on the therapeutic value of the waters, and, in serving such interest, this also has been the focus of Federal management since the area was established as the Hot Springs Reservation in 1832. This emphasis did not change when direct Federal supervision was implemented in 1877, and when the area was designated as a National Park in 1921. The purpose of the park today is to preserve and protect the Hot Springs for present and future generations.

Long-range planning for park values and uses takes into consideration, however, the prospect of a shifting of emphasis from therapeutic values of the spring waters to the scientific, esthetic, and recreational values of the park as a whole. In either case, the probable life of the springs and their thermal characteristics play an important role in attracting visitors to the area. For this reason this report and the investigational program recommended herein emphasize the origin and functioning of the spring system and the probable effects of man-imposed stresses on the future of the springs and the park.

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History of Spring Development and Scientific Study

The history of the Hot Springs area has been documented in numerous publications, many of which present detailed accounts of some aspect of the springs' environment and the cultural development of the area. For the purposes of this report, therefore, and to minimize duplication, only those historic events and developmental practices that relate to the technical management of the springs will be cited.

Early descriptions of the Hot Springs, dating from Hernando de Soto's expedition in 1541, give different accounts of as many as 72 spring openings, in a belt about one-fourth mile long and a few hundred feet wide, along the southwest slope of Hot Springs Mountain. Excavation and covering of springs to increase and concentrate flows and to protect them from contamination have so altered the natural spring environment that it bears no resemblance to the original condition. Among the early investigators, Owen (1860) reported 42 springs; Glasgow (1860), 54 springs; and Haywood (1902), 46 springs. In his detailed history of Hot Springs, Scully (1966, p. 139) reported that at that time (1966) there were 47 active springs, including the two exhibition springs.

The exact date is not known, but some time prior to 1877 (Scully, 1966, p. 118) some of the springs were walled in and covered by masonry arches to protect them from contamination.

By the 1890's most of the springs were covered and a complicated piping system had evolved for supplying the bathhouses with hot water. In 1901 the springs were uncovered to give access for sampling and analysis by J. K. Haywood (1902). They were opened again in 1931 for cleaning. Some of the springs were deepened and the collection system was reconstructed. At this time a new collecting main was installed to divert the flow of 44 springs to a central reservoir, from which the water is redistributed to individual bathhouses. Since 1948 all the water delivered to the bathhouses has been metered. Excess water overflows into Hot Springs Creek when storage reservoirs are full.

Through the years (1860 to the present), at least 20 scientific investigations, directly or indirectly involving the Hot Springs, have been made. Although each study generally had a separate and specific objective, many of the investigators became sufficiently interested in the Hot Springs to attempt to explain the origin of the water and the source of the heat.

The consensus of most earlier investigators, and the conclusion of this study, is that the waters discharged from the Hot Springs are of meteoric origin, having fallen as precipitation primarily in the anticlinal valley lying just northwest, north, and northeast of Hot Springs and between Sugarloaf Mountain and North and West Mountains. Another theory that is regarded by some to have a degree of scientific validity is that the water may be of juvenile origin; that is, derived from the interior of the earth and not having previously existed as atmospheric water (Meinzer, 1923, p. 31). The conclusion herein expressed, that of meteoric origin, does not reject entirely the possibility that some relation does exist between the spring water and a still hot, deeply buried, mass of igneous rock. That such a heated rock mass is the ultimate source of heat for the spring waters is a relative certainty; but, based on the evidence available, it is considered unlikely that even a small percentage of the water is released from the cooling igneous mass.

Bryan (1922, p. 426) posed the question as to the meteoric, juvenile, or mixed origin of the waters discharged from the Hot Springs. He indicated (p. 447-448) that the juvenile theory is perhaps more satisfactory, although it rests on an insecure foundation in postulating (1) a special igneous mass that is discharging water due to cooling and recrystallization, and (2) a special fault fissure through which the water rises to the land surface. Bryan (p. 444) analyzed the merits of both the juvenile and meteoric theories, but conceded that "... a definite conclusion as to the ultimate origin of the water in the Hot Springs cannot now be reached." He pointed out (p. 443-444) that "If the water is juvenile there is presumably a constant supply, diminishing very gradually through the centuries in quantity and temperature. ...If ... the water has a meteoric origin, it is variable in quantity, fluctuating with the seasons or with groups of years having heavy or light rainfall." Thus, Bryan recognized the critical value of precise measurements of temperature, discharge, and other parameters during a sufficient period of time to provide adequate data on which to base conclusions as to the water origin.

Arndt and Stroud (1953) suggested a mixed origin for the water. Meteoric water, they believed, entered the spring system through the lower member of the Arkansas Novaculite on Hot Springs and North Mountains. They calculated that this source of meteoric water could supply about one-sixth of the flow of the springs. The rest of the water, they considered, could be juvenile water rising from depth.

Proponents of the theory of meteoric origin of the spring waters include Weed (1902), Purdue (1910), and Purdue and Miser (1923). Purdue (1910, p. 283) described the geologic conditions supporting this view, and identified the "collecting area" as the anticlinal valley between Sugarloaf and West Mountains. Most of the valley is underlain by the Bigfork Chert, a much fractured formation of high permeability that is capable of absorbing a tremendous quantity of water from the annual precipitation of approximately 54 inches. According to Purdue (p. 284), the occurrence of this formation in anticlinal valleys with its highly inclined beds, affords the most favorable condition for the intake of water. He postulates further that the water passes through the Bigfork Chert beneath the North Mountain syncline, and is forced upward into the Hot Springs anticline to emerge at the Hot Springs.

This suggested movement of water from the recharge area requires geologic conditions that account for its passage through the Polk Creek Shale, Missouri Mountain Slate, and the Arkansas Novaculite, to discharge as it does from the Hot Springs Sandstone. Such conditions would ordinarily be thought to require a major fault, with associated jointing and fissuring, that would provide passage through these formations. Some authors have shown such a fault (Bryan, 1924), but recent mapping by Haley and Stone (fig. 1) indicates no direct evidence of a fault at the Hot Springs. Owing to the intensive folding and overturning of formations in the vicinity of Hot Springs, such faulting cannot be confirmed with certainty. However, even without the presence of a fault, the intensive jointing and fissuring of the slate, shale, and novaculite formations would provide conduits for the water.

Origin of the Hot Springs Water

Professor David Dale Owen in his report of 1860 on the Hot Springs said the following. "When we reflect on the boundless and never-ceasing flow of thermal waters that must have bathed the sides of Hot Springs Ridge for countless ages...and however inexplicable such wonderful phenomena and changes may at first appear, yet, when the chemical principles become properly understood, disclosed by the enlightened and accurate chemical analyses, these obscure geological transormations [and the origin of the water and operation of the springs] can be satisfactorily and clearly explained." It would seem that Owen's prophecy may finally be fulfilled.

Previous investigators of the Hot Springs were trained in disciplines other than hydrology. Although they speculated on the origin of the Hot Springs water, these early investigators did not have the advantage of today's advanced state of the art of hydrology to apply in attempting to explain the origin. Consequently, misinformation and erroneous conclusions caused some of the early investigators to believe that water flowing from the Hot Springs originated from deep within the earth, as primary or juvenile water.

The existence of juvenile water elsewhere in the world is not in question--water vapor has been observed emanating from volcanoes in dry-land areas where the rocks of the earth's crust contain little or no meteoric water. However, there is no evidence to support the concept of existing large quantities of juvenile water comparable to the volumes of water known to be of meteoric origin (McGuinness, 1963). According to F. J. Pearson (written commun., 1970) no study of natural water from any source to date has found water that could conclusively be juvenile in origin.

According to Clarke (1924), juvenile water should be fairly constant in chemical composition and concentration with time, and it should carry sodium bicarbonate, alkaline silicates, and heavy metals such as chromium, lead, zinc, boron, and others, as chief constituents. The water from the Hot Springs contains none of these substances in any large quantity, and traces of these substances may be found in ground waters from nearly any source in Arkansas. In addition, in most places where the ground water in Arkansas is definitely considered to be meteoric in origin, the chemical composition and concentration varies little with time. This statement is generally true with ground water from any aquifer, as it is a part of the nature of occurrence of ground water under meteoric conditions.

McGuinness (1963) also presents clear evidence that juvenile water is highly mineralized, because of the high temperature and pressure in the juvenile-water environment. Juvenile water collected for analysis (as in the form of vapor escaping from a volcano) has been so very highly mineralized and corrosive that it is unfit for use.

According to White, Hem, and Waring (1963, p. F10), there is still much disagreement in regard to the origin of waters of different chemical composition. Most students of the problem agree that most of the water discharged at the surface in thermal areas is meteoric in origin, but that a part may be juvenile.

Thus, juvenile water exists only in small quantities and possesses a distinctively high mineral content. Neither of these criteria describes the water issuing from the Hot Springs; the flow is large and sustained, and analyses of samples made at different times during the last 75 years show that the water is relatively low in mineral content.

The meteoric origin of the Hot Springs water is also supported by examination of variations in the Hot Springs flow, temperature data, gas content of the water, characteristics of nearby cold springs, radioactivity of the water, geologic setting, and chemistry and isotope content of the water.

In other words, all the data collected during the last hundred years, when properly evaluated, can be assembled into one logical complete description of the Hot Springs system, with none of the data in contradiction and all supporting the concept of meteoric origin for the Hot Springs water.

THE HOT SPRINGS FLOW SYSTEM

Geologic Setting

The rocks cropping out in the vicinity of the Hot Springs are all sedimentary rocks, although intruded igneous rocks are exposed in the Hot Springs district (Purdue and Miser, 1923). The sedimentary rocks are relatively old and consist of shale, slate, chert, and sandstone. The names of the geologic formations, their geologic age, and position in the geologic column are shown in table 1.

Though igneous rocks are not exposed in the immediate vicinity of the Hot Springs, their nearby occurrence is frequently alluded to in the literature when sources of heat for the Hot Springs are considered. The igneous rocks are younger and were intruded into

Table 1.—Generalized section of sedimentary rocks in the vicinity of the Hot Springs, Ark.
(modified from Purdue and Miser, 1923)

System	Formation	Character of rocks	Topography
Mississippian	Stanley Shale	Bluish-black and black shale, and gray sandstone.	Low ridges, and hills and narrow valleys.
Mississippian	Hot Springs Sandstone	Hard, gray, quartztitic sandstone, and conglomerate.	Steep slopes of sharp-crested ridges.
Mississippian / Devonian	Arkansas Novaculite	Massive novaculite and thin-bedded novaculite, interbedded with black clay and siliceous shale.	High ridges and steep slopes.
Silurian / Ordovician	Missouri Mountain Shale and Polk Creek Shale, undifferentiated.	Green to black clay, and shale.	Steep slopes, or narrow valleys.
Ordovician	Bigfork Chert	Thin-bedded chert, highly fractured, and interbedded thin shale.	Steep-sided low ridges, and round knobs.
Ordovician	Womble Shale	Clay shale, and thin interbedded lenses of limestone.	Low hills.

the sedimentary rocks during the early Late Cretaceous (about 87 million years before the present). The igneous rocks in the Hot Springs district are exposed in two small areas about 6 miles southeast of the Hot Springs, and in many dikes and sills.

The sedimentary rocks of the Hot Springs district were originally laid down on the bottom of the sea in nearly horizontal beds. At present the beds are not generally horizontal, but are inclined at many angles, so that a geologic map (fig. 1) shows their edges as they intersect the land surface. When the formations are crossed from northwest to southeast, they are seen in cross section (fig. 1) to lie in a series of anticlines and synclines.

The Hot Springs are in the Zigzag Mountains, on the southern margin of an anticlinorium. The Zigzag Mountains owe their presence to the outcrop of the resistant Arkansas Novaculite. The zigzag pattern of the novaculite outcrop is due to subordinate folding in the regional uplift. South of Hot Springs, Ark., is a large structural basin, the Mazarn Basin, in which the Stanley Shale is the predominant surface rock. The structural setting is illustrated by figure 6 in Purdue and Miser (1923).

The shales--Womble, Missouri Mountain, Polk Creek, and Stanley--are basically impermeable. Shales generally impede groundwater movement, except where open joints and fractures are developed. Wells in shales generally yield meager quantities of water; recharge to shales is also small.

The Bigfork Chert, in comparison with other formations in the region, is highly permeable, exhibiting intergranular and fracture permeability. Outcrops in the area north of Hot Springs show the Bigfork to be composed of silt-sized, generally poorly cemented to friable, siliceous particles 1-10 cm (centimeters) thick, interbedded with layers of dense chert 10-30 cm thick. The dense chert beds were rendered permeable by fracturing, which accompanied the intense folding of the beds; whereas the silt-sized material has significant intergranular permeability.

Wells of largest yield in the region tap the Bigfork Chert. At Belvedere Country Club, northeast of Hot Springs, the Bigfork was tested by Albin (1963) and found to have a transmissivity of 20,000 gpd per ft (gallons per day per foot). Although many of the springs do not issue from the Bigfork, their relation to topography and other formations suggests that the recharge areas for the springs are in the Bigfork outcrop area and that the springs' emergences are controlled by contact of the Bigfork with adjacent, less permeable, formations. This association of cold springs with the Bigfork was noted by Purdue and Miser (1923).

The Arkansas Novaculite is composed of three members--an upper and lower novaculite, and an intervening shale. The novaculite is generally dense, but closely fractured. Locally, the formation is tripolitic and possesses intergranular permeability. The novaculite is not as permeable in degree or uniformity as the Bigfork Chert. However, some cold springs issue from, and many water wells tap, the novaculite.

The Hot Springs Sandstone is a massive, quartzitic sandstone. Joints and fractures provide the permeability. The jointing is not as closely spaced as in the novaculite, but the fewer joints are highly permeable at the Hot Springs.

The Hot Springs emerge from the Hot Springs Sandstone near and northwest of the axis of a southwestward plunging anticline. The locations of springs within the Hot Springs Sandstone are shown on an early (1890) map by Capt. R. R. Stevens (fig. 2). According to Bryan (1924), the fault mapped by Captain Stevens is inferred from geologic structure and outcrop patterns, and the fissures are inferred from the alinement of spring openings. It is reasonable to conclude that the conduits from which the spring waters rise are tension joints associated with folding of the rocks.

Cross sections through the spring area by Bryan (1924) are shown in figure 3. The proposed well site in figure 3 is now the site of a well. A well, drilled in the 1800's, at the Fordyce Bathhouse also taps the Hot Springs Sandstone. Each of these wells yields hot water. Two wells drilled at the former site of the Arlington Hotel (fig. 2) are used for cooling spring water for the bathhouses, but Park Service personnel report that the temperature increases as the duration of pumping increases. Water of 23°C flows from a well at the present Arlington Hotel (north of the site shown in fig. 2).

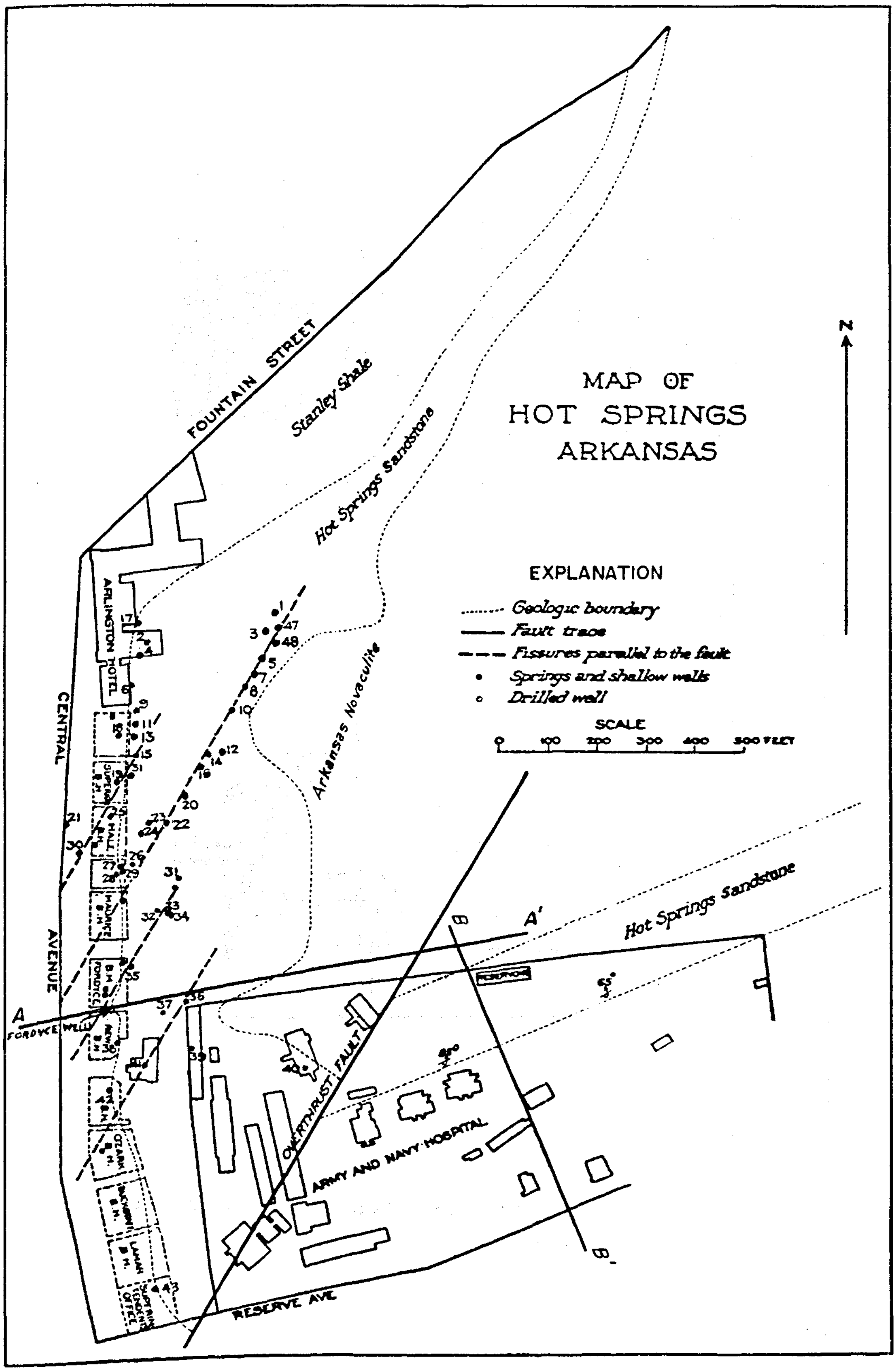
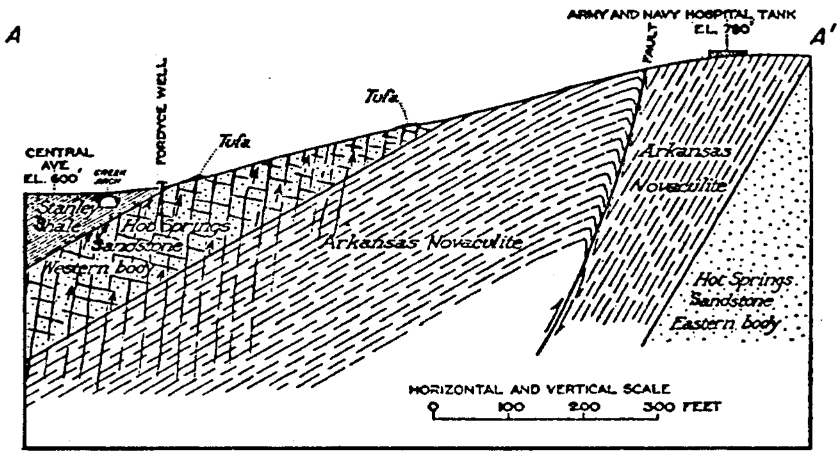


Figure 2.—Geology at the Hot Springs, Ark.
(after Capt. R. R. Stevens in Bryan, 1924)



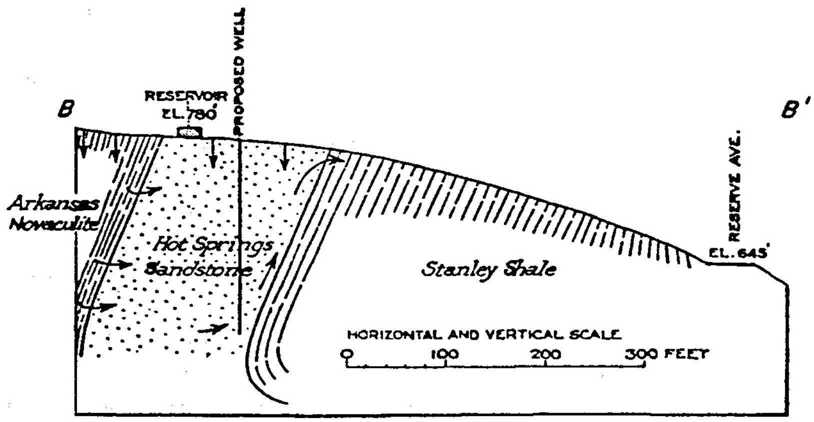


Figure 3.—Geologic cross sections at the Hot Springs, Ark.
(after Bryan, 1924)

Flow Model

An understanding of the nature of the rocks and their attitude in the vicinity of the Hot Springs provides a basis for developing a model of the flow system of the Hot Springs in which the water is of meteoric origin. The model, in turn, will provide a means of designing a data-collection program to verify the accuracy of the model; the verified model will aid in projecting effects of the activity of man on the Hot Springs.

The following elements must be considered in establishing the flow model: (1) recharge area, (2) flow lines of water from the recharge area to the springs, (3) the mechanism for heating the water, and (4) the head, flow, and permeability distribution in the flow system.

The shales in the region, because of their generally low permeability, are not considered recharge sources.

The Arkansas Novaculite and Hot Springs Sandstone provide some recharge to the spring system near the Hot Springs. These formations generally are low in permeability, and zones of high permeability are developed only locally. The recharge area in these formations is probably small and near the springs, within the park boundaries on West Mountain, Hot Springs Mountain, and North Mountain.

The area of Bigfork Chert exposed northwest, north, and northeast of the Hot Springs is the major recharge area (fig. 1). The outcrop of the Bigfork in Hot Springs Creek basin ranges in elevation from 650 to 940 feet above mean sea level. Spring openings range in elevation from about 576 to 683 feet. Because part of the outcrop of Bigfork is below the highest of the Hot Springs openings, Bryan (1924) concluded that the Bigfork was not a recharge source. Bryan's conclusion was endorsed later by Arndt and Stroud (1953), who discounted the Bigfork as a recharge source.

Though part of the Bigfork crops out at lower elevations than the highest of the Hot Springs, this does not prevent the Bigfork from acting as the recharge area. Two factors are involved and, although either could be used to explain Hot Spring outlets higher than the elevation of parts of the recharge area, both play a role in the operation of the flow system.

1. Above 4°C water expands and becomes less dense as the temperature rises. Water at 64°C is 98 percent as heavy as water at 18°C. In other words, a column of water at 18°C, 100 feet in length, will support a 102-foot column of water at 64°C.

2. Some of the water entering the Bigfork, especially water entering at elevations lower than the Hot Springs outlets, is discharged as cold-water seeps and springs within the Bigfork outcrop area; whereas, water entering at higher elevations supplies the artesian flow system of the Hot Springs.

Water is recharged in a large area through the Bigfork Chert. Some water is discharged in the outcrop area of the Bigfork Chert as springs and seeps. Ar-Scenic Spring and artesian wells in the city of Hot Springs in Hot Springs Creek basin are examples of discharge within the general recharge area. The recharge area for the Hot Springs is not limited to the drainage basin of Hot Springs Creek. The Bigfork outcrop extends in to the Gulpha Creek and South Fork Saline River basins and, although there is cold-spring discharge from these basins, water recharged at the higher elevations in Gulpha Creek basin, and possibly parts of south Fork Saline River basin, could provide water to the Hot Springs. (See figure 4.)

Water descending in the Bigfork Chert is heated as the earth temperature increases with depth. The water in the Bigfork is confined beneath the impermeable Polk Creek Shale until the permeable joint zone in the Hot Springs Anticline is reached. This joint zone provides a conduit system for upward movement of water through the Polk Creek Shale, Missouri Mountain Shale, Arkansas Novaculite, and Hot Springs Sandstone. In contrast to the descent of the water, which is slow and spread over a broad area, the ascent is rapid and concentrated along the permeable joint system. During its ascent, the water decreases in temperature. Bryan's (1924) data, though scarce, show that temperature of spring water increases as flow increases. This relation of flow to temperature indicates a body of rock at depth of high, relatively constant, temperature. In flowing through the rock, water is heated to near the temperature of the rock. During its ascent, the water is cooled, the degree of cooling varying inversely with the flow.

CHARACTERISTICS OF THE HOT SPRINGS

Mineralogical Quality of the Water

The mineralogical quality of the water from the Hot Springs in Arkansas has been of great interest to man, probably since the Hot Springs were first discovered. One of the earliest scientific approaches to determine the content of the Hot Springs waters is found in J. C. Branner's (1892) Annual Report for 1891, in which analyses of water samples collected in 1890 are tabulated in grains per gallon. Randomly, since 1890 to the present, analyses have been made for investigations. The purpose of many of these investigations has been to support some therapeutic claim for the water, or to determine whether or not the chemical content of the water has changed.

The hydrology of the Hot Springs is masked by complex stratigraphy and structure. Chemical analyses are useful in interpreting the hydrology and in determining whether or not there has been a change in chemical content of the water through the years, and perhaps as a clue to the future life of the Hot Springs. To supplement previous chemical analyses, seven samples of Hot Springs waters have been collected for this study.

Chemical analyses of well water, cold springs, and rock formations in the vicinity of the Hot Springs are also helpful in attempting to determine the hydrologic nature of the Hot Springs. Accordingly, data on these factors have been found through bibliographic research or, if absent, special analyses have been made. Representative data from past analyses and data collected for this study are shown in tables, 2, 3, and 4.

The water from the Hot Springs contains no unusual minerals, and is distinctive only in its relatively low mineral content.

The mineral content of the Hot Springs water is low, probably because the rocks associated with the Hot Springs are made up of only a few substances, each of which has low solubility. Most ground water in Arkansas contains from two to three times more dissolved minerals than the Hot Springs water.

There has been little change in the chemical quality of the Hot Springs water during the period of record from 1890 to 1970. Minor variations, normal in any ground water, are caused by changes in recharge and discharge. Many of the larger variations in chemical quality that seem evident in table 2, showing chemical analyses of spring waters, are between the results of analyses of the 1900's and contemporary analyses. Improved methodology and instrumentation available today probably account for the differences in the analyses.

Table 2.—Chemical analyses of springs in the vicinity of Hot Springs, Ark.

[Results in milligrams per liter unless otherwise indicated]

Source and location	Date of collection	Discharge (gpm)	Temperature °C	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Cromium (Cr^6)	Copper (Cu)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Vanadium (Va)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Remarks
Big Chalybeate Spring, NW¼SE¼ sec. 22, T. 2 S., R. 19 W.[a]	Fall 1890	186	26	3.8	7.4	--	--	--	--	70	4.1	1.4	3.1	--	--	259	--	9.4	2.0	--	--	--	--	207	--	--	--	--	--	Original analysis was reported as 128 mg/l CO_3.
Do.[b]	4-9-52	--	20	10	1.4	0.00	0.00	0.00	0.02	68	5.0	1.9	.6	0.08	0.00	216	--	8.7	3.2	0.1	0.2	0.01	0.00	194	190	13	336	7.2	4	
Do.[b]	3-4-70	125 (estimated)	20.5	9.6	.308	.140	--	.010	.02	67	2.6	1.3	.6	.000	.001	209	0	7.8	1.9	.1	.0	--	--	190	178	6	344	7.2	1	
Happy Hollow Spring, SE¼NW¼ sec. 33, T. 2 S., R. 19 W.[a]	Fall 1890	--	25.6	6.5	.17	T	--	--	--	5.3	.7	1.5	.3	.00	--	18	--	1.9	2.7	--	--	T	--	29	--	--	--	--	--	Original analysis reported as 9.1 mg/l CO_3; contains .07 mg/l Al and 78 mg/l free CO_2.
Do.[b]	4-9-52	--	17.2	9.7	.13	.00	.00	.00	.01	1.1	.6	1.8	.4	.00	.00	4	0	1.2	3.5	.0	.5	.05	.00	21	5	2	25.4	5.0	7	
Potash Sulfur Springs 3S-1W-17b[a]	Oct. 1887	--	17.8	32	2.6	T	--	--	--	3.2	T	294	6.8	--	--	221	--	388	52	--	--	--	--	888	--	--	--	--	--	Original analysis reported as 109 mg/l CO_3; contains trace of Al and H_2S and 44 mg/l free CO_2.
Do.[b]	8-10-51	--	17.8	34	.03	.00	.00	.00	.04	.9	.3	282	10	.08	.00	156	96	227	60	.14	.3	.00	.10	779	3	0	1190	9.6	5	
Average composition of 42 springs, analyses J. K. Haywood[a]	Prior to 1905	Total combined flow estimated at 826,000 gpd	55	47	.20	.1	--	--	--	46	4.9	4.8	1.7	T	--	164	.0	8.4	2.6	--	.4 (av. for 41 springs)	T	T	--	--	--	--	--	--	Fe and Al combined; boron shown as trace of BO_2; Sr, Ba, Br, I reported as trace.
Average composition of 45 springs from central collection reservoir fountain[b]	8-11-51	--	61.67	44	.02	.03	.00	.06	.07	47	5.8	4.6	1.7	.2	.00	163	0	9.9	2.8	.0	.8	.07	.05	196	141	8	271	7.4	6	
Exhibition Spring No. 1, NW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	4-9-52	--	57.78	43	.02	.00	.00	.00	.00	45	6.9	4.4	1.5	.06	.00	162	0	9.4	3.0	.0	.1	.00	.00	199	141	8	255	7.5	5	
Upper display spring, NW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	3-4-70	10 (estimated)	57.4	42	.184	.225	--	.010	.020	47	4.5	3.9	1.5	.000	.000	158	0	17	1.8	.1	.0	--	--	187	136	6	274	7.3	1	
Lower display spring, NW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	3-4-70	--	51	38	.178	.070	--	.000	.010	44	4.3	3.6	1.4	.000	.000	149	0	11	2.0	.2	.8	--	--	174	128	6	263	7.3	1	
Fountain fed from central collecting reservoir at National Park Service Headquarters Building, represents flow of 45 springs, SW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	3-4-70	Total combined flow estimated at 1,250,000 gpd	55.8	40	.180	.150	--	.000	.010	45	4.5	3.9	1.4	.000	.000	158	0	9.4	1.6	.2	.2	--	--	183	131	1	273	7.3	1	
National Park Service Well No. 2, NW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	3-4-70	100 (reported)	32.2	25	.180	.290	--	.000	.210	39	4.4	5.7	2.5	.010	.002	97	0	43	2.8	.1	1.0	--	--	171	116	36	272	6.5	1	
Combined free flow of springs 11, 13, and 15 at 80,000-gallon collecting reservoir, NW¼SW¼ sec. 33, T. 2 S., R. 19 W.[b]	3-4-70	--	61.8	40	.068	.240	--	.010	.020	48	4.6	3.7	1.4	.000	.000	163	0	8.4	1.7	.2	.0	--	--	187	139	6	275	7.4	1	
Whittington Avenue Spring, National Park Service Maintenance Center, NW¼SW¼ sec. 32, T. 2 S., R. 19 W.[b]	6-16-60	--	20	5.5	.05	--	--	--	--	48	2.6	1.8	.7	--	--	147	0	12	2.0	.0	.6	--	--	136	130	10	245	7.0	5	
Do.[b]	3-4-70	3 (estimated)	17	9.5	.216	.070	--	.000	.030	53	2.6	1.6	.9	.000	.002	158	0	12	1.9	.2	.0	--	--	159	143	13	280	6.9	1	

[a] Purdue and Miser (1923), after Ark. Geol. Survey.
[b] Analysis by U.S. Geol. Survey.

Table 3.—Chemical analyses of samples of water from wells in the vicinity of Hot Springs, Ark.

[Results in milligrams per liter unless otherwise indicated]

	Water well in Stanley Shale, 2S-20W-33cdc, 46 feet deep	Water well in Stanley Shale, 3S-17W-21dcal, 110 feet deep	Water well in Arkansas Novaculite, 3S-16W-21bda, 317 feet deep
Date of collection	10-22-62	8-9-62	7-5-63
Temperature (°C)	20.0	21.7	17.8
Silica (SiO_2)	----------	25	5.6
Iron (Fe)	.03	.26	.14
Manganese (Mn)	.04	.00	.00
Calcium (Ca)	47	20	29
Magnesium (Mg)	5.0	4.8	8.3
Sodium (Na)	10	15	27
Potassium (K)	2.2	3.6	3.5
Bicarbonate (HCO_3)	160	112	190
Sulfate (SO_4)	7.0	12	.0
Chloride (Cl)	16	2.5	9.8
Fluoride (F)	.2	.3	.1
Nitrate (NO_3)	5.5	.1	.6
Dissolved solids (residue at 180°C).	172	139	177
Hardness as $CaCO_3$: Calcium, magnesium	138	70	107
Noncarbonate	6	0	0
Specific conductance (micromhos at 25°C).	318	214	293
pH	8.2	8.1	7.8

Table 4.—Chemical analyses of rock samples collected in the vicinity of Hot Springs National Park, Ark.

	Big Fork Chert SW¼NW¼ sec. 32, T. 2 S., R. 19 W.[c]	Polk Creek Shale NW¼SW¼ sec. 34, T. 2 S., R. 19 W.[c]	Hot Springs Sandstone NW¼NW¼sec.34 T. 2 S., R. 19 W.[c]	Stanley Shale NW¼SW¼sec. 35, T. 25 S., R. 19 W.[c]	White Arkansas Novaculite from outcrop at Hot Springs[a]	Novaculite from Sutton's Quarry No. 6 on Indian Mountain[a]	Tufa collected east of the Arlington Hotel[b]
LOI	0.38	4.25	0.54	4.24	----	----	----
Silicon dioxide SiO_2	94.92	54.44	94.00	62.28	99.45	99.49	----
Iron oxide Fe_2O_3	1.44	6.71	2.03	6.43	----	----	----
Aluminum oxide Al_2O_3	3.56	24.49	3.69	20.89	----	----	----
Magnesium oxide MgO	0.28	2.66	0.15	2.32	----	----	----
Calcium oxide CaO	0.24	0.17	0.22	0.25	----	----	----
Calcium carbonate $CaCO_3$	----	----	----	----	----	----	98.93
Barium oxide BaO	Nil	Nil	Nil	Nil	----	----	----
Strantium oxide SrO	Nil	Nil	Nil	Nil	----	----	----
Sodium oxide Na_2O	0.03	0.52	0.41	2.23	----	----	----
Potassium oxide K_2O	0.63	6.62	0.61	2.54	----	----	----
Total percent	101.48	99.86	101.65	101.18	99.45	99.49	98.93
Remarks	----	----	----	----	Contains minor amounts of Al, Fe, Ca, Mg, Na, and K.	Contains minor amounts of Al, Fe, Ca, Mg, Na, and K.	Contains minor amounts of SiO_2, Al, Fe, Ca, Mg, Na, K, Mn, Cl, and S

a Branner (1892, p. 161).
b Purdue and Miser (1923), after Ark. Geol. Survey.
c Arkansas Geological Commission, 1970.

All springs in the area have the same general chemical characteristics; however, there is sufficient variation to indicate that all the water that emerges does not follow the same flow path.

Except for the silica content and the temperature, water from the Hot Springs is chemically similar to water from the cold springs and wells in the Stanley Shale and Arkansas Novaculite in the general vicinity of Hot Springs National Park. Analyses of water from these formations are given in table 3. Viewed on a State-wide basis, even the silica content of the Hot Springs water cannot be considered unusual, as many ground waters in Arkansas have a silica content of 20-40 mg/l (milligrams per liter).

The high silica content of the Hot Springs water is to be expected because of the increased solubility of silica in hot water and high silica content of the rocks with which the water is associated. As shown in the analyses of rock materials in the vicinity of Hot Springs (table 4), silica is the principal constituent of all rocks sampled and in the Arkansas Novaculite silica slightly exceeds 99 percent. Aluminum and iron are the other major constituents in the rocks, and their amounts are not unusual as compared to rocks elsewhere.

The tufa deposits associated with the Hot Springs are commonly found in association with hot springs elsewhere. As shown in the table of analyses of rock materials, the tufa consists of more than 98 percent calcium carbonate. As the carbon dioxide gas in solution in the Hot Springs water escapes when the water is exposed to the atmosphere or lower pressure, the solubility limit of calcium carbonate is exceeded, causing deposition of tufa.

Dissolved Gases in the Water

The gases contained in the water of the Hot Springs consist principally of oxygen, nitrogen, and carbon dioxide, as shown in table 5. The ratio of oxygen and nitrogen in the water corresponds closely to that of the atmosphere. Although the carbon dioxide content of the water may seem excessively high, air in the subsurface may contain 10-1,000 times more carbon dioxide than atmospheric air. Consequently, the dissolved gases in the Hot Springs cannot be construed as excessive when compared with gases dissolved in rainwater or in other ground water.

Radioactivity and Isotope Content of the Water

The radioactivity of the waters of the Hot Springs has been studied by many investigators. Probably the first was Haywood (1902), followed by Boltwood (1905), Schlundt (1935), and Kuroda and others (1953). Much of the early interest was because of the balneological use of the water. In 1953 Arndt and Damon submitted a progress report to the U.S. Atomic Energy Commission whose interest

Table 5.—Quantity of gases in water from the Hot Springs, Hot Springs, Ark., rainwater, and the atmosphere

	Oxygen (O_2)	Carbon dioxide (CO_2)	Nitrogen (N_2)	Remarks
Forty-three hot springs sampled and analyzed for gas content[1]	3.04	10.36	8.78	Results in cubic centimeters per liter at 0°C and 760 mm pressure. Also contained 29.66 cc of CO_2 set free from bicarbonates on evaporating to dryness. Results given are averages for 43 springs.
Rainwater analysis of gas content at 20°C[2]	34.17	2.14	62.69	Results in percent.
Approximate gas content of the atmosphere	20	.03	78	Results in percent.

1 Purdue and Miser (1923), after Ark. Geol. Survey.
2 Palmer (1911).

obviously was in the radioactivity of the Hot Springs waters, the radon content, and the source of the radioactivity. Successive analyses have become more sophisticated, covering a wider range of constituents, presumably with greater and greater accuracy. Only a part of the data available is given in this report.

The presence of radium in the water from the Hot Springs, although a mere trace, was established by Schlundt (1935) when he obtained an average value of 1.38 millimicrograms of radium per liter for three samples. Assuming a daily flow of 800,000 gallons from all the thermal springs at Hot Springs, Ark., the total radium carried in solution would amount to only 1.6 milligrams per year.

The radon content of the water from the Hot Springs has been observed by Kuroda and others (1953) to range from 0.14 to 30.5 millimicrocuries per liter (10^{-9} curie/l), as shown in table 6.

The presence of radon is not peculiar to the water of the Hot Springs, as shown by table 7. Waters from deep wells at Hope and Prescott, Ark., range in radon content from 0.05 to 1.88 millimicrocuries per liter. Waters from springs in the Caddo Gap, Ark., area range in radon content from 0.15 to 1.85 millimicrocuries per liter.

Previous investigators have reasoned that the tufa deposits are radioactive, thus causing the water from the Hot Springs to be radioactive. Such a conclusion cannot be valid, because the

Table 6.—Radon content of spring waters of Hot Springs National Park, Ark.

[Results in millimicrocuries per liter]

Haywood spring number (1902)	Name of spring	Boltwood (1905)	Schlundt (1935)	Kuroda and others (1953)
1	Egg	0.887	----------	2.13
2	Arsenic	.493	----------	----------
3	Arlington	1.037	----------	3.70
4	Cliff	.347	----------	----------
5	Avenue	.887	----------	.21
6	Boiler House	1.360	----------	----------
7	Imperial (North)	9.03	----------	30.5
8	Crystal	.466	----------	.61
9	Rector	.503	----------	2.21
10	Cave	.126	----------	----------
11	Little Iron (North)	.490	----------	----------
12	Little Geyser	.231	----------	----------
13	Little Iron (South)	.513	----------	----------
14	Ral	1.85	----------	----------
15	Big Iron	.052	----------	----------
16	Imperial (South)		----------	----------
17	Arsenic (North)	.813	----------	.87
18	Hitchcock	1.666	----------	2.51
19	Sumpter	----------	----------	----------
20	Superior (North)	.983	----------	----------
21	Alum	.401	----------	----------
22	Superior (South)	.996	----------	----------

Table 6.—Radon content of spring waters of Hot Springs National Park, Ark.--Con.

Haywood spring number (1902)	Name of spring	Boltwood (1905)	Schlundt (1935)	Kuroda and others (1953)
23	Twin (North)	2.224	-------------	0.38
24	Twin (South)	1.860	-------------	3.67
25	Old Hale	.350	-------------	.72
26	Palace	.116	0.199	-------------
27	Tunnel	1.414	-------------	3.24
28	Maurice	.520	-------------	.33
29	Dripping (Cups)	.262	-------------	8.62
30	Arch	-------------	-------------	-------------
31	Haywood (Display Cups)	.167	-------------	.80
32	J. W. Noble (Display 2)	.748	-------------	1.66
33	Lamar	.150	-------------	-------------
34	Wiley (Display 1)	.299	.43	.14
35	Ed Hardin	.799	-------------	0.22
36	Eisele	.167	-------------	-------------
37	Stevens	.282	-------------	-------------
38	Horse Shoe	.180	.20	.34
39	Army & Navy	.017	.125	-------------
40	W. J. Little (A&M)	-------------	-------------	-------------
41	Mud	.051	-------------	-------------
42	Magnesia	.272	-------------	.58
43	Reservoir	.027	-------------	-------------
44	Liver	.592	-------------	-------------

Table 6.—Radon content of spring waters of Hot Springs National Park, Ark.—Con.

Haywood spring number (1902)	Name of spring	Boltwood (1905)	Schlundt (1935)	Kuroda and others (1953)
45	Kidney	3.631	----------	----------
46	Fordyce	.439	0.449	0.81
-------	New Spring	----------	----------	.40
-------	New Spring	----------	----------	13.5
-------	No name	.503	----------	3.36
-------	Fordyce Well	3.308	----------	----------
-------	10'n 46	----------	----------	----------
-------	Spring in Maurice	----------	----------	----------
-------	Main Reservoir	----------	.46	.82

Table 7.— Radon content of cold springs in the vicinity of Hot Springs, Ark. (after Kuroda and others, 1953)

[Results in millimicrocuries per liter]

Source	Date	Radon content
Wilson Spring No. 1	9-13-52	1.83
Sleepy Valley No. 1	9-17-52	4.37
Sleepy Valley No. 2	9-17-52	2.80
Iron Spring	9-18-52	.41
Magnesia Spring	9-20-52	7.28
Spring No. 3, Camp	9-20-52	6.52
Happy Hollow Spring	9-20-52	.74
Artesian well at Whittington Park	9-23-52	.03
Three Sister Spring No. 1	9-24-52	.10
Three Sister Spring No. 2	9-24-52	.26
Three Sister Spring No. 3	9-24-52	.24
Whittington Spring	9-26-52	.36

tufa deposits are derived from the Hot Springs water. Also, such a conclusion does not account for the radioactivity of the water from the cold springs where there are no tufa deposits.

The rocks in the vicinity of Hot Springs, Ark., particularly the Polk Creek Shale (Arndt and Damon, 1953, p. 23), are slightly radioactive. Minor amounts of thorium, radium, and uranium have been identified in rocks in the general area. Natural rainfall is reported to have a radioactivity of from 6 to 60 millimicrocuries per liter. Consequently, the radioactivity of the water of the Hot Springs is not difficult to explain in the presence of so many sources for the radioactivity.

Furthermore, igneous rocks, such as the syenites and dikes, at the surface a short distance from Hot Springs, Ark., are radioactive. Rocks of this type are present at depth and provide an additional possible source of radioactivity of the Hot Springs water. As with the inorganic content, marked variations in radioactivity of the water of the different springs indicate that the water travels along several different flow paths.

There is no apparent correlation between the radon content and the flow, the temperature, the location, or the inorganic composition of the waters from the Hot Springs.

An examination of data from previous studies of radioactivity of the water of the Hot Springs in no way indicates that the water is of other than meteoric origin.

Analyses of hydrogen isotopes were made in an effort to provide information on the age and origin of the water from the Hot Springs. The following material provided by F. J. Pearson (written commun., 1970) gives the background regarding use of isotopic data and interpretation of the data collected for this study.

The element hydrogen has three naturally occurring isotopes. The most common has an atomic mass of 1 and is called protium (P), or simply hydrogen (H or H^1). Natural waters also contain the isotope of mass 2, called deuterium (D or H^2), at a concentration of about 320 parts of D to 10^6 parts H. Deuterium is measured using mass spectrometers which read ratios of D to H rather than absolute D concentrations (Friedman, 1953). Thus, deuterium measurements are expressed as deviations of the D/H ratio of the sample from the D/H ratio of a standard. These deviations are reported in delta (δ) units from the equation

$$\frac{(D/H)_{sample}}{(D/H)_{standard}} = 1 + \delta_D.$$

δ_D is generally given in parts per thousand ($^0/_{00}$).

The standard used is a standard mean ocean water (SMOW), for which $\delta_D = 0$ by definition (Craig, 1961). Natural waters are generally depleted in deuterium relative to SMOW--that is, their δ_D values are negative. This depletion occurs because the vapor pressure of water containing deuterium (HDO) is slightly less than that of common water (HHO). During evaporation and condensation in the hydrologic cycle, HDO tends to be concentrated in the liquid phase. As water evaporates from the ocean, the vapor is depleted in deuterium, and the amount of depletion becomes greater as the temperature of evaporation decreases. Further, isotope fractionation takes place as water is condensed and re-evaporated during atmospheric transport, again, with the amount of fractionation inversely proportional to temperature.

The deuterium content of meteoric water varies regularly throughout the land surface of the earth, because of the temperature effect on the fractionation of the water isotopes. According to Friedman and others (1964), in high latitudes and high elevations, there is less deuterium (high negative δ_D values) than at lower latitudes and elevations (low negative δ_D values).

The general pattern of deuterium concentrations in North America suggests that average precipitation in the Hot Springs region should have a δ_D value of about -30 per mil--that is, should have 30 parts per thousand less deuterium than sea water. The deuterium content of precipitation varies seasonally, though with less deuterium present in winter than in summer precipitation. Thus, ground water recharged by winter precipitation will have a lower deuterium content than the yearly average of precipitation in the recharge area.

The deuterium contents of several samples collected March 4, 1970, from the Hot Springs region are given in the following table.

Deuterium content of water from the Hot Springs and other ground water in the vicinity

[δ Dsmo: Deviation of deuterium-hydrogen ratio of sample from the deuterium-hydrogen ratio of standard ocean water]

Source	Temperature (°C)	δ Dsmow (percent)
Big Chalybeate Spring----------------	20.5	-53
Whittington Avenue Spring-----------	17.0	-51
NPS Water Well No. 2-----------------	32.2	-50
Hot Spring No. 33 (Upper Display Spring).	57.4	-50
Hot Spring No. 32 (Lower Display Spring).	51.0	-50
Hot Springs No. 11, 13, 15----------	61.8	-54

Water from the recharge area is represented by the sample from the Whittington Avenue Spring, and has a δD value of about -51 percent. This is in the range expected for winter precipitation in this region and suggests that recharge takes place primarily during that season. The deuterium contents of the Hot Springs, wells, and cold spring shown in the table are all of about the same value. This is strong evidence for the fact that the only significant source of water to the springs is local, meteoric water.

The third isotope of water is tritium (H^3 or T), which has an atomic mass of 3 and is radioactive, with a half-life of about 12¼ years. Tritium is formed continuously by cosmic rays impinging on the upper atmosphere, and this natural tritium is present in precipitation at levels of from 1 to 10 T atoms per 10^{18} H atoms. Tritium is measured by analyzing its rate of radioactive decay in a water sample and the results expressed as tritium units (TU), one of which equals to an H/T ratio of 10^{18}. Thus, natural tritium is present in the range of from 1 to 10 TU.

Large quantities of tritium are produced by nuclear devices and the atmospheric testing of such devices--particularly fusion devices (hydrogen bombs)--from the early 1950's through 1962 raised the level of tritium in precipitation to many times its natural level of from 1 to 10 TU. Peak tritium levels occurred in the spring of 1963, when precipitation at St. Louis, for example, reached levels of more than 2,500 TU. Since then, tritium levels have been decreasing at about 30 percent per year. During the 1950's tritium levels were in the range of several hundred tritium units, also well above natural levels.

The tritium contents of several samples collected March 4, 1970, from the Hot Springs area are given in the following table.

Tritium content of water from the Hot Springs and other ground water in the vicinity

Source	Temperature (°C)	Tritium units
Big Chalybeate Spring---------------	20.5	0.9±0.2
Whittington Avenue Spring-----------	17.0	4.0±0.3
NPS Water Well No. 2----------------	32.2	22.7±0.8
Hot Spring No. 33 (Upper Display Spring).	57.4	2.2±0.3
Hot Spring No. 32 (Lower Display Spring).	51.0	8.8±0.6
Hot Springs No. 11, 13, 15----------	61.8	1.7±0.3

All samples do contain tritium, but in concentrations well below the levels in precipitation during most of the past 20 years. This suggests that the majority of water in the springs entered the flow system at some time before the early 1950's. However, the fact that there is some tritium present in all samples suggests further that a part--albeit a small one--of the springs flow is post-1950 water. Thus, the spring system is at least in part open to the influence of local sources of water and should show the effects of changes in these sources rather rapidly.

Temperature of the Water

Temperature measurements were the first scientific data collected on the Hot Springs. Dunbar and Hunter in 1804 recorded 154°F (67.8°C) for the hottest spring (Weed, 1902). In 1860 the highest temperature measured by Owen was 148°F (64.4°C). Glasgow also measured temperatures in 1860, and recorded a maximum of 150°F (65.6°C).

Measurements of temperatures by several investigators from 1890 to 1953 (table 8) show maximum temperatures of 147°F (63.9°C) in 1901, 148°F (64.4°C) in 1931, and 146°F (63.3°C) in 1952. Thirteen of the same Hot Springs were measured by Haywood in 1901, Hamilton in 1931, and Kuroda in 1952. The average temperatures of these Hot Springs in 1901, 1931, and 1952 were 136.8°F (58.2°C), 135.2°F (57.3°C), and 137.8°F (58.9°C), respectively.

Upon examination of these data it would seem that there has been a slight decline in maximum water temperature with time. However, this conclusion is not valid because the difference is small and can be accounted for by instrument and observer error. Differences in sampling points, flow rates, changed flow paths of the water, and large temperature fluctuations in individual hot springs in response to changing air temperature, precipitation, and flow, make any conclusion regarding changes in temperature untenable.

Table 8.—Temperature, in degrees Celsius, of the Hot Springs at Hot Springs National Park, Ark.

Spring number, according to Haywood, 1902	Date of measurement				
	1890 (from Branner, 1892)	1900 (from Haywood, 1902)	1901 (from Haywood, 1902)	1931 (from Hamilton, 1932)	1952 (from Kuroda, 1953)
1	62.6	61.9	61.7	----------	62.0
2	----------	51.9	53.9	54.5	----------
3	----------	61.7	61.3	60.0	62.2
4	----------	55.9	52.4	57.2	----------
5	----------	61.4	61.9	61.1	61.7
6	----------	57.5	58.3	57.2	58.6
7	----------	60.1	60.8	----------	62.2
8	----------	35.2	36.2	61.1	----------
9	59.6	61.1	62.4	62.2	61.2
10	----------	57.4	57.2	60.0	----------
11	----------	----------	56.8	64.4	61.2
12	----------	36.2	36.2	----------	----------
13	----------	----------	56.3	----------	61.2
14	59.6	60.9	62.8	----------	----------
15	63.6	63.9	63.9	64.4	61.2
16	----------	60.8	60.9	----------	----------
17	----------	55.4	56.4	55.6	56.9
18	----------	57.3	57.3	52.8	59.6
19	----------	56.4	56.1	----------	----------
20	----------	46.3	44.5	44.7	----------
21	46.6	43.3	46.0	----------	----------
22	----------	57.1	56.5	56.1	----------
23	----------	62.0	62.4	50.0	59.6
24	----------	62.3	60.3	57.8	54.3
25	61.6	62.7	62.9	----------	63.3
26	----------	63.4	61.4	63.3	----------
27	----------	----------	51.9	----------	59.2
28	----------	----------	59.8	----------	60.0
29	----------	57.1	57.8	----------	61.1
30	----------	53.9	51.9	----------	----------
31	----------	51.4	51.4	54.4	54.0
32	----------	46.0	46.5	45.0	52.5
33	----------	48.3	49.2	----------	----------
34	----------	47.9	47.3	----------	57.5
35	----------	39.0	43.0	----------	----------
36	----------	48.9	48.8	----------	----------
37	----------	52.9	52.6	----------	----------

Table 8.—Temperature, in degrees Celsius, of the Hot Springs at Hot Springs National Park, Ark.--Continued

Spring number, according to Haywood, 1902	Date of measurement				
	1890 (from Branner, 1892)	1900 (from Haywood, 1902)	1901 (from Haywood, 1902)	1931 (from Hamilton, 1932)	1952 (from Kuroda, 1953)
38	----------	58.8	59.8	----------	60.3
39	----------	61.4	61.4	----------	----------
40	----------	48.9	48.9	----------	----------
41	----------	46.8	48.3	----------	----------
42	51.6	----------	58.3	60.6	60.8
43	----------	46.1	----------	50.0	----------
44	----------	8.0	----------	----------	----------
45	----------	13.0	----------	----------	----------
46	----------	51.5	----------	57.2	----------
47*	----------	----------	----------	58.6	61.7
48*	----------	----------	----------	----------	62.2
49*	----------	----------	----------	58.9	61.0
50*	----------	----------	----------	62.8	----------
V*	----------	----------	----------	50.0	61.1
W*	----------	----------	----------	46.4	----------
X*	----------	----------	----------	56.1	----------
Y*	----------	----------	----------	47.8	----------
Z*	----------	----------	----------	58.9	----------

* Spring number of Kuroda, 1952.

The average temperature of the combined Hot Springs flow together with flow data provides the best means of determining long-term changes in water temperature. The data from the same Hot Springs averaged for 1901-52 do not suggest a decline in temperature during the 51-year period.

Local folklore notwithstanding, fluctuations in temperature of individual hot springs are large and probably related to natural fluctuations associated with changes in the Hot Springs flow. Bryan (1924) recorded a variation of 20°C in the Stevens Spring during a period of 17 months. Bryan's data also show that in a given spring the temperature of the water increases as the flow increases, and the temperature of the water varies less with greater flow. This is strong evidence of an environmental-sensitive meteoric origin for the water.

Although the largest group of hot springs with the largest yield is in the Hot Springs National Park, many other springs and wells yielding water abnormally high in temperature are found in Arkansas. Noteworthy among these are wells (23°C to 37°C) in the vicinity of Hope, Prescott, Paris, Fordyce, Elaine, Warren, and Emmet, Ark., and springs in Randolph (28°C), Montgomery (23°C to 38°C), and Pike (25°C) Counties, Ark. (Miser and Purdue, 1929). The chemical content of these waters is not unusually different from any other ground waters in Arkansas.

Flow of the Hot Springs

Flow of the Hot Springs has been measured at infrequent intervals by several investigators. Among the first to attempt a measurement was Glasgow, who in 1860 determined that the Hot Springs flow was 450,480 gpd (gallons per day). Walter Harvey Weed, in 1902, measured or estimated the flow of each hot spring and found the total flow to be 850,000 gpd. Hamilton, in 1931, from the maximum rate of filling of the central-collecting reservoir, computed the flow to be 960,000 gpd. Park Superintendent Libbey, in 1945, recorded that the cental-collecting reservoir filled with 15 feet of water in 7 hours, which represents an average flow of about 800,000 gpd. As discussed in a later section of this report, the rate of filling of the upper half (above about 8 feet) of the central reservoir declines as depth of water in the reservoir increases, and may not represent the true rate of the Hot Springs flow. The authors measured the rate of overflow from the central reservoir to be 1,250,000 gpd on March 5, 1970.

Each of the preceding values represents measurements made under different conditions and using different measuring procedures. Because of this, the measurements are not directly comparable; but they certainly do not suggest a diminution of flow.

Measurements made by Weed (1902) and Hamilton (1931) afford the most accurate basis of sampling spring discharge from the same groups of springs to determine long-term variations. Many changes in individual spring flow occurred between 1901 and 1931 because of excavation and construction at spring outlets, opening new springs, and drilling the Fordyce well. Hamilton noted that the flow of springs in group 1, which includes those in higher elevations (springs numbered 1, 47, 48, 3, 5, 7, 8, 10, 49, 22, 23, 24, 26, 27, 28, 29, Maurice Spring, and one unnumbered spring) declined in flow from 168,000 gpd in 1901 to 124,000 gpd in 1931 (table 9). Hamilton ascribes the loss in flow to opening of new springs and drilling wells beneath certain bathhouses.

Another group of springs, at lower elevation along the base of a tufa cliff, showed practically no change in flow from 1901 to 1931. These springs (numbered 17, 2, 4, 6, 9, 11, 13, 15, 19, and two unnumbered springs) discharged 313,500 gpd in 1901 and 315,000 gpd in 1931.

Thirteen springs measured by Weed in 1901 were not included in the 1931 collection system described by Hamilton (1932). Two of these springs are on the Arkansas Rehabilitation Center, one of which, number 39, is used for supplying hot water to the Rehabilitation Center. Four springs were dry in 1931, and locations of six springs were unknown. Presumably, these six unlocated springs were dry or nad insignificant flow rates in 1931.

Table 9.—Flow of the Hot Springs in group 1 in 1931 and 1901 (after Hamilton, 1943)

Spring number	Flow, in gallons per day	
	1931	1901
1	9,600	28,800
47 and 48	13,500	Nonexistent
3, 5, and 8	21,800	39,218
7	1,760	18,516
10	14,400	18,514
49	(a)	Nonexistent
New	2,400	Nonexistent
22	2,460	1,723
23 and 24	5,000	10,800
26	10,950	25,847
27, 28, and 29	(a)	24,418
Maurice Spring	(a)	Nonexistent
Total	124,000	167,836

a Not measured individually.

MAN'S EFFECT ON THE HYDROLOGIC SYSTEM

The future water supply of the Hot Springs is dependent basically upon climate and man. The amount of water available for recharge depends upon climate--principally rainfall and evapotranspiration. Rainfall and evapotranspiration vary seasonally and from year to year. Though recharge varies as do rainfall and evapotranspiration, fluctuations in discharge are attenuated because of storage of water in the flow system and timelag of flow from the recharge to discharge areas.

Man exerts considerable influence on the amount of rainfall that enters the flow system by such activities as lumbering; agriculture; quarrying; terracing; building houses, roads, businesses, parking lots, parks, and storm sewers; and pumping wells.

Rural Land Cover

Man's activities in the recharge area can by design or accident affect recharge to the flow system. The same activity can either increase or decrease recharge, depending upon the interaction with the natural hydrologic system.

The land cover in the area north of the Hot Springs is shown in figure 4. Eighty percent of Hot Springs Creek and Gulpha Creek basins are forested with pine and deciduous hardwood. Forest cover affects water yield--runoff and recharge--in a basin.

Experimental work has shown that water yield can be increased by deforestation (Hoover, 1944). Timber operations in the recharge area can and probably do affect recharge and overland runoff. Even timber-management practices, which can change the species makeup of the forest or the ratio of deciduous to evergreen cover, can affect the water yield because of different water requirements for different species (Minckler, 1939, and Horton, 1923) and interception of rainfall by pine is greater than by deciduous trees (Davis, 1939).

About 4 percent of the rural area is deforested. The deforested area includes Belvedere Country Club, pastureland, and so-called old fields which are reverting to forests. A very small part of the area is under cultivation. The deforested area probably admits greater runoff than the forested area because of less interception of rainfall by foliage and less transpiration by plants. For the same reasons, recharge may be greater in deforested areas. However, recharge in deforested land is dependent upon subsequent land use. For example, land-use practices that compact the soil and reduce its permeability will reduce recharge.

Quarry operations provide accelerated recharge to the aquifer; but because of the small area covered, the net effect is small.

Urban Land Cover

Twenty-six percent of Hot Springs Creek basin and 5 percent of Gulpha Creek basin is urbanized. Urban land cover in the basins is shown in the following table.

Cover by roofs, roads, parking lots, and other impermeable material	Hot Springs Creek basin		Gulpha Creek basin	
	Urban area (sq mi)	Percent of urban area	Urban area (sq mi)	Percent of urban area
More than 80-percent covered.	0.112	12	0.0	0
40- to 80-percent covered-	.050	5	.014	7
10- to 40-percent covered-	.598	64	.165	85
Less than 10-ercent covered.	.183	19	.015	8
Total:				
Square miles--------	0.943	100	0.194	100
Percent of basin----	26	---------	5	--------

The storm drainage system and the street network and other impermeable cover facilitate runoff and reduce recharge. Because the land surface is hilly and not naturally suited to dense urbanization, the impermeable cover in most of the urban area is sparse to light (less than 40-percent covered).

The heavily covered area is mostly at lower elevations and in flatter areas. The heavy cover at the lowest elevations in the recharge area may, in effect, increase net recharge to the flow system by reducing evapotranspiration.

Landscape terracing for parks, ballfields, trailer parks, lawns, and other enterprises retards runoff; and if the permeability of the ground is not reduced or covered by an impervious surface, such terracing can facilitate recharge.

Lawn watering might seem to offer additional opportunity for recharge. But, considering that lawns are generally watered during the season of peak evapotranspiration and, by usual practice, in amounts less than actually required, this factor is probably negligible.

Ground-Water Pumping

Pumping wells in both the recharge and discharge areas can have a definite effect on the Hot Springs flow. A well that is pumped will draw water initially from storage in the aquifer. With time, the effect of pumping will reach areas of natural recharge or discharge. Pumping from wells in the recharge area may decrease discharge of the cold springs in the recharge area, as well as decrease flow of the Hot Springs in the discharge area. There are few wells in and near the recharge area, and total pumpage is probably small. Most of the wells are of small capacity and are used for rural domestic supplies. The larger wells include one at the Belvedere Country Club and a well at the Majestic Hotel.

Pumping from wells in the Hot Springs discharge area will have the immediate effect of reducing the natural spring flow. Wells in the discharge area are the emergency water well at the Rehabilitation Center, spring 39--a hot spring enlarged and deepened into a well--that supplies hot water to the Rehabilitation Center, a well at the Arlington Hotel, and two wells in the National Park used for cooling.

WATER PROBLEMS AND MANAGEMENT

Ground-Water Recharge and Surface Runoff

Future land-use practices in the recharge area can alter the flow and quality of the Hot Springs and the surface-water flood hazard from Hot Springs Creek along Central Avenue

The effect of urbanization in reducing flow of the springs could be offset by a storm sewer system designed to increase recharge by such measures as recharge pits or tunnels, detention reservoirs, or by spreading basins in the urban areas. Such facilities could also be designed and operated to reduce peak flood stages on Central Avenue.

Deforestation, as a method of increasing recharge, would likely increase the flood hazard, increase erosion from the basin, and have deleterious esthetic side effects.

Pumping of wells in the recharge or discharge area is a definite negative factor in spring flow.

Collection and Measurement of the Hot Springs Flow

The present hot-water collection and distribution system was constructed in 1931 (Hamilton, 1932; and Hamilton and Blood, 1931). A map of the Hot Springs and the collection system is shown in figure 5. The system conducts water from most of the springs by gravity to a central-collection reservoir having a capacity of 264,000 gallons, located underground at park headquarters. Water is pumped from the collection reservoir to elevated reservoirs on the side of Hot Springs Mountain and from there the water is distributed to the bathhouses. Prior to the present system, improvements were made in about 1891. A map of the 1891 collection system is included in the 1902 report of the Park Superintendent (Eisele, 1902). In 1891 the central-collection reservoir was built and supplied by gravity from about six springs. The central-collection reservoir was used to supply water to hotels at lower elevations in Hot Springs, Ark. Most of the bathhouses on Bathhouse Row were supplied by gravity flow from individual springs. In the reconstruction of the collection system in 1931, the old collection pipe and some of the springs connected thereto were left intact and still feed into the central-collection reservoir.

Figure 5 shows both the 1931 and 1891 collection lines, but probably does not show all springs connected to the 1891 collection line. Most of the springs are connected to the central-collection reservoir by either the 1931 or the 1891 collection pipes. Changes in the collection systems have not been completely documented and many questions arise concerning the present state of certain springs. Some springs located on old maps are not shown in later maps.

The spring flow uncollected by the park system is not known. Presumably, the water not collected discharges into Hot Springs Creek. Because of the high surface runoff, flow conditions in the creek have not been favorable during this investigation to date to measure any spring flow to the creek.

Two horizontal centrifugal pumps deliver water from the central-collection reservoir to elevated reservoirs. Water pumped to the elevated reservoirs is metered. Neither flow to the central reservoir nor overflow of the central reservoir to Hot Springs Creek is metered. Water level in the central reservoir is recorded continuously. The rate of filling of the reservoir after withdrawal of water is a potential means of measuring spring discharge. However, the stage record can only be read accurately to about one-fourth foot (4,000 gallons) and the time to about 5 minutes. Also, the rate of filling declines as the upper half of the reservoir is filled. Furthermore, the reservoir is rarely pumped down to half full. The reason for the decline in rate of filling is not satisfactorily known. This could represent leakage from the reservoir, or if the decline represents a real decline in flow to the central reservoir, this could be due to back pressure on the collection lines. Hamilton (1932) attributes the decline to loss of water from the reservoir to springs in the bottom of the reservoir, as head in the reservoir increases with filling.

The collection system apparently is adequate and efficient with relation to the springs connected to the system and the amount of water now required to supply the bathhouses and fountains. However, the spring flow to the system is not known nor is the flow of uncollected Hot Springs water known. In planning for future use of Hot Springs waters and for maintaining an assessment of current water availability, it is essential that the Hot Springs flow in the collection system be measured continuously. In addition, uncollected flow must be measured in order to estimate the additional flow that could be collected for use, as well as provide adequate data for projecting and recording any changes in the flow of the Hot Springs. The first requirement for measuring flows and management of the collection system is a knowledge of the park plumbing network.

Wells drilled in the Hot Springs area can be used to manage the hot-water supply. It was stated previously that pumping wells in the discharge area will decrease the natural spring flow. If wells are part of the National Park water system, pumping the wells can supply water temporarily at a rate in excess of the natural spring flow. Also, pumping of wells, or natural discharge of artesian wells, to the collection system could salvage water discharged to Hot Springs Creek and not collected by the park collection system.

Surface-Water Flooding

Hot Springs Creek at Hot Springs National Park Headquarters has a drainage area of 3.64 square miles. The drainage basin is shown in figure 4. Runoff in the higher elevations of the basin is overland in natural channels and along streets and open gutters. At lower elevations in the city of Hot Springs, drainage follows open and underground storm sewers. Two main storm sewers, one following Whittington Avenue and one following Park Avenue, combine at the head of Central Avenue. These two mains are underground from about 1,000 to 2,000 feet upstream from their junction. The Central Avenue sewer, or arch, as it is called, follows Central Avenue and opens to an uncovered channel about 2,000 feet below the park headquarters. Conveyance of water into the underground sewer along Central Avenue is by grated openings in street gutters and one underground lateral at the junction of Fountain Street and Central Avenue.

Runoff in the basin is accelerated by the impermeable cover in the urbanized part of the basin, and also by roads and drainageways, some of which are lined with concrete, corrugated metal, and laid stone on West and Hot Springs Mountains. The result is to accelerate runoff from rainfall and increase peak discharge in Hot Springs Creek.

Central Avenue is subject to periodic flash floods from Hot Springs Creek, such as occurred in 1956 and 1963. The July 1963 flood is described by Gilstrap and Christensen (1964). Extensive property damage in the downtown Hot Springs area was caused by the flood. Water flooded Central Avenue at park headquarters to a depth of about 5 feet, and cars were washed from the streets. Some business establishments, damaged by the floodwaters, were closed for about 2 weeks. Flood stage was above the park's central-collection reservoir, and storm drainage was forced into the collection system.

Flooding was the result of inadequate capacity of the storm sewer system to collect and carry runoff from the storm. Peak flows of the 1956 and 1963 floods were 4,350 and 4,900 cfs (cubic feet per second) from an area of 5.81 square miles at the crossing of Hot Springs Creek by Underwood Street (near the center of sec.9, T.3 S., R.19 W.). A theoretical computation of discharge capacity at the tunnel outlet indicates that the tunnel should carry about 4,500 cfs. Considering the increase in flow between the outlet and the measuring station on Hot Springs Creek, the size of the creek arch should have been adequate to carry the peak runoff from the 1956 and 1963 storms. The flooding on Central Avenue, therefore, was probably caused not by insufficient capacity of the tunnel, but by inadequate feeder drains and openings (grates, drop inlets, etc.) from the streets to carry the water to the tunnel. The capacity of the underground tunnel is near the floodflow that can be expected to occur periodically. Increased urbanization and park development in the basin, which increase runoff rates, will create peak flows that exceed the capacity of the sewer.

An adequate storm-drain system must be designed from a knowledge of floods. The main tunnel should be designed to carry the anticipated floodflows, considering future development in the basin. The design of grated openings and laterals to feed peak flows to the main stem of Hot Springs Creek must be based on tributary contributions along the length of the main stem.

Pollution

Biological pollution potential of the hot springs from the recharge area is not considered to be a problem because of the time and length of travel from the recharge area to the springs. Chemical pollutants, on the other hand, are not filtered out, although some chemical changes may take place by reactions between the chemical pollutants and the natural ground water and the aquifer. Generally a chemical pollutant entering the flow system in the recharge area will emerge from a spring. Threat of pollution from chemical contamination by accidental spillage is remote because of the relatively small volume of pollutants presumably involved and the mixing with and dilution by natural ground waters during the long period of flow from the recharge area to the springs. Chemical pollution would be possible by dumping large volumes of pollutants on the ground or in pits in the recharge area during a sustained period of time or extensive and sustained application of herbicides, pesticides, and fertilizer. Presently, there are no known potential sources of chemical pollution in the recharge area.

The Hot Springs collection system is designed to prevent pollution from surface sources of pollution in the discharge area. The water in the collection system is analyzed periodically by the Arkansas State Department of Health for biological contamination. The biological pollution potential is greater in the discharge area than in the recharge area. Recharge is known to occur near the discharge area and thus time-distance relations are short, making biological pollution possible.

The surface-water drains and sewage system in the city of Hot Springs were studied in 1963 by the Arkansas Water Pollution Control Commission. With regard to the Hot Springs Creek, the report states "The uppermost point sampled was Station 41, where the creek emerges from underground after passing beneath the downtown section. There are supposedly no pollutional discharges above this point, but in an average flow of 6 cubic feet per second, coliform bacteria averaged 621,250 per 100 ml, BOD averaged greater than 9.5 ppm, temperature averaged 88°F [31.1°C], and sewage slime (sphaerotilus) was abundant, indicating fecal contamination consisting of or in addition to, bathhouse discharges."

During high flows in Hot Springs Creek, the overflow from the Hot Springs collection system is submerged by the creek. A check valve has been installed in the overflow line to prevent contamination from Hot Springs Creek during high stage.

The 1963 study by the Arkansas Water Pollution Control Commission found the surface-water drains polluted and the sewage system inadequate. To the present time the city has taken no action to remedy the situation, prompting the Commission to issue an order on March 27, 1970, requiring that the city prevent and abate the pollution.

Proposed Developments

Several alterations of the Hot Springs National Park and vicinity have been advanced by various planners as a part of a long-range revitalization of the park. Future developments in the park and in proposed acquisitions to the park (and future water problems associated thereto) are in a fluid state. Until plans are firm, only the most general statements can be made.

Display springs

The National Park Service is considering opening one or more of the higher Hot Springs and providing landscaping to reconstruct a near pristine condition to enhance the beauty of the park and increase visitor interest and enjoyment. The flow rate needed for such a display must be carefully considered. The flows of the individual springs have not been measured since 1931, and the fluctuations in flow of the individual springs, except for a minor spring measured by Bryan (1924), have never been measured. If one or several springs are selected for supplying a display, the flow and variations in flow should be known. An alternative, which should be considered, is piping water from the elevated storage tank to the desired point on the hillside for the entire flow or flow augmentation. Flow rate and variation could then be controlled as closely as desired.

Tunnel through West Mountain

A tunnel through the east end of West Mountain has been proposed. The tunnel would divert both vehicular traffic and floodwater from Central Avenue. Cross section A-A' in figure 1 is near and parallel to the alinement of the proposed tunnel. However, whether or not a tunnel through West Mountain would affect the Hot Springs depends upon the grade and elevation of the tunnel. Gravity flow of Hot Springs Creek through such a tunnel might require excavation below the ground-water surface, in which case the tunnel would act as a drain on ground water in the recharge area, tending to reduce flow of the Hot Springs. A tunnel placed above the ground-water surface in this location probably would not affect the Hot Springs flow. However, exploration by test holes and a pilot tunnel along the proposed tunnel route should precede construction. The collection and evaluation of hydrogeologic data obtained from the test holes and pilot tunnel would provide the most reliable projections of full-scale construction effects on the Hot Springs.

The effects of blasting on the Hot Springs cannot be conclusively predicted. According to Frank M. Thompson (1890), Superintendent of the Hot Springs Reservation, blasting and excavations for bathhouse sites caused some of the springs to cease to flow at original points of discharge, and caused the head of water at other springs to be lowered several feet. Bathhouse sites, however, are much closer to spring orifices than the proposed tunnel site. Obviously, earth tremors in the vicinity of the springs could alter flow paths and cause temporary muddying of the water. Compacting of the fracture system that stores and transmits the water possibly could result from extremely heavy blasting shocks.

A system for monitoring individual and total spring flow and water characteristics should be installed prior to any renovation or innovation to provide an early warning system of the kind and extent of effects.

Use of the tunnel for conveying floodwaters will require consideration of design floodflows, elevations and gradelines, conveyance capacity of the tunnel, and rerouting storm drains at inlet and outlet of the tunnel.

Exposure and landscaping of Hot Springs Creek on Central Avenue

Plans for renewal of the Central Avenue area include opening of Hot Springs Creek for incorporation in the landscape. Hydrologic considerations in designing with an open creek are (1) the maximum flow that the channel must carry to avoid flooding, and (2) the minimum flow that will occur in the creek. Under the present conditions, the maximum flow is more than 4,500 cfs; the minimum flow is probably less than 1 cfs. The problems in designing a channel that retains its eye appeal through all ranges of flow are readily apparent.

If floodflows are diverted through a tunnel in West Mountain, design must be based on knowledge of the range in flows to be conveyed through the Central Avenue channel. A major point for consideration is that Hot Springs Creek is polluted by solid and liquid wastes. The drainage basin is not within the National Park, and abatement and control of pollution would be under local jurisdiction.

A reservoir in the watershed of Hot Springs Creek would provide a ready and reliable means of augmenting the flow of the creek during the dry season. Such a reservoir possibly would increase recharge to the spring system and would provide additional esthetic and recreational potential. A draft-storage study would be needed to provide the basis for reservoir specifications.

An alternative to using Hot Springs Creek flow in an exposed waterway would be to use the flow from the proposed display Hot Springs. After cascading down the mountain slope, the water from the springs could be routed along a separate waterway through the park grounds. Both flow and quality of the water could thus be controlled by the National Park Service.

Expansion of Hot Springs National Park facilities

Expansion of the park and development of the area for increased access by the National Park Service or other governmental agency in the Hot Springs Creek or Gulpha Creek basins will affect the hydrology. As with urbanization, developments in the outcrop of the Bigfork Chert can affect recharge to the Hot Springs flow system. Construction, especially on the upper slopes of the basins, will greatly affect surface runoff. Because the slopes are steep, measures to control erosion must be carefully designed in order not to accelerate runoff and increase flood hazard in the basins.

OUTLINE FOR HYDROLOGIC STUDY

A hydrologic study of the Hot Springs is needed for providing the National Park Service answers to questions concerning the future of the Hot Springs under conditions of expanded urbanization and park development.

The hydrologic study needs to include a more complete understanding of the hydrologic system and a knowledge of the effects of urbanization on recharge and surface runoff. Data on the hydrologic system will provide the basis for a model (or models) that can be used to guide data collection and can be used as a tool to project the effects of changes (such as urbanization) on the Hot Springs flow system and on surface runoff. When we speak of a model, we think actually of a series of models that progress in sophistication as knowledge of the flow system advances. Growth of the model continues until it is adequate for use in projecting effects of stress on the system. The initial model of the groundwater flow system, called a conceptual model, has been described in a previous section. Advanced stages of the model will progress to analog or digital flow models and augmentation of flow models with heat-flow models. Surface-runoff models will be of the form of relating equations for rainfall, topography, basin characteristics, and frequency of occurrence of given flows.

Information needed for refining the ground-water model includes the size of the recharge area for the Hot Springs, geologic structure, earth-temperature gradients, flow and temperature fluctuations of the total Hot Springs flow and of individual hot springs, response of the Hot Springs flow to pumping wells in the discharge area, and discharge of ground water in the recharge area.

Information needed for the surface-water model includes rainfall-runoff relationships in urbanized and rural parts of Hot Springs and Gulpha Creek basins, hydraulic characteristics of the storm sewer system in Hot Springs Creek basin, and the magnitude and frequency of flows that may be expected.

The recharge area is the outcrop of Bigfork Chert northwest, north, and northeast of the Hot Springs. The limits of the recharge area must be delineated in order to know the area of influence on flow of the Hot Springs. Data that will be useful in delineating the recharge area will be potentiometric maps of the Bigfork Chert in the outcrop, recharge rates to the Bigfork Chert, and discharge from the Bigfork Chert within the Hot Springs recharge area. Recharge to the Bigfork can be estimated by examination of base-flow hydrographs from streams draining the Bigfork outcrop area.

Detailed structural data on dip, strike, and jointing systems of the rocks in the vicinity will provide data on the skeleton of the flow system and on variations in permeability of the rocks. Test holes in the area would provide direct information on the nature and structure of the system that could be obtained in no other manner.

Flow measurements of the Hot Springs are necessary for understanding the flow system and for determining the amount of water available for National Park use. Temperature measurements are needed for documenting any changes that may take place in temperature of the water. Flow and temperature in the collection system should be metered continuously. It is recommended that the National Park Service install and maintain a meter on flow in the collection lines for use by this study and continue such measurements for long-term surveillance of the Hot Springs flow. With the present, but inadequate, knowledge of the collection system, it seems that the best location for measurement of flow in the system would be on the overflow line from the collection reservoir. At times when the reservoir is full, this would provide the total spring flow collected by the system.

Measurements should also be made of uncollected Hot Springs flow. Probably, seepage measurements in Hot Springs Creek would provide these data. Uncollected flow should be measured periodically.

In addition to total flow, continuous and periodic flow and temperature measurements are needed on selected individual springs. Flow and temperature measurements are needed to understand the natural conditions and also the response of these features to pumping of wells and springs.

Chemical analyses, particularly of isotopes of certain elements, will be continued to provide information on travel times of water from the recharge to discharge area.

Our understanding of the effects of urbanization on the Hot Springs flow and surface runoff is incomplete. To understand the effects of urbanization on the hydrology, three stream and precipitation gages should be placed in operation--one on the tributary to Hot

Springs Creek on Whittington Avenue, to monitor a watershed with light to no urbanization, and one on the tributary to Hot Springs Creek on Park Avenue, to measure runoff from an urbanized area. A third station, at the outflow of Hot Springs Creek arch, would monitor combined flow and be used in analysis of floods that can be expected to occur periodically.

Comparison of runoff from urbanized and rural watersheds will provide some basis for projecting effects of increased urbanization on peak runoff. Effect of urbanization on ground-water recharge is a more difficult problem. Rainfall and surface-runoff data from urbanized and rural areas can provide some insight. These data should be used in conjunction with base-flow and potentiometric data for urbanized and rural areas to establish criteria for effects of urbanization on recharge. The criteria can then be extrapolated for expanded urbanization to project the effects on the Hot Springs flow.

Aerial photographs are excellent for showing land cover. Photographs of the recharge area and drainage basins should be taken periodically and examined for changes in land cover. This will provide data for interpreting changes in floodflows and flow of the Hot Springs. Infrared and other multispectral imagery may also be useful in mapping land cover, land use, and ground temperatures.

It is recommended that study in the area progress at a rate that will permit preparation of a comprehensive report on the Hot Springs and surface-water flooding in 3 years. This report would include projected effects of urbanization on flooding and the Hot Springs flow. Plans for park development should be coordinated with data and interpretations made during the hydrologic study from beginning to completion. The report will document the hydrologic aspects of proposed park development and the projections of their effects on the hydrologic system.

Hydrologic observations and periodic documentation of urbanization and land use that should be continued will be recommended in the report. Continuing surveillance in the area will be designed to provide an early warning system for adverse changes in the Hot Springs flow potential, quality of the water, and flood hazard.

The study will, aside from yielding a hydrologic basis for future park planning, contribute to the scientific knowledge of hot-spring flow systems in general and of the Hot Springs, Ark., flow system in particular. Results of the study should be written for the scientific and lay audiences. Popularized reports and displays on the age and origin of the Hot Springs water, its source of heat, and paths of travel from recharge to discharge would be of interest to park visitors.

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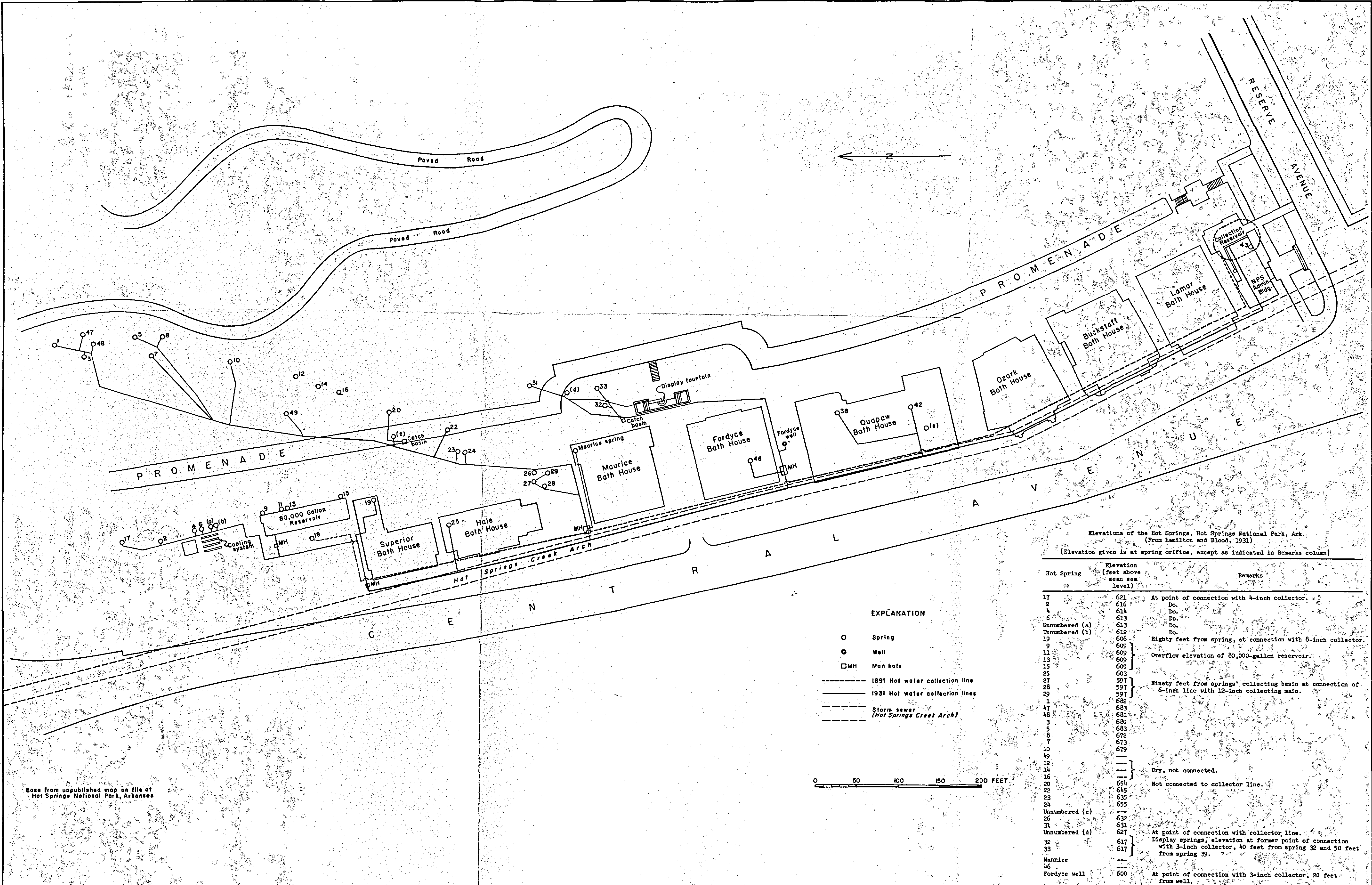

Figure 5.—Location of the Hot Springs and hot-water collection lines in the Hot Springs National Park, Ark.

Elevations of the Hot Springs, Hot Springs National Park, Ark.
(From Hamilton and Blood, 1931)

[Elevation given is at spring orifice, except as indicated in Remarks column]

Hot Spring	Elevation (feet above mean sea level)	Remarks
17	621	At point of connection with 4-inch collector.
2	616	Do.
4	614	Do.
6	613	Do.
Unnumbered (a)	613	Do.
Unnumbered (b)	612	Do.
19	606	Eighty feet from spring, at connection with 8-inch collector.
9	609	Overflow elevation of 80,000-gallon reservoir.
11	609	
13	609	
15	609	
25	603	
27	597	Ninety feet from springs' collecting basin at connection of 6-inch line with 12-inch collecting main.
28	597	
29	597	
1	682	
47	683	
48	681	
3	680	
5	683	
8	672	
7	673	
10	679	
49	---	
12	---	Dry, not connected.
14	---	
16	---	
20	654	Not connected to collector line.
22	645	
23	635	
24	655	
Unnumbered (c)	---	
26	632	
31	631	
Unnumbered (d)	627	At point of connection with collector line.
32	617	Display springs, elevation at former point of connection with 3-inch collector, 40 feet from spring 32 and 50 feet from spring 39.
33	617	
Maurice	---	
46	---	
Fordyce well	600	At point of connection with 3-inch collector, 20 feet from well.
42	---	
38	---	
43	576	Discharges into central collecting reservoir; elevation, bottom of reservoir.
18	---	
Unnumbered (e)	---	Elevation too low to feed by gravity into collection lines.