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HYDROGEOLOGY OF THE DEVIL'S HOLE AREA, ASH MEADOWS, NEVADA

by

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SUMMARY

The ground-water discharging from the major springs in Ash Meadows and the water level of the pool in Devil's Hole is an inherent part of a regional carbonate ground-water flow system. Ground-water movement and the location of the major springs is controlled in part by major faults. Water from the carbonate aquifer recharges most if not all of the overlying alluvial aquifers.

Large scale ground-water withdrawal by pumping from wells was initiated by Spring Meadows, Inc. in the spring of 1969. These wells draw water from the alluvial aquifers, which are highly transmissive in the Devil's Hole area. It is possible that some wells may penetrate the carbonate rock and may draw water directly from it. The relationship of the time of maximum pumping to the periods of water-level decline in Devil's Hole shows a high degree of correlation Continued heavy ground-water withdrawal by pumping will cause a continued decline in pool level in Devil's Hole and a reduction of discharge from the major springs in the Ash Meadows area.

A hydrologic alternative for irrigation is to utilize the natural spring discharge in conjunction with surface storage facilities. It is estimated that the annual 17,000 acre-feet discharge from springs will irrigate somewhat more than 3,000 acres of land. Additional ground-water development by pumping may be possible without materially interfering with the pool level of Devil's Hole or natural spring discharge, but this effect should be determined by additional hydrologic study.

A hydrologic monitoring system and a series of pumping tests should be initiated immediately to determine the discharge from each of the major springs and pumping centers and to determine aquifer characteristics. These data could be utilized to make predictive mathematical models of the local hydrologic system which would form the basis of a water management system for the Ash Meadows area.

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Scope of this Study

The Center for Water Resources Research, Desert Research Institute, University of Nevada System was requested by the Department of Interior to conduct a hydrologic study of Devil's Hole area, Nevada. This study includes only collection and analysis of pre-existing data derived from State and Federal agencies and from Spring Meadows, Inc. No additional field data were acquired by the investigators.

Devil's Hole is included in a 40-acre disjunct portion of Death Valley National Monument, and the area is under the jurisdiction of the National Park Service. A natural pool of water approximately 10 feet in width and 40 feet in length occupies Devil's Hole. The pool is the surface opening of a deep cavern with ground water being the source of water. *Cyprinodon diabolis*, the Devil's Hole pupfish, occupies the pool. This rare and endangered species is found only in Devil's Hole.

Extensive development of ground water in the Ash Meadows area, contiguous to Devil's Hole, has been initiated by Spring Meadows, Inc. Water-level decline in Devil's Hole has been

recorded by the U.S. Geological Survey since initiation of irrigation pumpage. Continued decline in water level may result in the extinction of the Devil's Hole pupfish.

The purpose of this study is to compile existing data, interpret the hydrogeology, determine whether ground-water development for irrigation is associated with the water-level decline in Devil's Hole, and make such recommendations as is possible in regard to actions which may result in preventing further decline of the water level in Devil's Hole.

Location of Study Area

Devil's Hole is in the southeast quarter of Section 36, T17S, R50E on the eastern side of Amargosa Valley, southwestern Nevada. The area is approximately 65 miles west of Las Vegas and 12 miles northeast of Death Valley Junction, California (Figure 1).

Previous Investigations

The geology of Ash Meadows Quadrangle has been mapped in detail by Denny and Drewes (1965). Previous reconnaissance hydrogeologic investigations of the Ash Meadows were conducted by Loeltz (1960) and Walker and Eakin (1963). Worts (1963) completed a brief reconnaissance of the effect of ground-water development on the pool level of Devil's Hole. A study of hydrogeologic conditions in Ash Meadows was conducted by Ed. L. Reed, a consultant for Spring Meadows, Inc. in 1967.

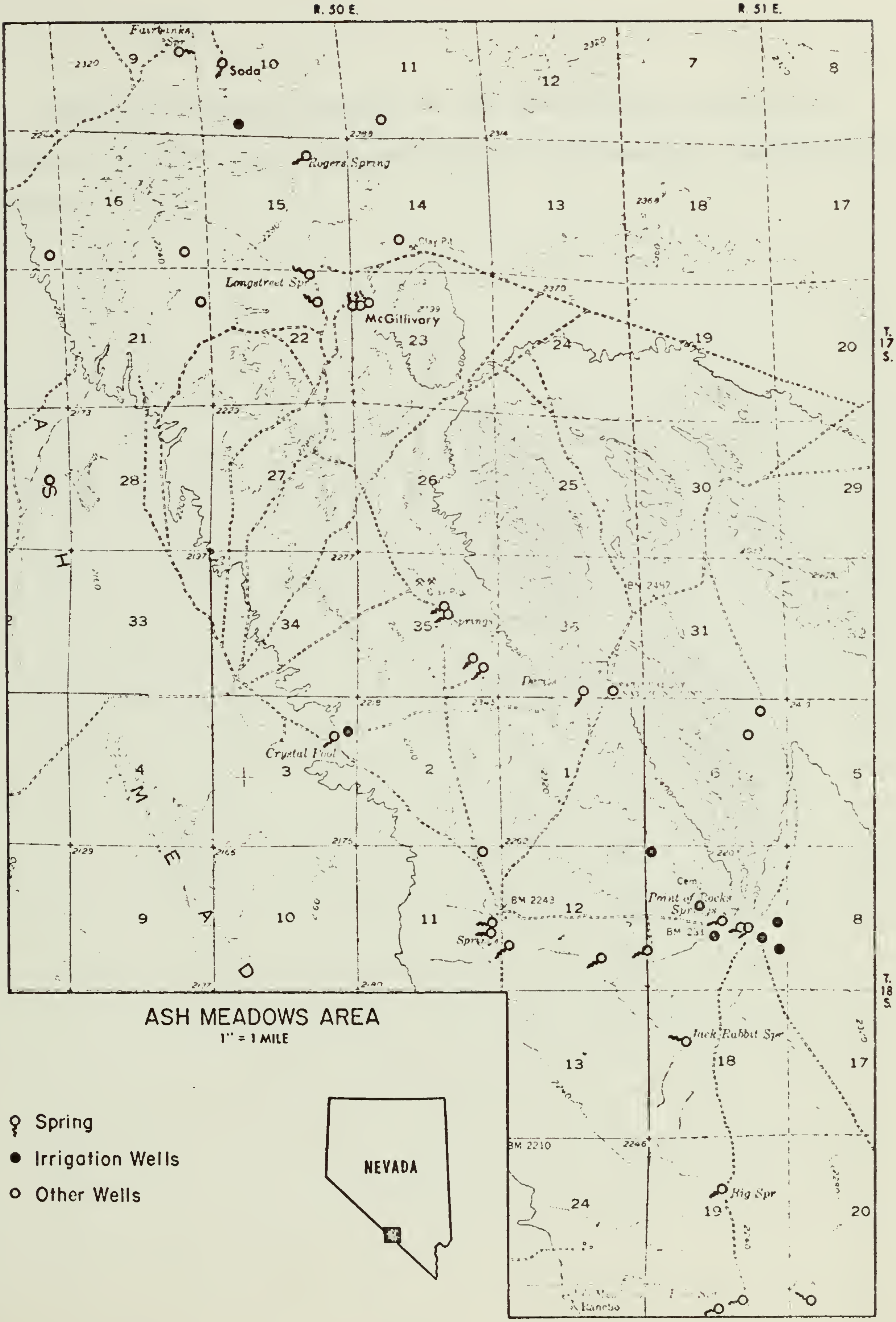

Figure 1. Location Map

Underwater investigations of the subterranean portion of Devil's Hole have been conducted by the Southwestern Speleological Society.

GEOLOGY

Regional Geology

Early Paleozoic rocks are exposed or underlie Ash Meadows. Dark-gray or banded medium-gray limestone, dolomite, and quartzite comprise the Paleozoic section. These rocks have been described in detail by Denny and Drewes (1965).

Tertiary rocks include alluvial fan and playa sediments. Rapid facies changes occur within these units depending upon the distance from the source areas. Some volcanic rocks and spring deposits are also found within the Ash Meadows area.

Unconsolidated or poorly indurated sediments of Quarternary age underlie most of Ash Meadows. These beds were deposited as alluvial fan and playa deposits. Some dune sand and spring deposits occur locally.

Many large-displacement, steeply-dipping faults transect exposed Paleozoic rocks. Thrust faults of undetermined magnitude are found in many bedrock exposures. Jointing and fracturing of consolidated rocks is common and extensive cavern and solution channel development has occurred in many of the carbonate rocks.

Geology of Devil's Hole Area

Devil's Hole is developed within the upper part of the middle Cambrian Bonanza King Formation. This unit is predominately light-gray to medium-gray, thick-bedded limestone and dolomite.

Alluvial deposits of coarse clastics overlie the Bonanza King formation in proximity of Devil's Hole. Fine-grained clastics deposited in a playa are exposed within a half-mile to the west and southwest of Devil's Hole.

Devil's Hole is developed by ground-water solution along a northeast-trending nearly vertical fault zone. The strike of the rock strata is almost at right angles to the trend of the major fault. Two additional faults of small displacement have been observed in the walls of Devil's Hole (Worts, 1963).

HYDROLOGY

Regional Ground-Water Flow System

Introduction: A ground-water flow system is characterized by the dynamic movement of ground-water through saturated geologic media from a source area of recharge to a discharge area. At every point within this system the ground water has the potential to move toward the discharge area. A regional ground-water flow system is defined as a large ground-water flow system which encompasses one or more topographic basins.

The Ash Meadows area is a discharge area for a regional ground-water flow system which extends to the north and east at least 70 miles, and includes Jackass Flats, Mercury Valley, Indian Spring Valley, Frenchman Flat, Yucca Flat, and Emigrant Valley (Figures 2 and 3 from Maxey, 1968). Water which recharges this system to the north and east moves laterally beneath the valleys and intervening mountain ranges through the fractured Paleozoic carbonate rocks, and most of it ultimately discharges in the springs of the Ash Meadows area (Figure 3). The water level of Devil's Hole pool represents the potential surface of the carbonate aquifer in the discharge area.

A regional carbonate rock ground-water flow system is usually

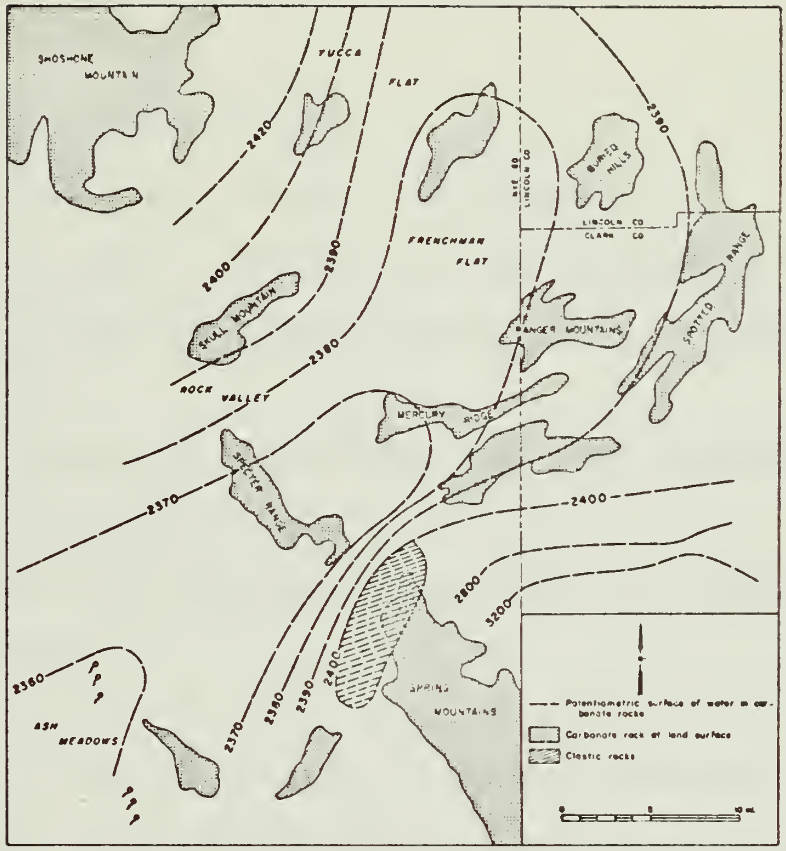

Figure 2 Regional flow system of the Nevada Test Site.

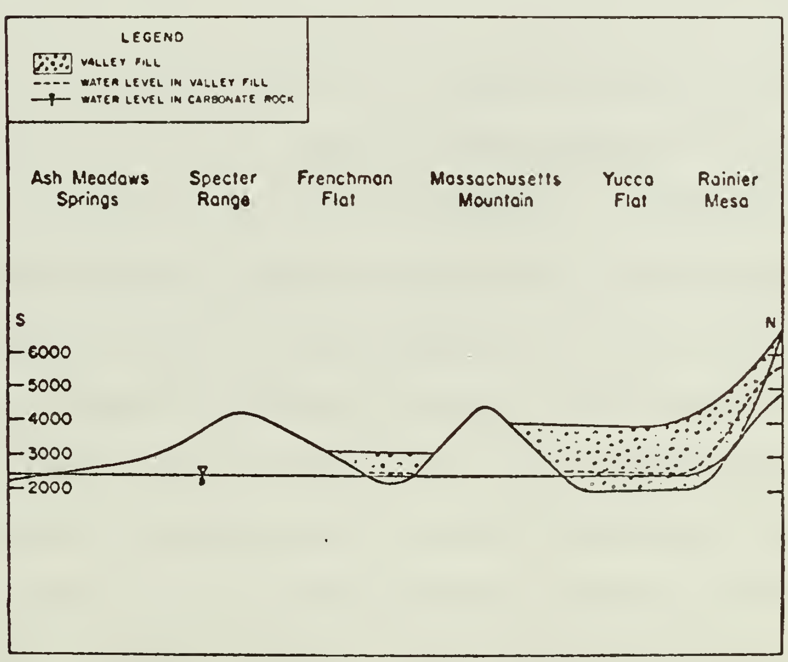

Figure 3 Profile of potentiometric surfaces in the Nevada Test Site and adjacent areas.

characterized by:

1. Long flow paths, usually interbasin;
2. Warm springs in the discharge area resulting from deep-circulating waters heated by the geothermal gradient;
3. Water chemistry characterized by high dissolved solids, especially Na, K, Cl, and SO_4; and
4. Springs with relatively large and nearly constant discharge.

Long Flow Paths: The U.S. Geological Survey (Winograd, 1962) and Mifflin (1968) have outlined the Amargosa-Nevada Test Site regional system, demonstrating long flow paths and interbasin transfer of ground water through the carbonate aquifer.

Warm Springs: The temperature of the major springs (over 100 gpm) ranges from 73° to 94°, which is approximately 8° to 29°F higher than the 65°F mean annual temperature at Lathrop Wells. These spring temperatures remain essentially constant seasonally and through long periods of time (Walker and Eakin, 1963). The warmest water is found in springs located in or close to the carbonate exposures of the ridges and in the highest-yielding springs. The water temperatures in Devil's Hole and Point of Rocks Springs, both issuing from carbonate rocks, are 92° and 90° respectively. Crystal Spring, the highest-yielding spring, is more tham a mile from the carbonate outcrops but has a

temperature of 91°F. The water temperature of Soda Spring, which discharges about 80 gpm is about 8°F lower than that of the nearby Fairbanks Spring, which discharges about 1,700 gpm. Thus, the temperature of springs in the Ash Meadows area is correlated with discharge rate which reflects the degree of connection of the orifice to the carbonate flow system or relates to physical proximity of carbonate outcrops.

The warm water results from heating of ground water by the natural increase in temperature with increasing depth below ground surface. The water within the carbonate aquifer has had a deep circulating path and hence is warm upon discharging.

Water Chemistry: The specific conductance, which reflects the amount and nature of dissolved solids in the water, ranges from 640 to 750 micromhos per cm. at 25°C for water sampled from all of the major springs (Walker and Eakin, 1963). The range for eight of these springs is from 640 to 675 micromhos per cm. This narrow range is indicative of water from a common source - the carbonate aquifer.

The chemical constituents and their concentrations in the ground water issuing from the major springs is also similar (Walker and Eakin, 1963) which lends additional evidence of a carbonate aquifer source.

Constant Discharge: Sporadic discharge measurements of the major springs in Ash Meadows indicate that the discharge has not changed significantly in the last 50 years (Walker and Eakin, 1963). This

is indicative of long flow paths which tend to modulate seasonal and long term climatic fluctuations.

Ground-Water Discharge

Ground water discharges in the Ash Meadows area through springs, evapotranspiration, underflow, and well withdrawal. The spring discharge in the area is approximately 17,000 acre-feet annually. Underflow calculations, to determine the amount of water moving through the area without discharge at the surface, has been estimated at approximately 6,000 acre-feet annually (Walker and Eakin, 1963). Evapotranspiration, supplied mostly from spring flow, is about 24,000 acre-feet. Walker and Eakin report a tentative ground-water discharge of 24,000 acre-feet annually for the Amargosa area.

The primary natural discharge, the high volume springs, lie along two N20°-25° W trending alignments over a distance of approximately 10 miles. Twenty of these springs lie within a rectangle 10 miles long and about 1 mile wide. The spring alignments parallel the dominant fault and fracture trends of the region, and are structurally controlled. Fault displacement probably places the less permeable Tertiary and Quaternary deposits in juxtaposition with the carbonate aquifer. This relationship would effectively seal the carbonate aquifer and hydraulic head would force the water to discharge upward from the aquifer along or to the east of the fault zones. Fairbanks (9/17S/50E), Soda (10/17S/50E), Rogers (15/17S/50E), Longstreet (22/17S/50E), McGillivary (22/17S/50E), Devil's Hole (36/17S/50E),

Point of Rocks (7/18S/51E), and Indian Springs (7/18S/51E) lie along one trend which parallels major faults exposed in the carbonate ridges. Crystal (3/18S/50E), Davis (11/18S/50E), Sink (12/18S/50E), Jack Rabbit (18/18S/51E) and Big Springs (19/18S/51E) are along a parallel alignment about one mile west.

EFFECTS OF GROUND WATER DEVELOPMENT

Introduction

Large-scale ground-water withdrawal from irrigation wells is a recent development in the Ash Meadows area. Prior to the farming operation initiated by Spring Meadows, Inc. the only ground-water withdrawal from pumping was the short-term test pumping of exploratory water wells and small withdrawals for domestic use. Spring Meadows, Inc. has utilized ground water for irrigation from eight wells (Figure 1). Concurrently with the increased pumpage, the water level in the pool at Devil's Hole has declined.

Transmissivity of Ground-Water Alluvial Reservoir

None of the eight irrigation wells drilled by Spring Meadows, Inc. penetrated tne carbonate aquifer according to interpretations from driller's logs. Pumping tests were conducted by Spring Meadows, Inc. on eight exploratory wells, of which two have been utilized for irrigation water. Transmissivity relates to the ability of the reservoir to transmit water. The transmissivity of the fine clastics associated with the Quaternary-Tertiary playa deposits is low, with a range of coefficients from 182 to

4,600 gallons per day per foot of width (gpd/ft). These wells are not currently being used for irrigation. Coefficients of transmissivity for test holes drilled to the east of the spring alignments and with coarse alluvium as a reservoir range from 620 to 183,777 gpd/ft.

The highest transmissivity was found in the well drilled 900 feet east of Devil's Hole (SWSE/4, 36/17S/50E). The well was pumped in 1967 at a rate of 900 to 1100 gpm for 167 minutes and had a total drawdown of only two feet. No decline in water level was noted at the U.S. Geological Survey recorder at Devil's Hole. The water pumped was reported to be similar in temperature and chemistry to that in Devil's Hole, and is undoubtedly drawn from the same carbonate aquifer. Assuming a storage coefficient of 0.15, and a pumping rate of 900 gpm, one investigator estimated in 1967 that the water level in Devil's Hole would decline less than 0.1 foot in one day and approximately 2.2 feet at the end of 100 days. This well has not been pumped since the original hydrologic testing in 1967.

The second highest transmissivity was determined from a pump test in 1967 in a well drilled 900 feet northeast of Crystal Spring (SENE/4, 3/18S/50E). This well was pumped at a rate of 600 to 1,000 gpm for 198 minutes. The coefficient of transmissivity was calculated as 42,240 gpd/ft. The water pumped was similar in temperature and chemistry to that in Crystal Spring, and to that in the carbonate aquifer. During the 198 minutes of the pump test with an average pumping discharge of 820 gpm, the measured flow of Crystal Spring was reduced by

175 gpm. A 50 horsepower pump was installed on this well and it was discontinuously pumped from August to December 1969. This well has not been pumped in 1970 up to May 28.

The coefficients of transmissivity and storage determined by these pump tests of the coarse-clastic alluvial aquifer indicate that a rapid pressure decline and thus lower ground-water levels and decreased spring discharge will occur through this section if ground-water withdrawal from wells is materially increased.

Ground-Water Withdrawal

Spring Meadows, Inc. has utilized ground water for irrigation purposes from eight wells. These wells have not been metered for pumping discharge; however the company has recently purchased flow meters for this purpose. In order to estimate pumping, the kilowat hours of energy consumed at each of the pumping sites has been tabulated on the basis of data supplied by Spring Meadows, Inc. (Table 1). The total monthly energy consumption for these wells has been plotted to illustrate relative changes in pumping rate (Figure 4).

The heaviest pumpage has occurred in the wells in the southeast quarter of Section 7, T18S, R51E, approximately two miles southeast of Devil's Hole. The closest irrigation well to Devil's Hole, in the northwest quarter of Section 7, T17S, R51E has only recently been pumped, with the initiation of energy consumption beginning in May 1970 according to reported information. Two wells recently completed in Section 6, 18S,51E, have not been pumped.

TABLE 1. Energy Consumption in Kilowatt Hours of Irrigation Wells, Ash Meadows, Nevada

Date	SESW/4, 10/17S/50E	NENE/4, 3/18S/50E	SENW/4, 7/18S/51E	NESW/4, 7/18S/51E	NENESE/4, 7/18S/51E	SENESE/4, 7/18S/51E	SWNESE/4, 7/18S/51E
January 1969	90	0	0	0	0	0	0
February	15,410	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0
June	0	0	10,710	0	37,450	0	0
July	0	0	10,970	0	34,310	0	0
August	,20	14,230	14,300	0	20,800	0	0
September	11,690	0	14,650		7,540	0	35,490
October	0	7,180	15,620	52,970	32,710	0	25,620
November	13,800	5,020	13,270	40,600	29,390	0	34,870
December 1969	100	5,230	8,950	3,430	3,920	0	12,640
January 1970	0	0	0	0	0	0	1,640
February	0	0	0	13,670	0	0	300
March	0	0	0	4,990	0	0	50
April	0	0	0	28,280	1,730	409	21,930

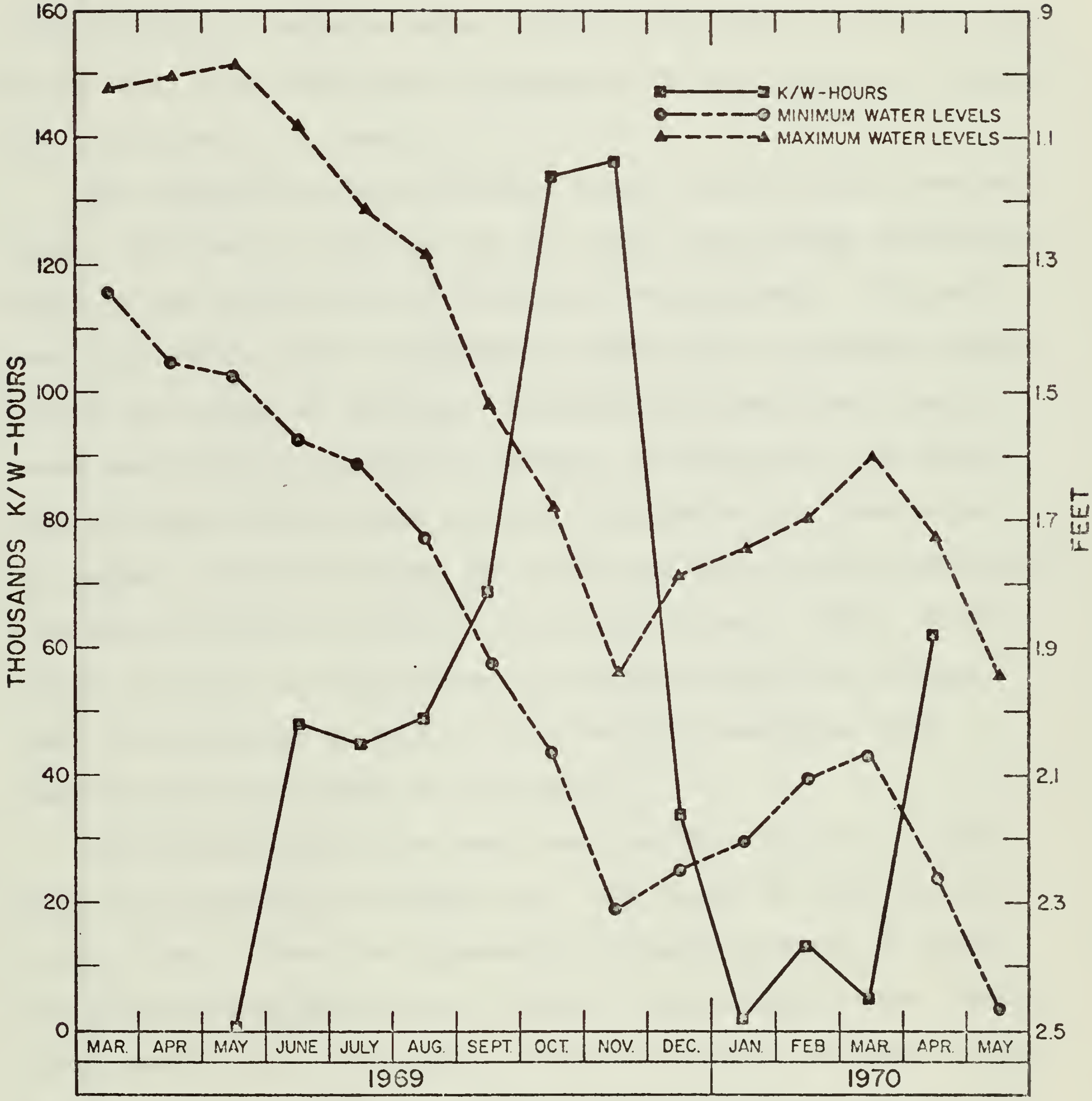

Figure 4 Water level of Devil's Hole and energy consumption of Ash Meadow irrigation wells.

Water-Level Decline in Devil's Hole

The United States Geological Survey has maintained a continuous recorder to measure water levels in the pool of Devil's Hole since 1956. The provisional hydrograph of pool level is illustrated in Figures 4, 5, and 6.

The apparent decline in water level from the early observations, 1956, until 1962 may not be valid, but perhaps represents error in the correlation of datum for the recorder. The pool level in Devil's Hole is extremely sensitive to pressure changes within the carbonate aquifer. Fluctuations resulting from diurnal earth tides, barometric changes, earthquakes, and underground nuclear detonations are all recorded on the continuous hydrograph. Monthly maxima and minima of water-level fluctuations have been plotted by the U.S. Geological Survey. Prior to the winter of 1968, the variations illustrated appear to reflect these fluctuations as well as fluctuations resulting from evapotranspiration loss in the system.

In December 1968, the pool level declined about 0.1 feet below the previously recorded low. The cause of this decline is not known. There was apparently no heavy pumping in wells in Ash Meadows at this time. However, some springs were cleaned out in Section 23, T17S, R50E (3 miles northwest of Devil's Hole) at this time, and this would have created a slight loss of pressure within the aquifer.

In June 1969, the pool again declined beyond its previous maximum low reading and attained a new low in October 1969, approximately 0.6 foot below the previous low in December 1968.

Figure 5 Water level of Devil's Hole, monthly maxima and minima.

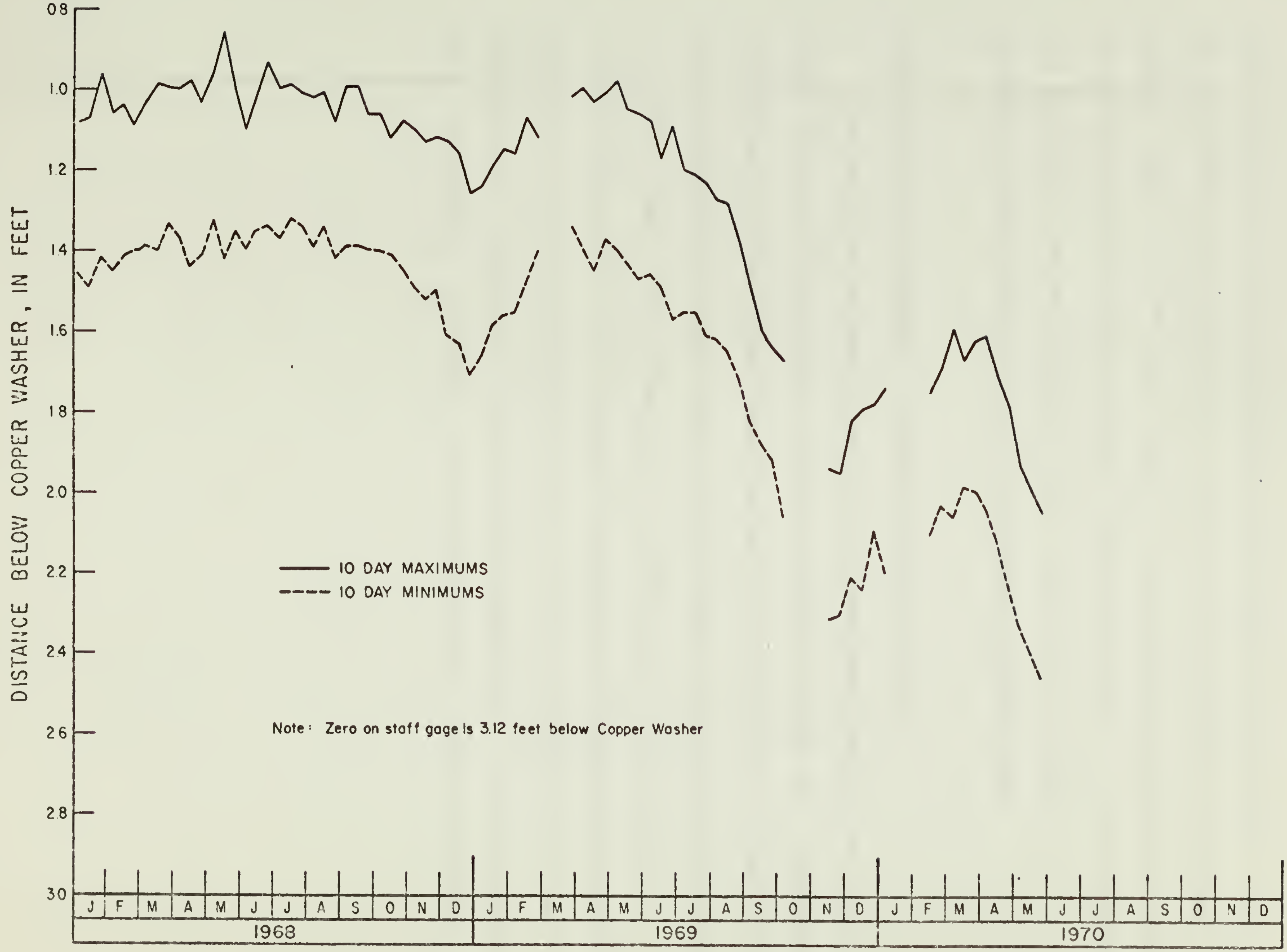

Figure 6 Water level of Devil's Hole, ten-day maxima and minima.

This decline is the maximum recorded drop in pool level since the recorder was installed. The pool has naturally attained its highest level in the late winter-early spring in previous years. In the spring of 1970, the pool recovered about 0.3 foot above its previous low of October 1969. Water level in May 1970 is declining and is almost to its previous maximum low.

Relationship of Pumping and Water-Level Decline

The periods of heavy pumping and maximum decline of pool level in Devil's Hole are closely related (Figure 4). Similar relationships have been noted in many arid valleys. Heavy ground-water withdrawal in Las Vegas and Pahrump Valleys caused a decline in spring flow and ultimately the drying-up of the springs. It is our conclusion that continued pumping at present rates will result in continued decline of pool level in Devil's Hole and a reduction of discharge from the major springs in the Ash Meadows area. Discharge from many of the springs may cease altogether.

HYDROLOGIC ALTERNATIVE

Spring production in the Ash Meadows area totals approximately 17,000 acre-feet annually. With a water use of approximately 5 acre-feet per acre annually, the natural spring flow is sufficient to irrigate somewhat more than 3,000 acres for agricultural development. Utilization of spring discharge could be so designed to prevent any deterioration of the habitat of indigenous wildlife. A distribution system for this water would be necessary, but could utilize relatively small horsepower pumps.

Additional hydrologic study could devise a water-management system based on predictive hydrologic models. Ground-water withdrawal by pumping could perhaps be instituted, using the predictive model as a guide and the pumped water combined with spring flow would make available most of the estimated 24,000 acre-feet of perennial recharge with negligible interference with spring discharge and no decline of the water level in Devil's Hole.

It should be clearly understood that extensive pumping will yield more water for use but will also result in diverting more and more spring water to well discharge. Ultimately, as more water is withdrawn from storage by wells, water levels will decline in the basin and the springs will decrease in flow and probably dry up completely, at least during the pumping season.

ADDITIONAL HYDROLOGIC STUDY

Essential to a detailed quantitative understanding of the hydrology of the Devil's Hole area and Ash Meadows is the initiation of a continuous hydrologic monitoring program of spring and well discharges and water levels and the development of predictive models for a water development system.

To develop the additional data, it is essential to have an adequate monitoring system. The installation of flumes and continuous recorders at each spring in the Ash Meadows area is required. Recordings of the data from the flow meters recently purchased by Spring Meadows, Inc. for their wells is essential. Pump tests on selected irrigation wells is necessary to determine the transmissivity, coefficient of storage, and time-distance relationships of the hydrologic effects of pumping.

Such a study is essential whether the irrigation requirements are fulfilled by pumping or utilization of natural flow. An adequate water management system in Ash Meadows will define the effects of any appreciable hydrologic change within the area.

RECOMMENDATIONS

As a result of this study we recommend:

A. That a monitoring system by initiated as soon as possible on the wells and springs in Ash Meadows, details of this system to be determined by an immediate field study. As a minimum action flumes and recording gages should be installed on all large springs, water-level recorders should be installed on selected wells, and discharge from wells should be continuously recorded.

B. Long-term (48 to 70-hour) pumping tests should be conducted on selected wells to determine aquifer characteristics from which a model for prediction of effects can be constructed.

C. As a short-range emergency measure, all pumping should immediately cease and irrigation should be accomplished from the natural discharge of the springs so that the water-level decline in Devil's Hole will be immediately arrested.

D. As a long-range measure, consideration should be made of use of spring water and water from wells, that may be pumped without materially affecting the water level

in Devil's Hole and the springs, for irrigation and other purposes.

This consideration must necessarily be based upon: 1) development of information from the predictive model and a well-spacing program, 2) economic evaluation, and 3) development of other natural or artificial habitats for the endangered species. Item 1 lies within our competence to develop. Items 2 and 3 should be studied by other agencies and experts.

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