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**WATER RESOURCES DATA OF THE
PIPE SPRING NATIONAL MONUMENT AREA, ARIZONA,
1977-1989**

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Technical Report NPS/NRWRD/NRTR-90/02

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**"RESOURCE MANAGEMENT
ZION NATIONAL PARK"**

ABSTRACT

The National Park Service is conducting a water resources study at Pipe Spring NM (PISP) for the purpose of evaluating spring flow trends. Ground water and spring flow data collected at PISP and vicinity from 1977-1989 indicate that total spring flow has steadily declined, while 2 and 4 miles outside of the Monument, respectively, ground water levels and spring flow appear to remain stable. While it is not possible to rule out regional ground water depletions as the cause of declining spring flows, two factors suggest that local physical changes in spring characteristics may account for at least part of the recent trends observed in spring flows at PISP. First, of the four springs which comprise Pipe Spring, two are experiencing significant declines in yield, one appears to remain stable and one--the most up-gradient of the four springs, is actually experiencing a gradual increase in yield. Secondly, a new monitoring well completed in 1989, suggests that the aquifer supplying Pipe Spring is artesian, whereas the aquifer 2 miles up-gradient is reported to be unconfined. While it is suspected that ground water at each location is a single aquifer, it has not been possible to document regional aquifer declines or to demonstrate the nature of the interconnection. By continuing the monitoring project, with the addition of the new monitoring well, information necessary for substantive management recommendations will be available.

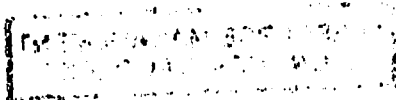


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INTRODUCTION

Since 1977, spring yields at Pipe Spring National Monument (PISP) have declined on the average of 2 gallons per minute per year. If this rate of decline continues, the springs will cease to flow by the mid 1990's (Barrett and Williams, 1986). Furthermore, Barrett and Williams (1986) concluded that the causes of declining spring flows likely were not natural, but were probably the result of large-scale ground water pumping in the area. A USDI/BIA (1976) study of the hydrology of the Kaibab Paiute Indian Reservation concluded that large-scale pumping of ground water from the fractured Navajo Sandstone along the west side of the Sevier Fault near Moccasin could be expected to decrease flow on area springs.

Barrett and Williams (1986) concluded that additional information on the cause of spring flow declines at Pipe Springs was necessary before suitable management recommendations could be developed. They developed and evaluated four alternative approaches to obtaining this information. The recommended approach involved collecting long-term data on ground water from: (1) the NPS-Kaibab well, (2) an observation well in the Navajo aquifer near the Sevier Fault, (3) Moccasin Spring, and (4) Pipe Springs. In addition, they recommended seeking additional sources of water to substitute for the tribal and village wells in the Navajo Sandstone aquifer adjacent to the Sevier Fault.

The Water Resources Division is conducting this study to determine if ground water pumping is causing the decline of spring flow at PISP. The purpose of this report is to summarize the information obtained to date from the Pipe Springs spring flow study and to evaluate whether the present approach will provide the information necessary to determine the cause of spring flow decline.

HYDROGEOLOGIC SETTING

PISP is a 40-acre tract within the Kaibab Paiute Indian Reservation. The monument is about 100 miles east of St. George, Utah and 20 miles southwest of Kanab, Utah (Fig. 1). PISP was established in 1923 to preserve the site of an historic Mormon cattle ranch with a fortification enclosing Pipe Spring. The existence of the springs was critical to the location of the ranch.

The springs occur at the base of the southern tip of Winsor Point of the Vermillion Cliffs, a southern extension of the Moccasin Terrace which is part of the famous "Grand Staircase" rising above the north rim of the Grand Canyon. PISP, at 4,950 ft, overlooks the southward spreading mesa of Pipe Valley and are bordered on the north by cliffs rising up to 6,500 feet in elevation (Fig. 2).

The cluster of springs at PISP issue from the Sevier Fault, a north trending, normal fault bisecting southern Utah. The fault contact is between the Navajo Sandstone on the west in the down thrown block and the Moenkopi formation to the east (Gregory, 1950).

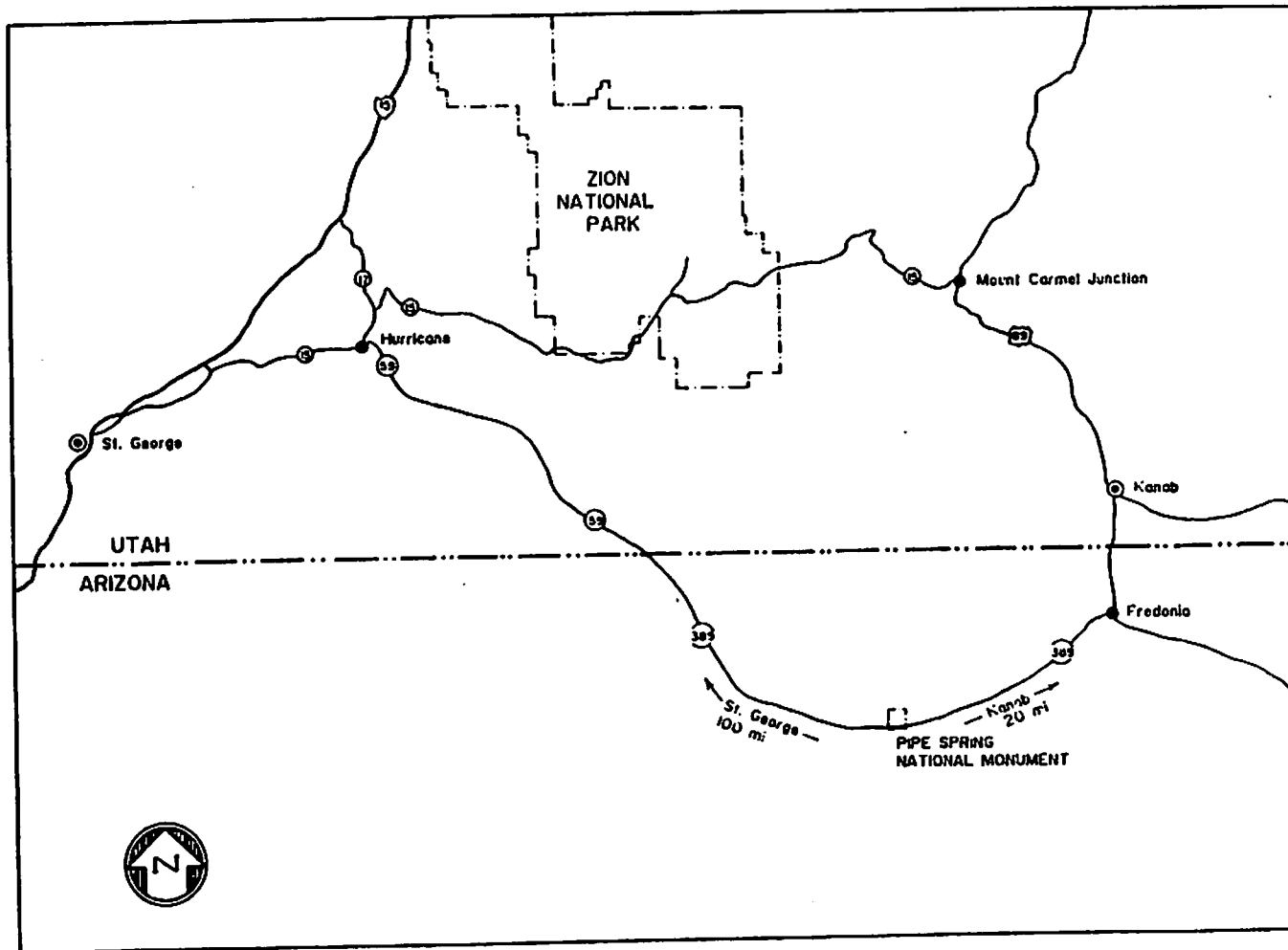


Figure 1. MAP OF NORTHERN ARIZONA SHOWING LOCATION OF PIPE SPRING NM AND REGION

The pervious Navajo Sandstone abuts the relatively impervious Shnabkaib member of the Moenkopi. Water absorbed by exposed Navajo Sandstone percolates downdip generally southeast until further advance is interrupted by the raised beds of the Moenkopi formation at the Sevier fault. In other words, the Navajo Sandstone conveys ground water down gradient until meeting, at the Sevier fault, the Moenkopi formation which provides a barrier to the further horizontal migration of water. The fault plane facilitates movement toward the ground surface of excess water which has become impounded against the impervious Moenkopi formation to form springs along the fault (Barrett and Williams, 1984). It is generally believed that the recharge area for the springs at the monument lies to the north or northwest.

Prior to the establishment of the monitoring program, sporadic discharge data existed for Pipe Springs. These early data often did not include how or where flow measurements were taken. It cannot be assumed that early measurements combined the discharges from the various spring openings near the fort. The following data were included in Barrett and Williams (1986):

In September 1933, a flow of about 42 gallons per minute (gpm) was reported for Pipe Springs, and 47 gpm was reported in May 1934. Other records indicate 35 gpm on March 12, 1959, 38 gpm on July 2, 1969 and 32 gpm on August 6, 1976. Levings and Farrar (1979) measured the flow of the springs at PISP on July 27, 1976. They reported the flow to be 35 gpm using a flume and volumetric measurements.

Levings and Farrar (1979) also prepared a map showing ground water conditions in the Kanab area. A compilation of well and spring information was prepared by the U.S. Geologic Survey (1979). That information is reproduced in part in Table 1 and Figure 2. (Wells in Figure 2 are labeled with the last part of their local number.)

MONITORING SITES

Pipe Springs: The four spring openings, collectively known as Pipe Springs, are described below and are displayed in Figure 2:

(1) The Historic Spring or Parlor Room Spring is now referred to as Spring Room Spring. Park documents indicate the spring opening was at one time below the parlor room in the northwest corner of the fort, but now issues from the courtyard cistern. The flow is piped to the southwest room (Spring Room) to maintain historical integrity. The altitude of the drain pipe in the cistern is 4957.38 ft determined by surveying from a bench mark in the building. This spring historically was thought to be the source for the other springs. The elevation of Spring Room Spring is used as a reference for the altitude of the other springs.

(2) Big Spring (also known as Main Spring), located about 20 ft west of the fort, emerges from the bottom of a small pool. Flow is channeled through a horse trough and then into the western duck pond. Foundation drains constructed around the fort in 1980 convey seepage

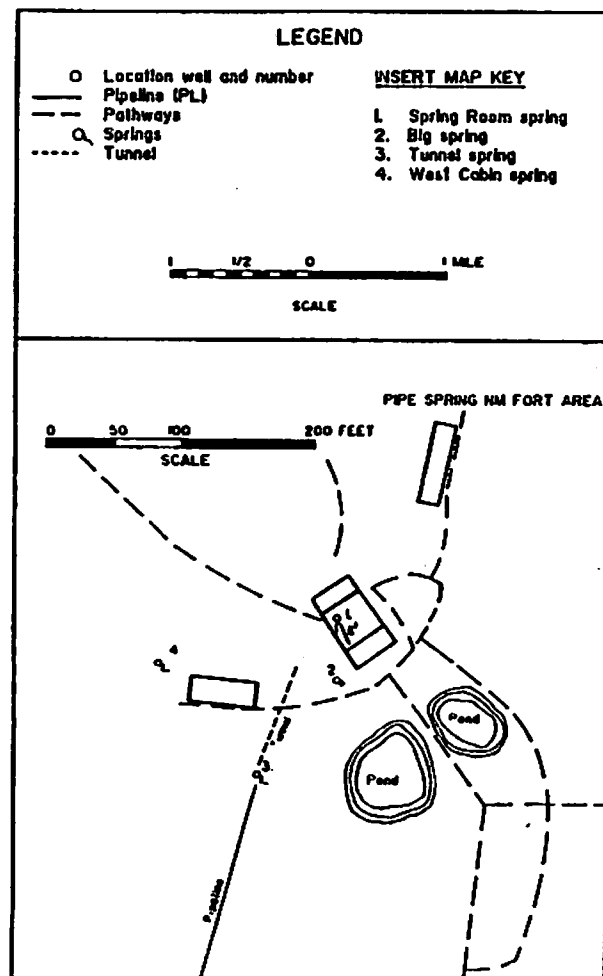


Figure 2. MAP OF PIPE SPRING NM SHOWING LOCATION OF MONITORING WELLS AND SPRINGS

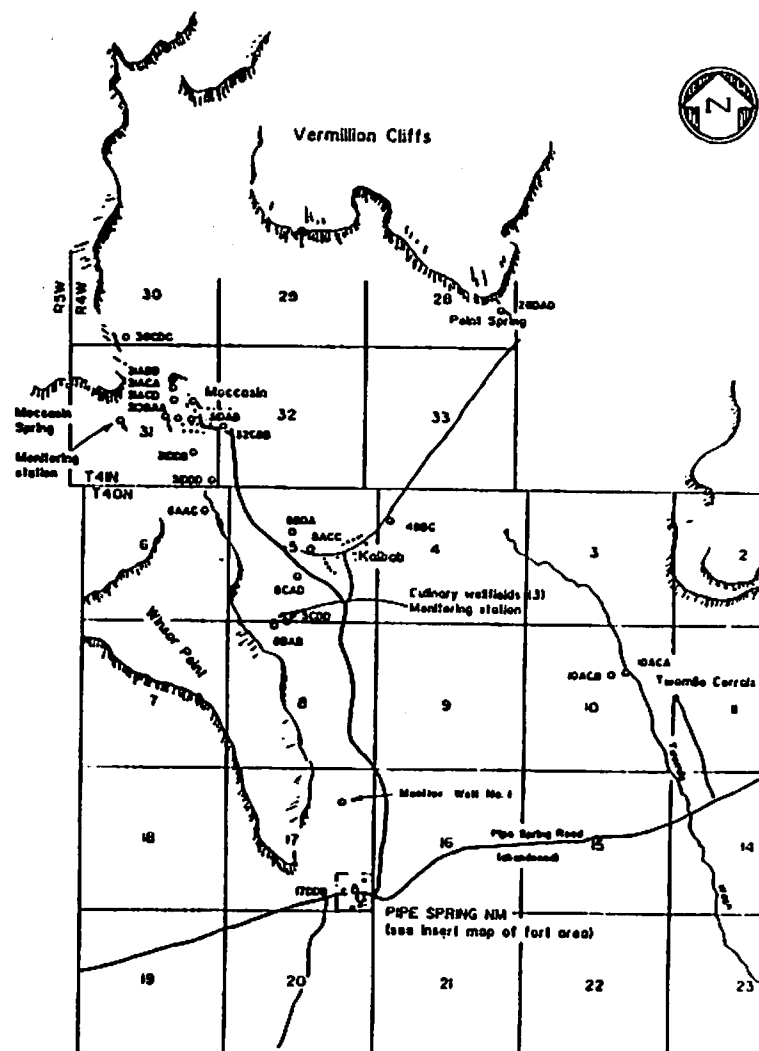


Table 1. Data from selected wells

LOCAL NUMBER	SITE-ID	DATE COMPLETED	CASING DIAMETER (INCHES)	DEPTH OF WELL (FEET)	ALT. OF LAND OF SURFACE (FEET)	WATER LEVEL (FEET)	DATE WATER LEVEL MEASURED
B-41-04 06C	365855112461001	—	—	—	5960	650.00	04/24/1973
B-41-04 11A	365820112410701	09/ /1973	8.62	490	5260	418.50	10/03/1973
B-41-04 30 CDC	365540112460501	08/12/1975	10	309	5260	58.30	08/14/1975
B-41-04 31ABD	365452112454201	03/20/1972	10	110	5200	75.00	03/20/1972
B-41-04 31ACA	365446112464001	02/10/1972	8	70	5170	10.50	02/10/1972
B-41-04 31ACD	365440112454101	03/ /1968	6	80	5140	37.75	04/15/1968
B-41-04 31DAB	365435112453701	01/19/1972	10.75	80	5120	19.00	01/19/1972
B-41-04 31DBA	365433112454501	03/ /1967	6	120	5110	3.70	01/17/1969
B-41-04 31DDb	365424112453401	03/21/1972	8	95	5120	18.00	03/21/1972
B-41-04 31DDD	365412112452401	—	—	65	5160	36.00	—
B-41-04 32CBB	365436112451801	/1968	—	120	5050	—	—
B-41-05 18CAC	365704112523801	—	42	—	5150	—	—
B-41-05 18CDD	365650112523101	—	10	—	5150	9.10	08/07/1976
B-41-06 06AAA1	365920112582501	/1946	—	87	4980	18.00	/1946
B-41-06 06AAA2	365920112582502	/1962	6	72	4980	15.00	08/12/1964
B-40-04 04BBC	365408112441201	02/09/1971	6	128	4970	—	02/09/1971
B-40-04 05ACC	365347112444301	11/ /1969	8	99	5020	69.00	04/28/1970
B-40-04 05BDA	365400112444801	02/08/1971	6	60	5025	—	02/08/1971
B-40-04 05CAD	365339112445201	04/22/1975	—	238	5060	—	—
B-40-04 05CDD	365325112445201	03/01/1971	8	205	5080	56.68	03/25/1971
B-40-04 06AAC	365403112452801	07/17/1975	8.62	202	5140	80.40	07/22/1975
B-40-04 08BAB	365324112445501	05/30/1975	8	155	5080	74.60	05/29/1975
B-40-04 10ACA	365310112422501	01/28/1971	6	100	4820	65.00	01/28/1971
B-40-04 10ACB	365310112422801	02/01/1971	6	100	4810	90.00	02/01/1971
B-40-05 19DCC	365050112521201	—	6	—	4900	—	02/01/1971

From: USGS, 1979

into this channel above the pond. The altitude of the pool crest of Big Spring is 4957.12 ft which is 0.26 ft below the Spring Room pipe in the cistern.

(3) Tunnel Spring, constructed before the establishment of the Monument, emerges from a hand-dug tunnel 22 ft lower and about 200 ft southwest of Big Spring. The date of construction and the length and condition of the tunnel, with its unsupported sandstone walls, is unknown. The spring flow is conveyed by pipeline outside of the monument to satisfy a water use agreement. The altitude of the base of the tunnel opening is 4931.07 ft which is 26.31 ft below the Spring Room pipe in the cistern.

(4) West Cabin Spring is located about 400 ft west of the fort, issues from a sandstone outcrop. Its discharge is low compared to any one of the other springs. No past or present uses or modifications are known for this spring. The altitude of the spring opening is 4972.69 ft which is 15.31 ft above the Spring Room pipe in the cistern.

Moccasin Spring: Moccasin Spring (also known as Sand Spring) was selected for the monitoring program to provide data on the regional aquifer that represents conditions that were unimpacted by withdrawals near Pipe Spring. This spring is believed to result from the Sevier fault dissecting the Navajo Sandstone which is the major aquifer in this region (Barrett and Williams, 1986). The spring, about four miles north of PISP (Fig. 2), surfaces on private land first claimed by early day Mormon pioneers. The elevation of Moccasin Spring is approximately 5130 ft (+ or - 20 ft) as determined from the Colorado City, Arizona 15 minute USGS topographic map. Water from this spring is shared between the village of Moccasin and the Kaibab Paiute Indian Reservation in a two thirds--one third split, respectively. Two splitting weirs were constructed in the past just below the spring opening. They are designed to divide the total flow of Moccasin Spring into equitable proportions at varying stages. The original flow of Moccasin Spring was reported to have been 190 gpm (Steve Turner, personal communication).

Observation Wells: Data from three observation wells were used in the study. A Culinary Well Field is located about 3 1/2 miles north of PISP on Tribal land and is composed of three water supply wells. Two of these wells provided information on ground water conditions. (Fig. 2). The third water supply well, Culinary Well No. 2, was not available for data collection. Additionally, in 1989, a fourth well was drilled closer to the monument for observing ground water levels.

Culinary Well No. 1: On Table 1 and Figure 2, this well is identified as B-40-04-08BAB. The well was drilled by the Kaibab Paiute Tribe after 1971. No drillers log is available. The elevation of the land surface at the well is approximately 5080 ft (+ or - 20 ft.) determined from the Fredonia, Arizona 15 minute USGS topographic map. The well is about 50 feet from and within the influence of the large, municipal well (Culinary Well No. 2) operated by the Tribe.

NPS Culinary Well: (B-40-04-05CDD on Table 1 and Figure 2.) This well was drilled to a depth of 205 ft in 1971 approximately midway between the two spring-discharge areas of Pipe and Moccasin Springs

(McGavock, 1974). The elevation of the land surface at the well is approximately 5080 ft (+ or - 20 ft) determined from the Fredonia, Arizona 15 minute USGS topographic map. Initial static water level was reported at 56.68 feet below land surface. During well development, pumping at 150 gpm for 20 hours resulted in lowering the water level 12.4 feet. A drillers log is published in a report by McGavock (1974). The NPS Culinary Well is connected to a 500,000 gallon storage reservoir that supplies all the domestic and irrigation needs of the monument. Through an agreement with the Tribe, the well also supplies several Tribal buildings near the monument.

Monitor Well No. 1 This well was drilled to provide an observation well in the Navajo Sandstone aquifer (as recommended in Barrett and Williams, 1984) that could not be accidentally pumped. The well was drilled in October, 1989 immediately west of the Sevier Fault about 1/4 mile north of the monument. Land surface elevation is about 5080 feet (+ or - 20 feet) determined from the Fredonia, Arizona 15 minute topographic map. The well is located and finished in Navajo Sandstone adjacent to the Sevier fault and a drillers log is available. This well will provide ground water levels further from the influence of pumping from the three water supply wells. Ground water level data is not expected to reflect major drawdowns from the cones of depression of the three water supply wells due to the distance of the monitoring well from the supply wells, i.e., data should reflect static water levels of the aquifer.

METHODS

To develop additional information on the nature and cause of spring flow decline at PISP, flow monitoring was established by the NPS at the four springs at PISP, Moccasin Spring, Culinary Well No. 1, Monitor Well No. 1, and NPS Culinary Well. In addition, power consumption data were collected from the local power distribution company as an index to ground water pumping in the Moccasin area. All data are being collected by park staff (except where noted) as part of the overall spring and ground water monitoring program.

More than 10 years of periodic measurements have been made at the four major springs within PISP. Volumetric measurements are made with a bucket and stop watch at established locations near the spring openings at approximately the same time each month. In past years, maintenance and preservation efforts of the historical features of the Monument have, in some cases, modified spring openings, etc., which caused changes in the data collection procedures. Where possible, corrections have been made to the data set, however, inaccurate values may have been recorded. Measurements that were obviously in error were removed from the record. Continuous digital recorders with pressure transducers or inline flowmeters were installed in 1988 to provide an improved discharge record. Specific information for each source of the present monitoring program is described below.

Spring Room Spring: Volumetric measurements are being taken monthly in the Spring Room at the end of the wash trough. A digital recorder, installed in the fall of 1988, records water level measurements in the cistern four times a day. The water level in the cistern is directly related to the flow in the wash trough.

Big Spring: Monthly volumetric measurements are made at the outlet of the channel at the entrance to the pond. Recently, a small V-Notch weir was placed at the outlet of the spring pool to produce a stage-discharge relationship from the flow. In October 1988, a digital recorder with a pressure transducer was installed to record four times a day the water levels of the spring pool.

Tunnel Spring: Monthly volumetric measurements are taken from the pipeline near the monument boundary. In the summer of 1988 the pipeline was reconstructed and a new vault was built to capture the spring flow at the mouth of the tunnel. An inline flowmeter was installed to allow continuous recording of flow in the pipe.

West Cabin Spring: Monthly volumetric measurements are made at the end of a small pipe placed in the spring opening.

Moccasin Spring: Water levels are measured in one of two splitting weirs that were constructed sometime in the past below the spring opening. The weirs were designed to divide the total flow of Moccasin Spring into equitable proportions at varying stages. To provide data of the spring flow in the upper weir, a digital recorder with a pressure transducer, scanning four times a day, was installed by WRD in August, 1986. In the upper weir splitter, the transducer was placed in the pool upstream from the weir plate to indicate water levels of incoming flows. Also, a tipping bucket rain gage was installed to provide precipitation data of the immediate area. The lower weir was not monitored because the upper weir is believed to represent a constant percentage of the total flow, i.e., to be representative of the long-term trend in spring flow at this site. The lower weir collects overflow, seepage and surface runoff from the area surrounding Moccasin Spring.

Culinary No. 1 Observation Well: In August of 1986, the Water Resources Division installed a digital recorder to monitor the water level four times a day. The purpose of monitoring this station is to record water levels in the Culinary Well Field to compare with previous water table elevations at this location to determine if any changes in local ground water levels are taking place. Inadvertent pumping of this well caused by a defective switch interrupted the observational aspect of this monitoring effort.

The NPS Culinary Well: Annual flow meter readings have been collected at the pumphouse since the construction of the well quantifies the use of ground water from this well. The distance between the NPS Culinary Well and Culinary Well No. 2 is about 500 ft.

Monitor Well No. 1: The NPS installed a new piezometric well in October 1989 to improve monitoring ground water levels nearer to PISP. Aquifer characteristics and water levels were measured during the construction of this well. A digital recorder and barometer have been installed to record water level and barometric pressure.

To provide an estimate of ground water withdrawal in the general area, power-consumption data for 18 pumps in the Moccasin area were obtained from Garkane Power Association, Inc. The annual power consumption for these pumps are totaled for the purpose of this study. The power-consumption data could be used to estimate the quantity of water pumped from individual wells. For best calculations, rates of power consumption need to be correlated with measured pumping rates in order to reconstruct the pumping history of each well in the field. Because of varying lift, pump condition, and well efficiency the estimates of withdrawals may be in error by as much as 20 percent (Dudley and Larson, 1976).

Statistics were used to evaluate data from the spring flow measurements in the monument. Hypotheses concerning spring flow were tested by using the linear least squares regression program on the Lotus spreadsheet software.

H_1 = Spring flow is increasing or decreasing with time.

H_0 = Spring flow is neither increasing or decreasing with time.

The F-test for lack of fit was used to determine the significance of the time-series flow trend. The accepted confidence level will be 95 percent or higher ($p = 0.95$). Use of the F statistic assumes that the flow observation for a given time are: (1) independent variables, (2) normally distributed, and (3) the flow distribution have equal variance.

RESULTS

Figure 3 presents over 10 years of monthly flow measurements for the four springs at PISP. The flow record of Big Spring indicates the greatest decline (from about 20 gpm to 7 gpm). Spring Room Spring flow also has declined (from about 8 gpm to 3 gpm). The record of Tunnel Spring flow (averaging about 8 gpm) does not show a significant trend at the 0.95 confidence level. West Cabin Spring data shows an increasing flow trend from below 1 gpm to almost 2 gpm at the 0.94 confidence level.

The results of the computations are presented in Table 2, "Summary of Statistics on Spring Flow Data".

Table 2. Summary of Statistics on Spring Flow Data

Name of Spring	Spring Rm.	Main	W.Cabin	Tunnel
Regression Output				
Constant	7.16	17.93	0.78	8.59
Std. Err. of Y Est.	1.23	1.87	0.30	1.48
R Squared	0.66	0.78	0.09	0.01
No. of Observations	158	158	158	99
Degrees of Freedom	156	156	156	97
X Coefficient				
X Coefficient	-0.037	-0.078	0.002	-0.004
Std. Err. of Coef.	0.002	0.003	0.001	0.005
f-test thresholds	6.85	6.85	3.92	4.00
f-test results	17.35	23.86	3.89	0.75
Confidence Level (p =)	0.99	0.99	0.95	0.95

Conclusions for each spring can be drawn from the above table. Spring Room and Big Spring flows reflect decreasing trends over time that are highly significant. West Cabin flows are significantly increasing over time. Tunnel Spring flow has no significant trend. The X Coefficient from the table is the overall rate (gpm per day) of the decrease or increase of spring flow calculated from the regression.

Figure 4 shows the instantaneous discharge of about 125 gpm at the upper weir at Moccasin Springs from August, 1986 through October, 1987. Water levels of the upper weir at Moccasin Spring have not declined or increased. Comparison of the spring discharge record to the rain gage record indicates that spring flow in the upper weir does not respond in the short-term to local rainfall. The lower weir, due to the design of the spring collection system, collects water from rainfall and overflow from the spring opening. The lower weir was not monitored. Barrett and Williams (1986) compared precipitation data from Kanab, UT with the decline in the flows at PISP and concluded that no significant relationship exists.

Recorded water levels in the Culinary No. 1 Observation Well are presented in Figure 5. Daily fluctuations of about 2 ft indicate influence of the cyclic pumping of the nearby Tribal municipal well. Figure 5 shows water levels fluctuation at about 82 ft to 84 ft below top of casing. The top of the casing is 2.5 ft above the land surface. When compared to initial water level determined during the well field development (from Table 1), present water levels are 4.9 ft lower. Data from 1986 to 1988 indicate little change in average water levels in the well field (Figure 5). Interruption of the monitoring aspect of the well occurred when accidental, continuous pumping lowered the water level in the well in late April 1987. A defective check valve and the resulting leakage from a storage reservoir is believed to be the cause of the elevated water levels in August of 1987.

DISCHARGE IN PIPE SPRINGS 1976-1988

MONTHLY VOLUMETRIC MEASUREMENTS

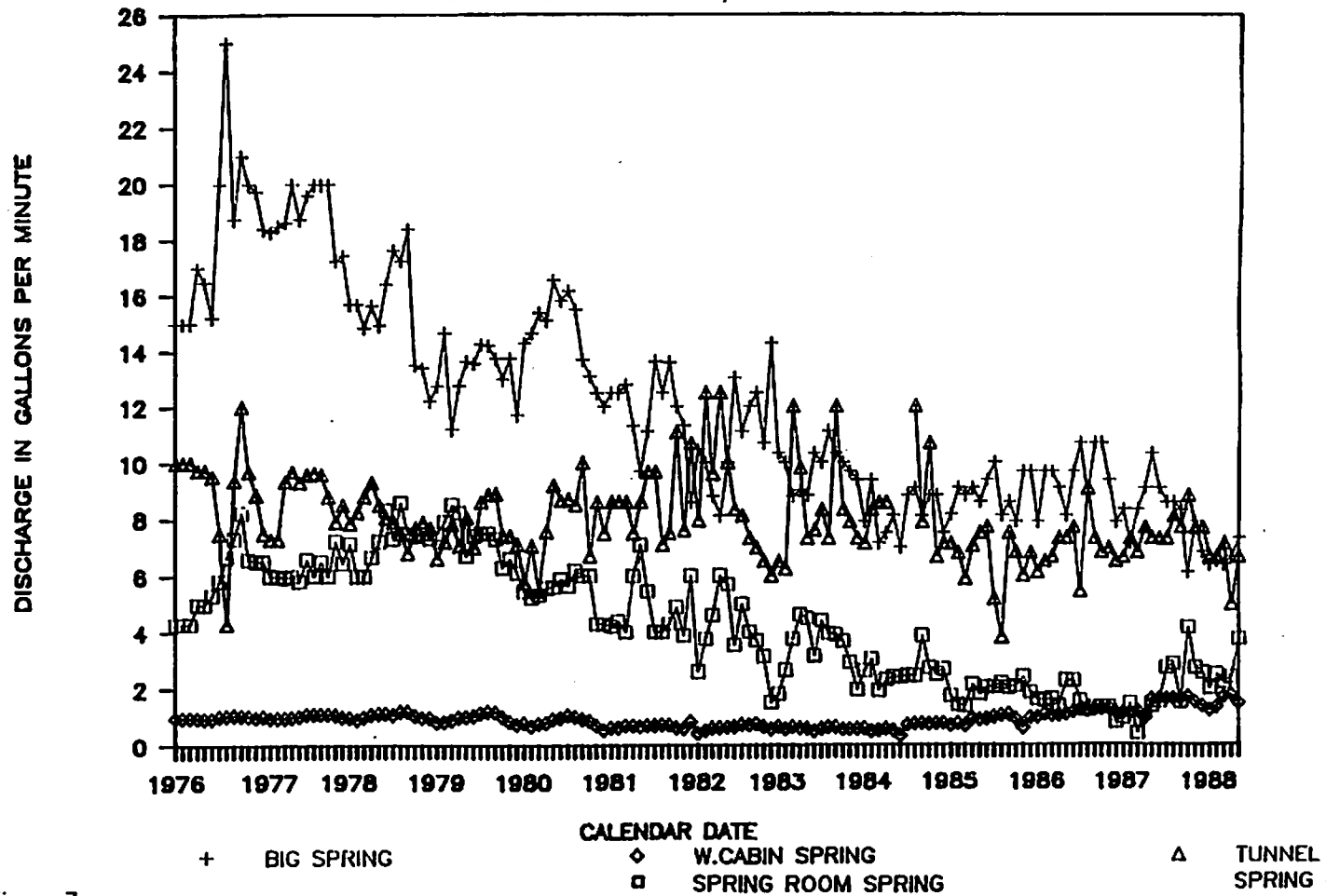


Figure 3.

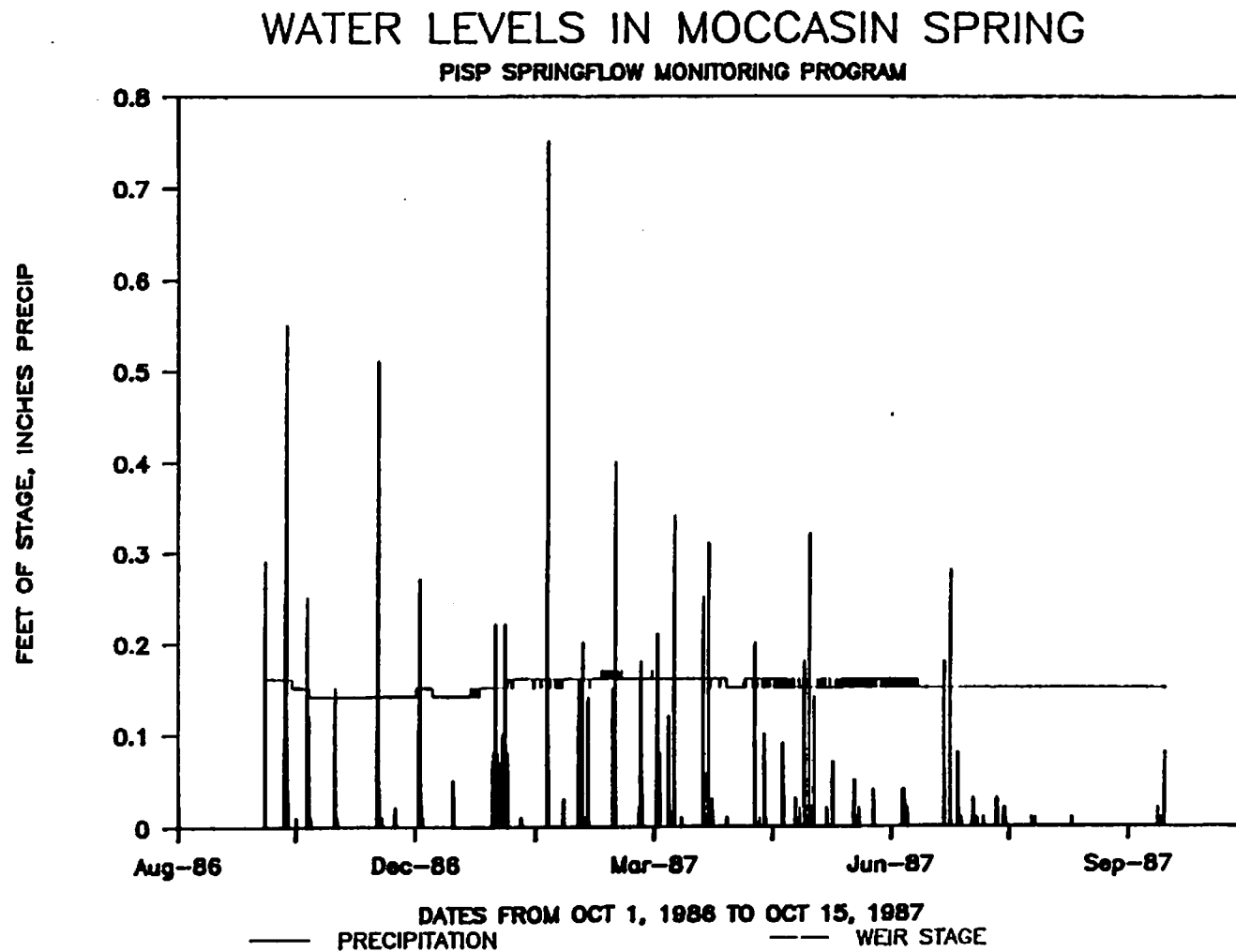


Figure 4.

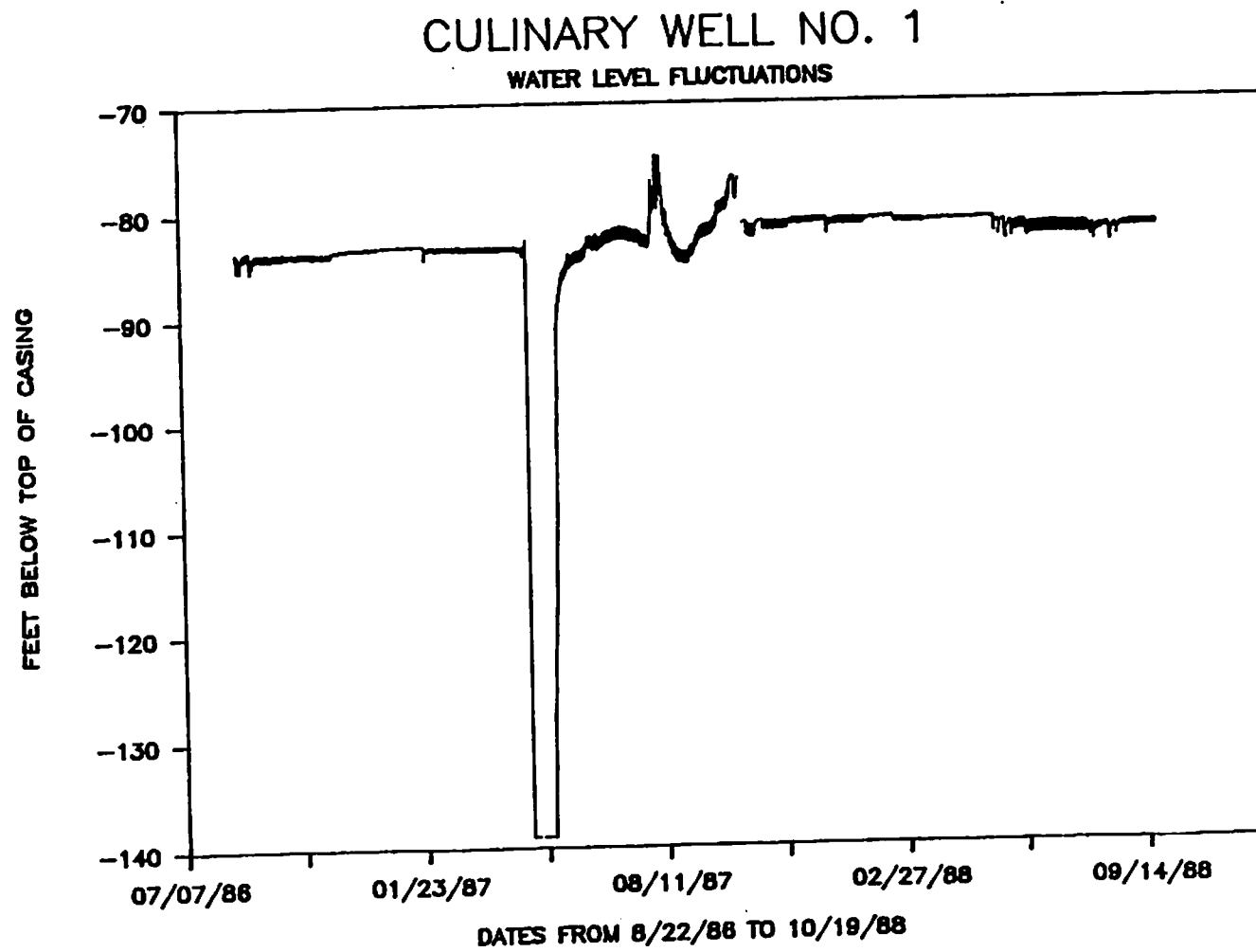


Figure 5.

Annual water use from the NPS Culinary Well is shown in Figure 6. Peak use occurred during a 2-year period of 1982-83. The data do not show a consistent trend of increased water use. The most recent (10/22/89) water level measured in the well about 63.6 ft below land surface elevation indicates a decrease in water level of about 6.9 ft since the well was constructed. McGavock (1974) reported that the aquifer tapped by this well is unconfined in the vicinity of this well.

Table 3 and Figure 7 present information on the amount of power consumption of irrigation wells in the Pipe Springs area. Total annual power consumption from 1976 to 1985 does not indicate a significant increase in power consumption by pumps in wells.

Construction of Monitor Well No. 1, 1/2 mile north of PISP, revealed information about the aquifer believed to supply the springs in the monument. The driller reported that water was first encountered in the well at 105 ft below land surface and rose in the well to 82.9 ft indicating that the aquifer is artesian; under piezometric pressure of about 22 ft. The driller also reported that the water producing zone is about 15 ft thick and clay layers indicative of the relatively impermeable Kayenta Formation was encountered about 155 ft below land surface (T. Ballard, personal communication). The static water elevation is at 4997 ft. which is about 40 ft above Spring Room Spring. The gradient of the ground water table appears greater between Monitor Well No. 1 and PISP than between Monitor Well No. 1 and the Culinary Well Field. Monitor Well No. 1 was tested by pumping at 60 gpm for 18 hours and resulted in a water level drawdown of 2.2 ft. Analysis of the aquifer test data (Appendix) indicates a transmissibility of 113,000 gallons per day per foot. This value is high when compared with published values for the Navajo Sandstone, but the proximity of the Sevier Fault and increased pathways along associated fracture zones may explain the difference.

DISCUSSION

Results of monitoring the water resources at PISP and vicinity shows that the flow of two springs are significantly decreasing over time--another is not showing any trends and one spring shows increasing flow. However, the combined spring flows (representing Pipe Spring) are decreasing. Flow records collected for Moccasin Spring since 1987 do not show a declining trend. Observations in Culinary Well No. 1 show no discernable trend of pumping in the well field. The small decrease observed in ground water levels are insignificant in the Culinary Well Field, however, the record is very short. Electrical power records for the irrigation wells in the Moccasin area indicate no trend in pumpage in the 10 year period of record. No conclusions can be stated at this time to explain the long term decline of spring flow within the monument.

The disparity in spring flow trends may be partially explained from the differences in altitude between the springs. The higher elevations of Spring Room and Big Springs position them nearly directly above Tunnel Springs should make them more susceptible to impacts from lower water table of the aquifer. Another factor which may have contribute to the decline in flow of Spring Room and Big Springs was the construction in 1980 of foundation drains located within close proximity of these spring openings and not the other springs. Although the drain outlets have been included in the periodic discharge measurements, no flow has been found. Construction of the drains may have caused previously surfacing spring flow to percolate into the soil before surfacing. The

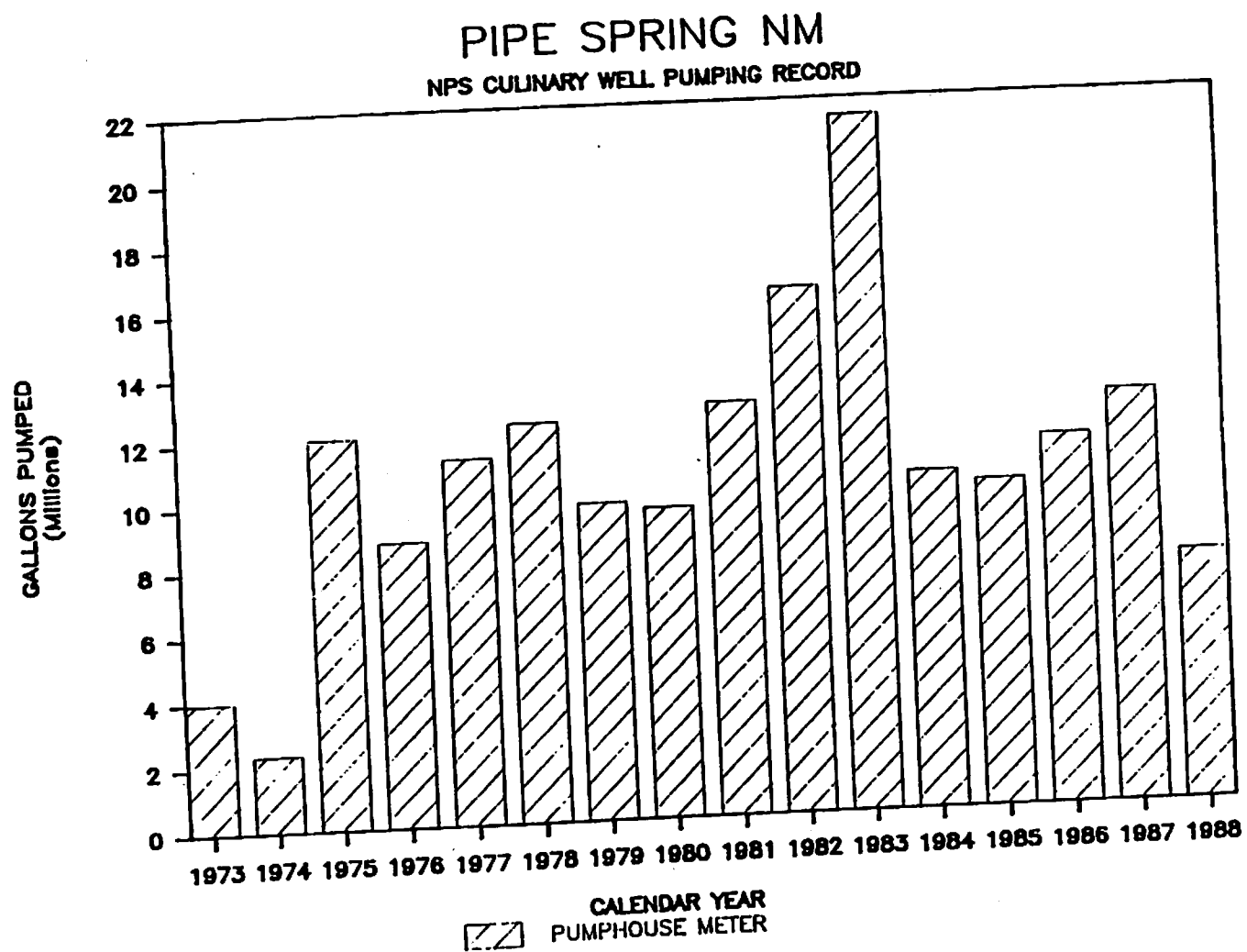


Figure 6.

Table 3. Power Consumption by Irrigation Wells

Kilo-watt Hours (KWH's) for Moccasin Pumps

ID	KWH'S 1976	KWH'S 1977	KWH'S 1978	KWH'S 1979	KWH'S 1980	KWH'S 1981	KWH'S 1982	KWH'S 1983	KWH'S 1984	KWH'S 1985
342500	9481	13188	11234	4903	4979	6080	5690	4297	3698	3694
542600	—	—	—	—	617	—	26	1004	—	—
345801	—	—	—	—	—	3474	4408	3394	2927	4668
345600	6425	18570	—	—	—	—	—	—	—	—
341800	3610	3627	3699	28574	19765	10359	8417	8650	9896	—
344900	9720	8080	10870	14135	14422	11328	12835	7074	10546	—
345100	—	—	2080	10388	9548	7168	4148	3448	2848	2698
339300	2400	2400	11275	11890	14670	18350	8120	2760	10030	17320
27292	6966	2400	44	12	—	—	—	—	—	—
341700	—	1416	2400	1330	700	—	—	—	—	—
345500	—	600	2400	—	—	4870	1480	9290	—	430
564100	—	—	—	—	—	51080	67920	60080	27360	20920
345800	6506	11948	7906	8871	4987	1001	—	—	—	—
345900	9349	14828	11044	11348	11077	9895	8985	10104	12280	10813
346000	11243	12628	8625	9481	8043	6544	6453	7430	7780	6955
346100	—	12048	9998	3357	7776	8105	7767	4508	9838	10756
343600	4280	10126	5990	5780	6180	4510	4420	4800	3490	2210
343000	—	—	680	3620	2510	2040	1850	1960	1890	2390
TOTAL	90306	116525	90601	113721	105104	144804	142519	128799	102583	82844

FROM: Personal Com. Garkane Power Association

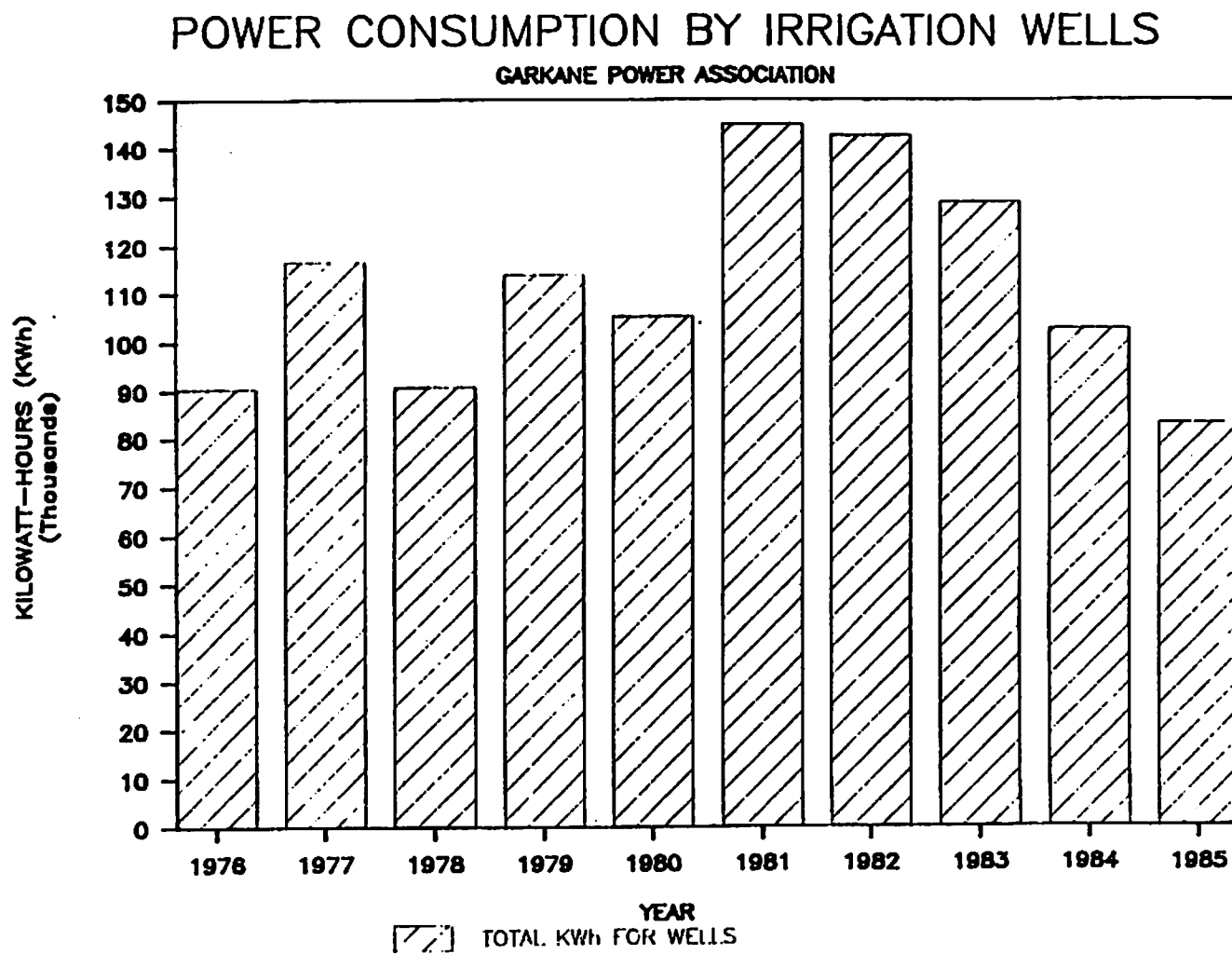


Figure 7.

18



Figure 8.

flow of West Cabin Spring may be less affected by historical manipulation at the fort due to its more remote location. Adequate information now exists to develop a conceptual model of ground water levels along the Sevier Fault (Figure 8). The diagram depicts a cross-section of the PISP area showing approximate elevation of the water levels at each monitoring site. The dash line indicates piezometric surface which is equal to the water table where the aquifer is unconfined (in the area of the Culinary Well Field). Although there is relatively little decline in water levels in the Culinary Well Field since these wells were drilled, the water table remains above the elevation of Pipe Springs. The diagram shows the new monitoring well as artesian. The confined aquifer and the piezometric head at the well are shown above the elevation of the springs in the monument. It is believed that the unconfined aquifer and the confined aquifer are connected and that they share the same recharge zone.

The springs in the monument are likely supplied by a confined aquifer with individual "connections" (primary and secondary porosity of the rock formations near the spring opening) to the aquifer. Artesian spring flow is controlled by piezometric head, the transmissivity and storativity of the confining strata, and the physical characteristics of the "connection" through the confining strata (the secondary porosity of the caprock). The flow rate of the topographically highest spring in the monument (West Cabin Spring) has been increasing while flow rates of the middle elevation springs (Big and Spring Room Springs) have been declining and flow rate of the lowest elevation spring (Tunnel Spring) has been unaffected. The "connection" of the middle elevation springs may have been affected by construction of the tunnel, installation of the cistern and/or foundation drains in and around the fort, however, the timing of these events do not coincide with the beginning of the decline of the spring flows.

Drawdown from pumping in the Culinary Well Field has lowered the water table less than 10 ft in the vicinity of the culinary wells, however, it is unknown if pumping and the associated cone of depression has lowered the piezometric surface at the new monitoring well. Based on the above concept of the ground water system, effects of current pumping in the Culinary Well Field should be observed in Monitor Well No. 1 without the local affects of manipulation near the spring openings.

RECOMMENDATIONS

Data, as acquired and analyzed to date are inconclusive as to the possible effects of ground water withdrawal from north of the monument. To determine if pumping at the Culinary Well Field is affected the spring flows PISP, it is recommended, initially, to record 1 year of water levels in the new observation well north of PISP. Three scenarios are presented below to compare water level fluctuations in the monitoring well, spring flows at PISP, and water levels at the Culinary Well Field.

- (1) Unaffected - If water level fluctuation in Monitor Well No. 1 correlates favorably with water levels at PISP and not with the water levels in the Culinary Well Field, then pumping at the well field can be eliminated as a cause of the spring flow decline. The cause of spring flow decline is site specific within the Monument. A clear example of this scenario would be observing no change in the trend of water levels the well field, and upwards trend in both spring flow in the monument and water levels in

Monitor Well No. 1. Likely causes may be changes in the primary or secondary porosity in the aquifer supplying the springs. This essentially eliminates outside factors causing the spring flow decline.

(2) Affected - If water level fluctuation in Monitor Well No. 1 correlates with water levels in the Culinary Well Field then the probable cause of spring flow decline is from the lowering of water levels in the well field. An example of this scenario is water level trends of the well field, Monitor Well No. 1 and total spring flow in the monument all decrease. The different trends of the individual springs may be due to a complex interaction of increased piezometric head in the aquifer and physical changes near individual springs.

(3) Inconclusive - If water levels in Monitor Well No. 1 fluctuate without correlation to either spring flow at PISP or water levels in the Culinary Well Field then the primary cause of spring flow decline cannot be determined with the available information. An example of this case would be an increase in spring flow in the monument, no change in water levels in Monitor Well No. 1 and a decrease in water levels in the Culinary Well Field. Further investigation of ground water use in the PISP area and the installation of other monitoring wells may be necessary.

The additional ground water levels should be gathered and analyzed to determine one of three possible scenarios of water levels in the aquifer supplying the springs in the monument. Assumptions for analysis of the three scenarios are based on: (1) at least one additional year of water level records from Monitor Well No. 1, (2) no major change precipitation in the recharge area, (3) no alteration in ground water use, (4) the total flow of spring flow at PISP represents trend in the aquifer of concern, (5) Monitor Well No. 1 is representative of the confined aquifer, (6) Culinary Well No. 1 is indicative of water levels in the Culinary Well Field, and (7) there is similar pumping regime in the same season 1 year apart.

If results of 1 year data collection indicate other cause(s), as presented above, regional ground water information should be collected. To achieve a regional understanding of the ground water system and trends, the investigation would require monitoring ground water levels and uses surrounding the monument. This regional monitoring network would need multiple observation wells, drilled in a phased-in sequence and pumping data supplied from ground water users in the basin. The number of monitoring wells would be based on the information learned from each site. This is to utilize information gained from each well to provide local ground water flow directions which are presently perceived to be north-south, but have not been verified. The ground water gradient and direction of flow would be triangulated from water levels in the monitoring wells.

The initial recommendation to collect data for 1 year will require servicing the data recorders in Monitor Well No. 1 and NPS Culinary Well located on Tribal lands. It is also recommended the raingage and data recorder at Moccasin Spring be removed and that water level measurements at Moccasin Spring be recorded every 3 months for the duration of the project. Data collection efforts should continue at the four springs in the monument.

Continuing for 1 year, the monitoring program may permit a relationship to be determined between the current trend in combined spring flows at the Monument and the current trend in water level in the Culinary Well Field. If such a relationship is determined, then a description of what has happened in the past can likely be reconstructed. This information will allow management to focus its efforts to protect spring flows at PISP.

APPENDIX

PIPE SPRING NATIONAL MONUMENT
AQUIFER TEST
MONITOR WELL NO. 1

by Richard Inglis, Hydrologist
Water Operations Branch
Water Resources Division
December, 1989

SW 1/4, NE 1/4, NE 1/4, Sec. 17, T. 40 N., R. 4 W.
Mohave County, Arizona

An aquifer test for Monitor Well No. 1 was conducted as a portion of the investigation to determine the decline of springflows in Pipe Spring NM (PISP). This report presents all data collected during the drilling and testing of Monitor Well No. 1, as well as interpretative analyses. Further information about groundwater near PISP is available in a report by Inglis (in press). The well is located on lands managed by the Kaibab-Paiute Indian Nation and is registered with the State of Arizona, #55-526126 by the U.S. Dept. of Interior c/o National Park Service.

DRILLING BACKGROUND: The construction of a new monitoring well was first proposed by Barrett and Williams (1986), but was not recommended for implementation at that time. Monitor Well No. 1 was constructed to reveal information about the aquifer supplying the springs in the monument. Monitor Well No. 1 is identified as Site #1 on Figure 1. There are no other wells in the immediate vicinity.

This site was selected because of the presence of the most eastern outcrop of sandstone layers that are continuous with the east slope of Winsor Point which has been identified as Navajo Sandstone by Hemphill (1956). Evidence of the Sevier Fault, a major structural feature controlling groundwater movement, has been located very near the wellsite.

Contract specifications for three monitoring wells for PISP were prepared by the Water Resource Division. Due to budget limitations, only one of the three wells was awarded under contract (No. PX-1200-9-C835) by the Rocky Mountain Region to Ballard Drilling CO. of Hurricane, UT. A permit application to drill a monitoring well was sent to the State of Arizona and was approved with modifications. Arrangements were made to commence drilling during the second week of October.

Drilling using cable tool started October 10, 1989 and was completed November 2, 1989. The well is located in Navajo Sandstone on a hillside immediately west of the Sevier Fault about 1/2 mile north of the monument. The land surface elevation is about 5080 ft as determined from the Fredonia, AZ 15 minute USGS topographic map and the well is located in Navajo Sandstone adjacent to the fault.

The contractor drilled a 9-inch borehole to 20 ft, and installed a steel, 6-inch surface casing with a grout seal. Total depth of well is 200 ft. Samples of cuttings every 5 ft were taken during drilling to allow the preparation of a geologic log of the strata, used to confirm that the well was drilled west of the Sevier Fault. The driller reported that water was first encountered in the well at 105 ft below land surface datum and rose in the well to 82.9 ft indicating that the aquifer is artesian at this site i.e. under piezometric pressure of about 22 ft. The driller also stated that the aquifer is about 15 ft thick and red clay was encountered at 155 ft which is indicative of the Kayenta Formation. See Table 1 for lithologic information from the Well Driller Report filed with the State of Arizona (File No. B(40-4)17aac). One hundred and ninety ft of 4-inch, PVC casing was installed with 10 ft of continuous slot, PVC well screen placed from 115 to 125 ft below land surface. A one foot long steel extension was welded to the top of the steel casing after completion of the aquifer test. An instrument shelter was constructed over the well by cementing a 2 ft diameter concrete pipe section to the exposed bedrock at the surface. The pipe section is covered with a lockable steel plate. See Figure 2 for a diagram of the well as constructed.

AQUIFER TEST METHODS: The well was pumped before the installation of the casing using a submersible pump supplied by the driller set at 150 ft below land surface. The measuring point was the top of the steel casing which was level with the ground surface. Water levels were measured with a Druck 10-psi pressure transducer with a theoretical range of 23 ft (accuracy of one tenth of one percent) set at 110 ft below land surface datum. Static water level before pumping was 82.9 ft. Discharge data was obtained by measuring water levels in a flume with Druck 1-psi pressure transducers (range of 2.3 ft).

Both pressure transducers were scanned and recorded in one minute intervals by an Omidata Easylogger Field Unit with a 16 kilobytes Data Storage Pack. Pumped water from the well was conveyed by a 2-inch pipe approximately 25 ft to a 1-inch Baski cutthroat flume (with a range of 1 to 120 gpm and an accuracy of approximately 10 percent) and discharged down a short hill slope into a dry wash. Discharge water flowed in the wash several hundred yards before soaking into the stream bed. Recirculating discharge water into the well is not suspected. Water levels measured by the transducer in the flume were recorded simultaneously with water levels in the well (see Figure 3 and 4). A hard copy of the recorded data is available from the Water Resources Division in Fort Collins. Discharge was verified using a 5 gallon container and a stopwatch. Static water levels were verified with a 500-ft Olympic Well Probe. Water quality of the well discharge was not analyzed.

RESULTS: Monitor Well No. 1 was tested by pumping at 60 gpm for 19 hrs, 5 min (started 16:13 10/30/89, ended 11:18 11/1/89) and resulted in a water level drawdown of 2.2 ft. The rate of discharge variation is within + or - 5 gpm throughout the test (Figure 3). Recovery of water level in the well was recorded for a duration of 27 hrs, 19 min at which time water levels were 0.2 ft below static water level. Analysis of the aquifer test data using the Modified Jacob's method on the recovery curve (see Figure 5) indicates a transmissibility of 113,000 gallons per day per foot. This value is high for published values for the Navajo Sandstone, but the proximity of the Sevier Fault and increased pathways along fracture zones may explain the difference in transmissibility. The slight water level variation during the final hours of recovery curve seen on both Figure 4 and 5 may be explained as barometric effects on artesian wells that would typically occur during the afternoons in the PISP area. The drawdown curve analysis (Figure 6) indicates very high transmissibility values which were rejected based on violations of the assumptions of the Theis equation, e.g., homogeneous aquifer.

Figure 7 depicts data of the first two attempts to pump the well at approximately 20 gpm on October 20, 1989. Pump failure caused ending the test prematurely. Very rapid recovery was partially due to the lack of a check valve which allowed drainage of the discharge pipe into the well. Analysis of this data set was not done.

The well screen, casing and construction of the instrument shelter was inspected and approved by park personnel. To complete the well as a monitoring station, a datalogger and pressure transducer must be installed in the finished well and the elevation of a reference point at the well must be established.

CONCLUSIONS Monitor Well No. 1 appears to be suitable to observe the water level in the aquifer supplying the springs at PISP. Drilling and pumping the well has revealed that the aquifer is artesian and has a very high transmissibility. Also revealed, is the 15 ft thickness of the water producing zone and that red clay, believed to be of the Kayenta Formation, was encountered at 155 ft below the ground surface. This information will be essential in understanding the groundwater system in the PISP area.

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Table 1 - Log of Well

From (ft)	To (ft)	Description of Formation Material
0	5	White Navajo Sandstone
5	10	Red Navajo Sandstone
10	15	Red Navajo Sandstone
15	20	Red Navajo Sandstone
20	25	Red Navajo Sandstone
25	30	Red Navajo Sandstone
30	35	Red Navajo Sandstone
35	40	Red Navajo Sandstone
40	45	Red Navajo Sandstone
45	55	Red Navajo Sandstone
55	65	Red Navajo Sandstone
65	75	Red Navajo Sandstone
75	85	Red Navajo Sandstone
85	95	Red Navajo Sandstone
95	105	Water at 105 ft, water raised in hole 22 ft up to 83 ft
105	115	Red Navajo Sandstone
115	125	Red Navajo Sandstone
125	135	Red shale
135	145	Red sandy shale
145	155	Red sandy shale
155	165	Red clay
165	175	Red clay
175	185	
185	200	Red clay

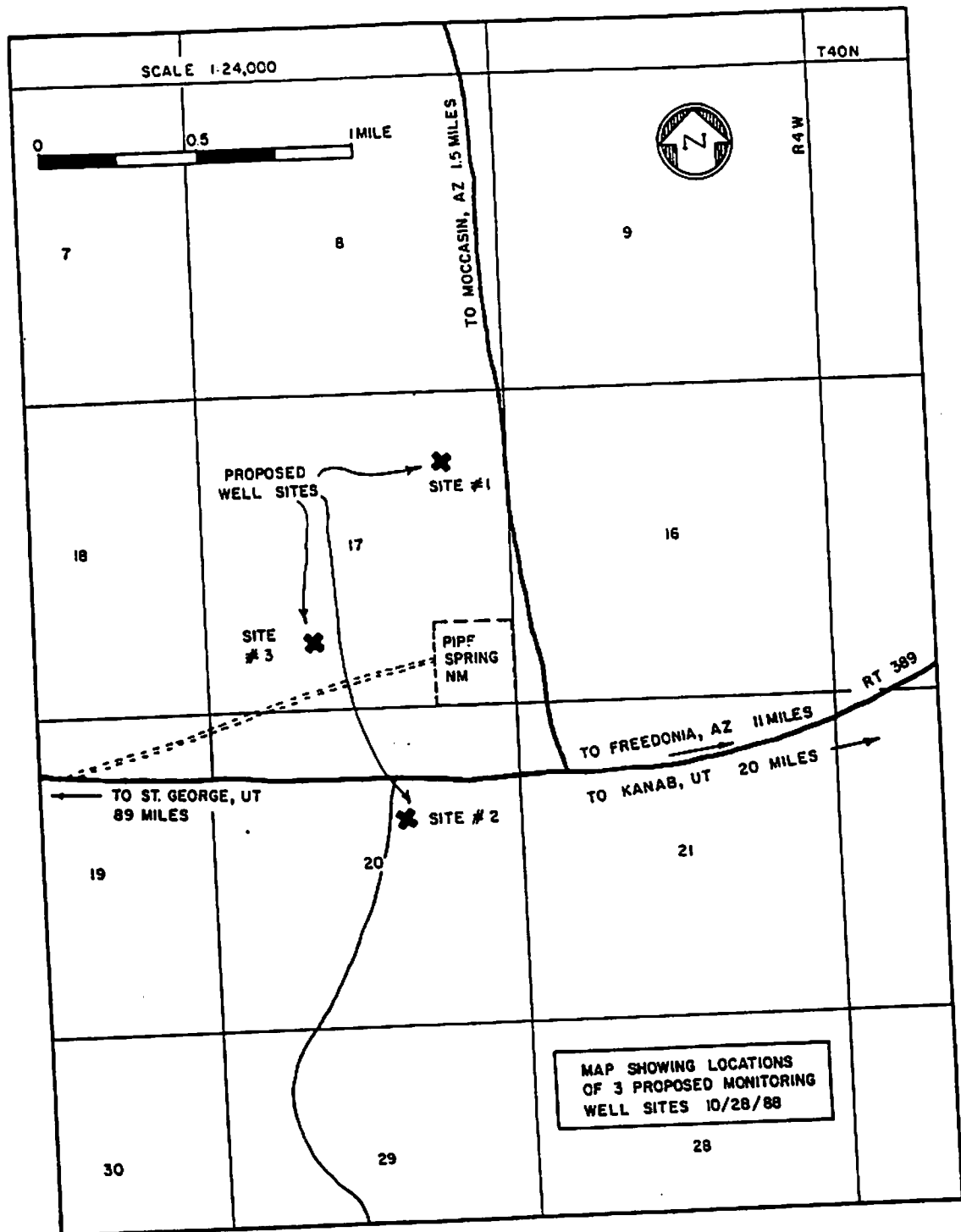


Figure 1.

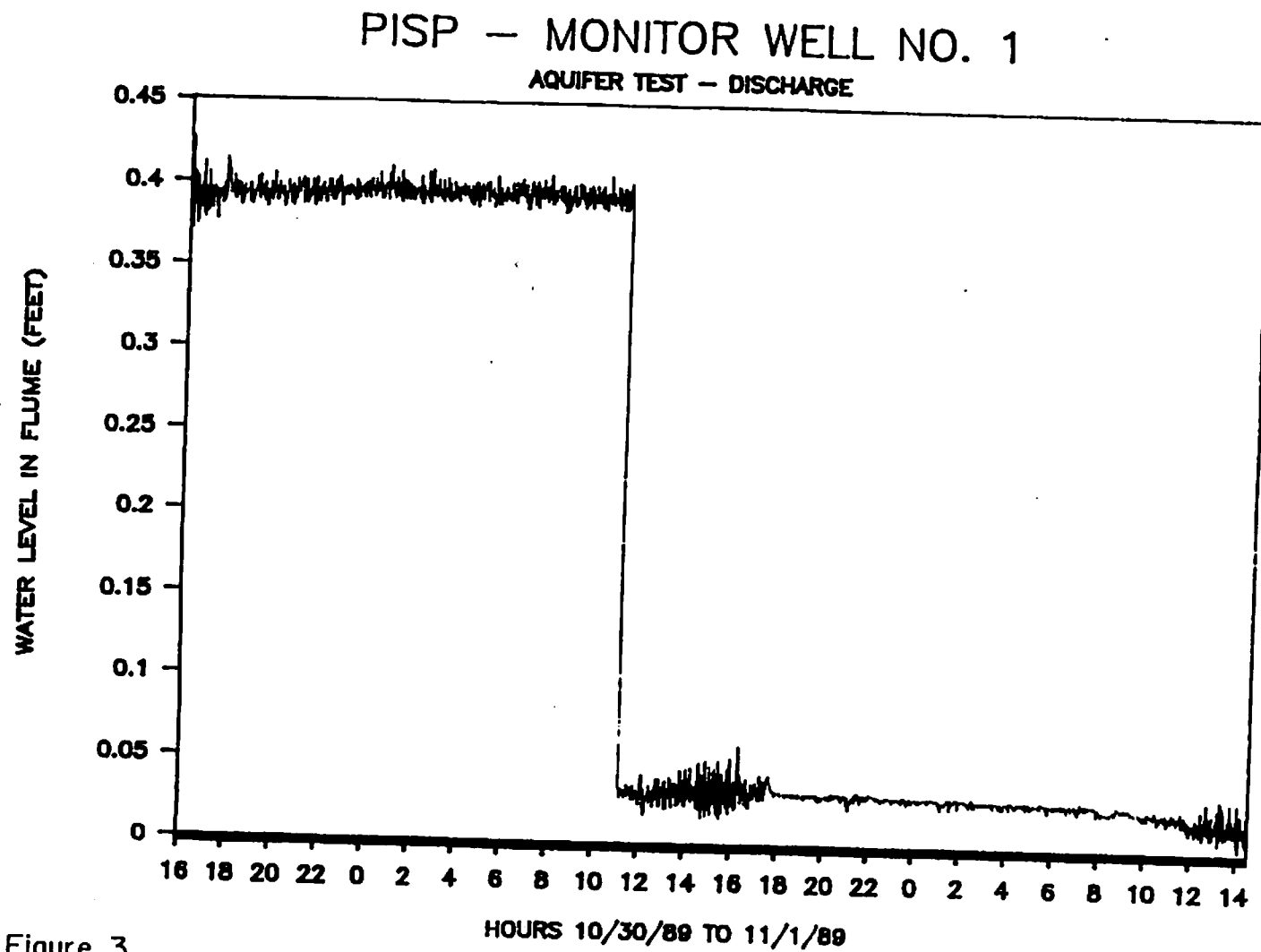


Figure 3.

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