



United States Department of the Interior
NATIONAL PARK SERVICE
WATER RESOURCES DIVISION
301 SOUTH HOWES ST., ROOM 343
FT. COLLINS, COLORADO 80521

IN REPLY REFER TO:

September 2, 1986

L54 (479)
RMR/PISP

Memorandum

To: Chief, Water Rights Branch
Water Resources Division

From: Hydrologist, Water Rights Branch
Hydrologist, Water Services Branch
Water Resources Division

Subject: Spring Flow Decline - PISP - Scoping Report

Attached please find a Scoping Report covering the technical, management and water right aspects of declining flow at the springs located at Pipe Spring NM. This document is intended to provide management with the information it needs to select an approach to determine the cause of the flow decline so that appropriate actions may be taken by management to protect the site's unique resource values.

The authors stand ready to provide explanation or additional assistance if either you or management have questions relative to the above.

Owen R. Williams

Donald C. Barrett

An Evaluation of the Decline in Spring Flow at Pipe Spring NM

by

Donald C. Barrett and
Owen R. Williams ^{1/}

I. EXECUTIVE SUMMARY

An analysis of water rights, the management situation, and available physical data was performed to assess the decline in spring flow at Pipe Spring National Monument (NM). Initial examination reveals that the decline is real and likely to be the result of man-caused changes in the delivery of ground water to the collective springs at the monument as opposed to natural variations in precipitation. Further, at the present rate of decline it is anticipated that spring flow will cease by the mid 1990s.

A review of the status of the water rights was completed and is presented in summary form. Three parties have recognized rights to pro rata use of the production of the combined flow at Pipe Spring but only the interests of the cattlemen have been registered with the State of Arizona.

A suitable course of action for management is unclear at this time due to the lack of certain data. Therefore, a set of alternatives for the correction of this deficiency was developed and is presented with a recommended alternative identified.

II. INTRODUCTION

Since 1977, the yield of the springs at Pipe Spring NM has experienced a decline of, on the average, two gallons per minute per year. If this rate of decline continues, the springs will cease to flow by the mid 1990s.

The continued flow of the springs is essential to monument purposes. The springs are the reason for the historic settlement at this location. They provide water for the monument's living history gardens, interpretation of the pioneer way of life, and for local cattlemen who have a right to one-third of the collective spring flows for livestock watering. This latter activity has been practiced for over 100 years.

Other regional water sources such as Moccasin Spring are exhibiting a decline in water quality and, possibly, flow. While they may be part of the same bedrock structure and aquifer as Pipe Spring, the Sevier fault and Navajo Sandstone, the specific cause of the decline in spring flow is unknown.

^{1/} Hydrologists, Water Services Branch and Water Rights Branch respectively, Water Resources Division, National Park Service, Federal Building, Room 335, 301 S. Howes Street, Fort Collins, Colorado 80521.

Until the cause of the spring flow decline is ascertained, reasonable strategies for protecting monument resources cannot be developed and other users of the water must function in an environment of uncertainty. However, the determination of such cause will remain a matter of conjecture until a better understanding of the hydrology of the system is at hand. It is the objective of the Water Rights Branch to develop a set of approaches for assessing the nature of the ground water delivery system. From this set of alternatives, management may select one approach for implementation. Once implemented, it is reasoned that the information produced can be used to develop a strategy to arrest the decline in spring flow.

In the following report we first evaluate existing information to provide an overview of the physical and legal aspects of the water resource at Pipe Spring NM. Second, we examine the management situation and finally, we present a set of management alternatives for consideration.

III. OVERVIEW OF WATER RESOURCES AT PIPE SPRING NM & SURROUNDING WATERSHED

Geology and Geography

Pipe Spring NM is situated in an area known as the Arizona strip, located in the northwestern part of the Colorado Plateau Province, in north central Arizona. The dominant topographic features of the area -- plateaus, cliffs, and canyons -- are marked by strongly contrasting colors. The rugged Vermillion Cliffs, a striking example, are visible northwest and northeast of the monument. Light yellowish-tan or gray Shinarump conglomerate is exposed in parallel cliffs to the south and northeast.

Formations exposed in the immediate area of the monument and north to Moccasin belong to the Triassic and Jurassic Systems. The generalized section is presented in Table 1 and Figure 1.

These sedimentary formations generally dip less than two degrees NE, but dips may steepen to nearly 10 degrees adjacent to major structures where they are displaced downward to the west. The steeply dipping Sevier fault which passes just east of Pipe Spring NM is such an example extending slightly east of north for 150 miles into the central Mountain and Valley province of Utah. North of the monument the fault divides into two main branches which rejoin eight miles to the north in Sand Canyon at the Utah border (see Figures 2 and 3). The Sevier Fault divides the area roughly north to south into the Kanab Plateau on the east and the Uinkaret Plateau to the west (see Figure 4). Displacement on the fault at the monument is estimated to be between 1850 and 2380 feet (Gregory, 1950, p. 147).

Geohydrology

The springs for which the monument is named, issue from the Sevier fault, a normal fault contact between the Navajo Sandstone on the west in the down thrown block and the Moenkopi formation to the east (Gregory 1950, p. 197). Here the basal Navajo Sandstone abuts against the impervious (gypsiferous) Shnabkaib member of the Moenkopi formation. Water absorbed by outcrops of porous Navajo Sandstone and underlying beds percolates down the dip slope

Table 1. General Section - Vicinity of Pipe Spring NM
(modified from Gregory, 1950)

SYSTEM	GROUP	FORMATION	CHARACTER	THICKNESS
		Navajo Sandstone	Lt. pinkish white & buff cross-bedded sandstone	1200'
Jurassic	Glen Canyon Gp.	-----Local unconformity-----		
		Kayenta formation	Maroon, coarse-grained sandstone, conglomerate with some dense limestone and shale in thin, irregular beds.	118'
		Wingate Sandstone	White to reddish-brown massive sandstone, jointed, cross-bedded	0-402'
		-----Unconformity-----		
		Chinle formation	Red, brown & buff sandstone with some limestone near top, with prominent sandstone ledge in middle and brightly variegated shale, & sandstone with fossil wood in lower half	1,460'
Triassic		Shinarump conglomerate	Light gray to yellow tan coarse-grained sandstone conglomerate with fossil wood.	100'
		Moenkopi formation	Brown, red and yellowish thin-bedded gypsiferous and calcareous sandstone with fossiliferous marine limestone	1,500'

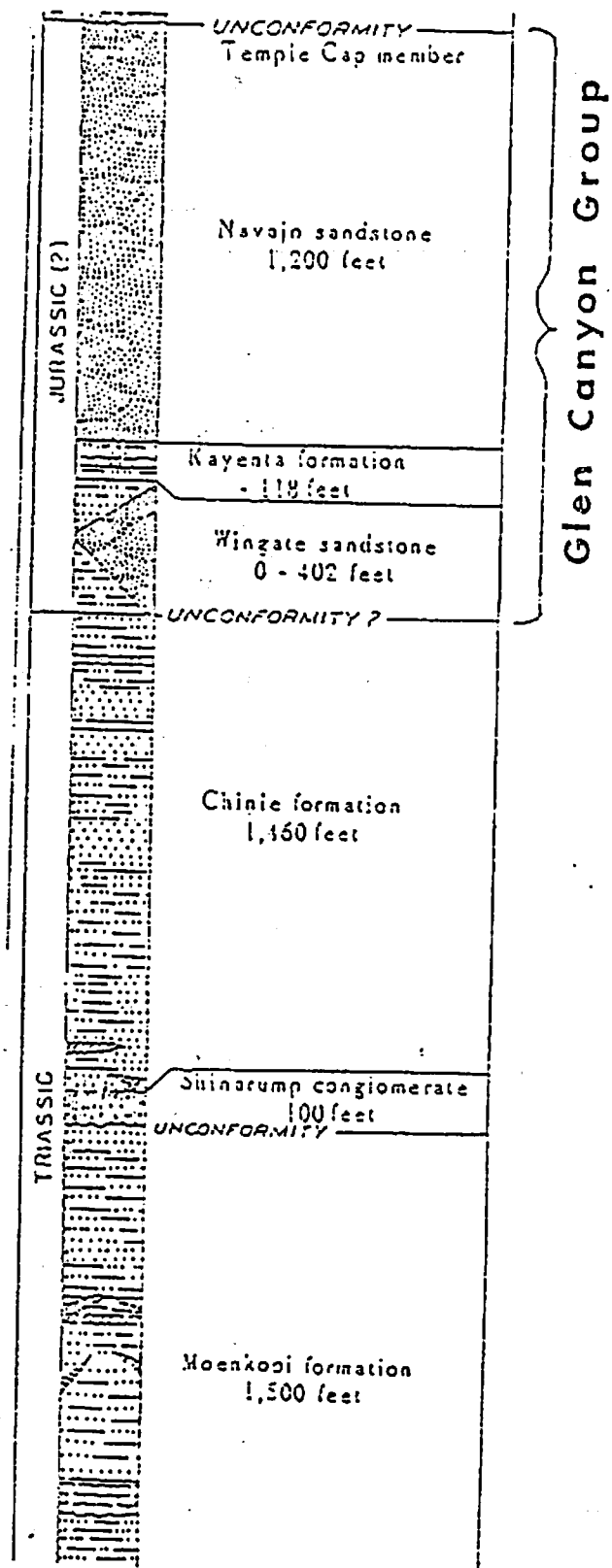
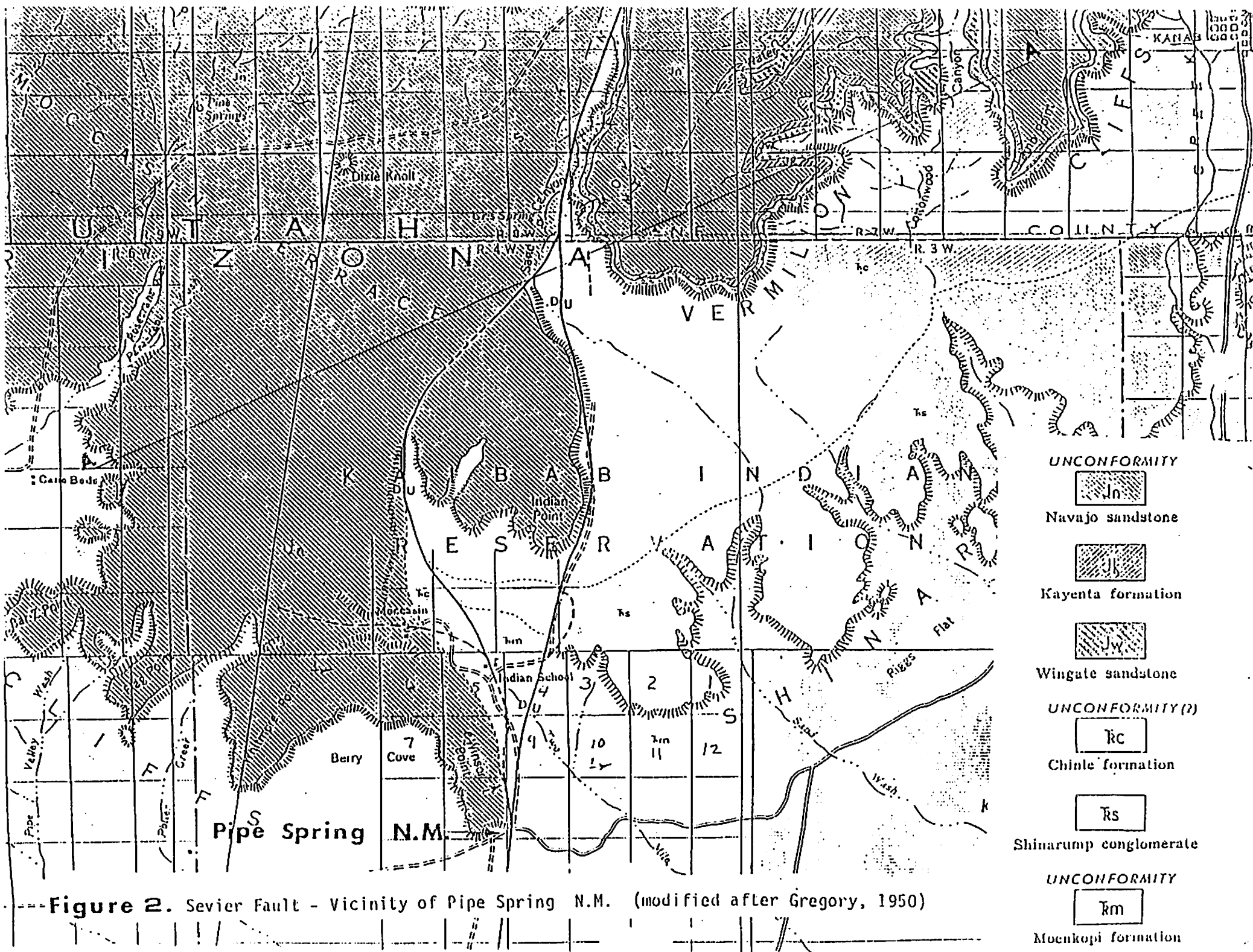


Figure 1. General Geologic Section - Vicinity of Pipe Spring N.M.
(modified after Gregory, 1950)



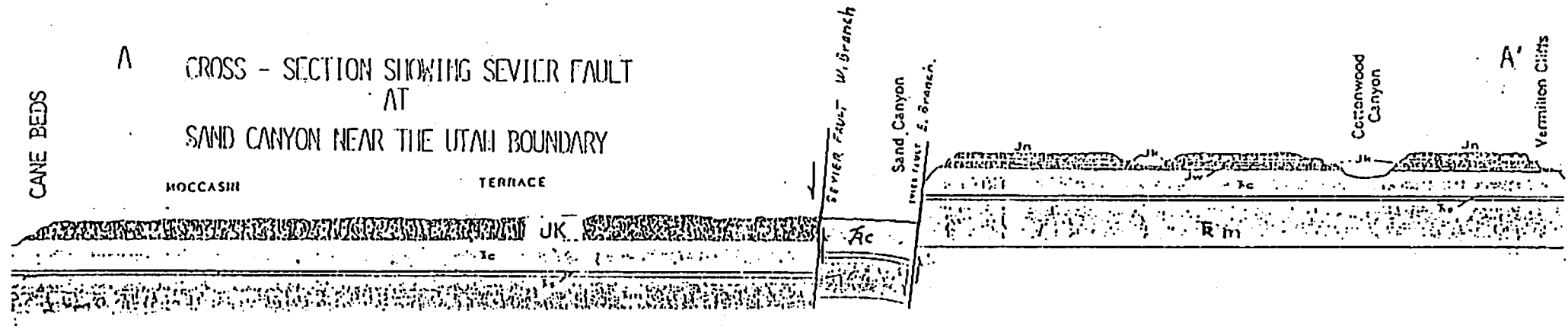


Figure 3. Geologic Cross Section - Vicinity of Pipe Spring N.M. (modified after Gregory, 1950)

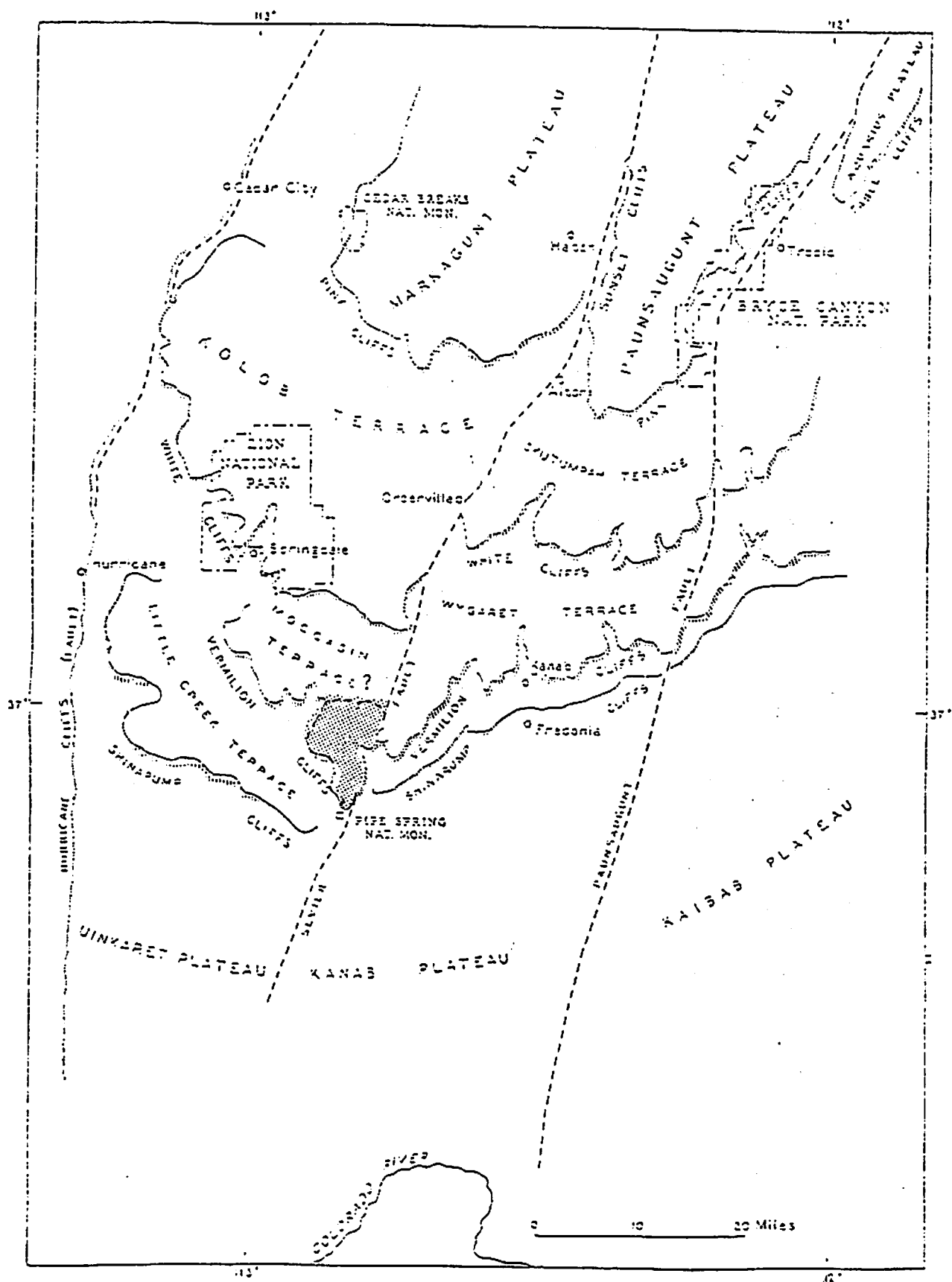


Figure 4. Sketch map of Zion Park Region Physiography (with potential recharge area shaded). (modified after Gregory, 1950)

until its further progress is interrupted by impervious beds of the Moenkopi formation, raised to this level by the Sevier fault. The fault plane facilitates upward movement of excess water which has become impounded against the impervious Moenkopi formation to form springs along the fault.

Aquifers

In the Kaibab Paiute Indian Reservation surrounding Pipe Spring NM, the principal sources of ground water are the fractured sandstone beds in the consolidated sedimentary rock units and, to a lesser degree, in the unconsolidated surficial deposits along the intermittent streams.

Surficial deposits range in thickness from a thin veneer to 100 feet or more. They mainly consist of silt, sand and clay. Irrigation wells in the alluvium in the Short Creek and Cane Beds area (see Figure 2) may yield up to 200 gallons per minute, but in the rest of the Kanab area permeability is usually low (Levings and Farrar, 1979). Where the deposits are thick enough, wells may yield modest amounts of poor quality water (Specific Conductance = 1500-2700 micromhos/cm)(USDI, BIA, 1976).

The greatest water producing consolidated sedimentary aquifer in the region is the Navajo Sandstone formation which crops out north and northwest of the monument in the Moccasin Mountains. Within the Kaibab Paiute Indian Reservation the thickness of the Navajo Sandstone may attain 1200 feet, consisting of fine-grained eolian sand with conspicuous cross-bedding. It is especially jointed and fractured along the west branch of the Sevier fault where well yields may exceed 250 gallons per minute. In unfractured areas, however, well yields may be quite small. Water quality is suitable for domestic use and irrigation.

The Kayenta and Wingate formations crop out along the flanks of the Moccasin Mountains and primarily consist of sandstone and siltstone. No wells are known to have been completed in either formation in the Kaibab Paiute Indian Reservation area, but the potential exists for the production of small amounts of water from these formations.

Of the two Chinle members, only the lower Shinarump conglomerate may yield appreciable amounts of water. However, the sulfate concentration generally exceeds U.S. Public Health Service standards for domestic water supply and the high sodium adsorption ratio (SAR) frequently renders the water unsuitable for irrigation.

Of the five Moenkopi members occurring in the reservation area, only one, the upper member, produces water, but in small quantities and of poor quality.

In summary, only the intensely fractured Navajo Sandstone yields water of adequate quality and quantity for both domestic and irrigation uses. Furthermore, according to a USDI/BIA (1976) study of the hydrology of the Kaibab Paiute Indian Reservation, large-scale pumping of ground water from the fractured Navajo Sandstone along the west side of the Sevier fault near Moccasin can be expected to decrease the flow of the springs in the area.

Recharge

The natural absorption of rain water and snowmelt by the Navajo Sandstone and formations above it contributes to the recharge of the aquifer along the west side of the Sevier fault contact. Recharge also occurs from seepage losses of streams in areas where elevations exceed 5000 feet. Cordova (1981) estimated the average annual volume of ground water recharge in the Upper Kanab Creek basin as 25,000 acre-feet using a base flow to precipitation ratio of 0.04.

Discharge

Ground water along the Sevier fault generally moves from the recharge areas in the highlands of southern Utah to the areas of natural discharge in northern Arizona. The general southward gradient of the potentiometric surface is indicated by the higher water surface elevations of wells to the north as compared to wells in the same formation in the south. Seepage into streams such as Two Mile Wash at Moccasin is probably the principal means of ground water discharge. Some seepage into alluvial aquifers occurs before being discharged as surface flow. Additional loss of ground water through evapotranspiration takes place in areas with phreatophyte growth where the ground water is near the land surface. Springs, wells, and subsurface outflow account for the remainder of the loss.

Spring flow throughout the area has been reported to be declining. It has been suggested that seismic activity during the 1950s may have caused the reduction in flow. However, subsurface outflow has probably not changed greatly in the past 30 years. Well use, on the other hand, has increased in the past 10 years (Garkane Power, 1986). There has been an overall increase in well use in this area. This trend is especially noticeable if one studies records from 40 or more years before the development of the modern water well and modern pumping systems.

Precipitation

In the Upper Virgin River and Kanab Creek basins annual precipitation, based on U.S. Weather Bureau data for Utah for the 1931-60 period, averages about 2 million acre-feet. Of this, about 1,375,000 acre-feet falls in the upper Virgin River basin and the remainder falls in the upper Kanab Creek basin. Most of this precipitation is consumed as evapotranspiration and sublimation at or near the place of fall leaving little to reach streams or to seep into rocks to enter the ground water system.

The amount of precipitation in southwestern Utah is minimal and is characterized by great annual and seasonal variations in place and time. In general, the influence of elevation is apparent but not consistent. Between 1903 and 1937, Kanab, at an elevation of 4,925 feet, had a mean annual precipitation of 14.5 inches with a range of 7.29 to 20.70 inches. Springdale (elevation 4,048 feet) had a mean of about 15.5 inches and a range of 7.98 to 20.78 inches for the same period. Because of its topographic setting, Springdale receives more precipitation than Kanab, even though Kanab is almost 900 feet higher in elevation.

At all stations in southwestern Utah, June is the driest month and February or March the wettest. However, the other months fit into no recognizable pattern. The complexity of the annual distribution of precipitation is enhanced by a sparse data collection network resulting in a poor understanding of the temporal and spatial distribution of precipitation.

The deficiencies of existing meteorological data are mentioned in the Gregory (1950, p. 31) report where it is stated that "The meteorological stations in the Zion Park region show no consistent wet and dry cycles. The records of precipitation are unsuited for general climatic studies. They are brief and fragmentary and lack other features needed for the recognition of climatic cycles. Their lack of accord with the long records at Fort Defiance...Los Angeles and Salt Lake remains to be explained."

Surface Water - Runoff

Most of the discharge of Kanab Creek and the Virgin River is derived from snowmelt. Estimates of total mean annual runoff from the upper Kanab Creek basin into Arizona are on the order of 50,000 acre-feet (Moore, 1968).

These streams can also receive significant flow from torrential summer rains. In Kanab Creek basin, instantaneous peak discharges of several hundred to more than 1,000 cu.ft./sec. have been commonly recorded as the result of summer cloudbursts. However, ground water seepage is generally regarded as the main source of flow for perennial streams during the low-flow periods of the dry summer months. In the Virgin River, at USGS site (C-41-10)22bc, it is estimated that ground water contributes as much as 43 percent of the average annual discharge.

Surface Water - Quality

Dissolved-solids concentrations in the surface waters of most streams in the Kaibab Paiute Reservation area are generally less than 1,000 mg/l during both high- and low-flow periods. Moreover, the dissolved-solids concentrations in the headwaters of Kanab Creek are less than 250 mg/l but have been found to exceed 500 mg/l in the lower reaches of the streams during low-flow periods. The water quality of springs in the Arizona Strip area adjacent to Pipe Spring NM is shown in Figure 5 using pattern diagrams (USDI/BIA, 1976).

Water Development and Use at Pipe Spring NM

The water resources at Pipe Spring NM consist of five springs or seeps in the SE 1/4 of Sec. 17, T 40 N, R 4 W. As shown in Figure 6, these are: 1) Big Spring, 2) Spring Room (Historic Spring), 3) West Cabin Springs, 4) Tunnel Spring (Cattlemen's line) and 5) Drainage seeps (2) from the fort foundation. Of these, Tunnel Spring, flowing from the base of the hill 60 feet southwest of the fort, is used entirely by cattlemen. Only two of the remaining springs contribute measurable amounts of water for interpretive use at the fort or the historic ponds. The largest flow issues from Big Spring which originates under the parlor floor within the fort. Historic Spring also issues here and flows outside the fort. About 125 feet west of the fort, along the side of a south facing hill, West Cabin Springs flow from two fissures in the hill. However, the flow here is too weak to recover and use.

SPRINGS AT PIPE SPRING NAT. MON.

- 1. Big Spring
- 2. Spring Room (historic spring)
- 3. West Cabin
- 4. Cattleman's Line
- 5. Drainage seep from fort foundation

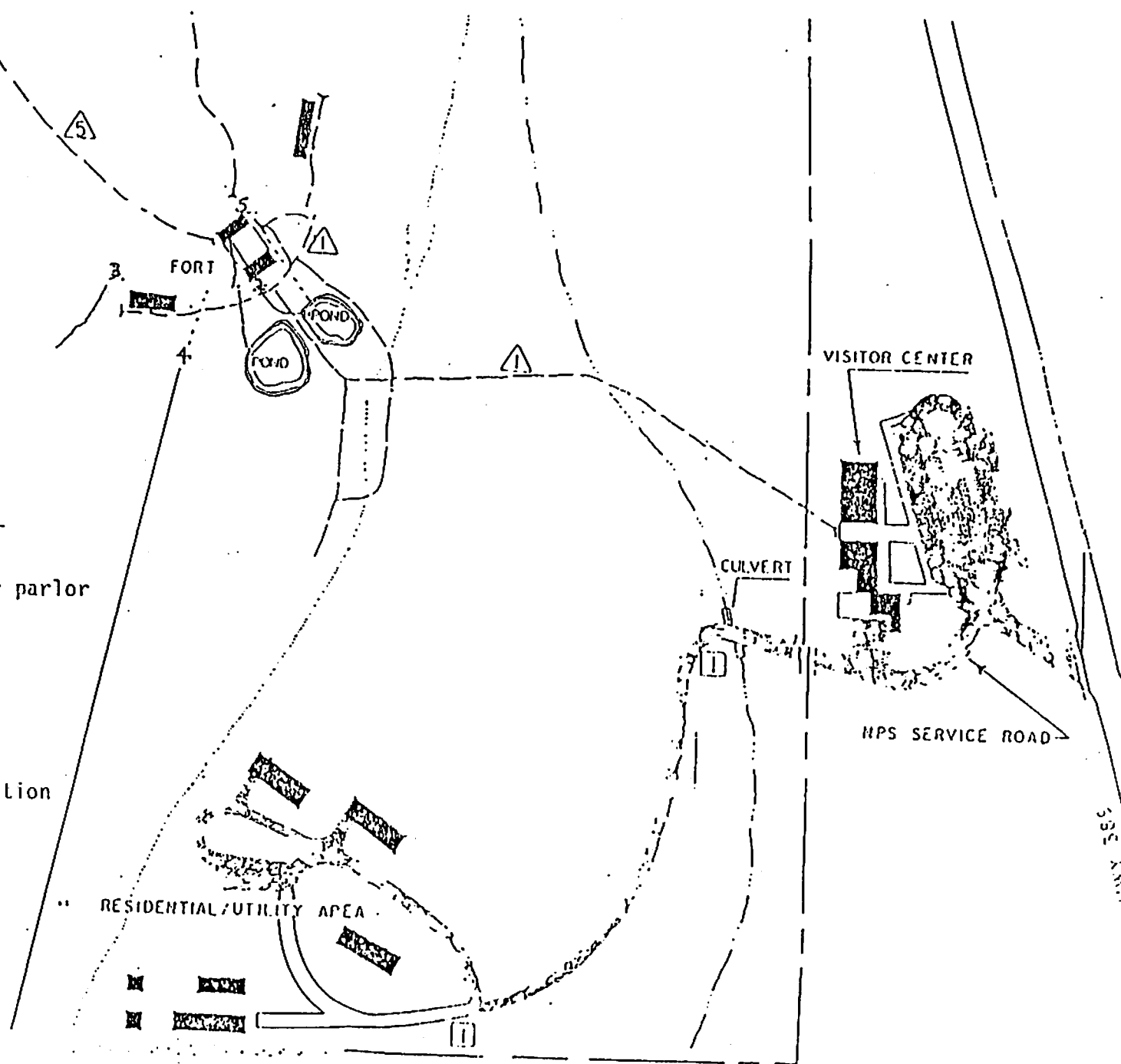


Figure 6. Springs at Pipe Spring N.M.

Domestic water requirements at the monument's visitor center and residence area are supplemented by an NPS well drilled in 1971. The well is located about two miles north of the monument on the Kaibab Paiute Indian Reservation land. By agreement dated April 13, 1972, this well serves both the monument and the Kaibab Paiute Indians. Water from the well is pumped through a 4-inch line to a 500,000-gallon reservoir. The water passes through a 6-inch line from the reservoir to the visitor center and the monument residential/utility area (see Figures 6-8).

Water Quantity & Quality -- Pipe Spring

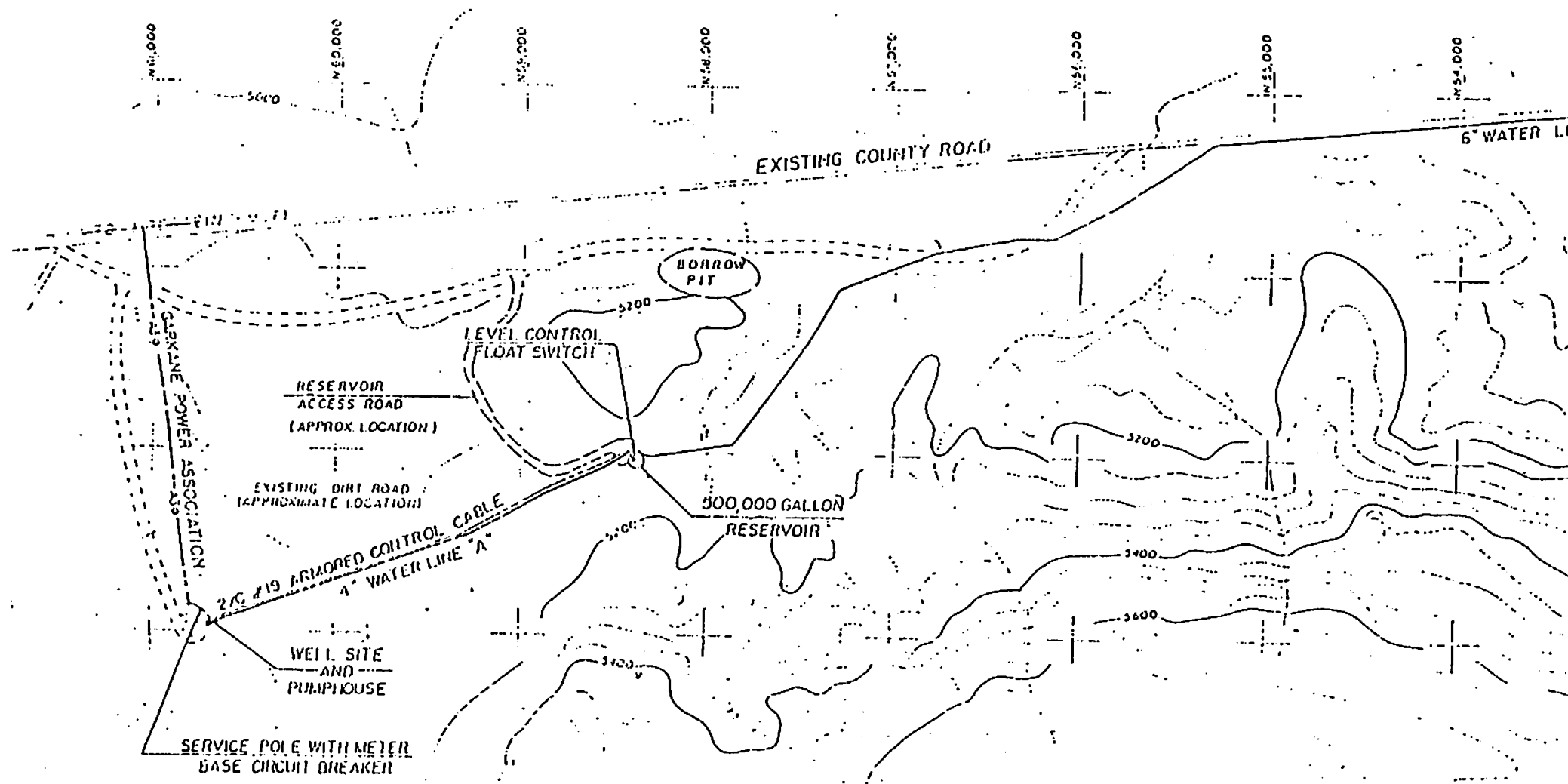
Prior to 1977, measurements of spring discharge at Pipe Spring NM were made on a spotty basis. Two early records report a flow of about 42 gallons per minute in September 1933, and 47 gallons per minute in May 1934. Other measurements are 35 gallons per minute on March 12, 1959, 38 gallons per minute on July 2, 1969, and 32 gallons per minute on August 6, 1976.

Levings & Farrar (1979) measured the flow of the springs at Pipe Spring NM on July 27, 1976, prior to the beginning of the decline in spring flow. They reported the flow to be 35 gallons per minute using a flume and volumetric measurements. The specific conductance was given as 550 micromhos/cm, and the temperature was 16° C. Sodium was estimated to be at <2 milliequivalents per liter, calcium at <2, magnesium at <2, chloride at <1, bicarbonate at 3, and sulfate at <2. Gregory (1950, p. 197), in an undated measurement, reported the springs to yield 56 gallons per minute at a temperature of 63° F.

In 1977 the staff at Pipe Spring NM began the systematic measurement of flow from the principal springs at the monument. The combined discharge of the springs was measured volumetrically at approximately the same time each month. Figure 9 presents the data graphically as annual averages and demonstrates, at least qualitatively, that a steady downward trend in discharge has been occurring since 1977. Presented in another format, Figure 10 reveals that this trend has been rather uniform between years, (i.e., January flows have been declining, February flows have been declining, etc.).

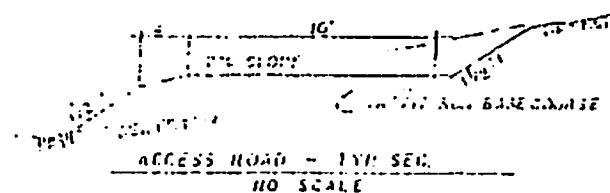
These data, for the period July 1976 to June 1986 inclusive, were paired with monthly precipitation data from the nearest weather station (Kanab). The relationship of spring flow as a function of precipitation was examined using multiple regression analyses. Less than 1 percent of the variance in spring flow was found to be associated with precipitation (that is -- the coefficient of determination, or "r squared," was less than .01).

To account for the possible effects of delayed transmission through the aquifer supplying the springs, the spring flow values were paired with precipitation values which had occurred one year, eighteen months, and two years previously. In each of these three analyses the lack of relationship between spring flow and precipitation remained evident (i.e., coefficient of determination less than 1 percent).



PLAN DRAWINGS OF PISP WATER SYSTEM

Figure 7.



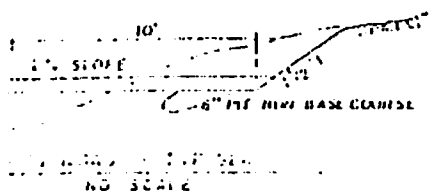
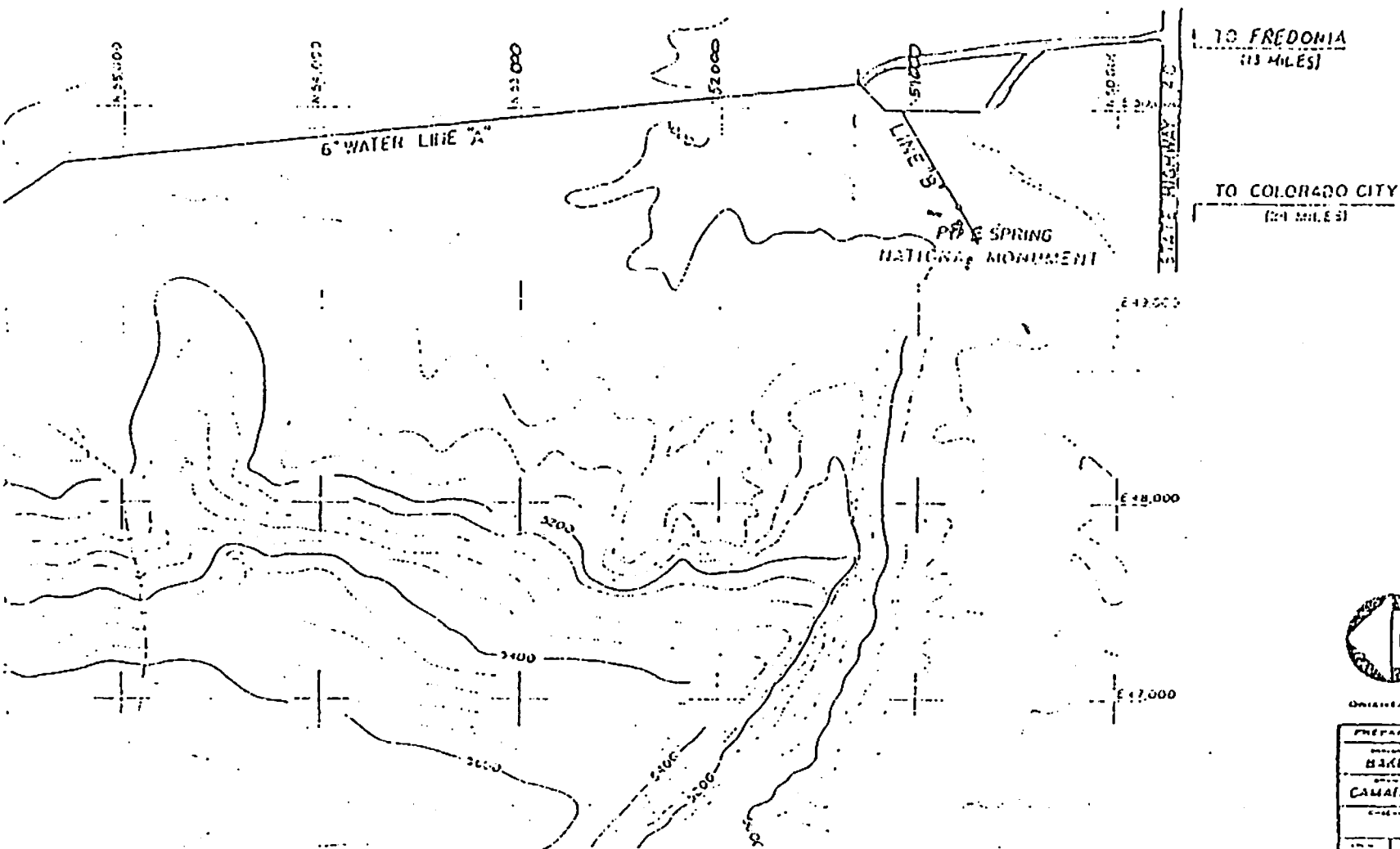


Figure 8.

CONSTRUCTION DRAWING HALF-SIZE REPRODUCTION
 PROJECT NO. 321-21402 PISP WATER SYSTEM
 CONTOUR INTERVAL 40'

DESIGNED BY	ALVIN M. HENNING
CHECKED BY	
IN CHARGE	
DATE	5-22-59
BY	

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION OFFICE OF ENGINEERING, PHOENIX, ARIZONA
WATER SUPPLY DIVISION KIMBARK INDIAN RESERVATION, ARIZONA



ORIENTATION

PREPARED BY	BAKER
CHECKED BY	CAMARERO
DATE	
REVISION	
DATE	
BY	
REGION	PHOENIX
PROJECT NO.	321
DRAWING NO.	321
DATE	5-22-59

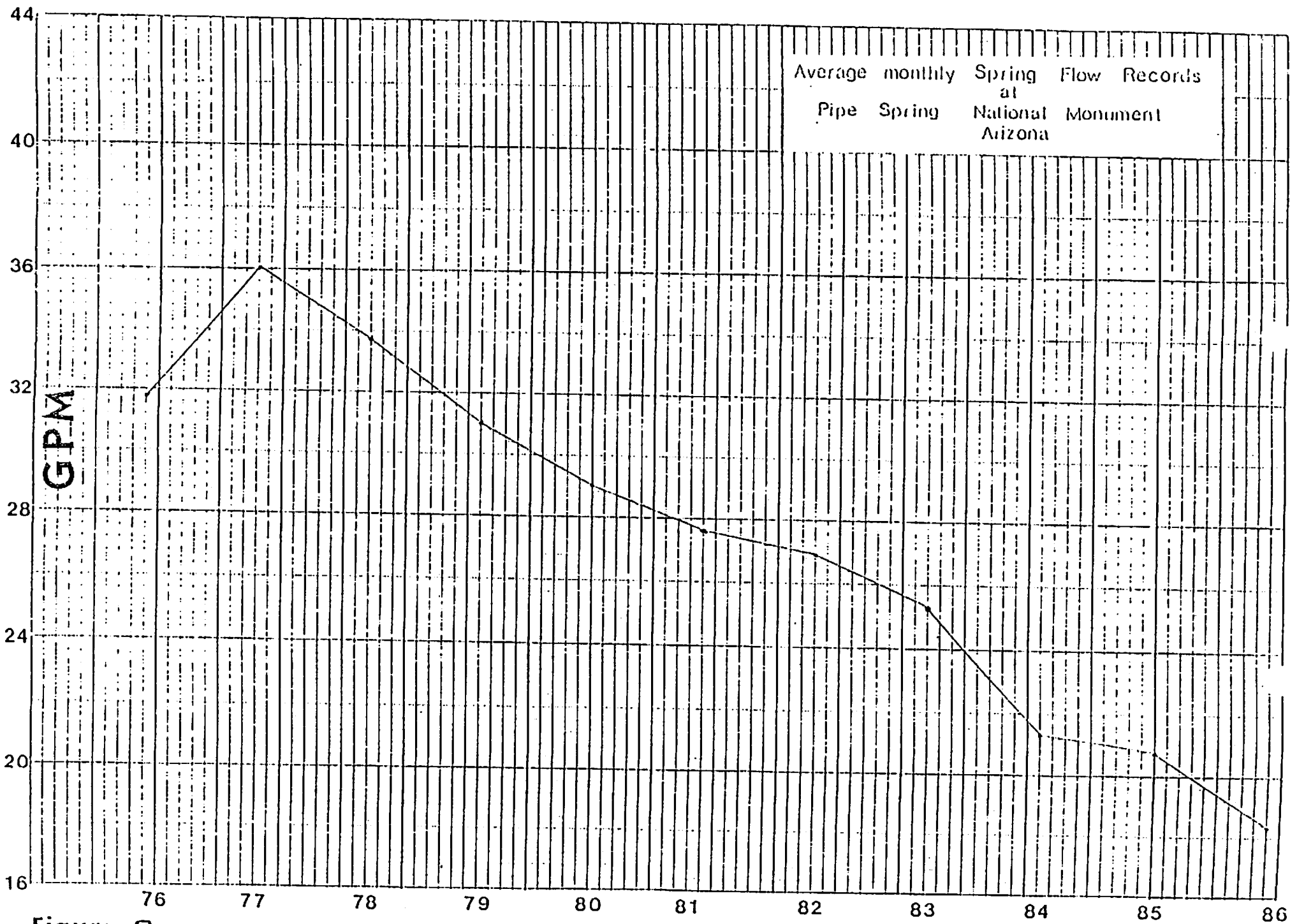


Figure 9.

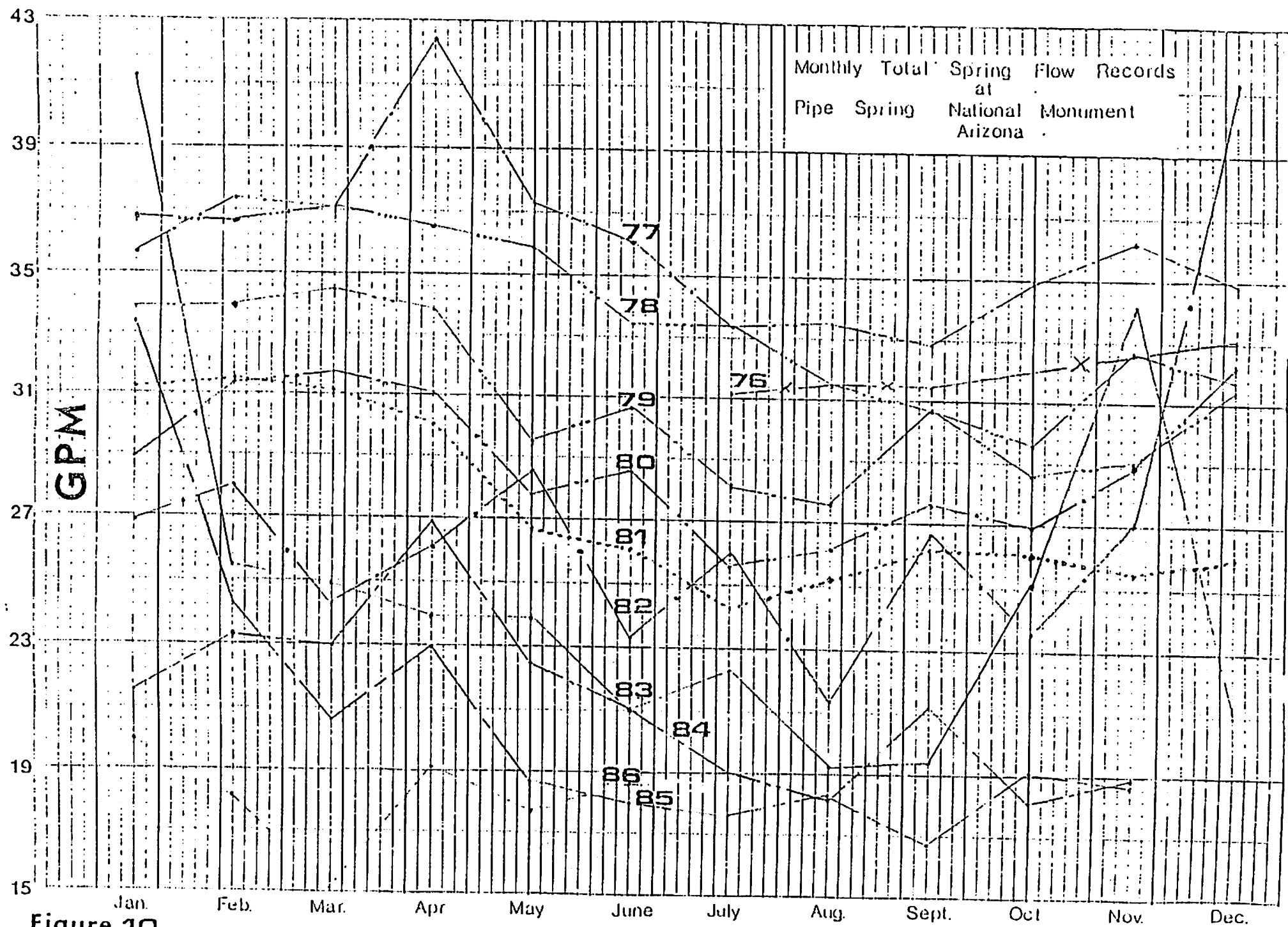


Figure 10.

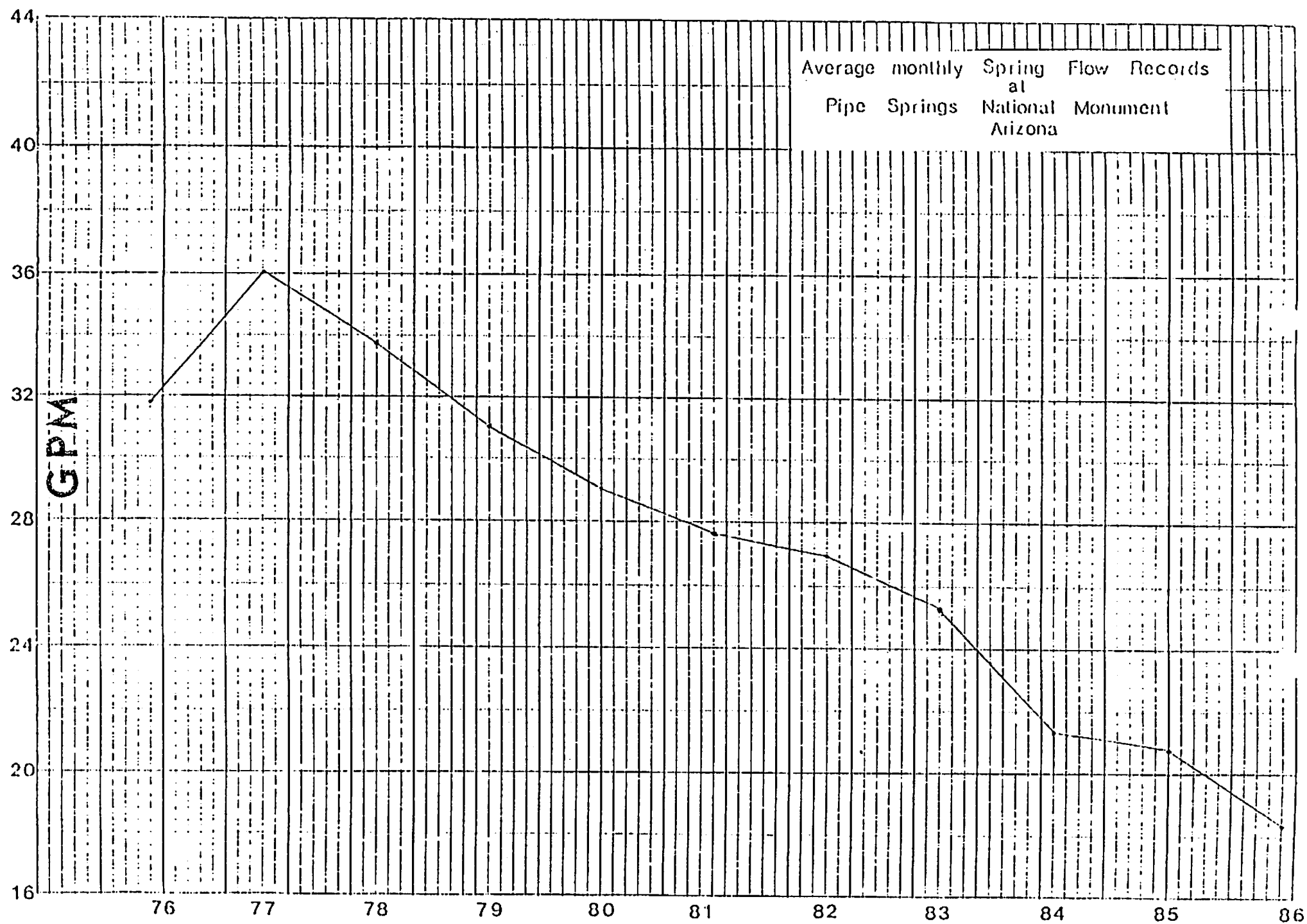


Figure 9.

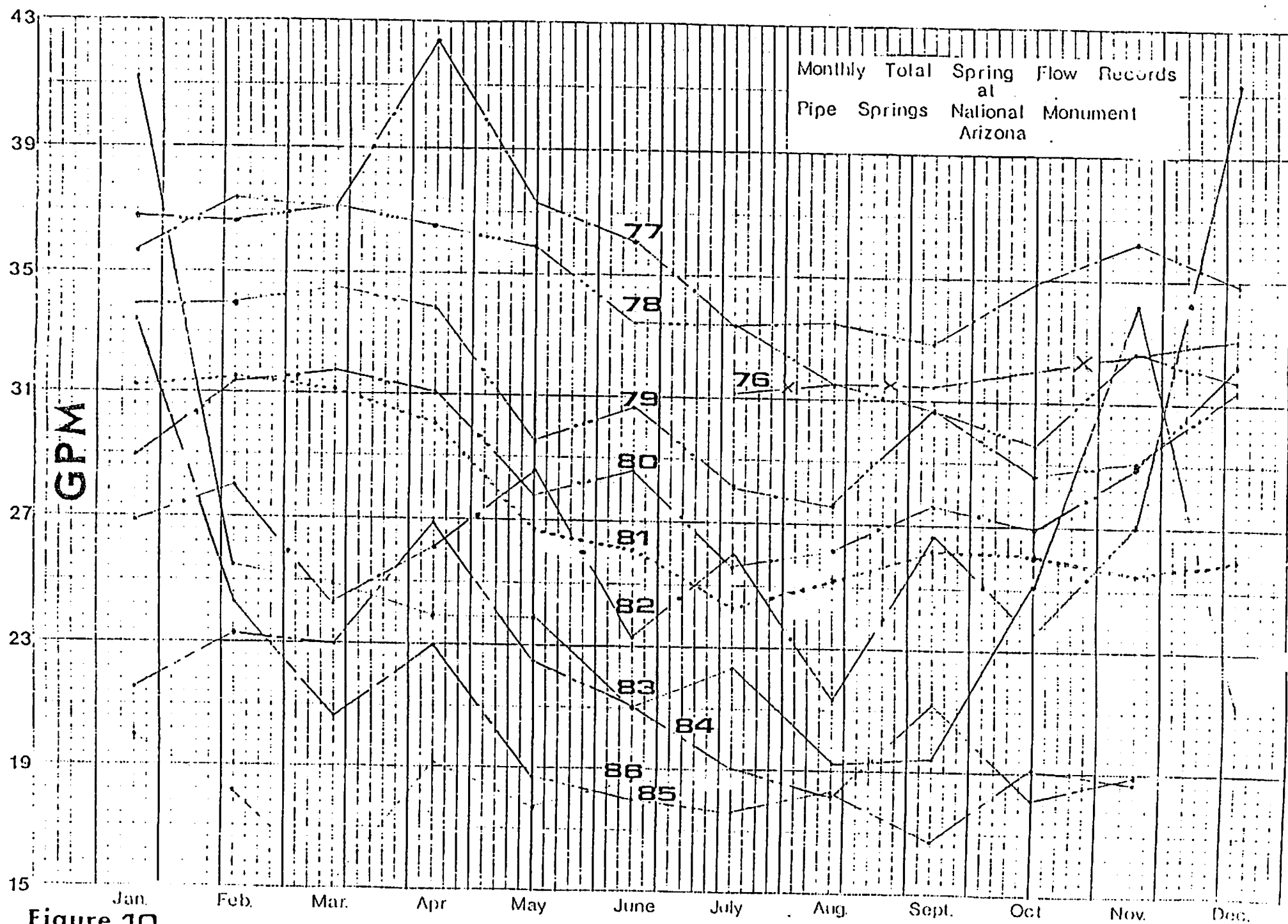


Figure 10.

Water Rights Situation at Pipe Spring NM

Pipe Spring NM exists because of the general absence of water between Zion NP and the north rim of Grand Canyon NP. The unique occurrence of water at this site has made it highly valuable to Indians, early settlers, and the traveling public. With water playing such an important role, both environmentally and socially, it is to be expected that water rights at this location are characterized by a complex interweaving of personalities and interests. The history of water rights at Pipe Spring to this day involves three parties -- the National Park Service, the Kaibab band of the Paiute Tribe, and local cattlemen.

The general understanding of the water rights situation at Pipe Spring is that the production of the springs is to be divided equally between the three parties. This understanding arises from an agreement developed in 1924. The degree to which it was binding is uncertain because the agreement does not appear to have been officially approved by the Secretary of the Interior.

The cattlemen's use of the flow from these springs seems to be founded upon their predecessor's purchase of such right from Charles C. Heaton whose claim to ownership was later purchased and donated to the United States. The right, which dates back to the late 1880s, is presumed to have arisen consequent to the original settlement of the site by Daniel Seegmiller. Since the Kaibab Paiute Indian Reservation was created in 1907 (confirmed in 1917) such a claim, if valid and applicable to water rights, could be senior to the rights of both the Indians and the NPS.

The validity of the claim, however, has been questioned. The basis of Seegmiller's title was his claim of ownership of the site as a "scrip location." Such a claim, to result in patent, required a completed land survey which, in the case of the Seegmiller property, did not occur until 1916 -- well after Seegmiller's death in 1899. The Government Land Office, as a result, showed no land to be privately owned in this area when the Indian reservation was created in 1907.

The division of spring flow between the NPS and the Kaibab Paiute Indians was a requirement of the Presidential Proclamation creating the monument (Proc. #16663, May 31, 1923). The division was further supported by the early contention of the Department of Indian Affairs that a reserved right was created for the Indians when the boundaries of the reservation were preliminarily established.

The initial and, more or less, informal agreement of 1924, dividing the flow of the three springs between the three principal interests, was essentially given recognition when regulations controlling the three-way division were promulgated by the Department of Interior in November 1933. The 1924 agreement and the resultant regulations produced a satisfactory accommodation but one which lacked formalization under Arizona water law.

In view of the questions of validity of past land ownership and the fact that the State, as of January 29, 1937, had no record of any water rights at

the springs, the NPS initiated action in April 1937 to secure State recognition of the three water rights. The amounts of water for which the NPS was initiating its claim was 42,500 gpd or 47.6 acre-feet per year for each of the three claimants.

However, as a result of consultation with the Bureau of Indian Affairs, the effort was scuttled. The reasons for not pursuing this course of action were 1) the Indians had a Federal reserved water right in the springs because the springs were included in the original reservation and there were no recognized outstanding rights to the land or water; and 2) the spring flow arose and fell on Indian property and, thus, did not create an appropriable flow in a defined channel beyond the limits of the reservation.

In April 1972, the NPS and the Kaibab Paiute Indians entered into a renewable 25-year agreement wherein the NPS was to drill a water well and provide associated delivery structures to the tribe in exchange for the tribe's one-third interest in Pipe Spring. The well was to provide the tribe with 7,884,000 gallons per year (24.2 acre-feet per year) and any shortfall in the delivery of this amount was to be made up from spring flow. The completed well subsequently was placed into service.

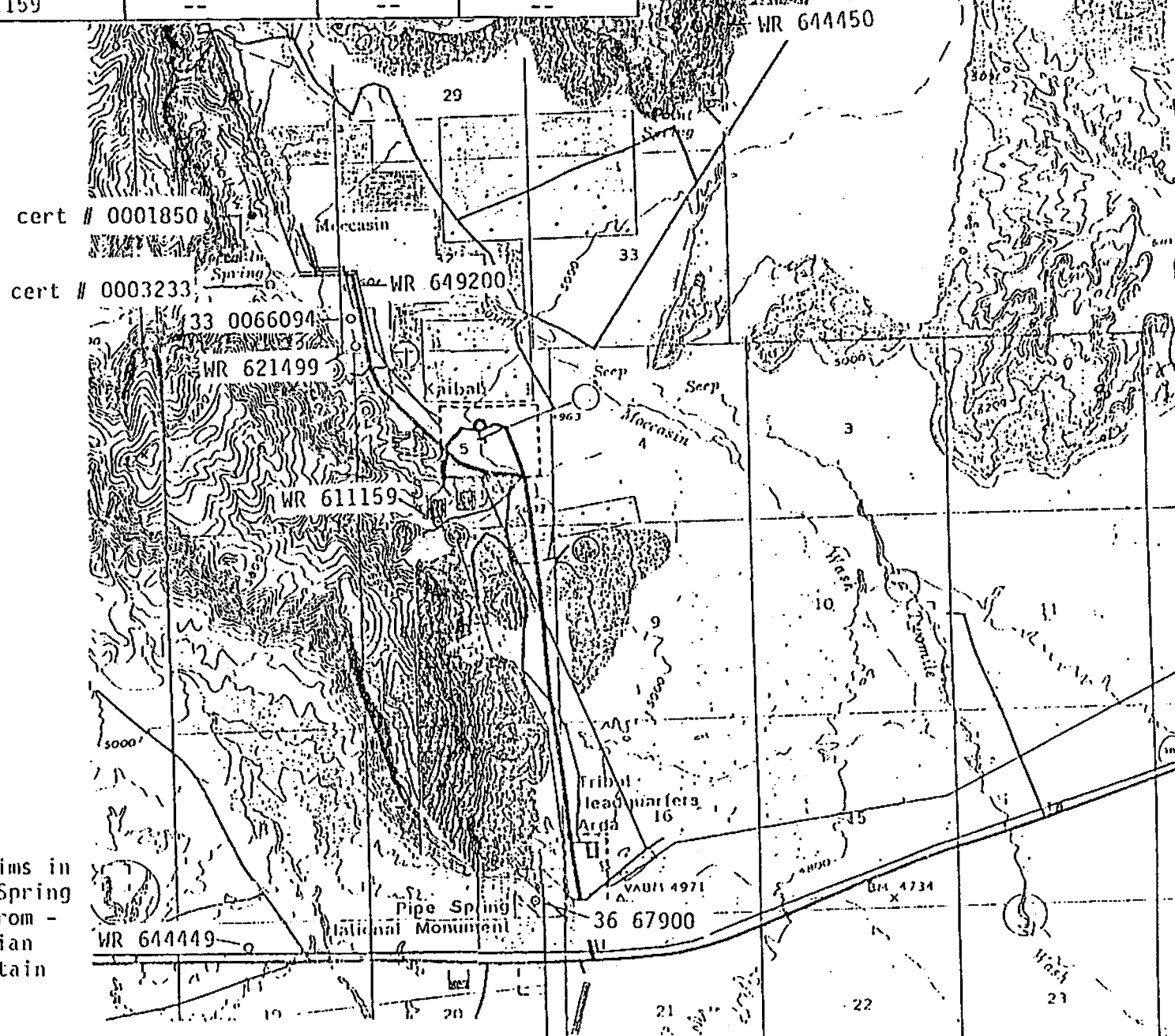
Since the agreement between the NPS and the Kaibab Indians talks to an amount of 24.2 acre-feet per year (with another 1.6 acre-feet per year from the springs for stock watering), it can be assumed that similar amounts are available to the NPS and the cattlemen under the terms of the three-way agreement and regulations mentioned earlier. This is of interest at this point in the discussion because a claim to a right to water from the Pipe Spring was filed on June 23, 1978, by eight individuals including Nora M., J. Grant, Fred E., Landell J., Derryll L., and I. McKay Heaton.

The application claimed a right to 14 gallons per minute, or 7,358,400 gallons per year (22.6 acre-feet per year), with first beneficial use occurring April 1, 1870. The claimed right to water was, according to the application, created by Jonathan and Lucy Heaton placing the water to beneficial use prior to 1890 with subsequent continuous use being made by their heirs and assigns.

In reviewing the foregoing summary, it becomes evident that prior to the Heaton's Statement of Claim and the agreement between the NPS and the Kaibab Paiute Indians, no statements had been made as to quantities of water to which each party held a right. The three parties to the division of the flow of Pipe Spring had previously only agreed to share equally in the springs' production. A decline in such production had not been directly addressed.

The State of Arizona has on file, for the area within approximately 4.75 miles of Pipe Spring NM, three additional water right applications, (totaling 282 acre-feet per annum) and five well registrations, (totaling 360 gpm for 581 acre-feet per annum) including the NPS well (150 gpm for 242 acre-feet per annum, see Figure 11). It seems likely that water use on the Kaibab Paiute Indian Reservation is substantial and may greatly overshadow the figures presented above. To the best of our knowledge, none of these water right claims have been adjudicated. The State of Arizona either did not have, or did not provide, information on wells or other water use within the Kaibab Paiute Indian Reservation.

surface	--	33 0066094	--	06/05/1978
spring	36 67900	--	--	04/01/1870
surface	cert # 0001850	A 0002819	2190	02/08/1947
surface	cert # 0003233	R 0002227	1556	04/19/1963
well	WR 621499	--	--	--
well	WR 649200	--	--	--
well	WR 644450	--	--	--
well	WR 644449	--	--	--
well	WR 611159	--	--	--



IV. MANAGEMENT SITUATION

The situation facing management at Pipe Spring NM is complex. The three users of the water from Pipe Spring have very different needs. As flow from the springs continues to decline, a point will be reached where some or all of these needs will no longer be met. With the 25th anniversary of the 1972 agreement with the Kaibab Paiute Indians approaching, the complexity of the situation increases.

The potential for conflict between uses and users can be expected to increase over time as spring flow declines. Furthermore, the very purpose for the creation of the monument eventually may be threatened.

Against this background are arrayed:

- 1) a paucity of historical data on spring flow prior to the onset of the flow decline;
- 2) an incomplete understanding of the hydrology of the ground water system feeding the springs;
- 3) an unknown (though not unknowable) level of ground water use on the Kaibab Paiute Indian Reservation;
- 4) an incomplete understanding of the effects of well pumping upon the production of the springs;
- 5) little or no knowledge of the rate of ground water transmission at Pipe Spring;
- 6) an incomplete technical understanding of the Sevier fault; and
- 7) uncertainty as to the areal extent of the decline in spring flow.

Before any strategy can be developed to protect monument resources and the needs of the other two users, at least some of the above data gaps need to be filled. This will require the initiation of a field study as soon as practicable. Such a study should alleviate a portion of the existing uncertainty and allow corrective actions which have a reasonable chance for success.

The extent of the study will depend upon the requirements of management. Due to the complex heterogeneity of the system, a substantial uncertainty will attend the study results. Uncertainty can be minimized but the difficulty and the cost to achieve this will vary inversely with the level of acceptable residual uncertainty.

For example, it would be desirable to know the approximate level of "natural flow" (the flow which would occur without the effects of natural or man-caused changes in the aquifer). One way to determine the "natural flow" would be to eliminate the effects of "unnatural" discharge from the springs' ground water system. This would mean shutting down all wells which may affect spring flow at Pipe Spring NM. Although this would be a simplistic and direct

approach to answering the question, it would be a complex and costly endeavor. Furthermore, it would be difficult to accomplish in light of the dependence of the Kaibab Paiute Indians and the Village of Moccasin upon water coming from wells along the Sevier fault.

An indirect approach to answering the same question would be to find other springs along the Sevier fault and in the same general area of recharge that are not declining in the manner of Pipe Spring. This method would, however, still take some time and require collection of additional supportive data.

In any case, the cause of the spring flow decline must be determined before any effective management strategy can be developed.

Alternative Study Approaches

Following are selected alternatives for determining the cause of spring flow decline. They are offered for management's consideration and admittedly are not exhaustive.

Alternative Approach #1.

Drill a series of ground water observation wells, install long-term monitoring systems on these and other wells, establish precipitation stations where needed, and monitor all existing uses.

Advantages: This approach will provide a reasonably accurate representation of the aquifer and its function, along with the role of the Sevier fault, and will allow development of input-output relations (i.e., a mass balance).

Disadvantages: While having low uncertainty, this approach is very costly and time consuming. The logistics of finding places to drill wells and getting permission, etc., may be prohibitive.

Alternative Approach #2.

Using continuous recording "data loggers", collect 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 Springs; and 4) Pipe Spring. Collect precipitation data in the Moccasin area.

Advantages: Data will be made available where, currently, no comprehensive data on the ground water budget for the Navajo aquifer exists. This data, when evaluated, may point to some hitherto unknown but subsequently obvious cause of the problem.

Disadvantages: This approach may not yield conclusive results before it is too late to arrest the decline in spring flow.

Alternative Approach #3.

Do not collect any additional data, just seek additional sources of water to substitute for the tribal and village wells in the Navajo Sandstone aquifer adjacent to the Sevier fault.

Advantages: The discovery of an alternative plentiful source of potable water near the monument would enable the NPS to bargain with the tribe and village of Moccasin over the use of their wells along the Sevier fault. This effort could be accomplished within one year.

Disadvantages: Although not all the hydrologic options for drilling a new high-yield well have been explored, the most promising option -- a deep test of the Shinarump conglomerate in the area west of the Sevier fault -- has some decided risks. The most significant risk is the chemical quality of deep water in this formation which has a reputation for a high dissolved-solids concentration and a high sulfate content, either of which would render the water unfit for domestic or irrigation use. Finding an adequate quantity of water may be less difficult than finding adequate quality of water. Furthermore, the potential for an adverse effect at the springs, while small, does exist.

Alternative #4.

Initiate the data collection effort described in alternative #2 and seek alternate water sources as described for alternative #3.

Advantages: This alternative entails less uncertainty than alternatives #2 and #3 in addition to the advantages already described for these alternatives.

Disadvantages: This alternative increases the costs above those of either alternative #2 or #3, but is still likely to have higher uncertainty than alternative #1.

We recommend Alternative #4.

V. CONCLUSIONS

From the foregoing, it appears that management faces a difficult decision at Pipe Spring NM. Furthermore, time is of the essence and solid data upon which a suitable strategy may be founded is largely unavailable.

Our initial analysis indicates the decline in spring flow is real rather than apparent and is the result of man's influence rather than climatological factors. A determination of the nature and extent of the operative factors seems to be required before any reasonable strategy with possibilities of effect may be initiated.

A statement of the obvious may be warranted at this point; if the NPS finds itself in any form of litigation (water rights or Tort claim), an adequate analysis based upon good data would be helpful.