MONITORING AND ANALYSIS OF SPRING FLOWS AT PIPE SPRING NATIONAL MONUMENT, MOJAVE COUNTY, ARIZONA

Richard Inglis

Technical Report NPS/NRWRD/NRTR-97/125

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
Fort Collins - Denver - Washington

United States Department of the Interior • National Park Service

The National Park Service Water Resources Division is responsible for providing water resources management policy and guidelines, planning, technical assistance, training, and operational support to units of the National Park System. Program areas include water rights, water resources planning, regulatory guidance and review, hydrology, water quality, watershed management, watershed studies, and aquatic ecology.

Technical Reports

The National Park Service disseminates the results of biological, physical, and social research through the Natural Resources Technical Report Series. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences are also disseminated through this series.

Copies of this report are available from the following:

National Park Service (303) 225-3500
Water Resources Division
1201 Oak Ridge Drive, Suite 250
Fort Collins, CO 80525

National Park Service (303) 969-2130
Technical Information Center
Denver Service Center
P.O. Box 25287
Denver, CO 80225-0287

MONITORING AND ANALYSIS OF SPRING FLOWS

AT PIPE SPRING NATIONAL MONUMENT,

MOJAVE COUNTY, ARIZONA

Richard Inglis, Hydrologist
Water Resources Division

Technical Report NPS/NRWRD/NRTR-97/125

July, 1997

United States Department of the Interior
National Park Service

TABLE OF CONTENTS

LIST OF FIGURES

Monitoring and Analysis of Spring Flows at Pipe Spring NM, Mojave County, Arizona

ABSTRACT

Concern that spring flows might be declining prompted initiation of a spring-flow monitoring program at Pipe Spring National Monument located in Mojave County in Northern Arizona. Analysis of monthly spring flow data collected by National Park Service (NPS) from 1977 through 1996 indicates significant changes. Measurements of spring flows revealed annual fluctuations, as well as a major decline of flow from one spring, increased flow of one spring, and no significant change in flows of two springs. Whether the fluctuations are caused by seasonal pumping or seasonal rainfall variation has not been determined. The combined flow of the springs increased slightly in 1990-1993, but remain about half of the highest flows on record in 1977. An aquifer test suggests a possible hydraulic connection between springs and wells within 2 miles of the Monument. Recommendations include initiating a series of geohydrologic investigations to determine if ground water pumping outside the park is causing the decline.

INTRODUCTION

Monitoring of spring flows at Pipe Spring NM (PISP) has assisted in addressing the issue of why the flows have been declining. Twenty years of monthly volumetric measurements have revealed interesting flow trends from each of the four spring openings. This analysis of the results of the monitoring program will provide an interpretation of the physical setting, methods used for analyzing water level trends, discussion of proposed scenarios explaining the spring flows relative to recharge and discharge areas, and recommendations for more study to assist in NPS management of water resources at PISP.

Previous ground water investigation is included in "Water Resources Data of the Pipe Spring National Monument Area, 1977-1989" which consists of descriptions of the monitoring sites, hydrogeologic setting, monitoring data and analysis (Inglis, 1990). Ground water and spring flow data collected at PISP and vicinity from 1977 to 1989 indicated that total spring flow has steadily declined while 2 and 4 miles outside the Monument, respectively ground water levels and spring flow appear to remain stable. Of the four springs which comprise Pipe Spring two experienced significant declines in yield, one spring remained stable and one experienced a small but significant increase.

The springs and their flowing water are a key historical element at PISP. A reliable source of water is necessary to interpret homesteading and ranching from the previous century in this isolated part of the West. In the otherwise arid, open country of the Arizona strip, Pipe

Spring is an oasis. Spring flows are an integral part of the Monument's historic setting and are used in many ways to interpret an early ranch homestead in desert country.

Spring flow was the major source of drinking water in the 1870's during the establishment of the historical "Fort Winsor" and the Mormon ranching operations. The "Fort" was built over a spring to secure a supply of water. As the ranch developed, the springs supplied water for irrigating orchards, vegetable gardens, and livestock. Later, a tunnel was dug into the sandstone bedrock to enhance the flow of water. Spring discharge prior to excavation of the tunnel is unknown.

The Monument, established in 1923, encompassed the historical ranch buildings and Pipe Spring. Over the years various improvements by the NPS to the utilities at the Monument have affected the springs. Early modifications to the water supply system were made by adding cisterns and pipelines from the springs to supply staff residences and historical areas. In 1971, a well was drilled outside the park to meet the potable water demand of increasing visitation (McGavock, 1974). The original domestic supply from the spring under the "Fort" was allowed to flow through the historical conveyances from the buildings and many of the early pipelines were abandoned. The spring developments of the early ranchers are maintained to preserve the historic setting. For example, rock-work channels and the ponds have been restored. Foundation drains and pipelines were constructed to stabilize the buildings from moisture damage seeping from the springs. A replacement pipeline was installed in 1988 from Tunnel Spring to convey water to outside the Monument to maintain a water right agreement. An historical description of water use in the Monument is contained in Barrett and Williams (1986).

Although at a diminished rate, water continues to flow from the springs in the Monument through the openings that survived the disturbance and reconstruction. They are referred to in this report as Main Spring, Spring Room Spring, Tunnel Spring, and West Cabin Spring and are the local names of the four spring openings of Pipe Spring (see Figure 1). A seep area documented by park staff north and east of the fort dried up in the late 1970's. Water has ceased flowing under the floor boards in the "Fort." Small flows emerging from the ground have recently been observed below Main Spring. A sizable wet area west of the historical buildings was observed in 1991.

The purpose of this report is to furnish new information on the ground water system near Pipe Spring and provide this information in support of future management actions. This includes analyzing water levels in a monitor well just north of the park to determine if spring flow decline is a natural process or caused by ground water pumping. Analyzing and distributing the results of the recent water monitoring efforts at PISP is the final aim of this project.

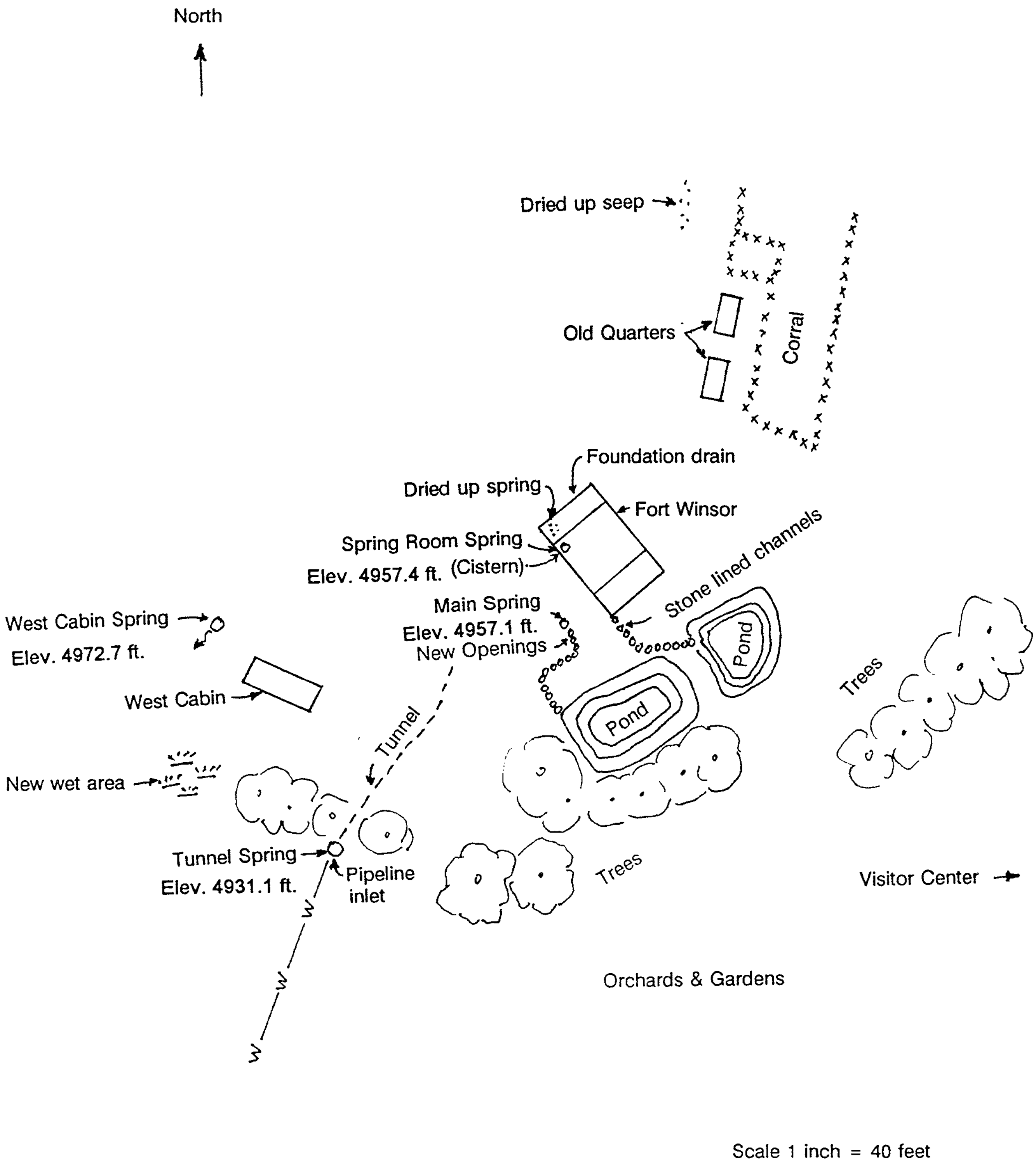


Figure 1. Map of Spring Openings at Pipe Spring NM

PHSICAL SETTING

Pipe Spring is located in proximity to the Sevier Fault which has displaced the Navajo Sandstone against the impermeable layers of the Moenkopi Formation (see Figure 2). The Navajo Sandstone, where saturated, is an extensive aquifer in the region (Heilweil and Freethey, 1992). The upper formations (including the Navajo Sandstone) of the up-thrown block on the east side of the fault have eroded away, leaving the Moenkopi exposed at the surface. To the west of the fault, the silty Kayenta Formation, which underlays the Navajo Sandstone, retards downward movement of ground water. The Kayenta outcrops on a sandstone cliff at the southern tip of Windsor Point to the west of the Monument. The outcrop defines the southern-most local extension of the Navajo aquifer and forms a ground water boundary to the south. A detailed geologic map is located in the appendix.

The local recharge area of the aquifer is surmised (explained later in this report) to be Moccasin Terrace and Windsor Point where the Navajo Sandstone is exposed at the surface. Moccasin Terrace is dissected with box canyons that cut through the Navajo Sandstone and the Kayenta to the underlaying Moenave Formation. The actual recharge area may be limited to selected Navajo blocks separated by box canyons from the main body of Navajo Sandstone on Moccasin Terrace.

Other ground water users in the area are domestic water wells of the village of Moccasin (estimate 100 population) and irrigation wells operated by the Tribe to irrigate approximatly 640 acres.

MONITORING PROGRAM

With assistance from the park, the NPS Water Resources Division has been monitoring water levels in three wells (Tribal Culinary Well No. 1, NPS Culinary Well, and Monitor Well No. 1) near PISP from 1985 to 1992. A summary of water resources data through 1989 describes the ground water monitoring efforts (Inglis, 1990).

Monitor Well No. 1 was drilled in 1989, one-half mile north of the Monument. The well is located between Pipe Spring and the Culinary Well Field which is 2 miles north of the Monument (see Figure 3). This well probably penetrates the aquifer (Navajo sandstone) which yields water through the springs. The well was constructed and water levels periodically measured to determine if the discharge from the springs correlate with water level changes. Water levels in two additional wells (Tribal Culinary Well No. 1 and NPS Cullinary Well) in the Culinary Well Field were measured to determine correlations with spring discharge.

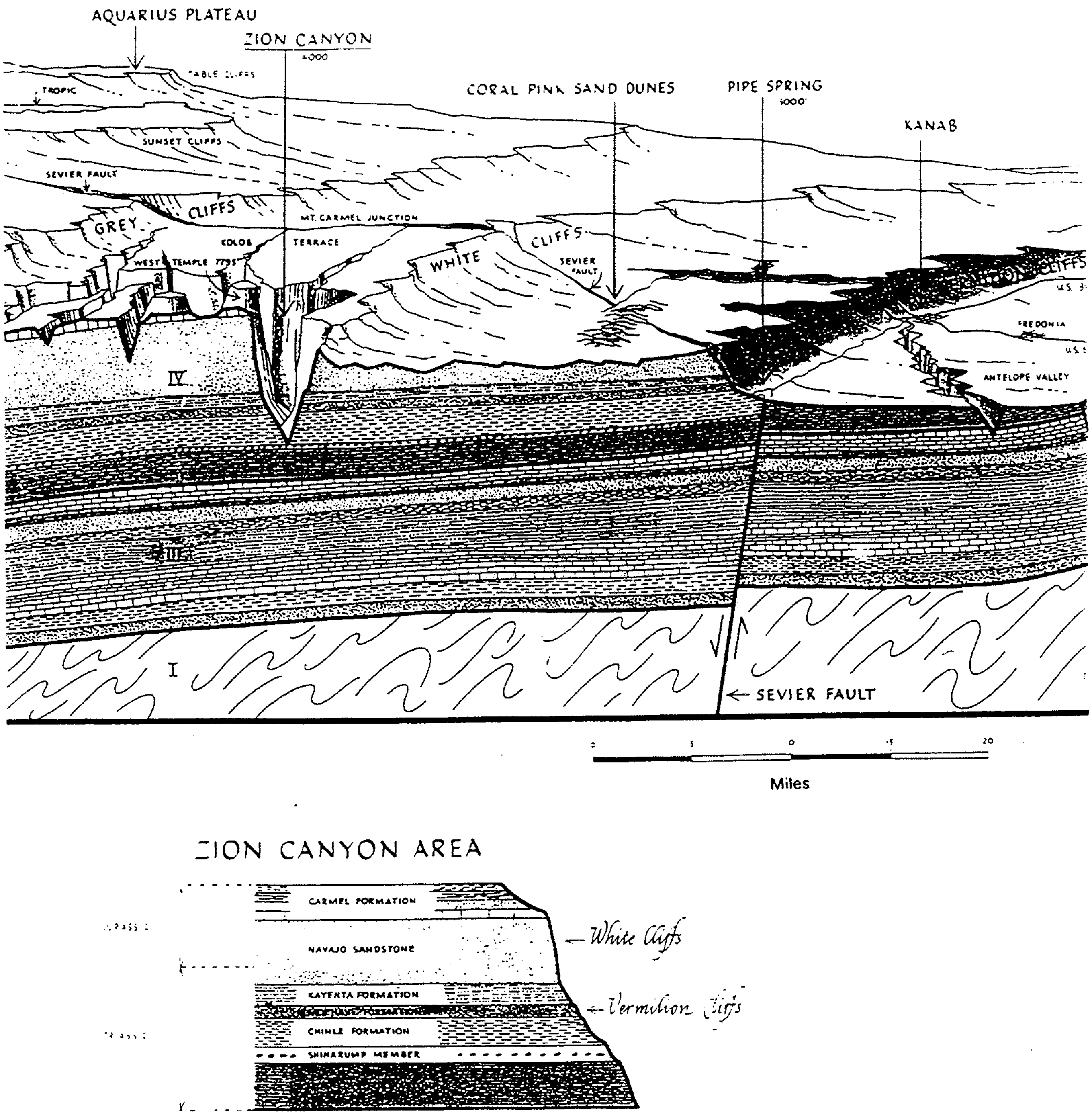


Figure 2. Geologic Cross Section of the Pipe Spring NM Area

From Zion Natural History Association (1975)

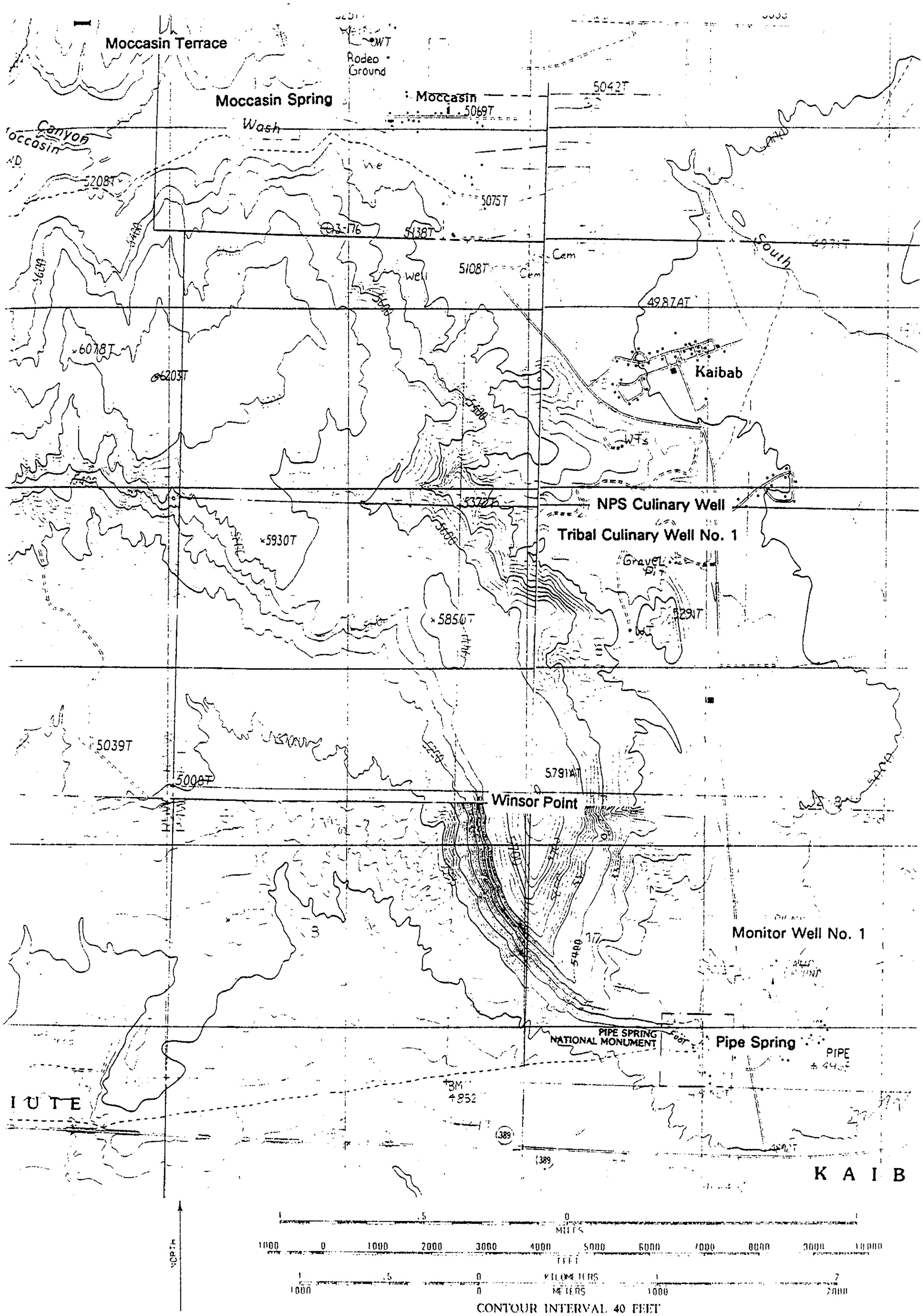


Figure 3. Map of Topographic and Hydrologic Features in the Pipe Spring NM Area

From Moccasin, AZ, Kaibab, AZ, Pipe Valley, AZ and Pipe Spring AZ, USGS 7-1/2 Min. Quadrangles.

METHODS

As recommended in Inglis (1990) water-level data collected for one year at Monitor Well No. 1 was analyzed to determine if pumping at the Culinary Well Field was affecting the spring flows at the Monument. Three scenarios were presented in the 1990 report (listed below) to provide a framework for interpreting changes in the water level in the monitoring well, in spring flows at the Monument, and in water levels at the Culinary Well Field.

1) Unaffected - If water level fluctuations in Monitor Well No.1 correlate positively with spring flows at the Monument, but not with the water levels in the Culinary Well Field, an inference that Culinary Well field Pumping is unrelated to spring flow decline can be drawn.

2) Affected - If water level fluctuation in Monitor Well No. 1 correlates both with water levels in the Culinary Well Field and spring flow, an inference that spring flow decline is related to Culinary Well Field pumping can be drawn.

3) Inconclusive - If water levels in Monitor Well No. 1 fluctuate without correlation to either spring flow at the Monument or water levels in the Culinary Well Field, then the primary cause of spring flow decline cannot be determined with the available information.

Assumptions in analyzing ground water and spring flow data include: (1) no major change in the amount of precipitation in the recharge area has occurred durring the monitoring period, (2) no alteration in ground water use, (3) the flow of the springs in the Monument is hydrologically connected to and reflects the status of the aquifer in which Monitor Well No. 1 was drilled, (4) water levels in Monitor Well No. 1 are representative of the aquifer, (5) water levels in Culinary Well No. 1 are indicative of water levels in the Culinary Well Field, and (6) there is a similarity in seasonal pumping regimes over the years.

Instantaneous water flows are measured monthly at the four spring openings of Pipe Spring and daily at three wells outside the Monument. Volumetric flow measurements at Main Spring, West Cabin Spring, Spring Room Spring, and Tunnel Spring are conducted by park staff with a stopwatch, and 1 and 5 gallon buckets. Digital recorders and pressure transducers record water levels 8 times a day at the NPS Culinary Well, Tribal Culinary Well No. 1, and Monitor Well No. 1. Monitoring sites are described in the appendix.

An aquifer test on the NPS Culinary Well was conducted to determine the condition of the well after a rupture occurred in the pipeline under the pumphouse. The rupture created a large cavity which undermined the pumphouse and caused it to collapse on June 2, 1992. The water supply was temporarily interrupted until the break was repaired, interfering with the normal pumping cycles of the well. The results of the aquifer test in the monitored wells are pertinent to, and included in, the present investigation.

MONITORING RESULTS

Figure 4 shows the monthly volumetric record collected by park staff for the four spring openings at Pipe Springs. From 1976 to 1996, the discharge from Spring Room Spring and Main Spring declined. While Tunnel Spring did not show any trend for the first 10 years, the discharge rate has increased during 1990 to 1996. The flow record of West Cabin Spring displays small, but distinct, annual fluctuations. Notice Figure 4 displays independent flow trends; unusual for springs in close vicinity of each other.

The combined spring discharge (Figure 5) varied from 30-35 gpm in 1976, and was about 20-25 gpm from 1990 to 1996, up from a low of 15-20 gpm in 1988. The 1976-85 declining trend was predominately due to decreased flow from Main Spring and Spring Room Spring. The 1986-89 stable trend was followed by an increasing trend, 1989-90, due to increase in the discharge rate of Tunnel Spring. Figure 5 also shows an annual fluctuation: lower discharge rates occur later in the summer and the higher ones in the winter and spring.

Figure 6 is annual precipitation recorded at the National Weather Service station at park headquarters from 1976 to 1996 (see Appendix C for complete record). While the trend of the two graphs are similar it does not explain why annual precipitation increased in 1992 when the increase in springflow occurred two years earlier in 1990.

Figure 7 portrays the combined discharge for springs in the Monument for the monitoring period 1990-1992, the same period of record as that of water-level measurements from the wells.

Figure 8 and Appendix D shows water levels in Monitor Well No. 1. Slightly higher water levels are observed in the spring and lower levels in the fall with the exception of 1992 when precipitation was considerably higher. Water levels at the end of the record are higher than the previous year indicating rising water levels in the aquifer. The change in water level is about 0.4 ft. which is small compared to flux ranges in the Culinary Well Field. The break in the record was caused by vandalism to the recording equipment. The apparent daily fluctuation in the second half of the record is due to erratic response in the pressure transducer and not of fluctuation in water levels.

Figures 9 and 10 show water levels of the two wells in the Culinary Well Field. Large daily fluctuations are a result of daily pumping and quick recovery of water levels. A weak annual fluctuation is also apparent in both wells. Again, lower water levels are evident in the summer (with the exception of 1992, a very wet year) and higher levels in the winter and spring.

Water level records from the ground water monitoring program have been examined with respect to the pump house collapse on June 2, 1992. Changes in water levels in the wells indicate that there is a hydraulic connection between the wells. Water levels in Monitor

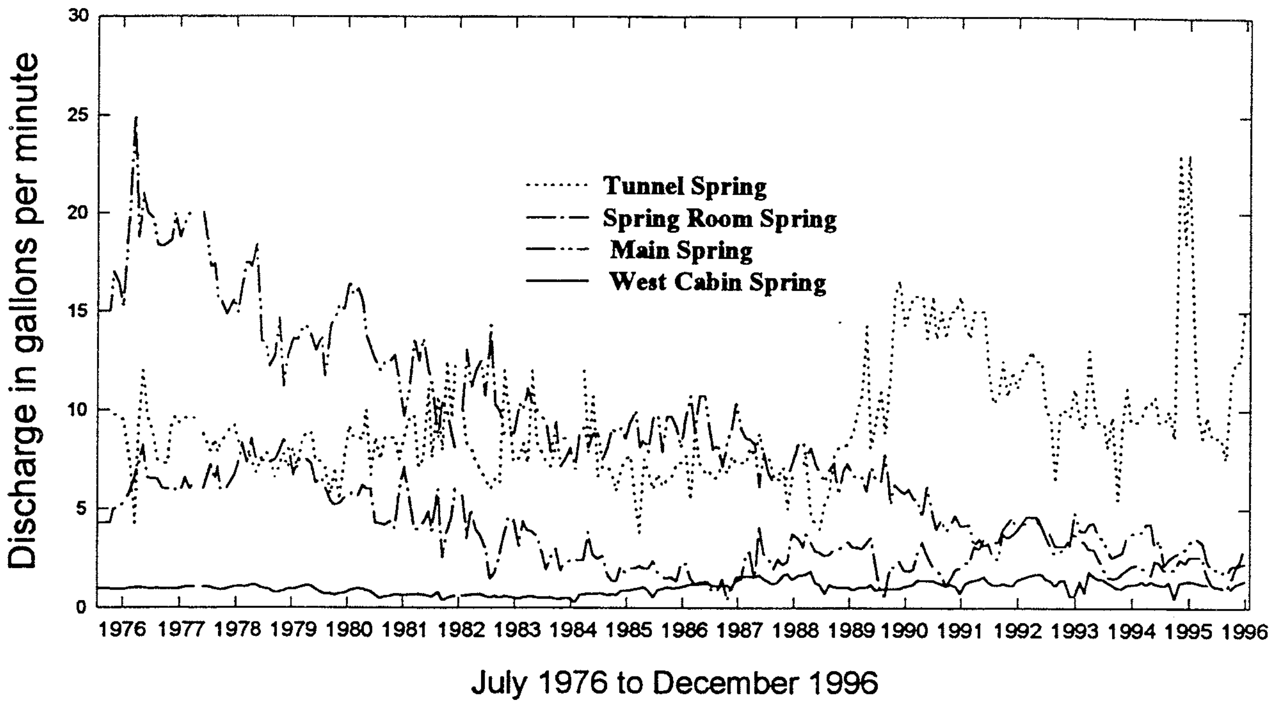


Figure 4. Monthly Volumetric Record of Four Springs, 1976 - 1996

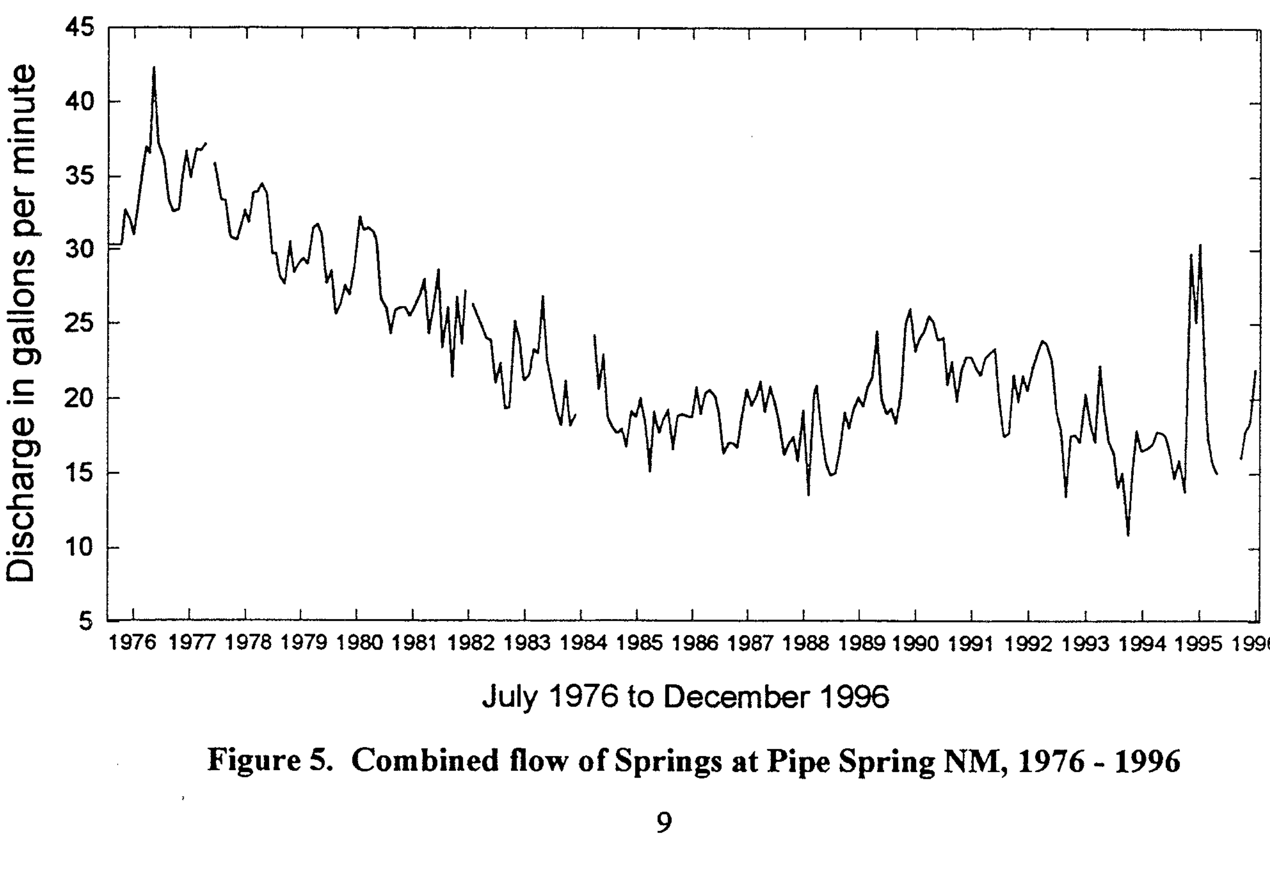


Figure 5. Combined flow of Springs at Pipe Spring NM, 1976 - 1996

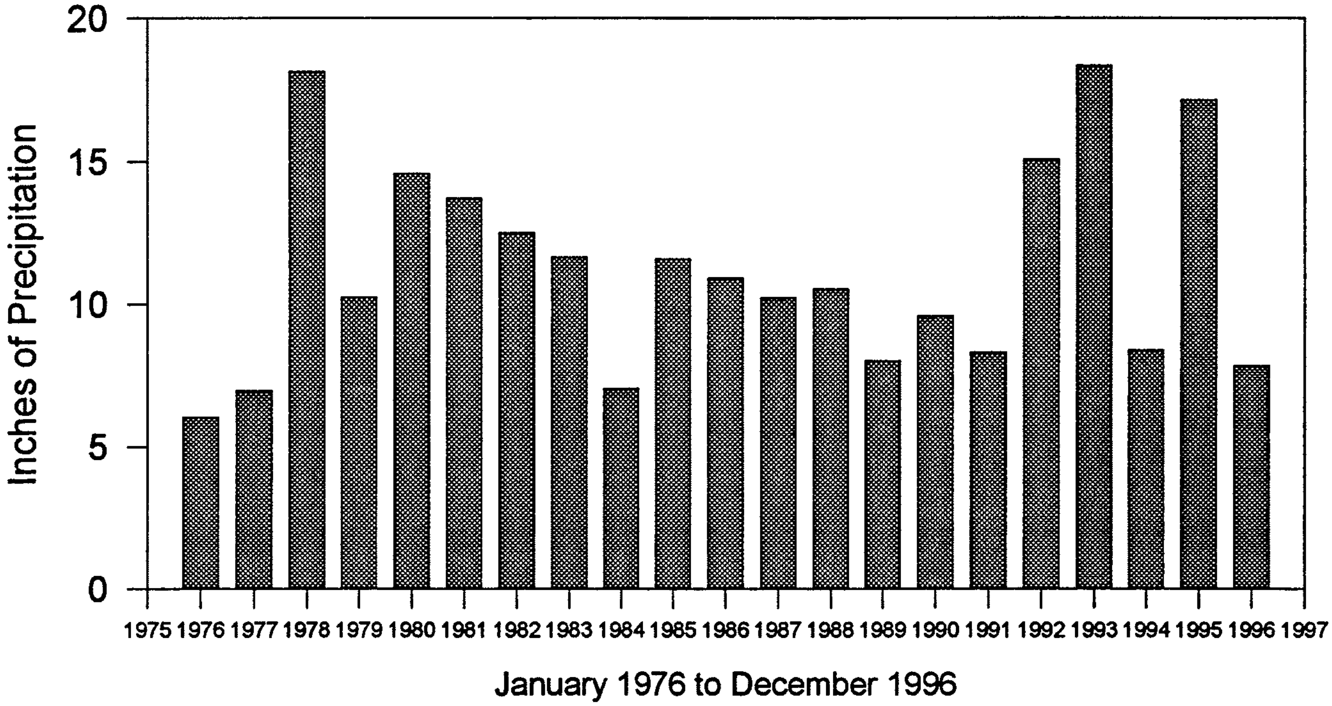


Figure 6. Annual Precipitation at Pipe Spring NM, 1976 - 1996

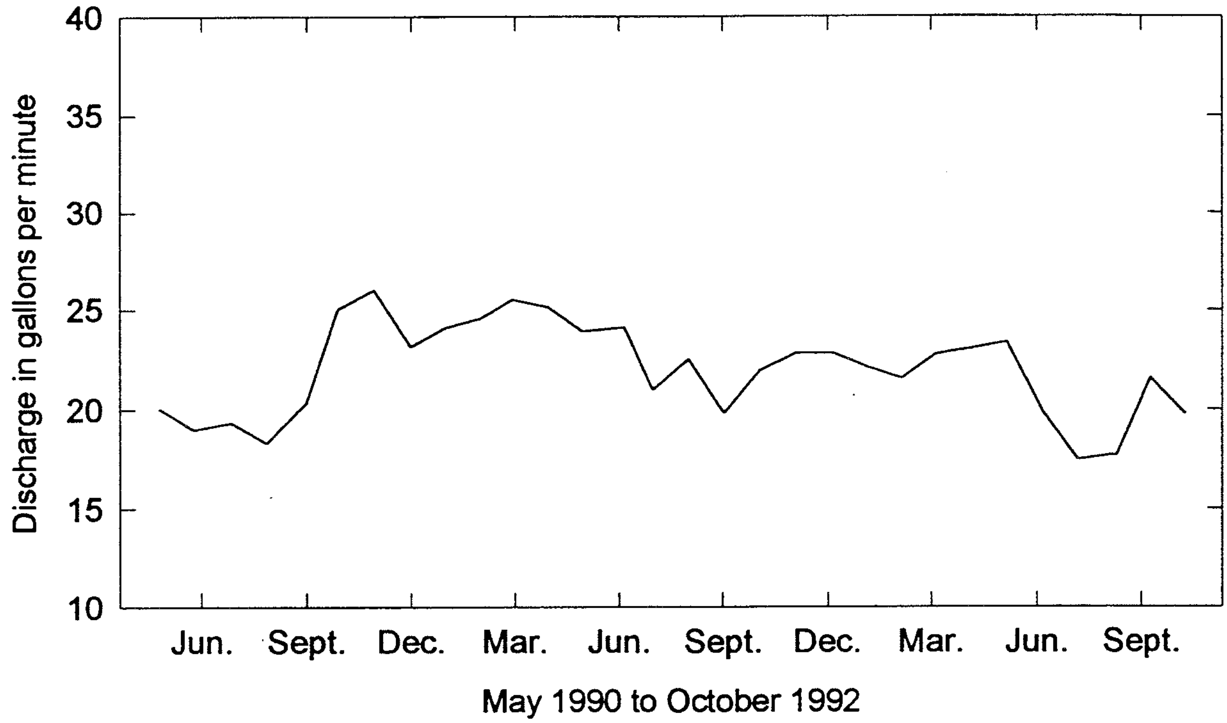


Figure 7. Combined Flow of Springs, 1990 - 1992

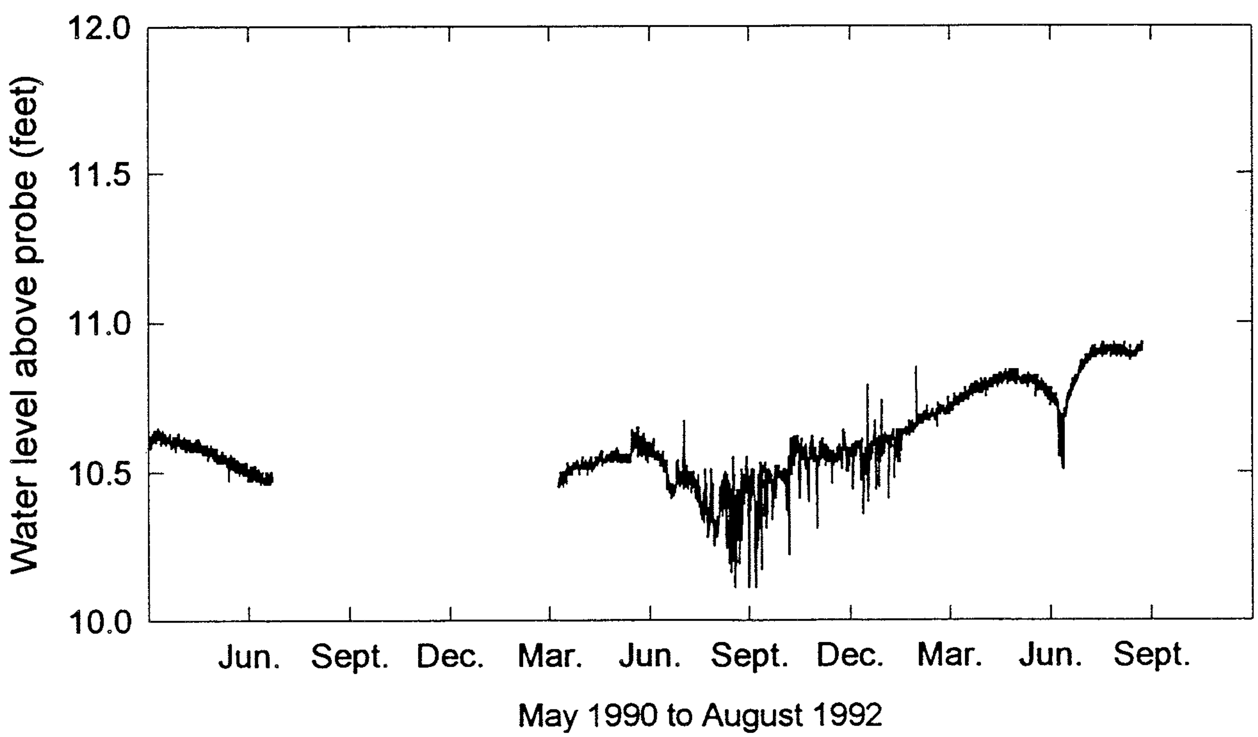


Figure 8. Water Levels in Monitor Well No. 1, 1990 - 1992

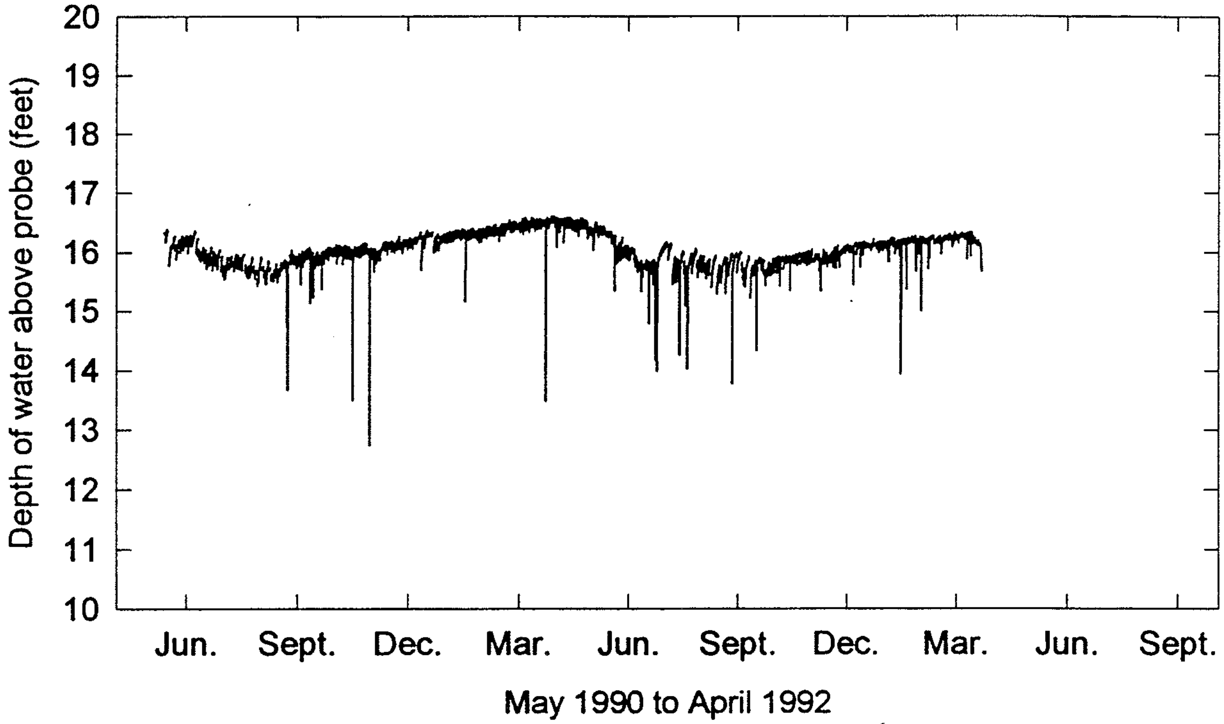


Figure 9. Water Levels in NPS Culnary Well, 1990-1992

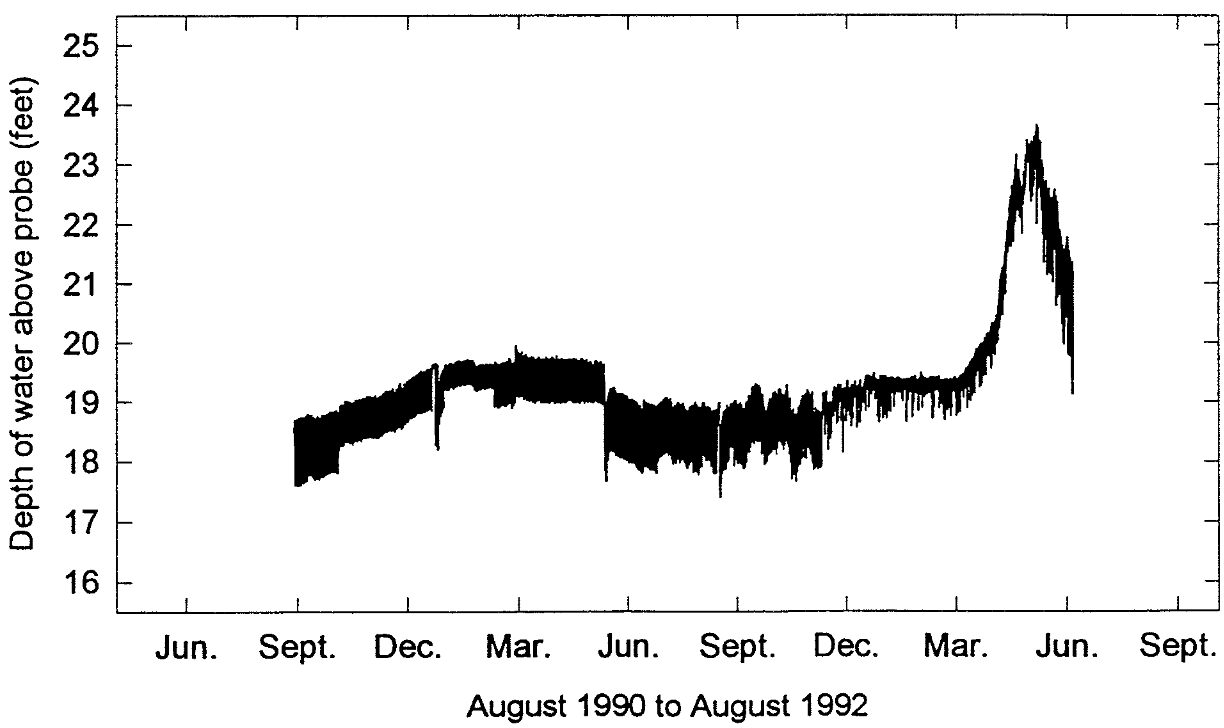


Figure 10. Water Levels in Tribal Culinary Well No. 1, 1990-1992

Well No. 1 had been increasing from August, 1991 to May, 1992, probably due to above average precipitation, then leveled off and began to decline when the pumphouse collapsed at the NPS Culinary Well (see Figure 11). Also, the water table at Monitor Well No. 1 decreased significantly during the time of the 24-hour pump test of the NPS Culinary Well. After the pump test, water levels in Monitor Well No. 1 increased rather rapidly to a level slightly higher than before the collapse of the pumphouse. After 2 months of rising, water levels in the Tribal Culinary Well began to decline at about the same time as the pumphouse collapse (see Figure 12).

Combined spring flows in the Monument declined 15 percent from 23.3 gpm on May 1st to 19.8 gpm on June 1st at the time of the pumphouse collapse. Spring flows remained low for July and August at 17.5 and 17.7 gpm, respectively. Spring flows measured on September 1st have increased to 21.6 gpm, which occured two months later than the increasing water levels in Monitor Well No. 1.

DISCUSSION

Considering the complexities of the ground water system and the results of our monitoring, several scenarios may be considered to address the question of pumping's effect on spring flows. The possible causes of the spring flow decline are grouped into two categories: macro and micro scale (the big picture and the small picture). The macro-view includes concepts dependent on the characteristics and extent of the aquifer, the climate, and different scenarios of ground water pumping in the area. The micro-view includes a theory on how local changes in the spring openings (both natural and anthropogenic) have affected spring flow. Based on existing information, it cannot be said which (if any) of these theories completely explain spring flow declines.

Macro-view -- The aquifer extent and characteristics are important because they set limits on the extent to which regional processes can physically affect ground water discharges at Pipe Spring. The aerial size of the aquifer may be surmised from distribution of the Navajo Sandstone, the effects of the Sevier Fault, and mapped geology. Other information such as thickness of the aquifer and depth to the water table is derived from driller's well logs and monitoring data of water levels and spring discharge.

The first scenario considers a huge ground water system. The Navajo Sandstone extends large distances north into Utah which, some have said, is where the recharge area is that supplies a whole, coherent aquifer (Gregory, 1950). This large aquifer has been subject to extensive development proposals. Coal mines, associated cities, and large reservoirs have been proposed and analyzed for the hydrology of this region (Heilweil and Freethey, 1992). Early conjecture tried to relate declining spring flows to activities hundreds of miles distant with little success. Conclusive evidence proving spring flows in the Monument are from a large regional aquifer is weak. Evidence for less extensive aquifers are the differences in chemical quality cation and anion ratios from different ground water sources in northern

Arizona (Levings and Farrar, 1979). Age-dating the water at PISP would provide additional evidence here.

A second scenario considers an intermediate sized aquifer. Some have thought the local ground water basin north of the Monument to be the recharge area of springs (Barrett and Williams, 1986). This basin of about 50 square miles roughly corresponds to the surface drainage of Two Mile Wash. The Paiute Nation and the village of Moccasin have been developing ground water in this area quite rapidly. Unfortunately, systematic monitoring and analysis of data have not been done. Most of these wells are probably developed in or near the Sevier Fault based on their relative locations (the exact location of the fault has not been mapped). The recharge area is likely to be the Navajo Sandstone west of the fault on Moccasin Terrace north of Moccasin Canyon. Flow from Moccasin Spring is also thought to be from this recharge area. Steady flows from Moccasin Spring does not match the declines and fluctuation of flow from Pipe Spring. A large cooperative effort in sharing and analyzing drilling and pumping data would be required to determine if it is indeed a "ground water basin" common to the springs and Culinary Well Field.

A new theory (third scenario) of a smaller aquifer supplying Pipe Spring is proposed based on evidence described below. The primary evidence is drillers logs from three wells (the only logs available) near PISP (McGavock, 1974, and Ballard, 1989). After encountering a water-producing zone, all three wells penetrated a dark red formation that has been suggested as Kayenta. The Kayenta is a poor aquifer in some regions and an aquitard in others. Drillers of the three wells did not report additional water production below the contact with the Kayenta. The Kayenta outcrops have been mapped in the PISP area (see Appendix A). It is exposed on cliff faces on nearly all sides of Winsor Point (nearly an isolated landmass), underlying the Navajo Sandstone. A narrow ridge of Navajo Sandstone remains between Winsor Point and Moccasin Terrace with Moccasin Canyon to the north and Berry Cove to the south. This remaining connection to Windsor Point through the ridge is not a likely conveyance of ground water because of the high, exposed position of the Navajo aquifer draining toward cliff outcrops on both sides of the ridge. The dip of the Winsor Point block of sandstone is to the east towards the Sevier Fault. About 10 square miles of this block lies to the northwest of Pipe Spring and is (in this hypothesis) the primary recharge area. If the aquifer is 10 square miles in size, only wells south of Moccasin Canyon would be able to "impact" the flow of springs in the Monument. This theory could be resolved by age-dating the water from the different areas. Two other similar geologic settings of springs existing on the southeast point of mesas composed of Navajo Sandstone exist in the immediate area (Moccasin and Point Springs).

Other evidence supporting a theory of a smaller aquifer is from analysis of water level data from the monitoring program. Water levels in the wells and combined flow of Pipe Spring fluctuate annually. Two years of record show a relationship between water levels in the NPS Culinary Well and Tribal Culinary Well No.1 to a yearly pattern of annual fluctuation. The combined flows of Tunnel, Main, Spring Room, and West Cabin Springs also show annual fluctuation. A large regional aquifer would likely not have a well-defined flux on a

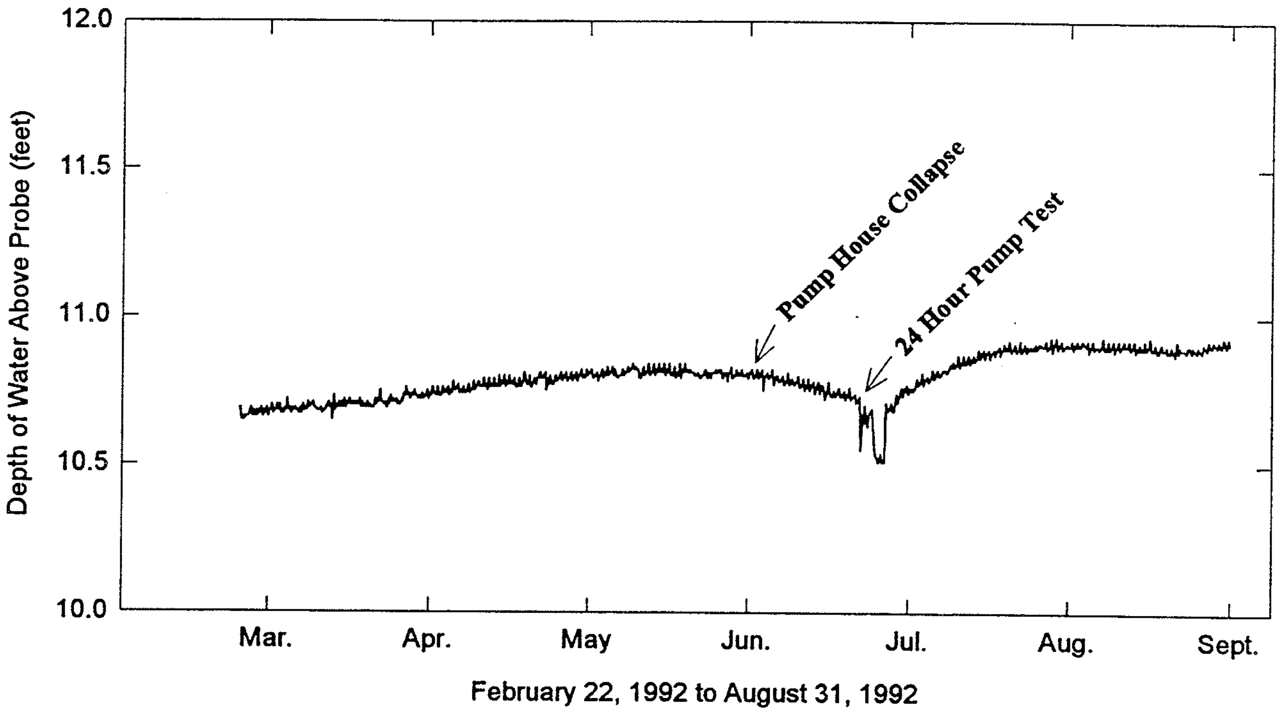


Figure 11. Water Levels in Monitor Well No. 1, Feb. - Aug. 1992

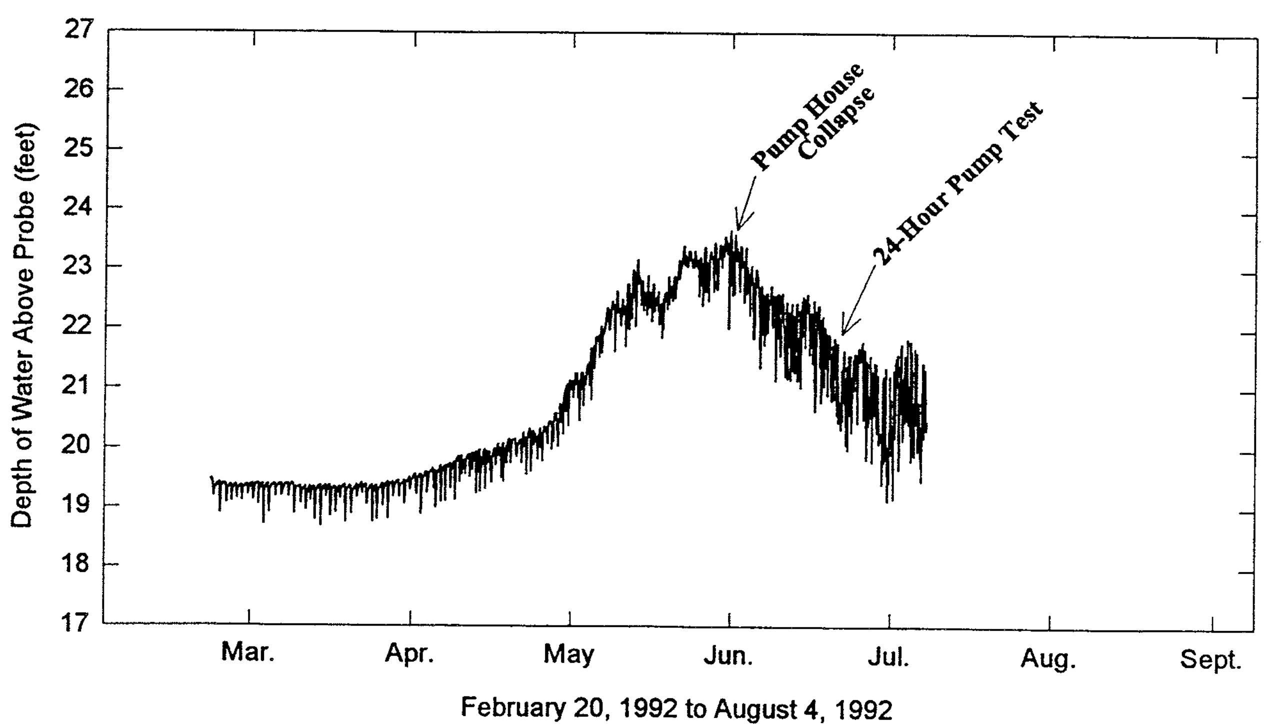


Figure 12. Water Levels in Tribal Culinary No. 1, Feb. - Aug. 1992

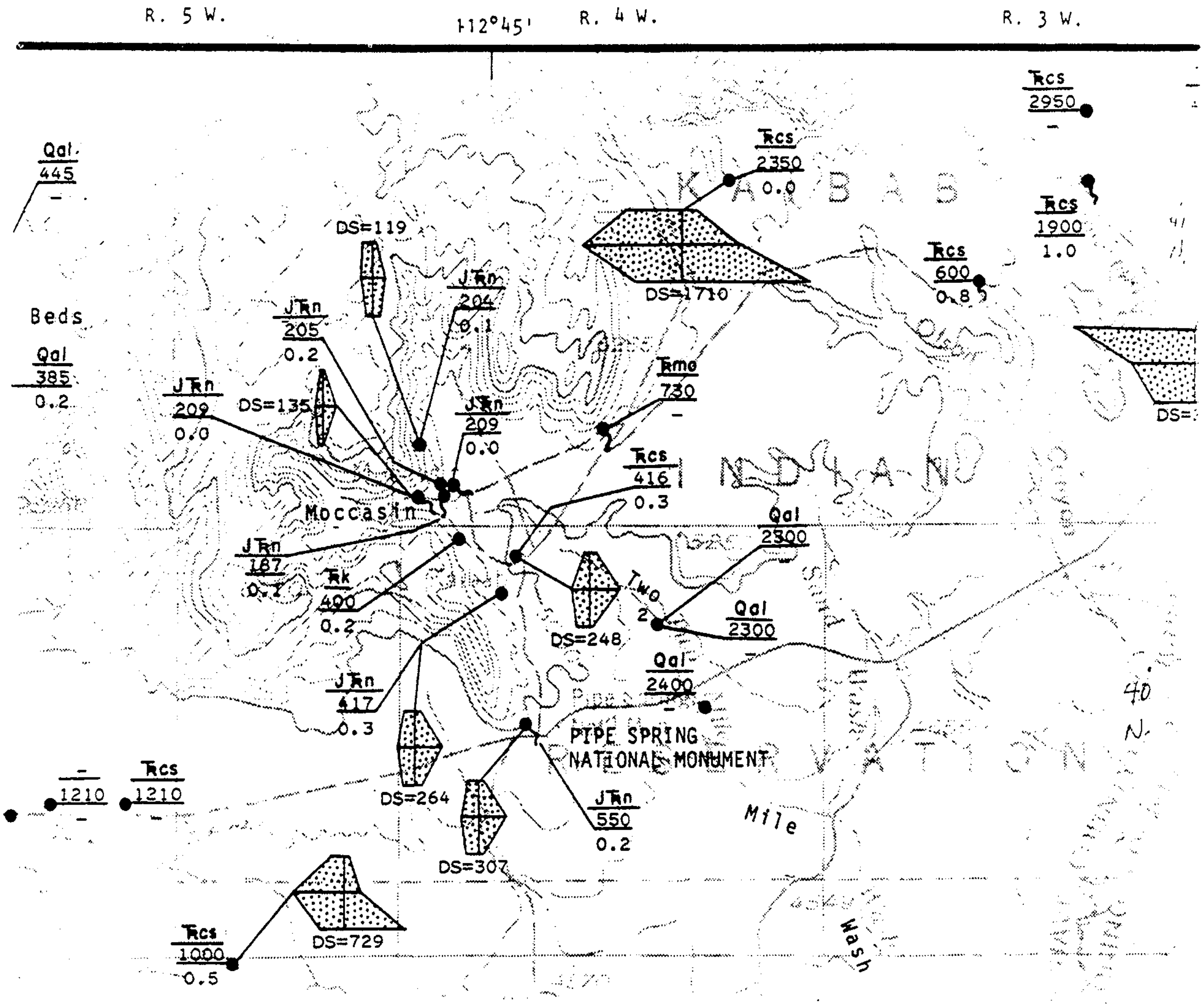
yearly basis. However, whether the fluctuation is caused by seasonal variation of the recharge from rainfall or by seasonal pumping of wells during increased summer demand has not been determined. Large aquifers would likely produce more mineralized water than do the springs in the Monument due to a longer residence and travel time in the formation.

A difference in chemical-quality patterns also supports the theory of a smaller aquifer. Chemical-quality patterns of major chemical constituents in milliequivalents per liter from Levings and Farrar (1979) are shown in Figure 13. The patterns have a variety of shapes and sizes, which provide a means of comparing similar or dissimilar types of water. The pattern tends to maintain its characteristic shape as the sample becomes dilute or concentrated and the pattern size varies in proportion to the variation in dissolved solids. Samples from the west half of T. 40 N., R. 4 W. (which include Pipe Spring and the Culinary Well Field) have nearly identical size and shape of chemical patterns. Samples from farther north, in the west half T. 41 N., R. 4 W. (which includes Moccasin Spring) are similar in shape, but smaller in size than farther south, this indicates fewer dissolved solids.

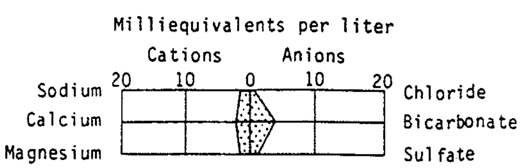
The annual flows from springs in the Monument have declined by approximately the amount pumped yearly from the NPS well. Pipe Spring combined flow declined from about 40 gpm to 20 gpm (from 21 million gallons per year (mg/y) to about 10.5 mg/y). The difference is similar to the annual amount of pumping from the NPS Culinary Well (10 mg/y). However, the true relevance of this is questionable because the amount pumped by the Tribal Culinary Well is unknown at this time and must be included in any such calculation for meaningful evaluation. Also, the decline of spring flow for the past 15 years does not match the rate of pumping from the NPS well. The NPS well yield has generally been 10 mg/y every year, while spring flow has declined a small additional amount every year until about 1985. An additional factor is that spring flow declines were first documented the same year that significant pumping occurred in the NPS well. The increase in flow since 1990 cannot be explained with available data.

Annual and monthly rainfall data from Pipe Spring Headquarters have also been examined for the cause of spring flow decline. There was no correlation between the amount of rainfall and the decline of spring flow from 1976 to 1985. While historical reports before 1976 place the flow of Pipe Spring above 40 gpm (Barrett and Williams, 1986), discharge measurements were infrequent (and of questionable quality). No written observations existed in the history of PISP if spring flow fluctuated between periods of historical measurements. It may be possible that the present decline in spring flow is an expression of a larger, undocumented, cyclic pattern independent of local pumping.

Micro-view -- A fourth scenario is proposed incorporating observations pertaining to the springs in the Monument. The hydrologic circumstances causing the presence of the springs is not well understood, but may be controlling spring flows. The different spring openings at Pipe Spring display a range of physical structures and functions. It is unknown why the springs are located exactly there, and not farther south, west, or north. The Sevier Fault and outcrops of Navajo Sandstone are important features, but this combination exists for miles



CHEMICAL-QUALITY PATTERN DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The patterns are in a variety of shapes and sizes, which provides a means of comparing, correlating, and characterizing similar or dissimilar types of water. The pattern tends to maintain its characteristic shape as the sample becomes dilute or concentrated, and the pattern size varies in proportion to the variation in dissolved solids. The general lithology of the water-bearing unit is designated in the chemical-quality pattern diagram



System	Group, formation, or member	Letter symbol for geologic unit
Quaternary	Alluvium	Qal
Quaternary and Tertiary	Basalt	QTb
Jurassic and Triassic(?)	Navajo Sandstone	JTRn
Triassic(?)	Kayenta Formation Moenave Formation	TRk TRmo
Triassic	Chinle Formation Petrified Forest Member Shinarump Member Moenkopi Formation	TRc TRcp TRcs TRm

Figure 13. Chemical-Quality Patterns of Water Sources Near Pipe Spring NM From Levings and Farrar (1979)

to the north. The occurrence of the springs is believed to be dependent upon where the Navajo aquifer is opposite of the Moenkopi Formation (an aquitard) due to the Sevier Fault as explained on page 2. Also, a degree of linearity is evident in the springs, trending east-west. This suggests the presence of an unmapped transverse fault, with spring flow issuing from the possible fault plane. Much of the area southwest of the monument is mantled with thick surficial deposits obscuring the underlying bedrock. An unusual feature rarely noticed about the springs in the Monument is the ground generally slopes downhill in three directions (east, south and west) from the spring openings.

Results from investigating water levels in the aquifer along the Sevier Fault to the north of Pipe Spring indicate a steep (approximately 80 feet per mile) southward ground water gradient between the monitor well and the springs, 1/2 mile apart (Inglis, 1990). The ground water gradient north of the monitor well to the culinary well field is nearly level for a mile and a quarter. This disparity in gradient does not explain, but may be related to, why the spring openings at PISP are at different elevations. The difference in elevation between the spring openings 100 yards apart is as much as the 40 feet elevation difference to water levels in the monitor well, indicating that local geologic features are puzzling.

Of the four spring openings presently flowing, only West Cabin Spring has not been modified in historical times. West Cabin Spring remains at a relatively constant discharge. However, it is topographically the highest spring. Tunnel Spring was excavated during the early settlement at an unknown time and primitive maps indicate that the tunnel was dug in a direction towards Main and Spring Room Springs. The opening of Tunnel Spring is at least 20 feet lower than the other springs and should have captured all the other spring flows. There is a partial cave-in visible from the mouth of the tunnel but the remainder of the tunnel has not been examined. West Cabin Spring flow has increased a small amount since 1985 years while the flow of Tunnel Spring has increased significantly in the since 1990 and the other two spring flows may have leveled off.

Coincident with the increased flow of Tunnel Spring in late 1988 was the rebuilding of the pipeline within the Monument to convey water to outside users. The external portion of the pipeline outside the Monument was not rebuilt and may constrict the discharge because water occasionally backs up at the pipe inlet and forms a pool. Tests were conducted to determine if measurements of increased flow were caused by draining the head of water pooled in the inlet when a discharge valve is opened briefly for measurements. After draining the pipeline and inlet for 24 hours, discharge measurements were repeated and similar results were obtained.

Main Spring, located outside the Fort structure, is connected to Spring Room Spring, about 50 feet away. Historical records indicate that in the 1880's the occupants of the Fort dug a trench from the Spring Room Spring source in the courtyard to a location outside the west doors and buried cedar bark and poles to create a new springfed pool (Naylor, 1996). The pipe which drained the Spring Room Spring from the cistern to the Spring Room was found leaking and full of roots and was repaired. This improved the spring flow somewhat (Terry

Strong, 1996). Main spring was recently pumped for a day to clean and maintain the pool where the spring emerges. Spring Room Spring ceased flowing during this short period, thus indicating a hydraulic connection. Tracer dye was injected in Spring Room Spring, earlier as part of this investigation, however, the dye did not appear in Main Spring. Results of the test indicate that Spring Room Spring flow does not infiltrate and reemerge at Main Spring. A hydraulic connection exists; both springs could derive their flow from the same source. Monitoring the flow of the two springs shows that when the level of Main Spring pool increases (as when a v-notch weir was installed) the flow of Spring Room Spring increases. However, the monthly flow measurements of the two springs have not been identical as shown in Figure 4.

The stonework lining the pool of the opening at Main Spring has deteriorated and been repaired over the years. Water emerged from underneath the rock-lined channel downstream from the spring. Flow measurements have been modified to incorporate this "new" water into the flow of Main Spring. However, less flow is coming from the Main Spring pool resulting in a lower pool level. The lower water level in the pool may be the reason for declining flows in Spring Room Spring. Also, large trees (but not of the historical period) have surrounded Main Spring and the Fort and are being removed. Roots may have interfered with water passage out of the water bearing rock and/or caused new fracturing and weathering of the bedrock with unknown consequence.

CONCLUSIONS AND RECOMMENDATIONS

It cannot be stated that well pumping is, or is not, the only cause of the decline of spring flow in the Monument; nor can continuing the present monitoring program firmly answer that question. The relationship between well monitoring data and spring flow at Pipe Spring is not enough evidence to justify continuing the present monitoring program in order to define the cause of reduced spring flows.

Site-specific water quality and geohydrologic information of the park area are needed. This will allow answers to important questions such as: Is spring water chemistry identical to that of pumped water from the wells? Are the springs fault-controlled? Could a monitoring well be drilled in the park to better and more easily monitor the aquifer?

The pump test on the NPS Culinary Well, which followed the pump house collapse, provided a needed test on the aquifer near Pipe Spring. The simultaneous changes in water levels in wells nearby indicate, that the wells may be hydraulically connected and able to influence each other. Less clear is the response of spring flows in the Monument to nearby ground water pumping. The decline and recovery of spring flows (during and after the pump test) during a year of above average rainfall point towards influence from other (outside) events in the aquifer. The most significant event during this time was the extended pumping of the NPS Culinary Well during the aquifer test. This incident indicates that spring flows may be affected by excessive use of the NPS well.

For which scenario defining the recharge area requires verification. Learning the location and hydraulic effect of the Sevier Fault(s) is needed for the placement of additional monitoring wells and monitoring of appropriate pumped wells.

A series of studies should be initiated to provide the most relevant information. Initially, a hydro-geochemical project should be used to identify geochemical characteristics of different sources to define recharge areas. Data should include age-dating and other parameters to characterize the chemistry of samples from different water sources. The results of this project will allow deduction of one of the recharge area hypotheses, providing focus for future management efforts.

A second proposed project would concentrate on the park area to understand the presence of the springs and their relation to the Sevier and, perhaps, other local faults. Geophysical investigations and selected test well drilling would be required. The results of this project would: (1) define the location of the Sevier Fault within the park, (2) determine if the spring openings are on the Sevier Fault, or on an unmapped, east-west fault, and (3) provide an evaluation of the feasibility of drilling a well to monitor park spring flows. The results will better explain the hydrologic circumstances of the springs and infer ground water origin. For example, if the springs are situated at the junction of two faults, spring flow may be derived from an extensive area. If not fault-controlled, it would be an inference that supports the small aquifer hypothesis (third scenario).

Based upon present understanding, a combination of the third and forth scenarios (small aquifer with complex changes at spring openings) may best explain the hydrogeology at PISP, but additional work is needed to confirm this. The proposed work will provide additional information to answer the basic question of what is causing spring flow interference by pumping from wells.

REFERENCES CITED

Ballard, T., 1989. Ballard Drilling Co., *pers. com.*

Barrett, D.C. and Williams, O.R., 1986. An Evaluation of the Decline in Spring Flow at Pipe Springs NM. Fort Collins, CO. National Park Service, 13 p.

Gregory, H.E., 1950. Geology and Geography of the Zion Park Area, Arizona and Utah. USGS Professional Paper 220, 200 p.

Heilweil, V.M. and Freethey, G.W., 1992. Simulation of Ground-Water Flow and Water-Level Declines that could be caused by Proposed Withdrawals, Navajo Sandstone, Southwestern Utah and Northwestern Arizona. U.S. Geological Survey Water-Resources Investigations Report 90-4105.

Hemphill, H.R., 1956. Photogeologic Map of the Fredonia NW Quadrangle, Mohave County, AZ. U.S. Geologic Survey Miscellaneous Investigations, Map I-133.

Inglis, R., 1990. Water Resources Data of the Pipe Spring National Monument Area, Arizona, 1977-1989. Technical Report NPS/NRWRD/NRTR-90/02, Ft. Collins, CO. 30 p.

Levings, G.W. and Farrar, C.D., 1979. Maps Showing Ground-Water Conditions in the Kanab Area, Coconino and Mohave Counties, Arizona - 1976. U.S. Geologic Survey Water-Resources Investigations Open-File Report 79-1070.

Marshall, C.C., 1956. Photogeologic Map of the Fredonia SW Quadrangle, Mohave County, AZ. U.S. Geologic Survey Miscellaneous Investigations, Map I-160.

Marshall, C.C., 1956. Photogeologic Map of the Short Creek SE Quadrangle, Mohave County, AZ. U.S. Geologic Survey Miscellaneous Investigations, Map I-153.

McGavock, E.H., 1974. Results of test drilling in the Pipe Spring National Monument, Mohave County, Arizona. U.S. Geologic Survey Memorandum Report.

Naylor, L.P., 1996. Archeological Testing of Spring Developments and Soil Moisture Sources in association With Deteriorating Masonry of the Pipe Spring Fort (Draft). National Park Service, Zion National Park

Pillmore, C.L., 1956. Photogeologic Map of the Short Creek NE Quadrangle, Mohave County, AZ. U.S. Geologic Survey Miscellaneous Investigations, Map I-142.

Strong, T., 1996. National Park Service, *pers. coms.*

Zion Natural History Association, 1975. Geologic Cross Section of the Cedar Breaks - Zion - Grand Canyon Region. Springdale, Utah.

APPENDIX A

Description of Monitoring Stations

Pipe Spring National Monument

Station Description

Monitor Well No. 1

SW1/4,NE1/4,NE1/4, Sec. 17, T.40, R.4 W.

History of Well - The well was drilled in October 1989, on lands managed by the Kaibab-Paiute Indian Nation. Construction information and an aquifer test that was conducted by the NPS are published in: Inglis, R.R. 1990, Water Resources Data of the Pipe Spring National Monument Area, Arizona 1977-1989, available from the NPS-WRD in Fort Collins, CO.

Purpose of Well - The well was drilled to monitor water levels in an aquifer suspected to be hydraulically connected to the springs in Pipe Spring NM.

Geohydrology of Well - The total depth of the well is 200 ft. with 6-inch steel surface casing and 4-inch pvc casing to full depth. There is 10 ft. of continuous slot pvc screen between 115 ft. and 125 ft. below land surface. Water was first encountered at 105 ft. and rose in the well to 82.9 ft. indicating an artesian aquifer. The driller also stated that the aquifer is 15 ft. thick. Red clay was encountered at 155 ft. indicative of the Kayenta formation. The well was located in Navajo Sandstone adjacent to the Sevier Fault.

Management of Well - The well head is covered at the ground surface by a cement and steel instrument shelter which contains monitoring equipment. The well is not designed to be pumped because of the proximity of Pipe Spring located about 1/4 mile to the south.

Data Record - Inital well construction and test data are reported in Inglis (1990). Water level records are kept in the NPS-WRD Library in Fort Collins. There is a break in the record from September, 1990, to April, 1991. Discontinued in July, 1995.

Data Collection - Water levels and barometric pressure were recorded at 6 hour intervals by an Omnidata Easylogger@ Field Unit, a Druck@ 10-psi pressure transducer and a Weathermetric@ barometer. Water level measurements are checked with a Leopold Stevens@ Metric Well Tape every three or four months. The barometer was removed in August 1990.

Data Storage - Raw data is stored and manipulated in PC based Lotus@ spreadsheets at the NPS-WRD Fort Collins Office. Water level plots and some hard copy printouts from the spreadsheets are kept in "Hydrologic Folders" located in the NPS-WRD Library. All geohydrologic information pertaining to this water source as well as maps, water quality and other data, are kept in this folder.

Brief Analysis - Plots of the water levels in this well generally indicate little fluctuation with a range of about 0.4 ft. over 10 months of record. Apparent malfunctioning of the probe is causing oscillation and possible drift of recorded water levels starting in August, 1991. Water levels recorded May through August 1990, are at an unexplained 1.5 ft. below more recent levels. Some changes in water levels may be related to earthquake activity.

Questions and Ideas - A better ground water monitoring system around the Monument is desired. Initially three monitoring sites were proposed but two wells (one 1/4 mile south of and one 1/4 mile west of the Monument were not drilled due to lack of funding. It has been suggested to drill a monitor well close to Pipe Spring (within 100 yards) to determine if changes in the spring openings are causing the decline of springflow. Water levels in a nearby well may respond to temporary manipulation to the spring pool levels.

Pipe Spring National Monument

Station Description

NPS Culinary Well
also known as Test Hole No. 6

NE1/4,NW1/4, Sec. 8, T.40 N.,R.4 W.

History of Well - The well was drilled in 1971 on land managed by the Kaibab-Paiute Indian Nation. At the request of NPS, the U.S. Geologic Survey conducted an aquifer test. The results of the aquifer test and drilling of 5 other test holes are reported in: McGavock, E.H. 1974, Results of Test Drilling Near the Pipe Spring National Monument, Mohave County, AZ. This USGS Memorandum Report is available from the NPS Water Resources Division Library. A trip report in April, 1971 by Donald Barrett, NPS Hydrologist describes the completion of the well. Collection of pump discharge records by Mel Heaton, NPS maintenance staff, began in 1973. After a break in the pipeline under, and subsequent collapse of, the pumphouse in June 1992, a 24-hour aquifer test was conducted. The water pipeline supplies several tribal facilities as well as the NPS Visitor Center, residences, and orchards.

Purpose of Well - The well was drilled to supply the culinary and irrigation needs of the Monument and nearby tribal buildings.

Geohydrology of Well - The well was drilled to 205 ft. deep, 8-inch diameter borehole, with a 6" perforated casing from 175 ft. to 205 ft. The producing formation is Navajo Sandstone. Initial static water level was 56.68 ft. below land surface. The location was chosen as a site where the Navajo Sandstone could be tested midway between Moccasin Spring and Pipe Spring. The presence of the Sevier Fault to the east is believed to have a strong influence on the aquifer.

Management of Well - The well head was contained in a pump house where chlorine is added to the water supply. A new pumphouse containing the chlorinator and meters was built nearby in 1992. A 4-inch water line is connected from the well to a 500,000 gallon reservoir. An automatic control system fills the reservoir on approximately a two day cycle. A two-mile pipeline from the reservoir supplies the Monument and Tribal buildings with flow meters located at major service connections.

Data Record - Initial well construction and test data are reported in McGavock (1974) and Barrett (1971). Pump discharge flow meter readings were recorded by park staff yearly from 1973 to 1982 and monthly thereafter. A digital recorder and pressure transducer was installed by Inglis, NPS Hydrologist, in May, 1990. The record continues to June 1992 when the equipment was removed due to the pumphouse collapse.

Collection - Flow meter data was collected from a Stirling@ 1-1/2 inch flowmeter from 1973 to June 1989 when it was replaced by a Rockwell@ flow meter. Water level data is collected by Omnidata Easylogger@ Field Unit with a Druck 10-psi Pressure transducer and 100 ft. of cable. Data are recorded every 6 hours and downloaded every 3 to 4 months.

Storage - Raw data is stored and manipulated in PC based Lotus@ spreadsheets at the NPS-WRD Fort Collins, CO Office. Water level plots and some hard copy printouts from the spreadsheets are kept in "Hydrologic Folders" located in the NPS-WRD Library. All geohydrologic information pertaining to this water source as well as maps, water quality and other data are kept in this folder. Construction blueprints and water utility information are kept at the NPS Denver Service Center. The original meter records are maintained at the park.

Brief Analysis - Initial monitoring results are published in: Inglis, R.R. 1990, Water Resources Data of Pipe Spring National Monument Area, Arizona, 1977-1989, Technical Report NPS/NRWRD/NRTR-90/02. Plots of recent water level data show pumping drawdown and recovery on two to three day cycles. Typical drawdown is 13 ft. with very quick recovery to within 6 inches of "static levels". Over longer periods of record, "static" water levels are seen to vary slightly, possibly due to seasonal climate or seasonal water demand. Increased pumping in May and June of 1991 coincides with a decline in the "static" levels in the well.

Questions and Ideas - It is desired to know more about the aquifer supplying this well. 1) The recharge area and rate are unknown. 2) The effects of the other wells in the culinary well field are unknown. 3) The effects of present or increased rate of pumping the NPS Culinary Well on the flow of Pipe Spring in unknown.

A hydrogeologic study is needed to determine: 1) aquifer boundaries, 2) water use/withdrawals, and 3) chemistry at various locations.

Pipe Spring National Monument

Station Description

Tribal Culinary Well No. 1

NW 1/4, NW 1/4, Sec.8, T.40 N., R.4 W.

History of Well - This well was drilled by the Kaibab Paiute Tribe after 1971. Culinary Well No. 1 apparently did not produce satisfactory amounts of water and it was replaced by larger, deeper well (Culinary Well No. 2) located about 50 feet away. Culinary Well No. 1 is within the influence of the newer Well No. 2, operated as a municipal well by the Tribe. These wells are located in a culinary well field about 3 1/2 miles north of Pipe Spring on Tribal Land. The well field is composed of three water supply wells.

Purpose of Well - The well was drilled to supply municipal water for the community of Kaibab, but is now replaced by a larger well (Culinary Well No. 2).

Geohydrology of Well - Culinary Well No. 1 has an 8-inch steel casing which extends 2.5 to 3 feet above the ground surface. Electrical wires are fed through conduit through an iron cap on the top of the casing to a submersible pump. No drillers log is available. Steve Turner, of the Tribal Housing Authority, reported that Well No. 1 was used as an observation well for the pump test of Well No. 2 and little drawdown was noted. Presently, water level fluctuation of about 2 feet is observed in Well No. 1 due to pumping in Well No. 2. The aquifer supplying this well (Navajo Sandstone) is believed to supply the NPS Culinary Well. Some information from the NPS well may be applicable to Culinary Well No. 1.

Management of Well - The well was the original water supply for the community of Kaibab and served as a backup water source and monitor station. The purpose of this monitor station was to record water levels in the well field and compare water levels to spring flow in the Monument over several years duration to determine if a regional decline in groundwater levels is taking place.

Data Record - A digital recorder and pressure transducer were installed by Inglis, NPS Hydrologist, in August 1986. The record continues to August, 1992 with two major interruptions, both due to equipment failure. It's record had also been affected by occasional pumping of the well. Data is missing from September 1988 to July 1989, and November 1989 to August 1990. Monitoring equipment was removed in August 1992. The last 30 to 40 days of record is erratic.

Data Collection - Water level data was collected by an Insitu@ Datalogger and pressure transducer until October 1987. This was replaced with a Omnidata Easylogger@ Field Unit with a 50-psi pressure transducer. Data are recorded every 6 hours and downloaded every 3 to 4 months.

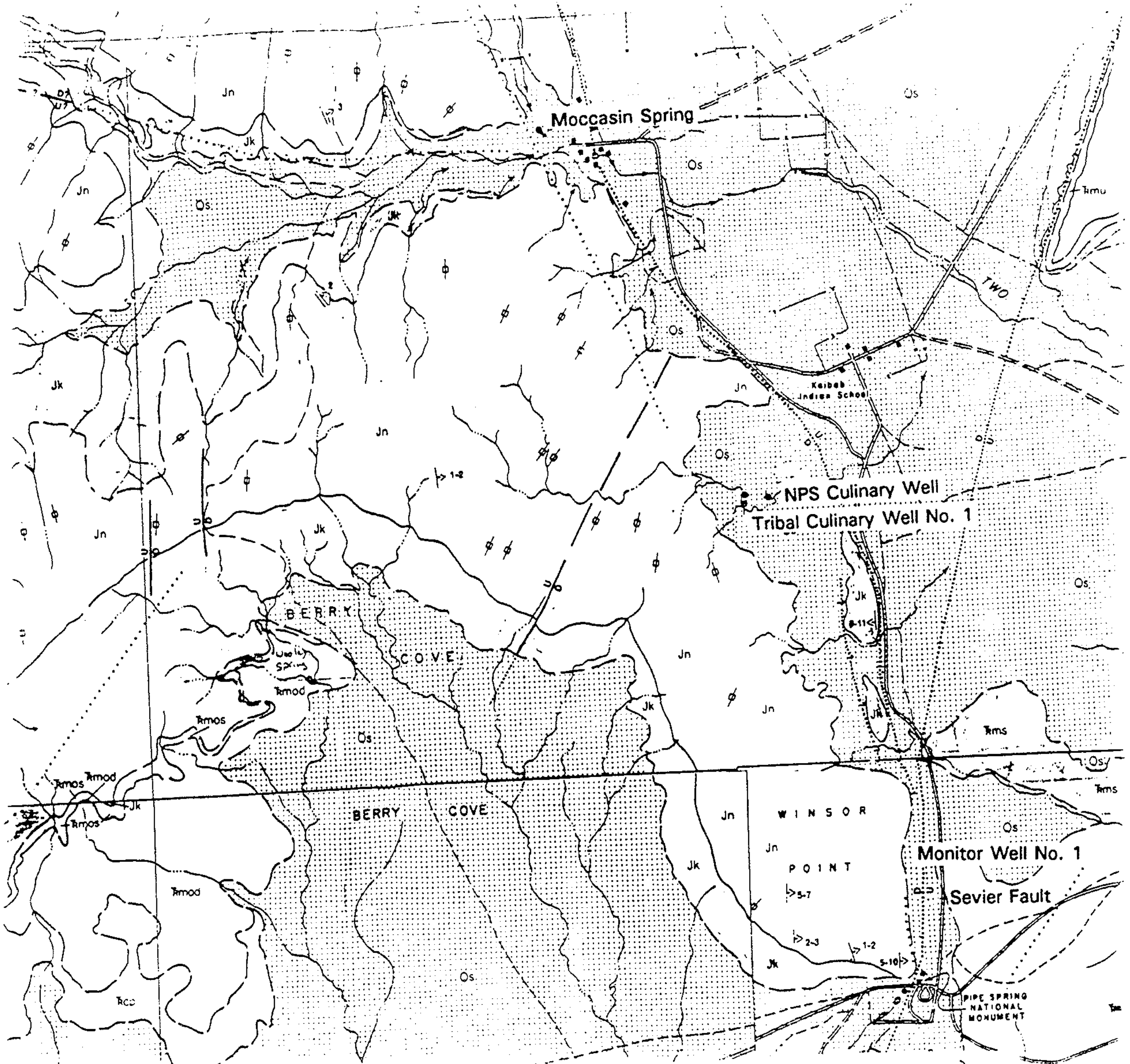
Storage - Raw data is stored and manipulated in PC based Lotus@ spreadsheets at the NPS-WRD Fort Collins, CO Office. Water level plots and some hard copy printouts from the spreadsheets are kept in "Hydrologic Folders" located in the NPS-WRD Library. All geohydrologic information pertaining to this water source as well as maps, water quality and other data are kept in this file.

Brief Analysis - 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. The affect of daily pumping cycle in Culinary Well No. 2 on Well No. 1 is typically between 0.8 and 1.0 feet of drawdown.

Questions and Ideas - The Drillers Log and well construction specifications for Culinary Well No. 1 are needed. How adequate does Well No. 1 represent water levels in the well field is unknown.

APPENDIX B

1:24000 Scale Geologic Map



EXPLANATION

Qs

Undifferentiated sand, residual mantle, slope wash, and alluvium — QUATERNARY

Jn

Navajo sandstone — JURASSIC

Jk

Kayenta formation
May include the Lamb Point tongue of the Navajo sandstone — JURASSIC(?)

Ŧms
Ŧmm
Ŧmv
Ŧml

Moenkopi formation
Shnabkaib member, Ŧms;
Middle red member, Ŧmm;
Virgin limestone member, Ŧmv;
Lower red member and Timpoweap member, undifferentiated, Ŧml
(Upper red member is covered by surficial deposits.) — TRIASSIC

Ŧmos
Ŧmod

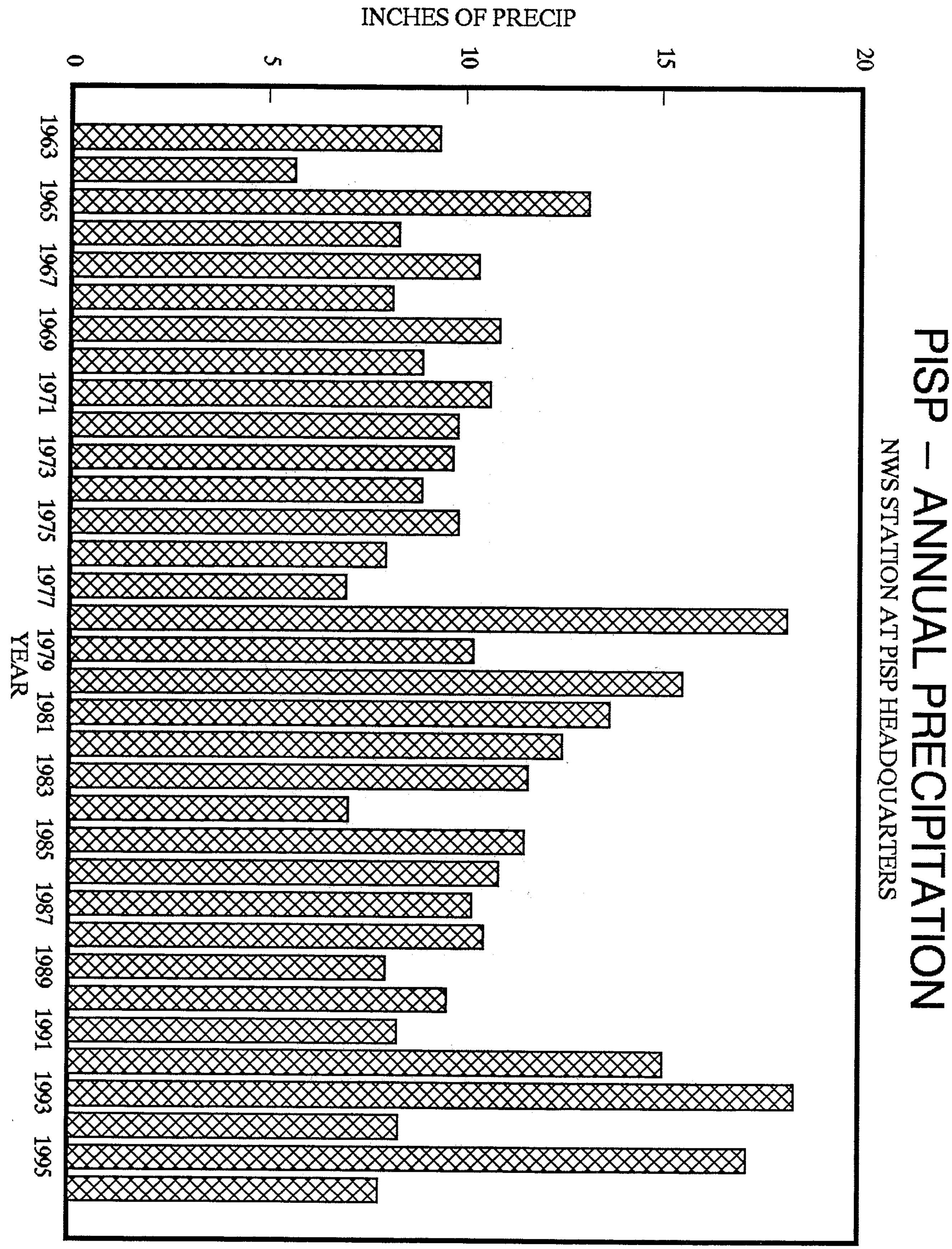
Moenave formation
Springdale sandstone member, Ŧmos;
Dinosaur Canyon sandstone member, Ŧmod — TRIASSIC

D
U
Fault
Dashed where approximately located; dotted where concealed. Questioned where probable. U, upthrown side; D, downthrown side.

From: Hemphill, 1956, Marshall, 1956, and Pillmore, 1956.

APPENDIX C

Plot of Annual Precipitation from 1963 to 1996

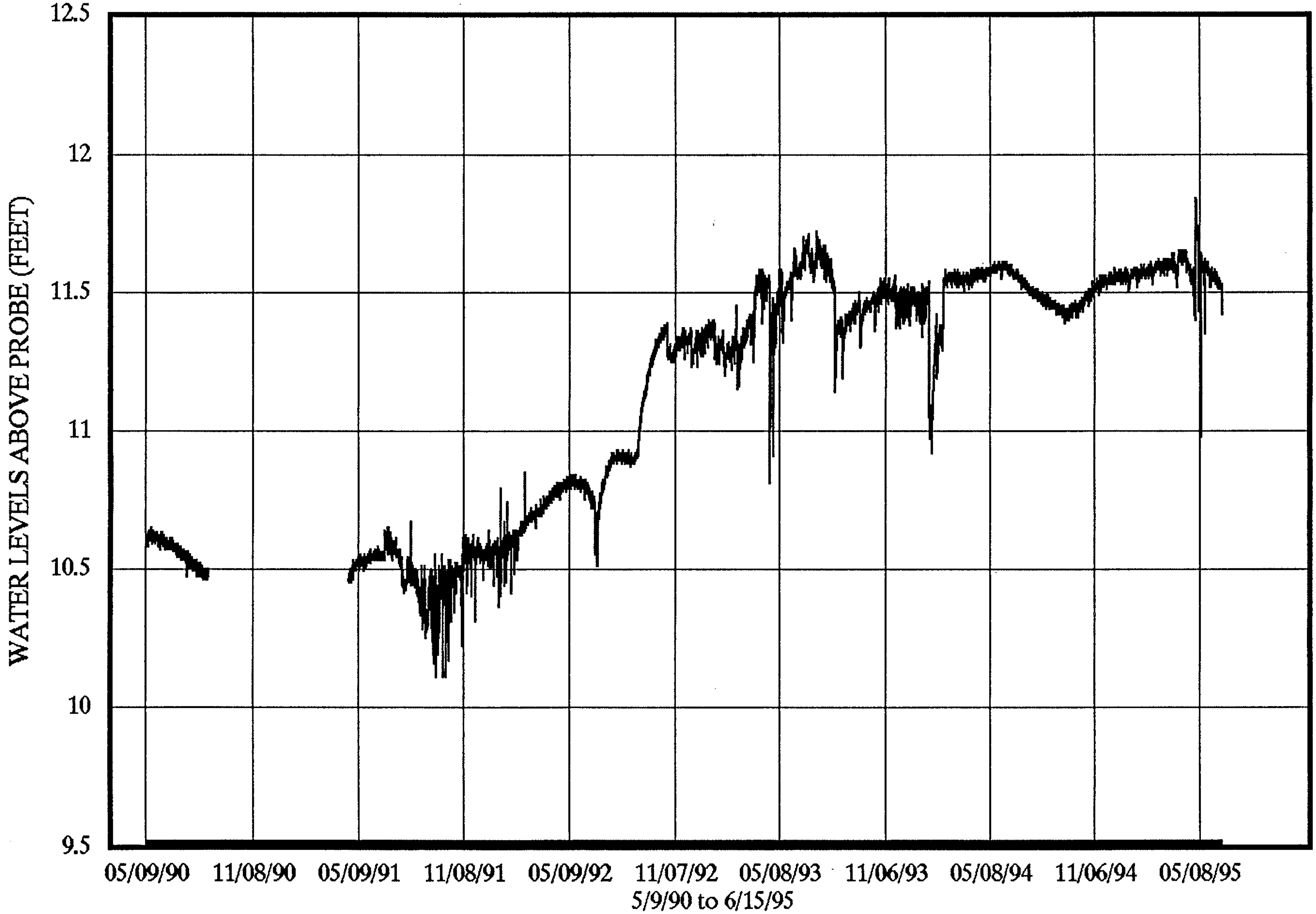

PISP – ANNUAL PRECIPITATION
NWS STATION AT PISP HEADQUARTERS
INCHES OF PRECIP
0
5
10
15
20
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
YEAR

APPENDIX D

Plot of Complete Record of Monitor Well No.1

PISP – MONITOR NO. 1

WATER LEVELS



As the nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-15 July, 1997