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Physical Resources Information and Issues Overview Report

Pipe Spring National Monument

Natural Resource Report NPS/NRPC/WRD/NRR—2009/149

ON THE COVER

Photograph: Historic Ponds at Winsor Castle in Pipe Spring National Monument (Dave Sharrow - National Park Service, 2005)

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal and informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Executive Summary

This *Physical Resources Information and Issues Overview Report* was originally designed to be a *Physical Resources Foundation Report* that supports some of the natural resource information needs for a *General Management Plan* for Pipe Spring National Monument scheduled to start in August 2009. The *Foundation for Park Planning and Management* document (Foundation Document) is required under the *2004 Park Planning Program Standards*, and describes a park's purpose, significance, primary interpretive themes and special mandates, and identifies and analyzes those resources and values determined to warrant primary consideration (*Fundamental* and *Important* Resources and Values) in park planning and management. Physical resources are the group of natural non-biological resources that include air, climate, geology, soils and water resources.

The primary objectives of this report are to:

1. Build from the National Monument's purpose and significance statements and identify the *important* physical resources critical to achieving the Monument's purpose and maintaining its significance.
2. Provide background information for the Monument's *important* physical resources (current condition, related trends, and issues/threats).
3. Define the relevant laws and policies related to physical resources that support management decisions, and identify stakeholder interest.

As the information and data were pulled together, the report expanded beyond the primary objectives of a *Physical Resources Foundation Report*. We did not want to lose the accumulated information and decided to change the report title to better reflect the expanded content, *Physical Resources Information and Issues Overview Report*. These overview reports serve as "stand alone" documents or as a precursor for the *Foundation Document,* GMP, or *Resource Stewardship Strategy* (RSS). This report will be valuable in supporting some elements in all three of these park planning products for the Monument, including implementation plans.

Purpose and Significance of Pipe Spring National Monument

Pipe Spring National Monument is located in northernmost Arizona at the base of the Vermillion Cliffs and overlooking the vast plateaus north of Grand Canyon. It consists of 40 acres of Federal land within the Kaibab Paiute Indian Reservation, established to preserve a historic ranching settlement and the springs that provided the only water on the road between Hurricane Utah and the North Rim of Grand Canyon.

It is important to state prominently that the diminished and, in some cases total loss of flow from the springs, is a primary concern and the restoration of natural spring flow is of paramount importance to the Monument. The following statements from park documents support this concern, but in the years since they have been written, a pattern of continued decline in spring flow raises this to the upmost physical resource concern for the Monument. Several recent scientific studies now point to the cause of the decline in spring flow as anthropogenic and it is likely to continue if current water use patterns persist, to a day in the relatively near future when all spring flow ceases.

Statements of the Mission, Purpose and Resource Significance have been developed for Pipe Spring National Monument for the 1995 Statement for Management (NPS, 1995) and the Long Range Interpretive Plan (NPS, 2000), which are applicable to this Physical Resources Information and Issues Overview Report. The statements or phrases with the most direct application to physical resources are <u>underlined</u>.

Monument Mission

The mission of Pipe Spring National Monument is to:

- Protect the <u>natural</u> and cultural <u>resources</u> of the Monument in an unimpaired state for the enjoyment of the public,
- Increase knowledge and understanding of, and convey the compelling stories of pioneer and American Indian culture, history, and relationships to the <u>natural environment</u>, and,
- <u>Protect the water of the springs to the greatest degree possible, yet allowing use as entitled by law</u>.

Monument Purpose

The purpose of Pipe Spring National Monument is the reason for which the Monument was set aside as part of the National Park System. The purpose statements that follow are based upon legislation, legislative history, and historic needs.

- Serve as a memorial of Western pioneer life, Kaibab Paiute culture, and interactions between Euro-American and Indian cultures,
- <u>Preserve and protect the springs and associated natural environment</u>,
- Preserve, protect, and develop a better understanding of the cultural significance and <u>resources present at the site</u>, and,
- Provide opportunities for visitors to experience, understand, and enjoy the site.

Resource Significance

Significance is summarized in statements that capture the essence of Pipe Spring National Monument's importance to our natural and cultural heritage. Significance statements are not an inventory of significance but rather describe the importance or distinctiveness of the aggregate resources of the park.

- Pipe Spring National Monument provides opportunities to understand the Mormon colonial expansion into Southern Utah and Arizona and its complex interchange with the resident American Indians. The Monument contains historic stone buildings and artifacts related to early pioneer settlement and cattle ranching, including a fortified ranch house known as "Winsor Castle," and the first telegraph station in Arizona.

- The presence of readily available water has provided for a sequence of cultural occupation and use at the site from prehistoric times to the present. The importance of the water source to ancestral Puebloans, Kaibab Paiutes, Mormon pioneers, and others presents a special opportunity for understanding these cultures and interactions among them.
- The springs at Pipe Spring National Monument form a unique natural oasis and riparian area in a large desert region, providing water for use by animals and humans since prehistoric times.
- This setting on the Arizona Strip provides visitors with a sense of isolation and serenity due to the vast and spectacular expanse reminiscent of prehistoric and pioneer eras.

Important Physical Resource Questions and Concerns

Responses to the following questions are used to summarize the most important pieces of information about the Monument's physical resources. These are intended to present a brief highlight for quick reference. A substantial amount of additional information and background is provided in the body of the report, but these specific responses are not repeated in the text in order to avoid redundancy.

WHAT IS THE IMPORTANCE OF PISP PHYSICAL RESOURCES?

Springs are the primary natural resource of the Monument because they are so rare in the area. They are the reason that this location was settled by Archaic and Ancestral Puebloan peoples, and later the Paiute people. Water for drinking and irrigation was essential. Later, Mormon settlers recognized the strategic and economic importance of the springs and settled there, building their most resilient defensive structure directly over one of the springs. The Mormons added livestock watering and butter and cheese making to the uses for the water. When tourism was first becoming popular in the area, travelers from Zion National Park to Grand Canyon, including Director of the National Park Service Stephen Mather, could not help but notice that Pipe Spring was a welcome oasis along a very long otherwise waterless journey. At Mather's encouragement, President Warren G. Harding issued a proclamation creating Pipe Spring National Monument on May 31, 1923. That proclamation specifically mentions the rarity and utility of the springs, and in recognition of their importance, prescribes that the waters be shared with the Kaibab Paiute Indians.

Water from the springs is currently shared in equal thirds by the NPS, Kaibab Paiute Tribe, and the Cattlemen's Association under a formal agreement signed by the Secretary of the Interior in 1933. Under a separate agreement from 1972, the NPS uses the Tribal third of the flow in exchange for providing domestic water for some of the tribal needs from the NPS well on the Kaibab Paiute Reservation.

The springs are an integral part of the interpretation of the site. They are a useful link for tying the stories of natural history, native American history, pioneer history and tourism together. They are the reason that Winsor Castle is located where it is, and the cooling spring water made the making of butter and cheese possible.

Geology is the basis for the landscape that surrounds the Monument, including the high ground of Winsor Point and the vast expanse of plateaus that extend south from Pipe Spring to Grand Canyon. The existence of springs at Winsor Point is a product of a special set of geologic circumstances dictated by the properties of the rock strata and the geologic structures that control groundwater movement.

Seismic Hazard

One of the geologic structures, the Sevier Fault, presents a significant seismic hazard that should be recognized in facility planning and design, and emergency response plans. The surface trace of the fault passes directly through the Monument and under the historic structures. This is a major fault system capable of producing large earthquakes (up to magnitude 7.5) and surface rupture, however, the recurrence interval between events appears to be several thousand years.

Problematic Soils and Geology

Site development in some areas in and near the Monument could encounter geologic layers that contain expansive clays or gypsumiferous layers are present that are prone to collapse. This is a relatively low risk but one that should be considered in the location and design of park structures.

WHAT IS THE ADEQUACY OF THE INFORMATION ON PISP'S EXISTING PHYSICAL RESOURCES?

The physical resources of the Monument might be among the best known and best studied of all NPS units of this size. Geologic maps have been published for the area at a scale of 1:24,000 (Billingsley and others, 2004) and a NPS Geologic Resources Inventory (GRI) Scoping Summary (Graham, 2007) is available. The final GRI report for the Monument has not been completed. Additionally, being near Grand Canyon and other prominent geological features, the area has been the subject of countless geological investigations since Clarence Dutton’s first publication in 1882. The stratigraphy and structural geology is readily apparent and well understood. Five geophysical studies using various techniques have also described the subsurface geology. Dinosaur tracks in the Monument have been the subject of two reports, though, given the spectacular paleontological finds in the region in the same strata, it is likely that much more remains to be found in the Monument and adjacent reservation lands. The Geologic Resources Division has also prepared a Paleontological Resource Inventory and Monitoring report for the Northern Colorado Plateau Network (NPS 2006). Two studies specifically address the movement of the Sevier Fault.

The water resources of Pipe Spring have also been the subject of numerous studies over the past 35 years. These have focused on finding a public water supply, documenting the spring flow and groundwater levels, and investigating the decline of spring flow. Notable among these are the initiation of monitoring and the first compilation of data by Inglis (1990 and 1997), the first comprehensive investigation into the geohydrology of the springs by Truini (1999), and an excellent compilation and analysis of all the work done on the springs by Martin (2007). Regular monthly measurements of spring flow by

Monument Staff began in 1976. Two wells are monitored up gradient from the Monument, one with continuous real-time monitoring, the other monitored quarterly. The Monument has proposed converting the second well to continuous monitoring, and beginning monitoring on an additional well north of the community of Moccasin.

The status of water rights is uncertain primarily due to the complexity of land ownership and water use at the site. There is general agreement among the water users that the spring water is a resource to be shared among the Kaibab Band of Paiute Indians, the Cattlemen's Association, and the NPS.

Soil mapping is adequate for general planning purposes, but given the possible presence of expansive and gypsumiferous soils, an on-site geotechnical investigation is recommended before any construction in or near the Monument.

WHAT ARE THE CURRENT STATE OR CONDITION AND THE RELATED TRENDS OF PISP'S PHYSICAL RESOURCES?

Water flow from the springs is declining and if current trends continue will cease entirely in 10-20 years. Of four named "springs" in the Monument, flow ceased from two springs in 1999 and they remain dry. (There are actually two natural springs, one developed to have two points of discharge "Spring Room Spring" and "Main Spring", the other "West Cabin Spring", and an adit or "qanat" developed as "Tunnel Spring.") The primary cause of the decline has been determined to be pumping of water supply wells of the NPS and Kaibab Paiute Tribe, and private wells in Moccasin. Mitigation involving water conservation has been partly implemented, and there are prospects for some improvement, but the only means for substantial resolution is locating a new groundwater source. Discussions of the possibility of a new groundwater source somewhere on the reservation have been initiated with the tribal government. Such a major decision will take time, and funding for the project remains uncertain.

Though the amount of sampling is very limited, water quality appears to be generally good. An exception is recent samples from the park and tribal culinary wells that had lead levels in excess of state standards. This may be an anomaly and is currently being investigated.

Air Quality

Visibility at the Monument is consistent with the surrounding parks, which have some of the best visibility in North America yet visibility is noticeably degraded from natural conditions. Over the last 30 years the trend is improving somewhat on the clearest days, but little changed on the haziest days. Ozone levels are believed to approach and on rare occasions exceed the 75 ppb standard. The anthropogenic sources are almost entirely distant, and the trend is a gradual deterioration in ozone levels.

Seismic

The seismic risk from the Sevier Fault exists. The potential for a large damaging earthquake is rare but if it were to occur, could be catastrophic t opark reosurces and infrastructure.

Soils
Soils are subject to wind and water erosion in portions of the Monument due to current use and the long history of disturbance. Soils are disturbed in corrals by Monument livestock, in the garden and orchard, and around the Monument grounds by visitor foot traffic. Some of this is inevitable and consistent with historic uses. Otherwise the condition of physical resources is good and does not present a limitation on management planning.

WHAT ARE THE CURRENT OR POTENTIAL THREATS TO THESE RESOURCES?

Loss of Spring Flow from Continued Consumptive Use of Water
The primary threat to the natural resources of the Monument is the decline and eventual loss of spring flow, which is believed to be primarily due to groundwater pumping by the NPS, Kaibab Paiute Band, and Moccasin. Measurements of discharge from the springs show that it is clearly in decline. Discharge from Main Spring and Spring Room Spring ceased in 1999, and the discharge of Tunnel Spring continues to decline. Combined discharge from the spring that was about 40 gallons per minute (gpm) when regular measurements began in the 1970's, has declined to only 8 gpm. Groundwater levels measured in two monitoring wells parallel this decline in discharge. The aquifer that supports all of the producing wells in the area and Pipe Spring is known to be a long U-shaped trough of fractured sandstone called a syncline that extends from north of the community of Moccasin along the Sevier Fault and its West Branch southward to Pipe Spring. It is a long narrow structure measuring roughly 6 miles long and 500-1,000 feet wide. Pipe Spring is at the downstream end of the aquifer, so flow from the springs can be viewed as the overflow emptying from the bottom end of the trough. The Tribal and NPS wells are the closest point to the springs where water is withdrawn, and the amount of water pumped is suspiciously similar in magnitude to the loss of discharge from the springs. Wells farther away in Moccasin are also taking water from this aquifer, but, while the exact amount of pumping there is not known, their greater distance seemingly implies that the impact is less.

The solution is to find a new source of water that would be less impacting, and in the interim to reduce water consumption through conservation. Two alternative locations for new wells are (1) north of Moccasin near the Tribal irrigation well, and (2) near the Arizona-Utah state line and the main Sevier Fault. The former has the advantage that it is in an area where successful wells have been drilled, but the disadvantage is that it would be in the same aquifer that feeds Pipe Spring. The greater distance from the springs, and the fact that it would be north of Moccasin Wash is thought to provide some isolation from the springs. The second alternative has the advantage that it would be completely isolated from the Pipe Spring aquifer, unfortunately it is in an area where no wells have been drilled so the potential for groundwater development is uncertain. Hydrologists are cautiously optimistic about this area because of the presence of porous rock and geologic structures that could convey water from an area of higher precipitation. Another possible means of mitigation would be to discharge treated wastewater above the aquifer.

Potential for New Wells
Arizona water law does not recognize the connection between groundwater and surface waters. Thus land owners could drill new wells into the Pipe Spring aquifer from private lands (in this case the community of Moccasin is the only possibility), or the Tribe could drill additional wells on reservation lands, and increase withdrawals.

Mining on the Arizona Strip
Some threat exists from mining development on the Arizona Strip sited within several miles of the Monument. The primary concern for the Monument is from degradation of the scenic view from dust plumes associated with mine vehicle traffic across the strip, and the limited risk that mine facilities would be built in the viewshed. The threat from mining or oil and gas development in the near vicinity is minimal, because the presence of economically viable minerals is low, and the Kaibab Paiute Band has expressed a desire to avoid mineral development on their lands.

Climate Change
Predictions of warming driven by the accumulation of greenhouse gasses in the atmosphere are made with a high degree of certainty, while predictions for changes in precipitation are much less certain. The following are the consequences most likely to be seen at Pipe Spring and most likely to influence long range planning. Warmer temperatures will reduce the amount of groundwater recharge, and thus spring flow, due to the combined effects of the increase in evaporation and transpiration of moisture, and a reduction in the amount of precipitation that falls as snow. There may be some offset of this if, as some models predict, summer monsoons become stronger or there are more frequent El Niño events. Wildfires on adjacent lands will probably be more numerous and larger because the growing season is longer and temperatures are higher. New plant and animal species, both native and exotic, may invade.

WHO ARE THE STAKEHOLDERS WHO HAVE AN INTEREST IN PISP'S PHYSICAL RESOURCES?

The *Kaibab Band of Paiute Indians* have reservation lands surrounding the Monument and a history of occupation in the area that predates Anglo settlement. The park Visitor Center and Administrative Offices are located on tribal lands, and managed through lease and cooperative agreements. The Monument and Kaibab Paiute Band have a joint water supply system where water is supplied to some tribal residents from the NPS well in exchange for use of the Tribal share of spring water within the Monument by the NPS. Park visitors cross the reservation to reach the Monument, camp in the tribal campground, and shop in the tribal store.

Cattlemen's Association uses a share of water from Pipe Spring, based on agreement and a historic pattern of use, to water livestock several miles away on the Arizona Strip.

U.S. Geological Survey monitors two wells on tribal lands using a combination of USGS and NPS funding. USGS provides quality assurance and control, and maintains data. They also partners with the NPS and Kaibab Paiute Band to conduct investigations into the geology and hydrology of the Pipe Spring aquifer.

Coral Pink Sand Dunes State Park is located about 20 miles north of the Monument in Utah. If the NPS/Tribe develop a new water supply well along the north boundary of the reservation, the state park will be the nearest existing well.

Bureau of Land Management offices in Arizona (Arizona Strip Field Office) and Utah (Kanab Field Office) are responsible for managing public lands outside of the Kaibab Paiute Reservation.

Grand Canyon National Park is also a destination for many Monument visitors. The Monument partners with Grand Canyon NP to issue camping permits for remote parts of the North Rim.

Grand Canyon-Parashant National Monument is located on the Arizona Strip southwest of Pipe Spring. An area of over one million acres is jointly managed by the NPS and BLM. The Pipe Spring visitor center serves as a primary visitor center facility for the Grand Canyon-Parashant National Monument.

Arizona Department of Water Resources manages water rights in the state. The Arizona Water Protection Fund has been, and may be a source for funding of water conservation measures or developing a new well.

Arizona Department of Environmental Quality manages air quality and wastewater disposal in the state.

WHICH LAWS AND POLICIES APPLY TO PISP'S PHYSICAL RESOURCES AND WHAT GUIDANCE DO THE LAWS PROVIDE?

Select legislation and management policies that support physical resource management at the Monument are presented below. Laws that apply to general park management such as NEPA and NHPA are not included. Some additional legislation and management policies where they apply to specific physical resources are included in the body of this report.

Proclamation No. 1663 - May 31, 1923 -[43 Stat. 1913] established Pipe Spring National Monument identifying it as the only spring for "distance of sixty-two miles" on the road from Zion to Grand Canyon. It also specifically identified "a large dwelling place, called 'Winsor Castle.'" The lands were withdrawn from claim or settlement "to serve as a memorial of western pioneer life." The proclamation included specific direction with regard to the use of the springs, "Provided, that in the administration of this Monument, the Indians of the Kaibab Reservation, shall have the privilege of utilizing waters from Pipe Spring for irrigation, stock watering and other purposes, under regulations to be prescribed by the Secretary of the Interior." See Appendix A for the full text of the proclamation.

The *National Park Service Organic Act* of 1916 created the NPS and includes a significant management provision stating that the NPS,

> shall promote and regulate the use of the federal areas known as national parks, monuments, and reservations by such means and measures as conform to the

> fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for future generations.

The *Redwoods Act* of 1978 clarifies that all units of the National Park System must be managed under the NPS Organic Act and further directs,

> the authorization of activities shall be construed and the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress. (16 USC 1a-1)

The *National Parks Omnibus Management Act* of 1998 outlined a strategy to improve the ability of the NPS to provide high-quality resource management, protection, interpretation and research in the national park system.

The 1972 *Federal Water Pollution Control Act*, also known as the *Clean Water Act*, strives to restore and maintain the integrity of U.S. waters. Provisions of this act, as implemented by the State of Arizona, will apply to wastewater disposal and surface water quality at the Monument. Under current interpretation the wetland at West Cabin Spring will not be covered under section 404, while the application to Heart Canyon Wash (the ephemeral channel through the Monument) is uncertain.

The 2009 *Paleontological Resources Protection Act* will serve as a primary authority for the management, protection and interpretation of paleontological resources on NPS lands. The Act specifically provides the NPS with the following seven mandates to enhance stewardship: 1) management and protection of paleontological resources using scientific principles and expertise, 2) establishment of education programs to increase public awareness about the significance of paleontological resources, 3) development of a specific permit for the collection of NPS paleontological resources, 4) calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories, 5) provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts, 6) along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources, and 7) directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act.

2006 *NPS Management Policies* provide NPS management requirements for natural resources, including water resources (water quality, floodplains, wetlands, watershed and stream processes, water rights).

Executive Order 11990: Wetlands Protection requirements for the NPS as Implemented in Directors Order 77-1 and Procedural Manual 77-1. The requirements of this manual will apply to the wetland at West Cabin Spring should there be a proposed action that will disturb that wetland. They also apply to artificial wetlands including Main Spring, ditches and ponds, though these **may**, after consideration under NEPA, be excepted from the requirements for a Statement of Findings. Routine maintenance activities for the artificial wetlands, and their impacts, should be described in the GMP with an assessment of the need for a Statement of Findings.

Executive Order 11988: *Floodplain Management* requirements for the NPS as Implemented in Directors Order 77-2 and Procedural Manual 77-2. The requirements of this manual will apply to any modifications of Heart Canyon Wash.

Arizona Water Law (Arizona Revised statutes Title 45) governs the use of waters in the State of Arizona. They apply to water uses in the Monument, but given the uncertain status of water rights, and the lack of water rights certificates, or claims filed with the state, they will probably only come into play if there is an adjudication of water rights.

Secretarial Regulations for the Division of the Waters of Pipe Springs, November 2, 1933 - formalizes the equal division of the flow from Pipe spring among the NPS, Kaibab Paiute Band and the Cattlemen's Association.

1972 Agreement with Kaibab Paiute Band and *Supplementary Agreement of 1996* - the former is a renewable 25-year agreement wherein the NPS was to drill a well and provide delivery of water to the Tribe in exchange for use of the Tribe's one-third share of the spring flow. Though this agreement expired in 1997, it has been extended on a formal or informal interim basis until a new agreement can be made. The general terms of water use have remained unchanged. The Supplementary Agreement provided for the Tribe to connect a pipeline to the joint NPS/Tribal water system and extended it onto reservation lands for stock watering. See Appendix A for the full text of the Agreements.

WHAT PLANNING DECISIONS AND DESIRES EXIST FOR PISP'S PHYSICAL RESOURCES?

Restoration of the natural discharge from Monument' springs is of paramount importance. Given that it appears that discharge from the springs is declining primarily due to NPS and tribal pumping, it is the desire of the NPS to work with the Kaibab Paiute Band to seek an alternative water supply source that is less impacting to the springs. This desire has been shared with the tribal governance and staff. Any new source would necessarily be on tribal reservation land or piped from sources off of the reservation. The Paiute people are very protective of their land and water resources and are very careful in considering major new approaches such as this.

Monument staff have established a positive working relationship with the Kaibab Paiute Band involving frequent communication (written and verbal) with the tribal government and tribal staff. Almost all physical resource studies have involved work on tribal lands and have been coordinated with them. All unpublished data, and published results are shared with the Tribe, and oral presentations of study results have been made. The band is sensitive to the release of information regarding natural resources on reservation lands.

All new facilities should maximize water conservation, as should retrofits of existing structures. Water consumption should be tracked with a system of meters at strategic locations in the distribution system. Opportunities for xeriscaping should be explored. Similar conservation efforts should be encouraged with the Tribe and Moccasin.

The Secretarial Order of 1933 governing the shared distribution of water from Pipe Spring remains in effect. A pipeline installed by the Cattlemen's Association carries water from the weir box at Tunnel Spring to several livestock watering stations on the Arizona Strip.

The Monument seeks to enter into a new agreement with the Kaibab Paiute Band that extends the terms of the expired water use agreement of 1972.

Agreements are in place with USGS for continued well monitoring but these are subject to future availability of funds.

When Main Spring and Tunnel Spring went dry in 1999, the Monument stabilized the crumbling tunnel of Tunnel Spring and installed a system to pump water up to the Winsor Castle and ponds to maintain the historic appearance. The Monument desires to continue this use so long as water is available.

Acknowledgments

This report is a compilation of many years of dedicated work by others.

The staff of the Monument have taken the lead in identifying the problems facing the springs and obtaining funding for scientific investigations into the hydrogeology and to maintain monitoring wells. The excellent data that we have to document the decline in spring flow is a result of the dedication of Monument staff who have made regular measurements of spring flow 34 years. Specifically, John Hiscock, Terry Strong and Andrea Bornemeier have worked consistently to protect the springs and all resources of the park, to document their condition, and have provided many of the bits of information included in this report.

Scientists from the USGS office on Flagstaff, Arizona have conducted several important studies of the geology and aquifer and have been a ready resource when information or advice was needed. Specifically, Margot Truini's geohydrology report in 1999 provided core insights and a foundation for all that followed, George Billingsley's geologic mapping of the area is second to none, and Jamie Macy has maintained the monitoring wells and conducted geophysical investigations that have answered many of the specific questions about the structural controls on the aquifer.

The NPS Water Resources Division has been a major contributor to advancing our knowledge of Pipe Spring. Rick Inglis began the investigations into the decline of spring flow in the 1980s and initiated groundwater monitoring that continues today. Larry Martin has contributed greatly over the years to our understanding of the hydrogeology of Pipe Spring. This report borrows liberally from his outstanding summary report of 2007. Eric Lord prepared a very thorough summary and analysis of the water rights situation facing the Monument which will be useful guide to a very complex situation. The short summary of water rights that is included in this report is only a tiny part of the larger work.

The members and leadership of the Kaibab Band of Paiute Indians have consistently expressed a concern for the wellbeing of Pipe Spring and have been a cooperative partner in the use and management of the water resources. The Band has permitted the NPS, USGS and other cooperators to have access to Tribal lands to conduct water monitoring and various investigations into the geology and hydrology. Tribal staff have assisted with almost all of the field investigations conducted on Tribal lands. Our current understanding of the groundwater system that supports the springs, and how it is being impacted by our water use would not have been possible without Tribal support.

Several generous people provided a thorough review of the draft report, including John Hiscock, Don Weeks, Dave Thoma, Dusty Perkins, Eric Lord, Larry Martin, Lisa Norby, Pete Biggam, , and Mark Flora. Their thoughtful and insightful comments greatly improved the quality, accuracy and thoroughness of the report and are very much appreciated.

Introduction

Pipe Spring National Monument is located in northernmost Arizona at the base of the Vermillion Cliffs and overlooking the vast plateaus north of Grand Canyon. It consists of 40 acres of Federal land within the Kaibab Paiute Indian Reservation, established to preserve a historic ranching settlement and the springs that provided the only water on the road between Hurricane Utah and the North Rim of Grand Canyon.

Pipe Spring National Monument (PISP) was established in 1923 to preserve the remote historic ranching site that developed around Pipe Spring, and also provided a welcome oasis along a very long and otherwise waterless journey for early tourists. It has been long recognized as a special place of abundance in a vast and dry landscape. The scenery is a product of the geology of this part of the Colorado Plateau north of Grand Canyon and the semiarid climate. The existence of the springs is result of the special geohydrologic circumstances that force water to the surface at this point.

The history and prehistory of settlement and use at this location are intimately tied to the presence of water. Water has been recognized as the most important feature of the site by every individual who visited the site and recorded their thoughts or observations. Over the centuries it has been the subject of admiration, utility and dispute. The springs are prominent in the Monument's enabling legislation and the subject of agreements that remain binding today. For a more detailed summary of the Monument history as related to water see the *Water Resources* section of this document.

There are actually four closely spaced water sources - Main Spring, Spring Room Spring, Tunnel Spring, and West Cabin Spring - that are known collectively as Pipe Spring (see inset box and Figure 1). They all discharge at the base of Winsor Point, the southernmost extent of the Vermilion Cliffs.

The Monument is a 40-acre tract of Federal land that is surrounded by the Kaibab Paiute Reservation, and many aspects of Monument management are conducted in partnership with the Tribe. Some Monument facilities are leased from the Kaibab Paiute Tribe (administrative offices), some are located on tribal lands and operated under agreement (museum collection storage facility (under construction), visitor center, book store, water supply well), and the park shares the flow of the springs with the Tribe. The

How Many "Springs?"

There are four water sources in close proximity at the Monument that are collectively referred to as "Pipe Spring." While each of these are called a spring in common usage, only two are probably natural springs - Spring Room Spring and West Cabin Spring. The pool referred to as Main Spring is probably a man-made feature just outside Winsor Castle that was filled by water conveyed from Spring Room Spring that is inside the structure. The other water source called Tunnel Spring is actually water discharging from a 100 year-old hand dug horizontal well, or more correctly a "qanat" (pronounced ka-nat′ from Arabic). In this report they will all be referred to as "springs" following long common usage, but recognizing that for two of the "springs" this is not technically accurate.

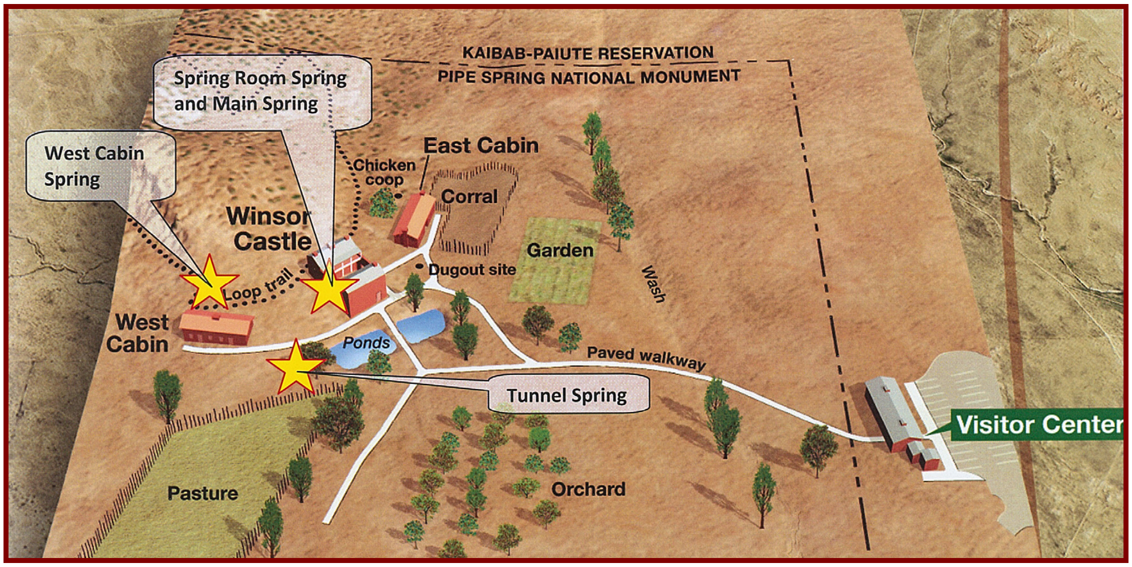

Figure 1. The location of water discharge points at Pipe spring NM, some of which are natural springs, while Tunnel Spring is a man-made development and Main Spring was constructed, but may also have once had some natural flow. (from, Martin 2007).

spring flow is also shared, by agreement, with a local Cattleman's Association that has asserted that it has a history of spring use that pre-dates the Monument.

Physical resources are the group of natural non-biological resources that include climate, air, geology, soils and water resources. Each is described in the sections that follow, including a description of the particular resource, how it is involved in park history and management, and where that resource has a direct influence on park planning. Examples of the latter would include regulatory wetlands, seismic hazards and agreements governing water use.

With the springs being the most significant natural resources of the Monument, and the fact that the diminished and in some cases total loss of flow from the springs is a primary concern, it is important to state prominently that the restoration of natural spring flow is of paramount importance to the Monument.

Objectives of this Report

The Monument is beginning the preparation of a Foundation Document in 2009. This *Physical Resources Information and Issues Overview Report* is designed to support the Monument's Foundation Document which is the formalized precursor to the General Management Plan. The Foundation Report/Document is required under the 2004 Park Planning Program Standards, and is intended to provide an information base and description of the legal and policy direction that form a foundation for park planning. The change in title indicates a more comprehensive presentation of information in this document when compared to a typical Foundation Document.

The primary objectives of this report are to:

1. Build from the National Monument's purpose and significance statements and identify the fundamental and important physical resources critical to achieving the Monument's purpose and maintaining its significance.
2. Provide background information for the fundamental and important physical resources (current condition, related trends, and issues/threats).
3. Define the relevant laws and policies that support management decisions, and identify stakeholder interest.

Purpose and Significance of Pipe Spring National Monument

Statements of the Mission, Purpose and Resource Significance have been developed for Pipe Spring National Monument for the 1995 Statement for Management (NPS, 1995) and the Long Range Interpretive Plan (NPS, 2000). These statements are presented in the Executive Summary of this report and are not duplicated here. In brief, it is the Mission of the Monument to protect natural and cultural resources, to convey the compelling stories of Indian and pioneer interaction with the natural environment, and to protect the water of the springs while allowing the uses entitled by law. The purpose of the Monument includes the preservation and protection of the springs and associated natural environment, development of a better understanding of the cultural significance and resources present at the site, and to provide for visitor experiences, understanding, and enjoyment of the site. The presence of readily available water is central to the cultural occupation and use at the site from prehistoric times to the present. The importance of the water source to ancestral Puebloans, Kaibab Paiutes, Mormon pioneers, and others presents a special opportunity for understanding these cultures and interactions among them. The springs at Pipe Spring National Monument form a unique natural oasis and riparian area in a large desert region, providing water for use by animals and humans since prehistoric times.

It is important to state prominently that the diminished and, in some cases total loss of flow from the springs, is a primary concern for the Monument and the restoration of natural spring flow is of paramount importance. The statements of significance from Monument planning documents from a decade ago do not fully express this concern because the peril to the springs, and the cause of spring flow decline were not fully understood at that time. Several recent scientific studies now point to the cause of the decline in spring flow as anthropogenic and it is likely to continue if current water use patterns persist, to a day in the relatively near future when all spring flow ceases. For a full explanation of the status of spring flow, causes of decline and recommendations for mitigation refer to the sections groundwater and spring flow near the end of this document.

Physical Resources Planning

This *Physical Resources Information and Issues Overview Report* is primarily designed to support development of the Foundation Document for the Monument's planning process, but also provides detailed information to support some of the information needs in other future planning products for the national monument (i.e., GMP, RSS, and Implementation Plans). This section outlines the individual elements of the NPS planning framework (National Park Service, 2004), including the Foundation Document, and describes how this report fits into the framework.

Presently overall park planning is guided by the Park Planning Program Standards issued in 2004. Within this new planning framework, six discrete elements of planning are captured in six planning-related documents (Figure 2).

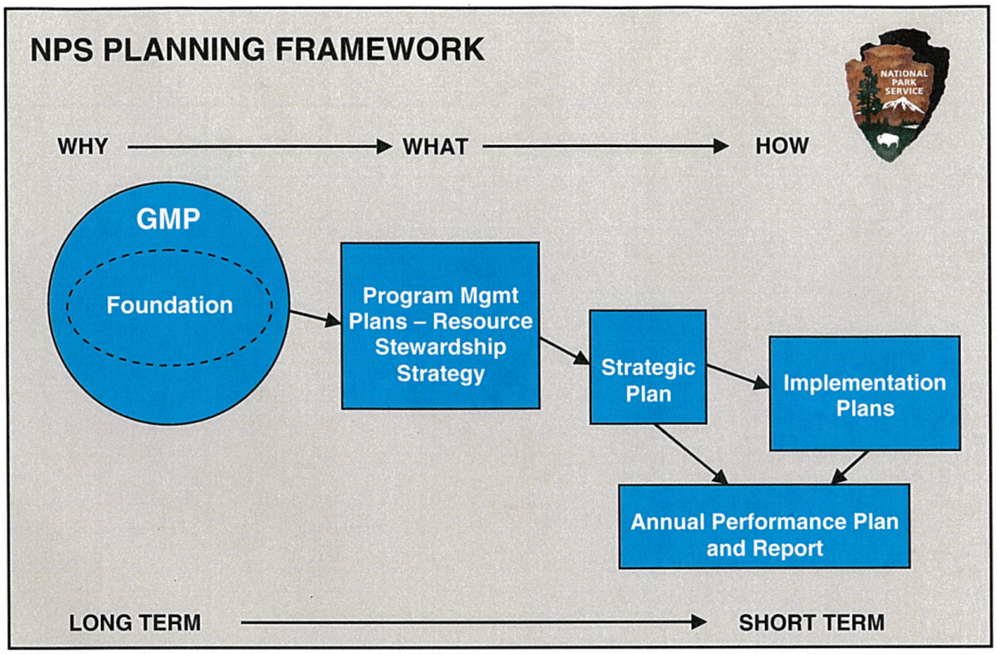

Figure 2. The NPS framework for planning and decision making. Planning documents are indicated by the blue polygons. GMP = General Management Plan.

The *Foundation for Planning and Management* (Foundation) document defines the legal and policy requirements that mandate the park's basic management responsibilities, and identifies and analyzes the resources and values that are fundamental to achieving the park's purpose or otherwise important to park planning and management.

The *General Management Plan* (GMP) uses information from the Foundation document to define broad direction for resource preservation and visitor use in a park, and serves as the basic foundation for park decision-making, including long-term direction for *desired conditions* of park resources and visitor experiences.

The *Program Management Plan* tiers off the GMP, identifying and recommending the best strategies for achieving the desired resource conditions and visitor experiences presented in the GMP. Program planning serves as a bridge to translate the qualitative statements of *desired conditions* established in the GMP into measurable or objective indicators that can be monitored to assess the degree to which the *desired conditions* are being achieved. Based on information obtained through this analysis, comprehensive strategies are developed to achieve the *desired conditions*. The Program Management Plan component for natural and cultural resources is the Resource Stewardship Strategy (Figure 2).

The *Strategic Plan* tiers off the Program Management Plan identifying the highest-priority strategies, including measurable goals that work toward maintaining and/or restoring the park's *desired conditions* over the next 3 to 5 years.

Implementation Plans tier off the Strategic Plan describing in detail (including methods, cost estimates, and schedules) the high-priority actions that will be taken over the next several years to help achieve the *desired conditions* for the park. For example, these would include a Fire Management Plan and an Interpretive Plan.

The *Annual Performance Plan and Report* measures the progress of projects from the Implementation Plan with objectives from the Strategic Plan.

The *Physical Resources Information and Issues Overview Report* provides information on the park's physical resources and analyzes major issues within the context of that information. These reports maintain a flexible design that can serve a park's unique physical resource needs. The report can serve as a "stand alone" document or as a precursor for the Foundation Document, GMP or Resources Stewardship Strategy.

Location and Demography

Pipe Spring National Monument is located in northernmost Arizona at the base of the Vermillion Cliffs and overlooking the vast plateaus north of Grand Canyon (Figure 3). It consists of 40 acres of Federal land within the Kaibab Paiute Indian Reservation established to preserve a historic ranching settlement and the springs that provided the only water on the road between Hurricane, Utah and the North Rim of Grand Canyon.

The Monument is in a very rural setting, where communities are small and widely separated (Figure 4). The Kaibab Band has three communities near the Monument; Kaibab and Juniper with about 25 residents each are 2 miles north, and Red Hill also with about 25 residents is ¼ mile east of the Monument. The non-tribal community of Moccasin, with about 30 residents is located 4 miles north. The nearest larger communities are Fredonia, Arizona (pop. 1,000) and Kanab, Utah (pop. 3,500) that and are about 20 miles east. Several cities and towns in Washington County, UT, including Hurricane, 30 miles west and St. George, 65 miles west, have a combined population of over 140,000.

Land Ownership and Management in the Vicinity

The 40 acres of land that are the Monument are surrounded entirely by the Kaibab Paiute Indian reservation, and the Monument Visitor Center and Administrative Offices are located on Tribal Lands. Another non-Indian inholding is the 480 acres of private land in the community of Moccasin. Both of these inholdings exist by virtue of having been homesteaded prior to the creation of the Indian reservation in 1907. The Kaibab Band of Paiute Indians uses most of their reservation lands for wildlife habitat and guided hunts and low density grazing. They have about 150 acres of agricultural lands north of Kaibab and Moccasin. Water drawn for irrigation is from the same aquifer that supports the springs at Pipe Springs and watering has been irregular over the last several years apparently due to equipment failures and concern over groundwater overuse.

Figure 3. Location Map for Pipe Spring National Monument. The portion of Arizona north of Grand Canyon is called the Arizona Strip.

To the south of the Reservation, and about 2 miles south of the Monument, is a mixture of state and private lands, then several miles where BLM lands predominate. Grand Canyon National Park is about 40 miles south. Land ownership east and west of the reservation is a mixture of state, private and BLM. BLM lands in this part of Arizona are managed out of the Arizona Strip office in St. George Utah. Outside of the communities, the predominant land uses are livestock grazing, wildlife, and dispersed recreation. There is interest in uranium mining on the Arizona strip, with active exploration occurring and a history of mining that fluctuated with the price of uranium.

To the north of the Arizona-Utah state line, and the north boundary of the reservation, federal lands managed by the BLM Kanab Field Office predominate. There are isolated tracts of private and state land. Coral Pink Sand Dunes State Park is located 1 mile north of the state line. It encompasses about seven square miles with uses divided among off-highway vehicle (OHV) use, non-motorized recreation, and resource preservation. OHV use is also popular on BLM and state lands, along with grazing and dispersed recreation. The southeast corner of Zion National Park is about 10 miles north of the state line and 20 miles north of the Monument.

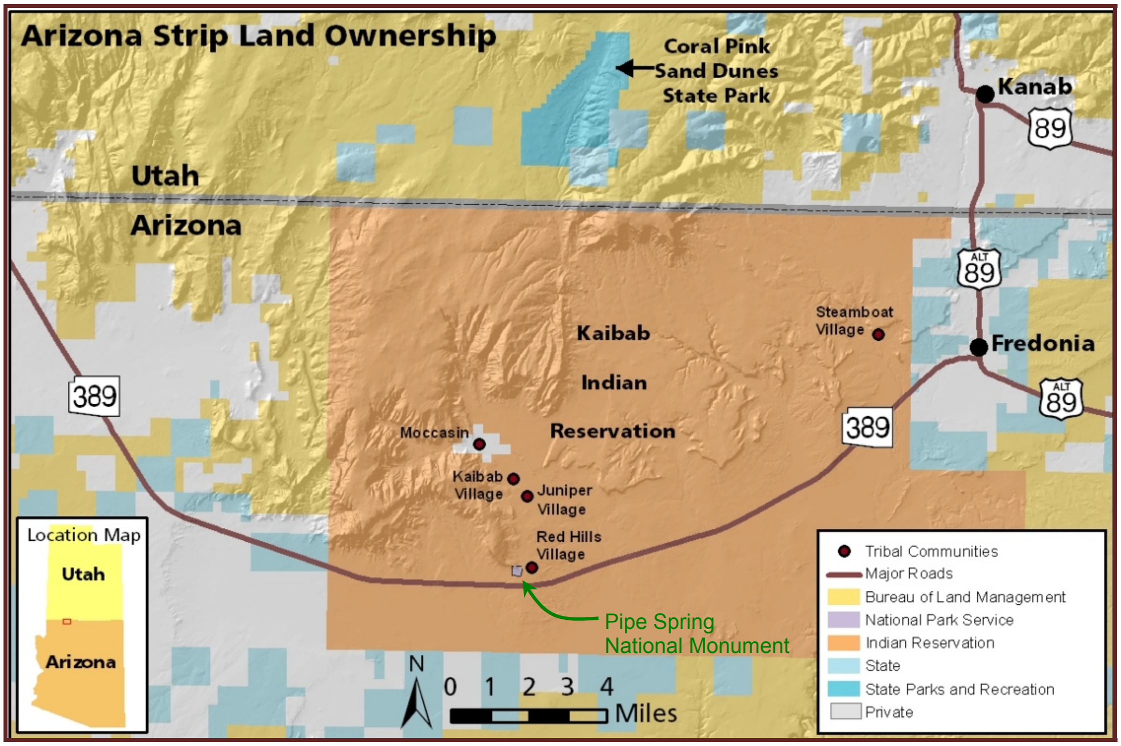

Figure 4. Pipe Spring National Monument's adjacent landownership.

Description of Physical Resources

Climate

Climate Overview

The high desert climate at Pipe Spring is controlled by its location on the Colorado Plateau far from the nearest ocean. Moisture flow from most directions is blocked by intervening mountains so the land is arid, with average annual precipitation totaling 10.86 inches. Due to the general aridity, daily temperatures vary by an average of 32 degrees and daily changes of over 40 degrees are common, particularly during the dry spring months. Summers are hot, however due to an elevation near 5,000 feet the temperature exceeds 100 degrees only on about 9 days per year. Winters are cool, with an average of 138 days when nighttime temperatures drop below freezing, though it is very unusual that day-time temperatures fail to rise above freezing. Winds are often high and gusty at this location on a point overlooking a broad expanse of flat plateaus.

Precipitation is strongly influenced by elevation in this region, so nearby plateaus have higher precipitation including nearby Moccasin Mountain that can receive as much as 18 inches per year and the larger Kaibab Plateau that can receive 25-30 inches a year.

One of the most pronounced characteristics of precipitation at Pipe Spring is a high year-to-year variability. The driest year on record (2002) recorded only 5.33 inches, while 1995 recorded 19.46 inches or about 4 times as much. Most years are drier than average because annual precipitation has a pronounced right skewed distribution resulting from wet years that are few in number but can be very wet and pull the average up above the more numerous dry years. Most precipitation falls during winter months (60%) while 40% falls during the summer. Winter precipitation is strongly influenced by the El Nino/La Nina patterns. Winters during a moderate or strong El Nino have a 60% chance of being wetter than normal, while during La Nina conditions not a single wetter-than-average year has been recorded. Summer precipitation is not influenced by El Nino/La Nina conditions.

Climate Data

The Monument has participated as a National Weather Service Cooperative Observer since 1963 monitoring temperature and precipitation daily. This data is summarized in Appendix B which includes an overall climate summary, a table of monthly precipitation, and a temperature summary table. The record has some gaps when key staff was absent on furlough. For a longer record Kanab provides measurements from as early as 1903. For estimating large precipitation events of various frequency and duration, Point Precipitation Frequency Estimates are also provided in Appendix B.

Typical Seasonal Patterns

Four seasons can be described and these are apparent in Figure 5, depicting mean monthly precipitation.

Summer Monsoon

The monsoon arrives when southerly air flow brings moisture up from western Mexico, typically beginning in mid-July and continuing to mid-September. It is highly variable year-to-year and day-to-day due to the patchy nature of convective storms. Part of this is due to the fact that the circulation is inherently variable, and part to the fact that the Monument is near the western edge of the typical moisture flow. August is the wettest month of the year, though the monsoon accounts for only about 30% of the year-long precipitation total. Some regional studies have shown a contrary pattern where wet summers tend to follow dry winters and vice versa, but this pattern is not strongly apparent in the 80-year record from Zion National Park.

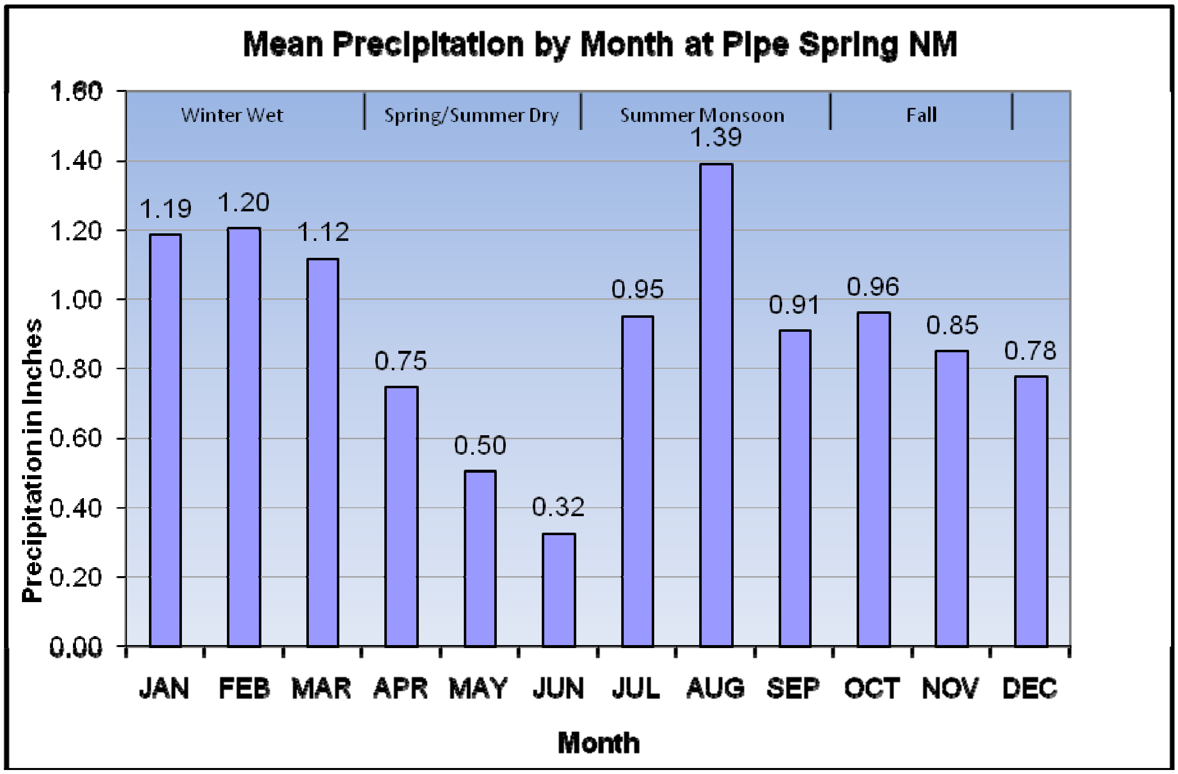

Figure 5. Average monthly precipitation at Pipe Spring for the period 1963 to 2007.

Thunderstorms typically occur in the afternoon and evening as a result of daytime heating of the moist air, but when moisture and instability levels are high they can occur any time of day or night with patchy distribution. Though they are uncommon, some of the largest summer flood events have been produced by storms during the night or early morning. The monsoon flow tends to produce storms in clusters of 2-4 stormy days, interspersed by a few days that are drier. The storms are enhanced by areas of instability, which are not frontal systems or organized low pressure systems, rather they are clusters of storms and instability that can be followed as they move up out of Mexico. Floods from the small watersheds that drain through the Monument are almost exclusively from summer thunderstorms.

Fall
The period from mid September, when the monsoon usually is disrupted by frontal systems, until true winter type storms begin around Thanksgiving, is a typically a period of general stability. In the majority of years this is a fairly dry period. Weeks can go by between storms and even these are fairly weak. So when looking at a "typical" year, the fall is somewhat dry. But, this is also the period of some large but uncommon rainfall events occur when tropical moisture or remnants of tropical storms can be carried into the area, resulting in an increase in the average precipitation.

Winter Storms
Sixty percent of precipitation falls during the winter as the result of frontal systems. Cold snow-producing storms arrive when frontal systems move through the Great Basin. Snowfall amounts are typically light with accumulations from single storms rarely exceeding 4-6 inches. Wetter and somewhat warmer winter storms occur when storm systems move down the California coast and come inland through southern California and Arizona because these can tap sub tropical moisture off the Pacific Ocean. Storms following this southerly pathway are more common during El Nino conditions. Continental high pressure systems can occasionally bring Canadian air masses from the north resulting in a few days of sub-zero nighttime temperatures. Little snow accumulates at Pipe Spring. At higher elevations on Moccasin Mountain snow can accumulate and provides a major part of groundwater recharge.

Spring and Early Summer Dry Season
Winter storms weaken and the storm track moves north beginning in April, to be replaced by a dry and often windy season that lasts until the monsoon begins. This is the most consistent season of the year. Though some small amounts of rain occur in May and June, a month or more with no precipitation is fairly common. Prevailing dry southerly winds can be strong in April and May, and usually taper off once summer heat arrives in June. Temperatures exceed 100 degrees by June and the spring vegetation cures quickly.

Influence of Climate on Planning and Design
Structures should be designed for a maximum freezing depth of 18" and snow loading of 30 pounds per square foot (Dan Thebeau, local contractor, personnel comm.). The very large year-to-year variability in precipitation means that designers should plan for providing supplemental water for at least one growing season for revegetation plantings and some seeding. Fall is typically the best time for planting cool-season plants, and July is best for warm-season species.

Climate Change

Climate change, to the degree that it occurs, will affect park natural resources and operations. Some aspects of climate change have already been observed, with the following examples coming from climate and streamflow records at Zion National Park. Since the mid 1920s:

- The average number of days each year over 100º have increased from 33 to 41,
- The average number of days below freezing each winter have declined from 77 to 69,
- The centroid of spring runoff arrives 8 days earlier each year (May 6 to April 28), and
- The annual mean temperature has increased 1ºF (60.9 to 61.9) and since 1980 is increasing at a rate of .77ºF/decade,

These observations are consistent with what others have found in the western United States.

Though there is much discussion about the magnitude of future climate changes, there is near consensus that anthropogenic warming of 2.7ºF globally has already been observed and there is 95% confidence interval for global temperatures by 2100 rising 5-20°F (IPCC, 2007, Karl and others, 2009). There is also credible evidence that, even if greenhouse gas emissions ended today, 4.5ºF of warming would occur (Ramanathan and Feng, 2008). In a survey of several studies Udall (2007) concludes that warming in the intermountain west would be accompanied by reduced precipitation (0-10%) and an even greater reduction in Colorado River flow (17% - 40%) would occur, with the difference primarily due to greater losses from evapotranspiration.

Applying such projections to a specific site like Pipe Spring requires some inference and should only be made in the most general terms. Table 1 provides a best estimate of the qualitative impacts of expected warming at the Monument. Some of these are obviously counterbalancing, but the net trend is toward warmer and drier conditions. It is valuable to note that even under a warming scenario, day-to-day and year-to-year variability will continue, much as it does today. That is, there will be wetter years and drier years, hotter months and cooler months; it is just that there will be more warmer and drier periods than have been observed in the past.

The primary significance to the Monument is that several effects combine to reduce the amount of groundwater recharge and thus the spring discharge. When winters are warmer less precipitation falls as snow and more falls as rain which is less effective for groundwater recharge. While snow can accumulate through several storms and slowly melt so that water has time to infiltrate into the soil and rock, rainfall often runs off quickly, or separate small events tend to be captured by plant roots more effectively than a single large spring melt. Also, warmer temperatures result in a longer growing season so plants transpire more water. There is some expectation of more frequent El Niño events, when winter precipitation tends to be greater, or a more energetic monsoon flow that might being more summer precipitation, but these are both far less certain than the result of higher temperatures.

Table 1. Qualitative effects of predicted climatic change at Pipe Spring National Monument.

Primary Effect	Secondary Effects	Consequence at PISP	Relative Magnitude of Impact [1]	Relative Certainty [2]
Increased Temperatures, primarily nighttime minimums [c,d]	Increased Temperature	Lower heating cost Higher Cooling Cost	Low	High
	Greater Evapotranspiration	Greater water demand for irrigation	Moderate	High
Longer Warm/Growing Season [d] /Longer fire season [c,d]	More numerous and larger wildfires [c,d]	Possible loss of vegetation, or shift in vegetation type on Moccasin Mountain resulting in an increase in groundwater recharge	Variable by place and time	Moderate
	Greater Evapotranspiration	Greater water demand for irrigation	Low	High
Warmer Winters [e]	Less precipitation falls as snow	Reduction in Groundwater Recharge Reduction in spring flow Reduction in groundwater levels	Moderate	Moderate
	Earlier Snowmelt [e]		Low	High
	Greater Evapotranspiration	Greater water demand for irrigation	Moderate	High
	Shift in Plant and Animal Habitats [b,c,d]	Species shifts up-slope and from south to north	Moderate	Moderate
Decrease in winter/spring precipitation [a,c,d]	Reduced Groundwater Recharge	Reduction in spring flow Reduction in groundwater levels	High	Moderate
Increase in Multi-year droughts [c,d]	Reduced Groundwater Recharge	Reduction in spring flow Reduction in groundwater levels	High	High
	More numerous and larger wildfires [c,d]	Possible loss of vegetation, or shift in veg type on Moccasin Mountain resulting in an increase in groundwater recharge	Variable by place and time	Low
	Widespread water stress in plants, some catastrophic die-offs. [b]	Shift of vegetation types upslope, possible loss of PJ at lower end of range and	Moderate	High
Possible Increase in El Nino Events [d]	Partial off-set of water loss due to warming	Increase in wet winters partly offsets treads toward greater aridity	Moderate	Low
Increase in Strength and possible duration of Monsoon [f]	More Summer Precipitation	More cloudbursts & flood events, somewhat lower summer daily high temperatures; Increase in erosion and sediment transport	High	Low
	More cloudbursts & flood events			

[1] The magnitude of impact if the primary and secondary effects occur. [2] The relative certainty of the occurrence of the primary and secondary effects.

Sources for Climate Projections: [a] Udall, 2007; [b] Bresherars and others, 2005; [c] IPCC, 2007; [d] Karl and others, 2009; [e] USGS, 2005: [f] Castro, 2007. Where no citation is made, the pattern is the conclusion of the author based on general predictions.

Air Resources and Visibility

> "In the Plateau Country the eye is not merely invited but compelled to notice the large things. From any point of vantage the view… is often fifty and sometimes seventy-five miles - and that is a long way to look, especially if there is nothing human in sight. "
>
> Wallace Stegner, Mormon Country 1942

The view from Pipe Spring is extraordinary, extending across the vast expanses of plateaus that extend south to Grand Canyon 35 miles away and a similar distance to the east where the Kaibab Plateau forms the horizon. The canyons of Kanab Creek are discernable to the south east. To the southwest the flattened volcanic dome of Mount Trumbull is clearly visible 40 miles away. Because the intervening ground is generally lower than Winsor Point almost all of this plateau country is visible from the Monument encompassing an estimated 300 square miles.

Such a panoramic view is rare in the United States, and is particularly significant here for three reasons:

1. Visitors can enjoy the esthetic beauty of this lonely landscape and appreciate the great distances to "nearby" communities, and other significant geographic locations,
2. It is clear that one of the attributes that attracted native Americans and Mormon settlers to the location is the commanding view of the surrounding terrain and the security that is provided by the high ground, as well as long distance views of other historically important resource utilization locations, conversely the unfettered and long distance view of the site from other far-distant locations aided long distance travel and transit, and
3. The exceptionally clear air that is normally present in modern times permits this view to be appreciated much as it was by the historic and pre-historic residents of Pipe Spring.

The Monument does not conduct air quality monitoring, relying instead on the monitoring systems at Grand Canyon National Park, Zion National Park, and Bryce Canyon National Park. Trend in air quality conditions are best indicated by patterns at Grand Canyon which has the longest history of monitoring among the nearby parks. All of these larger parks are Class I areas under the Clean Air Act while Pipe Spring NM is a Class II area. Visibility deterioration (from particulates) and ozone are the primary pollutants of concern at the Monument.

Visibility at the Monument is consistent with the surrounding parks, which have some of the best visibility in North America yet visibility is noticeably degraded from natural conditions (NPS, 2008a). Haze from fine particles in the air can obscure distant objects and mute the vibrant colors of nearby cliffs. It does this because the particles scatter light. Visibility at the Monument is about 110 miles on an average day. It is clearest in the winter, averaging 140 miles and generally hazier in the summer when the visibility averages about 80 miles. The difference is due to the way in which the cold, stable air of winter tends to trap many haze-causing pollutants near their source, while the warm air of summer mixes much more allowing the pollutants to travel greater distances. Haze at the Monument comes from sources as far away as southern and central California, southern Arizona and northern Mexico. Nearer sources can include wildfire smoke and windblown dust which can be aggravated by land use practices. Trends show that visibility on the best days at Grand Canyon has improved, but has not changed on the haziest days.

Ozone occasionally approaches or exceeds the standard for human exposure at Zion National Park, and probably also does at the Monument. Exposure indices continue to rise significantly in Grand Canyon. A similar pattern probably occurs at the Monument. Current exposures are within the range known to cause leaf damage in sensitive plant species, but only occasionally violate standards for human health. Given the lack of local large sources of ozone precursors, it is suspected that most of the ozone at the Monument is arriving from distant sources to the south and west of the park. Smoke from wildfires in the region can also contribute to elevated ozone when they occur.

Grand Canyon's wet atmospheric deposition levels of nitrate, ammonium, and sulfate have increased, but the ten year trend is not statistically significant.

Physiography

Regional Setting

The Monument lies within the Colorado Plateau Province, a roughly circular region bordered by the Rocky Mountains on the north and east and the Basin-and-Range Province on the west and south. The Colorado Plateau, named for the Colorado River, is a region of high plateaus and isolated mountains that includes large parts of Arizona, Utah, Colorado, and New Mexico. The Colorado River drains at least 90% of the plateau.

Pipe Spring National Monument is south of Zion National Park and in that portion of Arizona north of the Grand Canyon known as the Arizona Strip (figure 6). This landscape in the southern Colorado Plateau province is dominated by broad expanses of sedimentary rock deposited in countless layers that remain generally horizontal. The uplift of the Colorado Plateau occurred in relatively recent geologic time, and this combined with its carving by the Colorado River and its tributaries forms a landscape that is dominated by the forces of erosion. Layers of rock vary greatly in their color and resistance to erosion with the more resistant layers forming cliffs and the softer rocks forming slopes, plateau caps or flatter terraces. The result is a landscape of broad plateaus several miles wide, with sparse vegetation, separated by multicolored bands of vertical cliffs. Locally, this cliff-terrace-cliff-terrace pattern is so prominent that the area was called the Grand Staircase by the first geologists to explore that area in the late 1800's. From bottom to top, and south to north, the giant steps are called the Chocolate Cliffs (made by the Shinarump Conglomerate) the Vermillion Cliffs (Kayenta Formation and lower Navajo Sandstone), the White Cliffs (upper Navajo Sandstone), the Gray Cliffs (Straight Cliffs Formation), all capped by the Pink Cliffs (the Claron Formation).

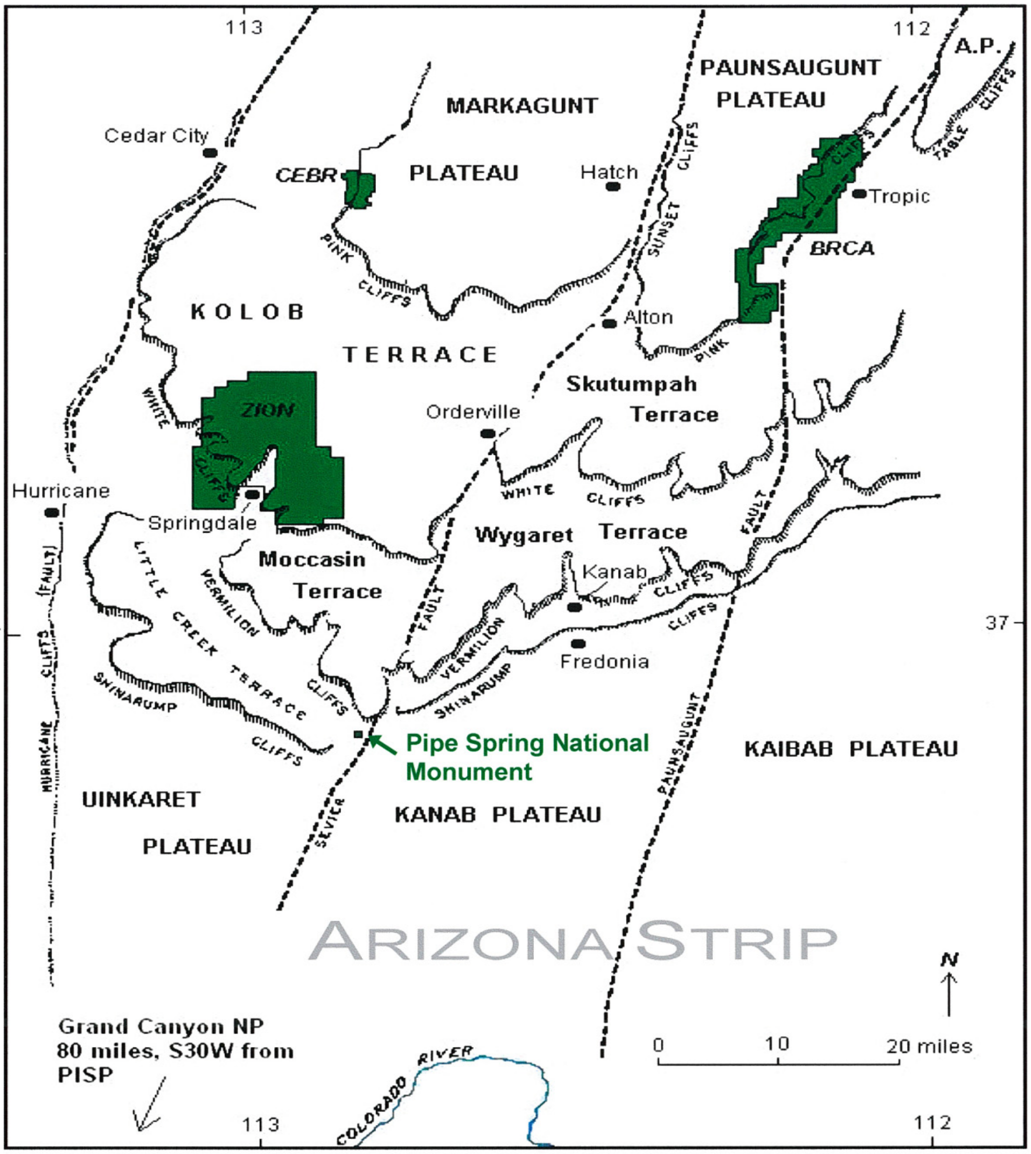

Figure 6. The physiographic setting of Pipe Spring National Monument (PISP) on the Arizona Strip at the intersecting of the Vermillion Cliffs and Sevier Fault. Modified from Gregory (1950) by Graham (2007).

The Monument is located along the escarpment of the Vermillion Cliffs where the plateau of Moccasin Mountain tapers to Winsor Point (Figure 7). Here the sinuous east-west trend of the Vermillion Cliffs is disrupted where the Sevier Fault and Moccasin Monocline cut through it. The cliffs east of the fault are offset 9 miles to the north, leaving Winsor Point as a distinctive southward projection of the Vermillion Cliffs. This high ground projecting into the Arizona Strip is significantly visible for great distances east and west, and therefore, significantly important to pre-historic and historic travelers

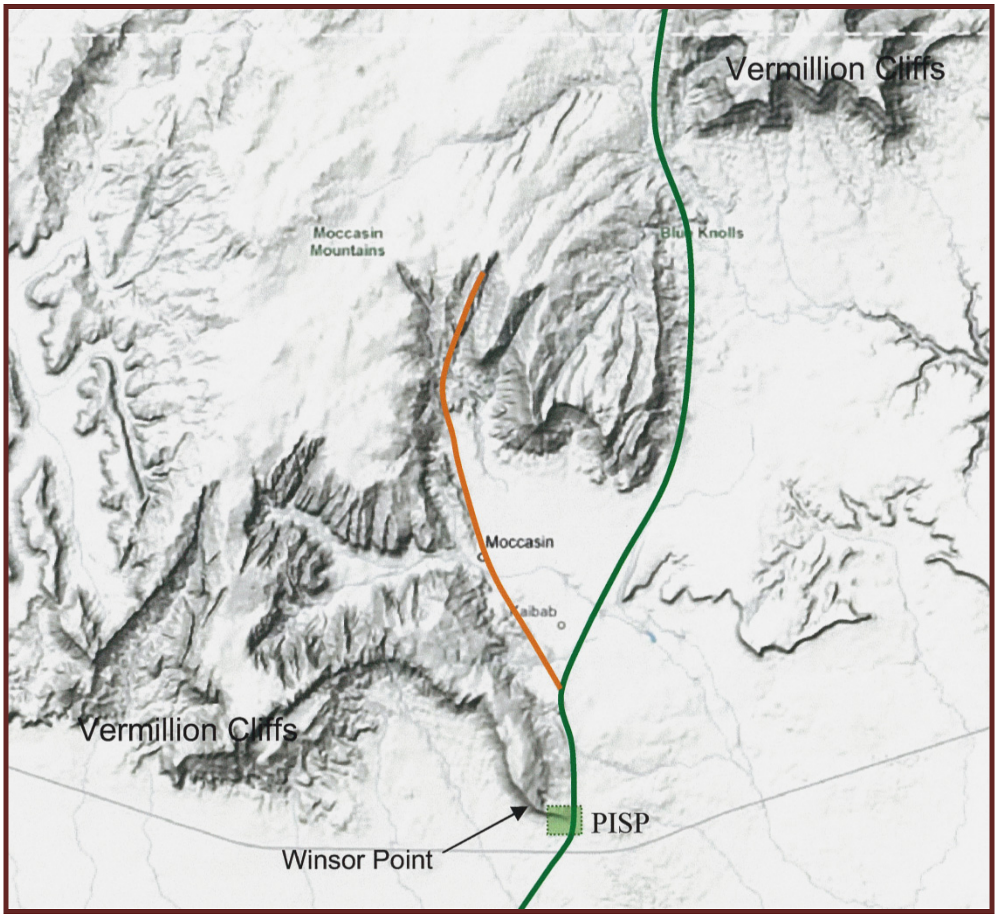

Figure 7. Location of Pipe Spring National Monument at Winsor Point on the Vermillion Cliffs. The main Sevier Fault is shown in green and the West Branch of the Sevier Fault is depicted in orange. (based on mapping by Billingsley and others, 2004)

from a navigation and wayfaring standpoint, especially when coupled with the presence of water at Pipe Springs.

Nearly all of the Colorado Plateau is above 4,000 ft (1,200 m) with the highest plateaus reaching an elevation of 11,000 ft (3,350 m). Elevations at Pipe Spring National Monument range from 4,923 ft (1,501 m) to 5,100 ft (1,554 m).

Geological Resources

All of the important physical and cultural resources of Pipe Spring exist at this location because of the geological setting. The combination of this topographic high that provides a commanding position over the vast plateaus to the south, and the discharge of essential water, is what made Pipe Spring attractive to every civilization that has settled this area. The accumulation, storage and movement of groundwater is controlled by the sequence of sedimentary rock layers, how they have been uplifted and eroded, and how they have been tipped, warped and faulted.

Geological resources are important for management planning at Pipe Spring for three primary reasons:

- Geology is the foundation for the landscape that gives rise to the Monument,
- There are significant seismic hazards associated with this location, and
- Geology controls the accumulation and movement of groundwater that support the springs.

The first and second of these are described in this Geologic Resources section, while the third is included in the Groundwater Section.

Regional Geological Setting

Pipe Spring is located on the southwestern Colorado Plateau Province, an area in the intermountain west known for its vast expanses of cliffs, plateaus and buttes eroded from a thick sequence of sedimentary rocks. The accumulation of sediments began about 550 million years ago when sediments began to accumulate on the basement metamorphic rocks that are exposed in the bottom of the Grand Canyon, Black Canyon of the Gunnison and a few other locations. The accumulation of sediment reached 15,000 feet in thickness, during roughly 500 million years when the area moved slowly up and down, sometimes a little above sea level, sometimes below sea level. During the Paleocene, about 55 million years ago, the area was uplifted beginning a period when little deposition occurred and erosion came to dominate the surface processes. This erosion continues today, and has increased in the last 4.5 million years since the Colorado River began flowing through Grand Canyon.

Pipe Spring sits at the base of a segment of the Vermillion cliffs approximately 1/3 of the way up through the sequence of sedimentary rocks. Below it lies the Paleozoic rock sequence exposed in Grand Canyon. Above it are the spires of Jurassic Sandstone found in Zion Canyon, which are themselves overlain by the multi-colored Cretaceous strata of the Grand Staircase - Escalante National Monument. At the very top of the rock sequence are the Pink Cliffs of Bryce Canyon National Park and Cedar Breaks National Monument. The Vermillion Cliffs are a prominent and scenic step in the staircase that extend from near St. George, Utah to Lees Ferry in north central Arizona.

Geologic Information Base

The geology of Pipe Spring is well described, benefitting from recent geological mapping and geohydrologic and geophysical studies of the aquifer. Additionally, the myriad of studies of the geology of the Grand Canyon and surrounding Colorado Plateau add to the knowledge base. Geological maps of the four quadrangles near the Monument were completed by Billingsley and others (2004) and have been published by the USGS. The Monument has a GIS database of these maps. Two excerpts of the geological map for the vicinity of Pipe Spring are included, a close view of the Monument in Figure 8, and a wider view in Figure 9. The text accompanying this map in Billingsley and others (2004)

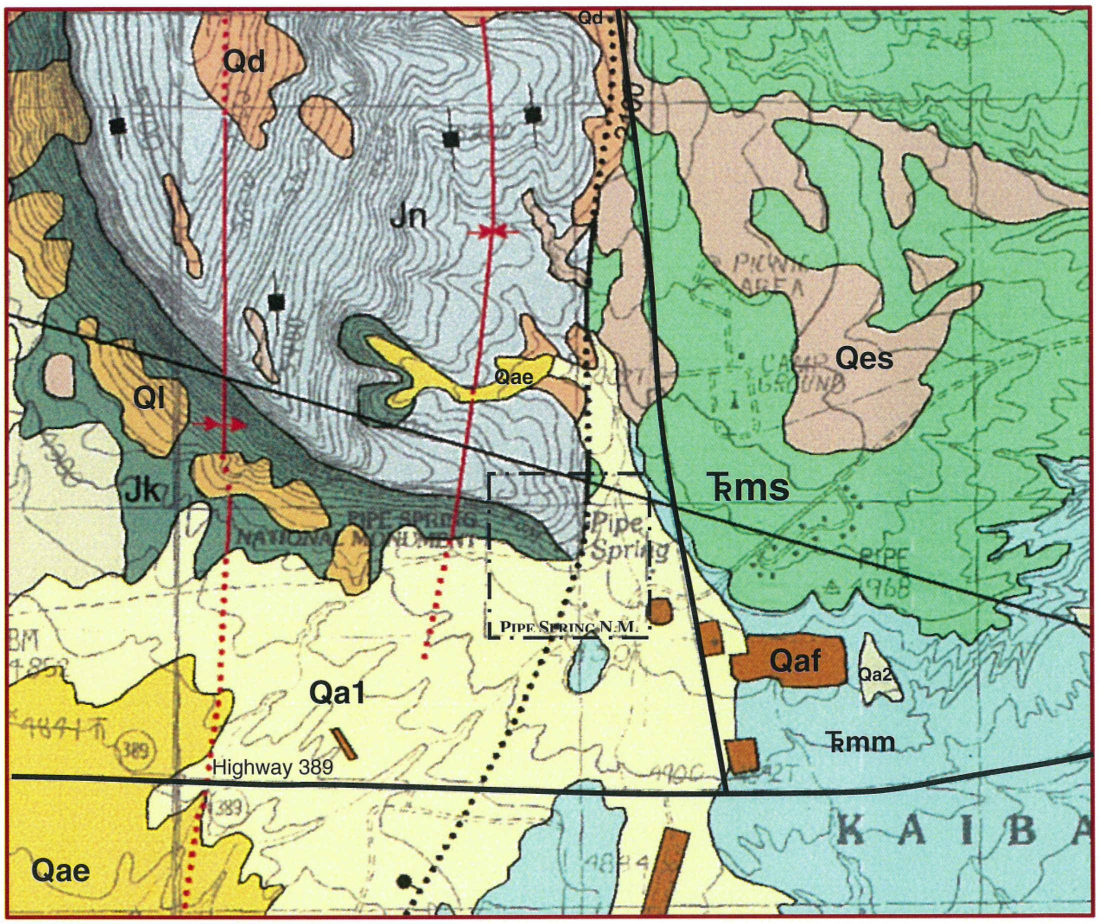

Figure 8. An excerpt of the geological map of Pipe Spring NM and adjacent Kaibab Paiute Indian Reservation (Billingsley and others, 2004). The map units in this view are: Qaf = recent artificial fill, Qes = Eolian sand sheet deposits, Qd = Eolian sand dunes, Qae = mixed eolian and fluvial deposits, Qa1 = young alluvial fan deposits, Qa2 = intermediate age alluvial fan deposits, Ql = landslide deposits, Jn = Navajo sandstone, Jk = Kayenta formation, Ŧms = Shnabkaib member of the Moenkopi formation, Ŧmm = Middle red member of the Moenkopi formation.

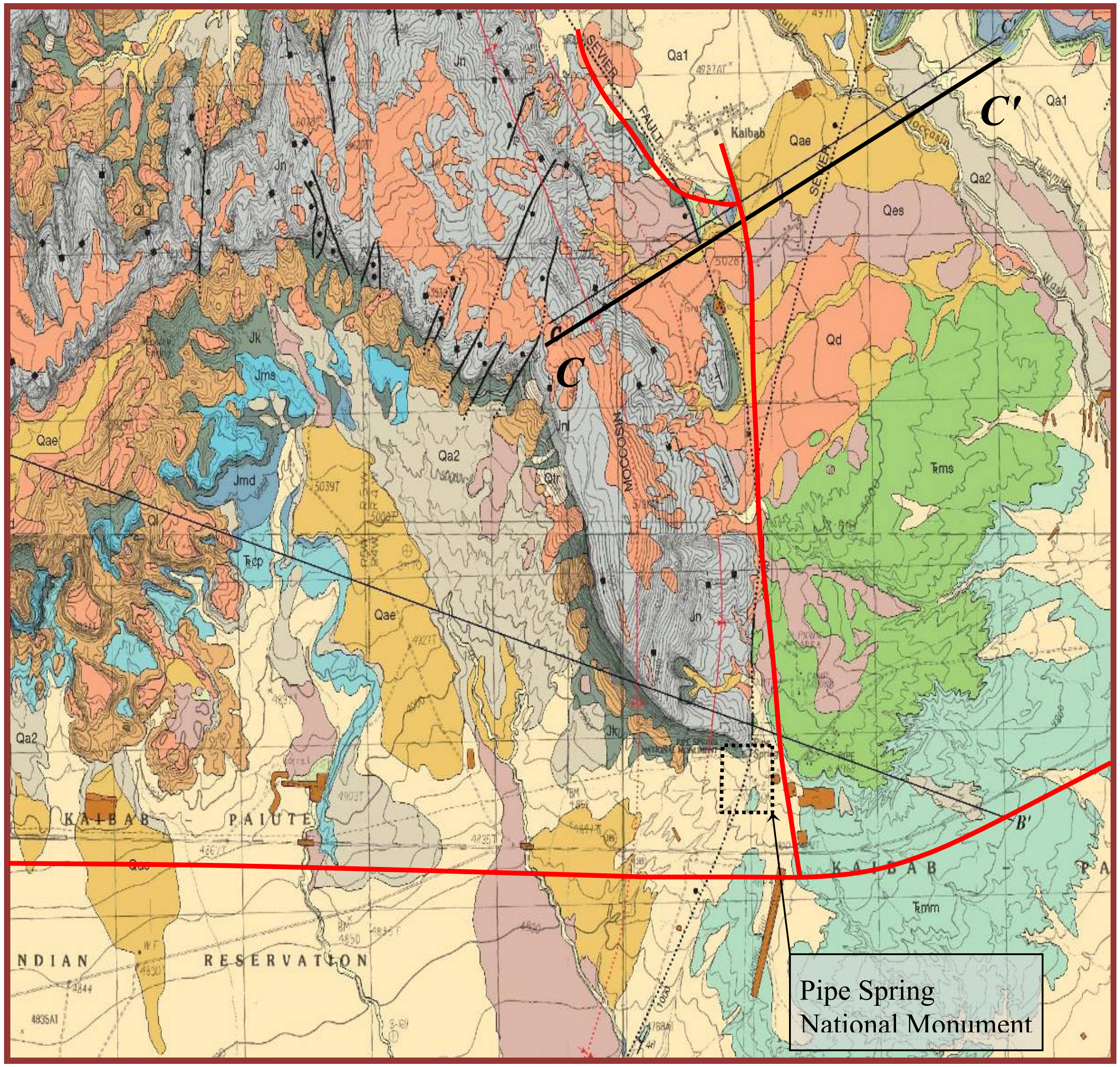

Figure 9. Excerpt of Geologic Map showing the location of cross section along line ***C-C′*** that is depicted in Figure 10 below (modified from Billingsley, 2004).

This image is compressed to show the area surrounding the Monument. For practical use refer to the full sized 1:24,000 scale Geologic Map or Figure 7.

Major Roads

provides a description of area geology and detailed descriptions of each geologic layer (reproduced in Appendix D).

Truini (1999) described the stratigraphy and the influence of rock strata on groundwater flow paths and quality. Lund and others (2008) provide a description of the seismic risk associated with the Sevier Fault to the north, while Fenton and others (2001) investigated the same fault system to the south. A useful description of the geology of Coral Pink Sand Dunes State Park, with relevance to the Monument, is provided by Ford and Gillman (2000). The Draft Geologic Resource Evaluation Report for the Monument (Graham, 2007) provides a description of the area and park geology and discussion of geology-related issues (the Table of Contents of this report is reproduced in Appendix D).

Geology in and near Pipe Spring

Stratigraphy
The significant rock layers exposed in the vicinity of Pipe Spring are described in Table 2 and depicted in Figure 10 as a cross section of geology north of Winsor Point. These layers constitute a 1,000 to 2,000 foot sequence of sedimentary rock of Mesozoic age

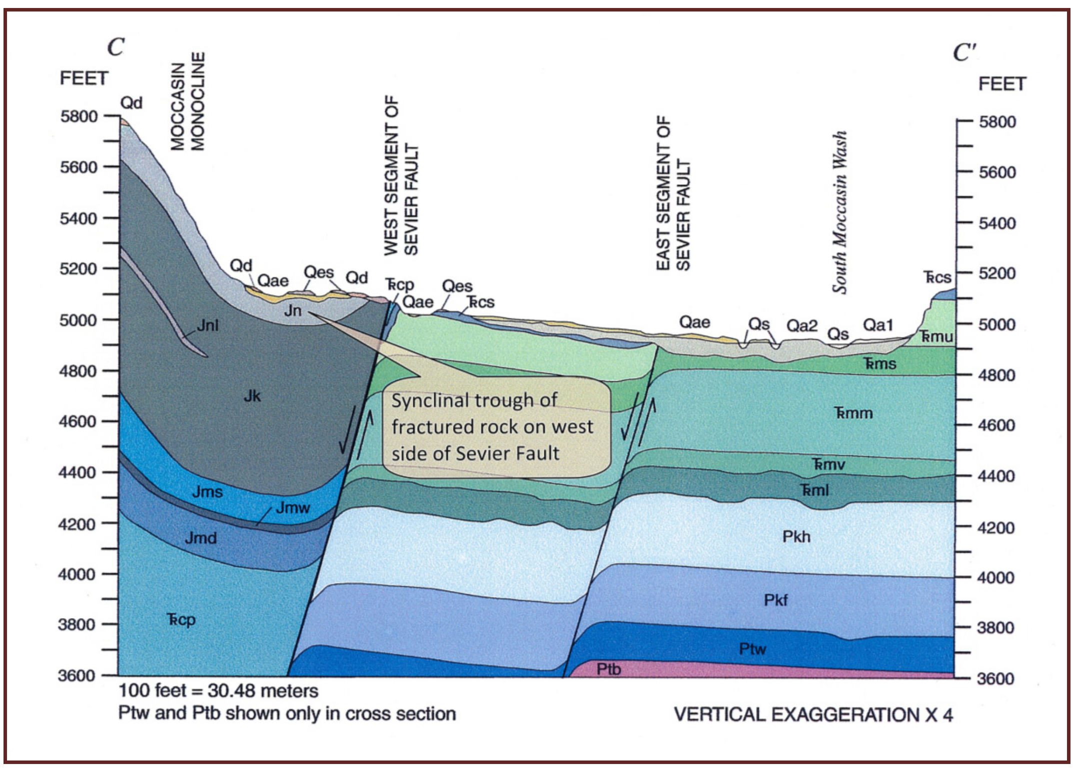

Figure 10. Cross section of geologic strata a short distance north of PISP illustrating the offset of strata across two branches of the Sevier Fault, and the syncline west of the fault (from Billingsley 2004). A brief explanation of symbols for the geologic layers is provided in Table 2, detailed descriptions are provided in Appendix D.

Table 2. Geologic Strata exposed in the vicinity of Pipe Spring National Monument, which are listed from youngest to oldest. (adapted from Graham, 2007 and Billingsley and others 2004) The map units listed correspond with those in Figures 8, 10 and 11. See Appendix D for a detailed description of geologic strata.

Period	Formation (Map Symbols)	Thickness and [Age[1]]	General Description	Exposed within PISP boundary
Quaternary	Young alluvial fans (Qa1)	5-40 ft (1.5-12m) [recent]	Mostly sandy, water deposited alluvium washed off of nearby steep slopes.	Yes
	Various recent surface deposits (Qd, Qae, Qes, Qa1, Qa2 & Qs)	5-40 ft (1.5-12m) [recent]	Several recent deposits of eolian, alluvial and fluvial origin. See Appendix D or Billingsley and others 2004 for a detailed description of these map units	No
Lower Jurassic	Navajo Sandstone, Lamb Point Tongue (Jnl)	0-140 ft (0-43 m) [195 MY]	Fine- to medium-grained sandstone with large-scale cross-beds; grains are rounded and frosted quartz. Massive sandstone derived from dunes. Present in PISP as a cap on top of the Vermillion Cliffs and the top of nearby Moccasin Mountain.	Yes West of Sevier Fault
	Kayenta Formation, main body (Jk)	270-400 ft (82-122 m) [195 MY]	Deep red and light red-brown, slope-forming calcareous mudstone, siltstone and sandstones deposited in rivers and floodplains. Forms the steep slopes and cliffs near the top of the Vermillion Cliffs at PISP.	Yes West of Sevier Fault
	Moenave Formation (Jms, Jmw and Jmd)	295-449 ft (90-137 m) [200 MY]	**Springdale Member (Jms)** - Red-orange sandstones from a capping cliff. **Whitmore Point Member (Jmw)** forms thin lakebed deposits that include distinctive blue-green mudstones. **Dinosaur Canyon Member (Jmd)** is the bottom of the formation and includes thick deposits of red-brown silty sandstones. Deposited mostly from streams with some lake deposits.	No
Upper Triassic	Chinle Formation (₸cp,₸cs)	610-814 ft (186-248 m) [210 MY]	**Petrified Forest Member (₸cp)** - Brilliantly banded white, blue, purple and red, sandstones and claystones. Many contain abundant bentonite clays and quickly weather into badlands with the classic "Painted Desert" badlands appearance with a popcorn surface. **Shinarump Member (₸cs)** - a durable basal cliff of conglomerate and coarse sandstone.	No
Lower Triassic	Moenkopi Formation Shnabkaib Member (₸mu, ₸ms, ₸mm, ₸mv, ₸ml)	770-870 ft (234-265 m) [240 MY]	A thick sequence of red sandstones, siltstone, mudstone, and gypsum beds. It has a gray limestone member near the base. From top to bottom the members are, Upper Red (₸*mu*) Member, Shnabkaib (₸*ms*), Middle Red (₸*mm*), Virgin Limestone (₸*mv*), and Lower Red (₸*ml*). The middle Shnabkaib Member is at the ground surface east of the Sevier Fault where soft thin beds and evaporates form spectacular red and white banded slopes and eroded bare ground.	Yes East of Sevier Fault
Lower Permian	Kaibab Formation (Pkh, Pkw,)	410 ft (125 m) [260 MY]	This hard sandy marine limestone is very resistant to erosion; it forms the rim of Grand Canyon and caps the expansive plateaus to the south of PISP.	No
	Toroweap Fm. (Ptw, Ptb)	300-400 ft (90-120m) [270 MY]	Exposed in Grand Canyon, found only at great depth near Pipe Spring NM.	No

[1]Formation ages are approximate and MY = million years old.

(except Permian Kaibab Formation). Given the relatively small elevation range in the park the number of strata of interest would be very limited, however the 1,500-foot offset of the Sevier Fault brings several more layers into play. Though all these layers are sedimentary in origin, they differ strikingly in appearance and resistance to erosion.

At the bottom of the sequence are the hard sandy limestones of the Kaibab (pronounced kī′–bab) Formation, a very erosion resistant rock that forms the rim of Grand Canyon and caps the wide flat plateaus that extend for many miles south of the Monument. Above that are the soft beds of Moenkopi (pronounced mō′-ĕn-kō′-pē) Formation; some fine outcrops of which can be seen between Pipe Spring and Fredonia. The middle member of the Moenkopi Formation, the Shnabkaib (pronounced shnab′-kīb) is exposed on the surface east of the Monument at the tribal Campground and Service Station. This layer erodes into badlands with an alternating red and white stair-step configuration. Inside of the Monument the soft beds of Moenkopi are covered by a mantle of recent alluvial deposits and soils.

Moving upward, the next two formations, the Chinle (pronounced chin′-lē) Formation and Moenave (pronounced mō′-ĕ-nä′-vē) Formation are not exposed in the Monument because they have been lost to erosion east of the Sevier Fault, and are well below the surface on
The west side. There are some fine exposures visible along Arizona highway 359 five to seven miles west of the Monument. Where they are exposed, the hard pebbly sandstone of the Shinarump (pronounced shin-a-rump′) Member of the Chinle Formation forms a durable short cliff prominently capping the soft slopes of Moenkopi Formation. Above it the bentonitic beds of the petrified forest Member of the Chinle Formation decompose into the classic colorful badlands of the “Painted Desert.” Where the Moenave Formation is exposed it forms orange, pink and gray banded slopes capped by a short (20-30 foot) light red sandstone cliff.

The most obvious rock layer in the Monument is the deep red sandstone and mudstone beds of the Kayenta (pronounced kā-yen′-ta)Formation, that are prominent as the exposed slopes of the Vermillion Cliffs (illustrated in Figure 11). The soft erodible beds that make up most of the Kayenta are protected by the more durable sandstones at the very top of the formation.

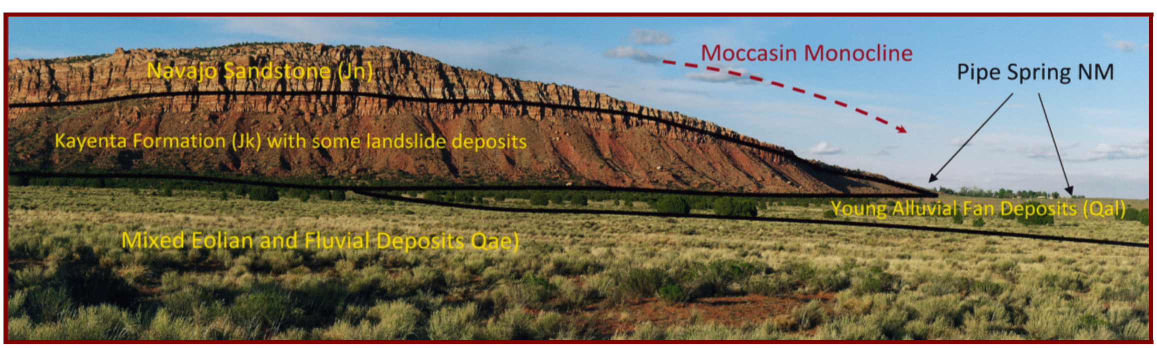

Figure 11. Winsor Point of the Vermillion Cliffs and Pipe Spring National Monument with geologic layers and the Moccasin Monocline highlighted. The photograph is from Arizona highway 359 facing northeast about 1 mile from the Monument.

Over most of their length, the Vermillion Cliffs are capped by a massive vertical wall of Navajo (pronounced nav′-ə-hō′) Sandstone that is from a few hundred to well over 1,000 feet thick. At Pipe Spring however, the Navajo Sandstone is present only as a thin light-colored cap on the top of the Vermillion Cliffs a few tens of feet thick. This particular section of Navajo Sandstone is called the Lamb Point Tongue, named for a prominent point on the Vermillion Cliffs located on tribal lands just 17 miles northeast of the Monument. Its presence is due to the transition between the Kayenta and Navajo being continuous, that is with no time gap or "unconformity." As the Kayenta was being deposited by rivers flowing from the south, a cluster of sand dunes blew in from the north. It was a precursor of things to come, but in this case they just deposited a few feet (0-140′) of light colored crossbedded sands in the area that would eventually extend from the east side of Zion NP to a few miles east of Kanab. Then the rivers returned and deposited another 200 or more feet of Kayenta before the sand dunes moved in to deposit the main body of Navajo Sandstone. So in this area the rock sequence from bottom to top is Kayenta - Navajo - Kayenta - Navajo. On the ground, what has happened is the main body of the Navajo Sandstone and upper most Kayenta (the Tenny Canyon Tongue) are eroded well back from the Vermillion Cliffs leaving a relatively flat bench 20 or more miles wide. What remains at the Monument is a thin cap of the Lamb Point tongue of Navajo Sandstone on top of the main body of Kayenta, and together these form the Vermillion Cliffs.

Structural Geology

Faults and folds in the rock layers have a significant influence on the landscape and management of the area. Faults, folds and joints in the area are described by Billingsley and others (2004) and summarized here. Major structures are depicted in a map view in Figure 8, and in cross section in Figure 10 above and in greater detail in Figure 12 that follows.

The Sevier Fault is the principle structural feature in the map area and forms the boundary between the Uinkaret Plateau west of the fault and the Kanab Plateau east of the fault (Billingsley and others, 1997). The Sevier Fault north of Pipe Spring National Monument generally has a north-south orientation and extends over 100 miles north into central Utah. Fifteen miles north of Pipe Spring NM the fault passes through Coral Pink Sand Dunes State Park and farther north is paralleled by Highway 89. South of the Monument the fault has a slightly southwest-northeast orientation and becomes the Toroweap Fault south of the map area extending across Grand Canyon. Paleozoic and Mesozoic strata have a north-northeast regional dip about 1° to 2° throughout the map area.

Displacement of the rock strata across the Sevier Fault has reversed over geologic time. Very ancient faults at great depth were reactivated by compression of the earth's crust during the building of the Rocky Mountains 40 to 60 million years ago. At that time, rocks to the west of the fault were pushed upward and friction along the fault caused them to be bent downward near the fault. Locally this bending is called the Moccasin Monocline which is visible as the tilting of the rock layers as much as 10º on the east side of Winsor Point and Moccasin Mountain. Much later, beginning about 17 million years ago, the crust was stretched and the Sea of Cortez and basin and range province were formed. Movement along the Sevier Fault reversed and rocks to the west dropped relative to those to the east so that near Pipe Spring they are now as much as 1,300 ft lower than matching layers on the east side of the fault. This movement continues today.

West Segment of the Sevier Fault
A western segment of the Sevier Fault branches from the main fault just north of Pipe Spring National Monument near the tribal recreation center (figures 7 and 12). It extends to the east then north under the community of Moccasin before dying out about 2 miles north. Associated with the west segment is an east-dipping monocline herein referred to as the Moccasin Monocline. At the base of the Moccasin Monocline is a small syncline, or up-warp, that parallels the strike of the monocline. In effect this creates a double flexure of the rock, first a large flex down to the east, then a much smaller bend upward in the immediate vicinity of the fault (figures 10 and 11). This structure is significant because the small syncline of fractured rock forms the main structure where groundwater is collected, stored and transmitted to Pipe Spring (see the groundwater section below for more detail).

The monocline and syncline extend through Pipe Spring National Monument and gradually die out to the southwest. These structures, while very visible north of the Monument, are almost invisible to the south because the strata are positioned with soft erodible rocks on both sides of the fault. The monocline, syncline, and Sevier Fault all parallel the west side of the paved road between Pipe Spring National Monument and Moccasin, Arizona.

Geologic Hazards

Rockfall
Rockfall is a hazard along the slopes of the Vermillion Cliffs from the West Cabin westward to the Monument boundary. Park facilities in the hazard area are the southern leg of the Ridge Trail and the boundary fence. Though this is an actively eroding escarpment in a geologic time frame, the magnitude of the hazard given current activity along the escarpment (hiking) is low, and consistent with trails in many other NPS units. Placement of any new facilities in this area that would involve longer occupancy should be avoided.

Seismic - The Sevier Fault
The seismic risk in the Monument is significant. The small 40-acre tract of the Monument is bisected by the surface trace of the Sevier Fault, a major fault system extending for over 100 miles to the north, and 100 miles south across Grand Canyon where it is called the Toroweap Fault. This fault is typical of several large fault systems on the western Colorado Plateau where movement along the faults is breaking the landscape in to large blocks, each block is down-dropped down along a fault on its east side, and up-thrown along a similar fault on its west side. The blocks are being tilted 1 to 2^{o} up to the west.

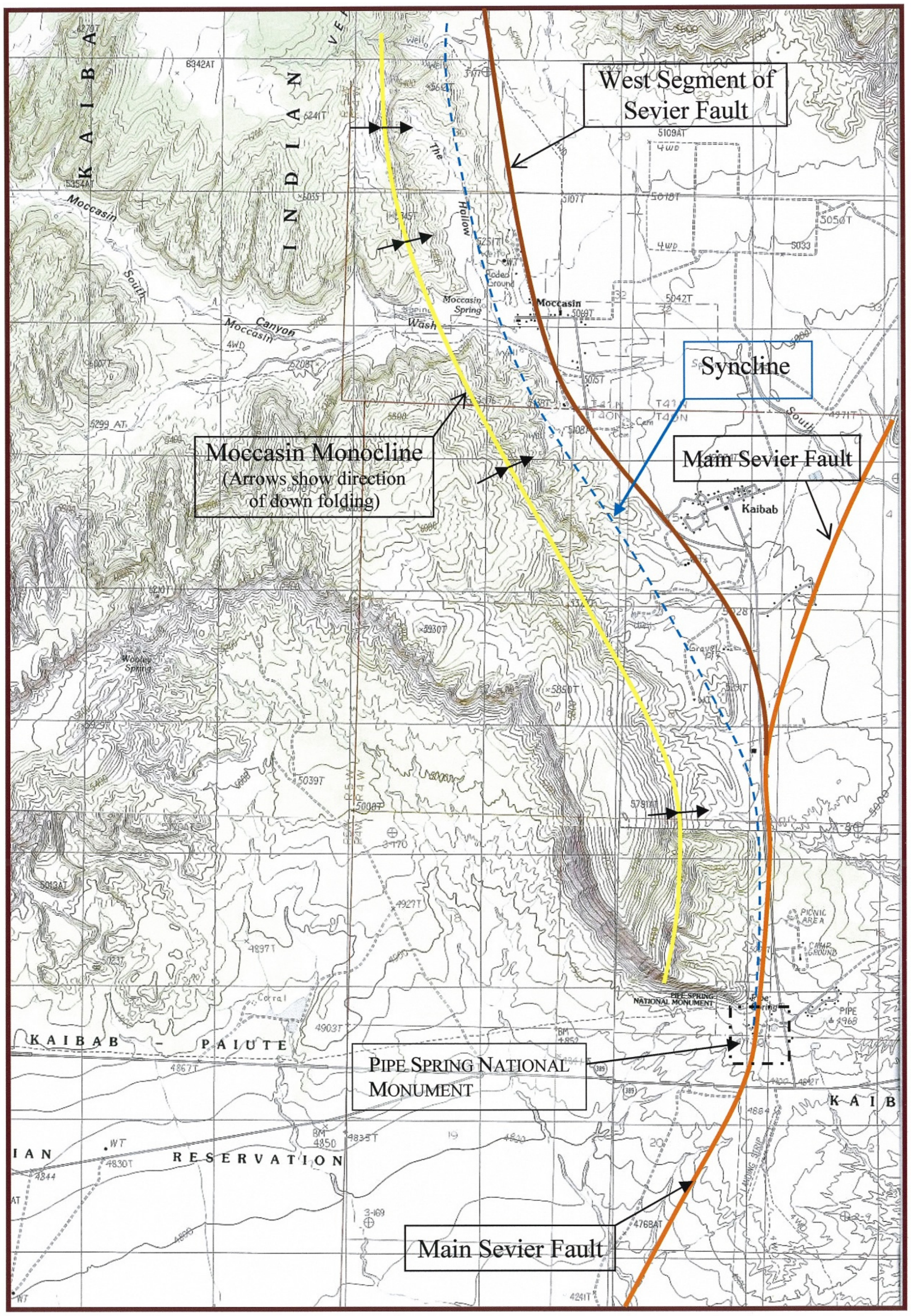

Figure 12. Map of the vicinity of Pipe Spring showing the Sevier Fault and other geologic structures.

These long north-south blocks are each given two names, one for the high plateaus in Utah and a different one for the lower plateaus in Arizona. These long north-south blocks are each given two names, one for the high plateaus in Utah and a different one for the lower plateaus in Arizona. From east to west they are; the Aquarius / Kaibab Plateaus, Paunsaugunt / Kanab Plateaus, Markagunt / Uinkaret Plateau, and (only in Arizona) the Shivwits Plateau. The respective dividing faults are the Paunsaugunt Fault, Sevier Fault, Hurricane Fault, and Grand Wash Fault. In each case, the break is a "normal" fault where the west side has moved downward relative to the east. The slip face of the fault is steeply tilted at the surface (50º - 60º) and gradually flattens at great depth near the boundary where the earth's crust transitions from brittle above to plastic below.

Displacement on the Sevier Fault in the Monument is 1,500 to 2,000 feet (Billingsley and others, 2004). It is believed that this fault has been active for 12-15 million years and is coincident with the stretching of the Basin and Range Province to the west. Studies by the Utah Geological Survey (Knudsen and Lund, 2007) found no recent fault scarps in unconsolidated surface deposits along the Utah portion of the fault. Based on the displacement of dated basalt lava flows across the fault they estimated vertical slip rates of 0.38 - 0.44 mm/year over the last 5 million years, and 0.05-0.07 mm/year over the last 0.5 million years. During recent geologic time (the Quaternary period) the amount of movement on the fault appears to be less on the fault segment near the Monument than on segments to the north near Panguich, UT, or to the south at Grand Canyon.

The surface expression of the Sevier Fault at Pipe Spring is contrary to what might be expected and also contrary to how these faults appear over most of their length. Where typically the up-thrown side of the fault forms a prominent escarpment rising over the down-thrown side, at Pipe Spring the up-thrown side is lower and flatter, while the down-thrown side is higher gradually climbing up the side of Winsor Point. This juxtaposition occurs because, while the resistant cliff-forming rock layers east of the fault have been lifted about 2,000 feet, they have also been eroded away exposing the very soft Moenkopi Formation. The more resistant Navajo Sandstone is at the surface on the west side of the fault so in this place, at this time, it forms the high terrain. (A very similar situation exists at Bryce Canyon looking down to the east across "raised" strata on the other side of the Paunsaugunt Fault.) The trace of the Sevier Fault is visible as the base of the hill extending north of the Winsor Castle through the chicken coop.

Seismic Risk: The west corner of Winsor Castle is on the west (downward moving) side of the Sevier Fault, while the east corner may well be on the east (upward moving) side of the fault. Since this is an active fault, this structure and all in the vicinity are an area of high seismic risk from shaking and surface rupture during large events, and surface deformation. Obviously, when movement occurs on this fault, powerful shaking and possible surface displacement would be very destructive. The entire park is within the zone of potential deformation.

Recent work by Lund and others (2008) on the Sevier Fault in Utah, and Fenton and others (2001) on the Arizona segment in Grand Canyon result in estimated vertical slip rates on the fault of .36 mm/year and 0.11 mm/year respectively. To put this in perspective, these rates are similar to those for the Hurricane Fault, where the seismic hazard is more widely recognized, about 1/3 the rate of the Wasatch and Teton Faults and 1/100th the slip rate of the San Andreas Fault. It is estimated that this fault is capable of producing a magnitude 7.3 - 7.5 earthquake. Estimating the recurrence interval of such large events includes considerable uncertainty because, at these low slip rates, it takes many years to build up sufficient slip (estimated at 2 meters) to produce a major surface-rupturing earthquake. The time interval between large earthquakes (magnitude 6.5-7.5) ranges from approximately once every 5,000 to 33,000 years (Lund and others, 2008). So while large quakes occur, they are infrequent. The lack of a surface scarp in the the Monument vicinity indicates that it has been a very long time since a large quake has occurred.

The Universal Building Code (UBC) Seismic Zone Maps place this area in Class 2B, however, given the immediate proximity to a major fault, and the very general nature of the UBC maps, seismic Class 3 is more appropriate. Predicted horizontal acceleration rates for a 2, 5 and 10% chance of occurring in 50-years are presented in Table 3.

Table 3. Estimation of seismic risk as represented by the probabilistic occurrence of horizontal acceleration during seismic events at Pipe Spring National Monument from USGS National Seismic Hazard Maps (Peterson and others, 2008a)

Type of Movement	Structures Most Affected	Acceleration as a fraction of g Probability of Occurrence in 50 years		
		2%	5%	10%
Long Period (1 second, 1Hz)	Multi Story Buildings	.12	.08	.05
Short Period (0.2 second, 5Hz)	One or few story Buildings	.40	.26	.17
Peak Horizontal Acceleration		.17	.10	.07

Mining and Mineral Development

There has been relatively little mining activity in the area because the sedimentary rocks have low concentrations of valuable minerals, and with the exception of breccia pipes, have undergone little thermal or chemical alteration necessary for the concentration of minerals. The most common mining activities have been scattered small quarries for mineral materials such as building stone, gravel and flagstone, and borrow pits.

A notable exception to the above is the presence of breccia pipes in the Paleozoic and Triassic strata around Grand Canyon which is the largest breccia-pipe-hosted uranium province in the world (Wenrich and others, 1994). These are vertical collapse features that penetrate several of the horizontal rock layers. The pipes are typically cylindrical in shape, and about fifty to several hundred feet in diameter. They bottom in the Redwall Limestone and can extend upward 3,000 feet or more to the Kaibab Limestone and beyond. They originate as a karst void in the Redwall Limestone that collapses progressively upward until the void is filled with rubble. Groundwater moving through the rock at some time in the past has deposited valuable minerals, notably copper, silver, uranium, and vanadium in less than 5% of the pipes. The ore bodies are generally small but some are very high grade (Billingsley and others, 1997). Breccia pipes have been mined sporadically since the late 1800's, at first for copper and silver, then after World War II for uranium. The level of mining activity has fluctuated greatly with the price of the minerals. There was a flurry of uranium mining activity on the Arizona Strip in the 1970's and 1980's when eight breccia pipe ore bodies were mined with production totaling approximately 19 million pounds of U_3O_8 (Uranium Producers of America, 2009). The price of uranium fell and there was essentially no mining or exploration for about a decade. Then in recent years the price has climbed and a large amount of exploration has resumed and existing mines that had suspended operations have reopened. The claims are concentrated in an area 7 to 30 miles south and southeast of the Monument.

Uranium Mines in this area have been underground mines and the surface workings are relatively small with a disturbed area of about 20 acres each and an operational life of one to two decades. Concerns for impacts to Pipe Spring NM are primarily associated with visible dust plumes created by mining vehicles on the dirt roads in the viewshed, and exploratory drill rigs or nighttime lighting that could be visible from Monument viewpoints. The threat of surface or groundwater contamination in the Monument nonexistent because the mine workings and ore bodies are well above the groundwater table, and the groundwater below the mines is well below and isolated from the small perched aquifer the feeds Pipe Spring.

The threat from mining or oil and gas development in the near vicinity is minimal, because the presence of economically viable minerals is low, and the Kaibab Paiute Band has expressed a desire to avoid mineral development on their lands.

Paleontology

The three tridactyl dinosaur footprints (Figure 13) preserved at Pipe Spring National Monument are in orange-red cross-bedded sandstone 2 m (6 ft) near the contact between the Early Jurassic Navajo Sandstone and Kayenta Formation (Santucci and others 1998; Cuffey and others, 1998). First reported by Stokes (1988), the tracks are located on a mesa behind the visitor center. Preservation is poor, but the footprints have been identified as a species belonging to *Eubrontes*, a name which means "true thunder." Reasonable possibilities for the Pipe Spring footprints include *Eubrontes approximatus*, *Eubrontes divaricatus*, *Eubrontes giganteus*, *Eubrontes platypus*, or *Eubrontes tuberatus* (Cuffey and others, 1998).

Eubrontes genera are known only from fossilized footprints. No skeletal remains have ever been found associated with *Eubrontes* tracks either at Pipe Spring or any other site where Eubrontes' prints have been discovered (Cuffey and others, 1998). The size of the tracks at Pipe Spring suggests that they are the prints of a moderately large theropod. The best-preserved print at Pipe Spring National Monument (Figure 13) is 30 cm (12 in) long from toe-tip to heel and about as wide between the two lateral toes' tips.

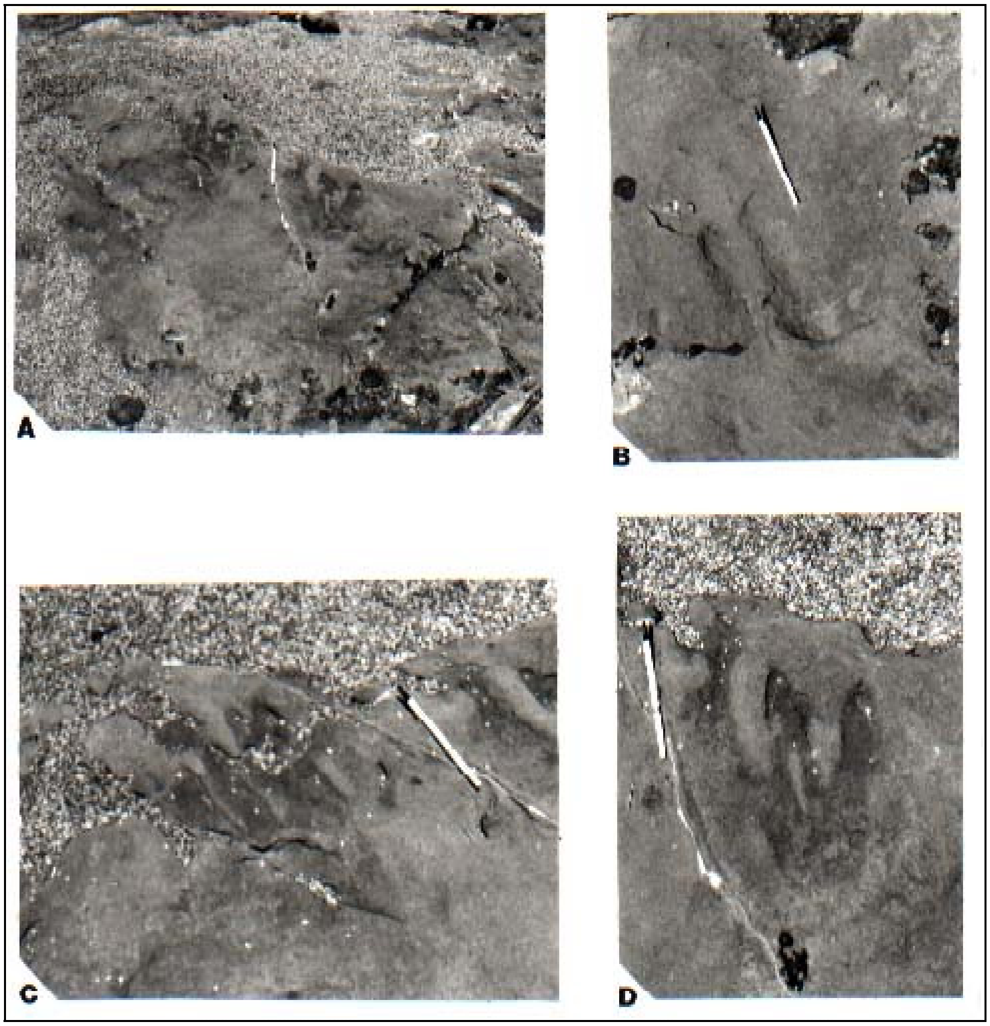

Figure 13. Dinosaur footprints in Pipe Spring National Monument. The pen is 15 cm (6 in) long. A, left and right footprints together. B, isolated footprint. C, left footprint. D, right footprint. Photo from Cuffey and others (1998).

Suggestions to protect the footprints and to enhance their value to visitors at Pipe Spring include (Cuffey and others, 1998):

- Add an exhibit in the visitor center
- Add plaque at the site of the footprints
- Install a protective fence or railing around the tracks
- Produce a one-page handout for visitors to guide hikers to the footprints

Other paleontological resources are present or are likely present but as yet undocumented in the Monument. These include numerous examples of mud cracks and other depositional features in the Kayenta Formation. It is also likely that burrows and worm holes are present.

The 2009 *Paleontological Resources Protection Act* will serve as a primary authority for the management, protection and interpretation of paleontological resources on NPS lands. The Act specifically provides the NPS with the following seven mandates to enhance stewardship: 1) management and protection of paleontological resources using scientific principles and expertise, 2) establishment of education programs to increase public awareness about the significance of paleontological resources, 3) development of a specific permit for the collection of NPS paleontological resources, 4) calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories, 5) provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts, 6) along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources, and 7) directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act.

Soil Resources - Description and Unit Limitations

Soil Mapping

The NPS Soil Resources Inventory of Pipe Spring National Monument was completed in 1994 by the USDA, Natural Resources Conservation Service as part of the Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County Soil Survey. The official NPS Soil Resources Inventory for Pipe Spring is available on line from the NPS Data Store http://science.nature.nps.gov/nrdata/datastore.cfm?ID=43778. Soil Maps and descriptions are also available at the NRCS Soil Data Mart at: http://soildatamart.nrcs.usda.gov/Default.aspx.

Soils in and near the Monument are generally young, developed in a warm arid environment from alluvium and eolian materials, and the source material came from nearby. For these reasons, the soils have only moderate development of horizons, weak structure and little in the way of organic matter accumulation. Having derived from sandy alluvium and eolian parent materials the texture is mostly fine sand or fine sandy loam, so unprotected soil surfaces are easily eroded by wind or water.

Soil Descriptions and Limitations

Four soil units are mapped inside the Monument (37, 42, 55, and 63). Two additional units (5 and 15) found on nearby tribal lands and because the NPS has a history of using buildings on tribal lands, or building NPS structures there, these are included in this description. The soils are briefly described here along with some of the most significant management limitations. A soil map, complete soil map unit descriptions, and soil property tables can be found in Appendix C. The information on soils presented here is generally adequate for planning, but is not substitute for an on-site investigation prior to design and construction activities.

Soils Inside the Monument

Map Unit 42 - *Monue fine sandy loam, 1 to 5 percent slopes:* This soil occurs on about 60% of the Monument in most of the flatter lands and includes most of the historic and modern developments. The parent material is water transported and derived from weathering of local sandstone. These soils are very deep, sandy to loamy, though, unlike other soils in the area, the Monue has a thin silty clay loam horizon at depth. Due to the depth and relatively fine texture this soil has a high water holding capacity. Of the soils in the area, this one presents the fewest limitations to most management activities; most prominent among these are the vulnerability to wind and water erosion, and the need to compact the soils prior to construction in order to prevent subsidence.

Map Unit 37 - *Mido fine sand, 1 to 10 percent slopes* and ***Map Unit 55 -*** *Sheppard fine sand, 1 to 7 percent slopes:* These soils are grouped for planning purposes because they have very similar properties, though they are separated by the mappers because the Mido has more horizon development, and extends into higher elevations that are somewhat wetter and have more mesic vegetation than the Mido. Mido fine sand is found at the north boundary of the park occupying <5% of the Monument, and the entire area around the park administrative offices on tribal lands. Sheppard fine sand is found only along the southern boundary of the Monument occupying about 10% of the land area, and extends onto to tribal lands to the southwest. The source of the parent material for both soils is wind-blown sand. These soils are very deep similar to the Monue soils, but sandy throughout. Water infiltrates rapidly but the soils have a low capacity to store water. Significant limitations are that these soils are very vulnerable to wind erosion, cut banks are vulnerable to collapse, it has low strength so is a poor material for road base, and is suitable for foundations only after compaction.

Map Unit 63 - *Torriorthents - Rock outcrop complex, 30 to 70 percent slopes:* Includes the rocky and steep slopes of Kayenta Formation or Navajo Sandstone upslope from the Winsor Castle amounting to about 30 percent of the Monument. These soils are very different from the rest of the Monument being generally shallow and rocky with a significant component of rock outcrop of sandstone, shale or mudstone. These soils are described as highly variable in surface and subsurface textures and in depth to bedrock, though in the Monument they are consistently shallow. They support a higher diversity of plant species than other soils in the Monument. The primary limitations to management activities are the shallow depth to bedrock, and the high vulnerability to water erosion.

Soils on Adjacent Tribal Lands

Map Unit 5 - *Begay fine sandy loam, 3 to 12 percent slopes:* Includes alluvial fans and fan terraces derived from the sandstones of the Vermillion Cliff. They are found at the base of the cliffs west of the Monument. Because soil is accumulating in a depositional environment these soils are deep (>60 inches). The soil profile is dominated by fine sand throughout. These soils are not considered to be subject to flooding, but their position on alluvial fans indicates that they receive brief overwash following extreme rainfall events.

Map unit 15 - *Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 percent slopes:* Found east of the Monument on tribal lands in the vicinity of outcrops of the gypsum rich shales of the moenkopi Formation. They are arid land soils with an abundance of gypsum (hydrous calcium sulfate). This unit includes soils that are shallow (less than 20 inches) to deep, and steep to relatively flat. They provide habitat for the threatened Siler pincushion cactus (*Pediocactus sileri*) and other gypsum loving plants. These soils have significant limitations for building as summarized in the following excerpt from Lund and Knudson (2009):

> Gypsum-bearing soil and rock are subject to dissolution of the gypsum ($CaSO_4 \cdot 2H_2O$), which causes a loss of internal structure and volume. Where the percentage of gypsum is ≥10 percent, dissolution can result in localized land subsidence and sinkhole formation (Mulvey, 1992; Muckel, 2004; Santi, 2005). Dissolution of gypsum may lead to foundation problems and may affect roads, dikes, underground utilities, and other infrastructure. Gypsum dissolution can be greatly accelerated by application of water, such as that provided by reservoirs; septic-tank drain fields; street, roof, or parking lot runoff; and irrigation (Martinez and others, 1998). Gypsum is also a weak material with low bearing strength and is not well suited as a foundation material for heavy structures. Additionally, when gypsum weathers it forms dilute sulfuric acid and sulfate, which can react with certain types of cement, corroding and weakening unprotected concrete. Type V sulfate-resistant cement is typically required in such areas.

Before leaving soils it is important to note that deep excavations could penetrate the soil mantle into the underlying bedrock. In the east half of the Monument this would likely be the Shnabkaib Member of the Moenkopi Formation which presents engineering challenges similar to those described for gypsum soils, so an on-site geotechnical assessment is warranted for deep excavations and major structures.

Unmapped Former Wetland Soil Inclusion

During the excavation of Tunnel Spring in 2000 a dark organic rich wetland soil layer was discovered at the base of the slope below West Cabin and extending a short distance into the horse corral. The area of this soil appears to be less than ½ acre, too small to be included on current soil maps. The presence of organic layers is an indicator of the accumulation of plant materials in a wetland environment, and an analysis of pollen showed an abundance of wetland species (Cummins and others, 2001). Here it indicates that a discharge point of Pipe Spring once existed at the base of the hill, and a marshy wetland existed here. The soil is no longer wet and in 2001was carbon dated in to 210 ± 40 years before present (Beta Analytic, 2001).

Prime Farmland

There are no soils that meet the definition of Prime Farmland in Pipe Springs National Monument

Water Resources

Brief History of Water Use at Pipe Spring

There was extensive use of Pipe Spring by the Ancestral Puebloan people. A large pueblo site is located on tribal lands near the Monument that dates roughly from 900-1150 AD (pueblo II). Use by archaic peoples that pre-date the Ancestral Puebloans undoubtedly occurred. Evidence exists for their presence on the Arizona Strip for 10,000 years, and a site as important as Pipe Spring would have been used. The physical evidence of archaic peoples is present at the Monument, but the artifacts that have been documented are typically in a disturbed context due the later activities of other prehistoric and historic peoples.

According to archeologists, the Kaibab Paiute culture became apparent in the area in about AD 1,100. Oral and cultural traditions among the Paiute people are that their people were created in this area and have been there since creation. They engaged in the full complement of life-sustaining activities including, farming, gathering, hunting and trade. The overall population was limited by the availability of water and low productivity of the land. One area of permanent residence was at *Matungwa'va*, which very roughly translates to Yellow Dripping Rock, which later came to be known as Pipe Spring.

> "We discharge a number of Indians, but take two with us for the purpose of showing us the springs, for they are very scarce, very small, and not easily found. Half a dozen are not known in a district of country large enough to make as many good sized counties in Illinois. There are no running streams, and these springs and water pockets are our sole dependence."
>
> John Wesley Powell, 1870,

Later, Mormon settlers also recognized the strategic and economic importance of the springs and settled there, building their most resilient defensive structure directly over one of the springs. The Mormons added livestock watering and butter and cheese making to the uses for the water. James M. Whitmore ran cattle in the area and built the first small settlement at the spring in 1863. He was killed on January 9, 1866 apparently by a group of Navajos that had stolen some sheep. Resistance from the Indians kept settlement activities to a minimum for the next four years. After a negotiated calm, Brigham Young designated Anison Perry Winsor as ranch manager on September 13, 1870. Construction of a substantial fort, which would later be known as Winsor Castle, began over the largest of the springs during the spring of 1870 (Engle, 1924).

Legend has it that the name "Pipe Spring" had its origin in an impromptu test of marksmanship, when, in 1858, William Hamblin was reported to have shot out the bowl of a tobacco pipe.

The portions of the Arizona Strip where soils were well developed were very productive for forage, having never been grazed by domestic livestock. The herds flourished and the numbers soon exceeded the capacity of the range. This was particularly true near water supplies. Walter Clement Powell noted in an 1872 letter that, “the spring gushes from a cliff of red sandstone, and spreads out over a bottom in quite a stream, affording excellent pasturage”. He also notes that, “eleven thousand sheep, 500 cattle and some horses are kept here” (Kelly, 1949). A short decade later Clarence Dutton wrote that,

> Pipe Spring is situated at the foot of the southernmost promontory of the Vermillion Cliffs, and is famous throughout southern Utah as a watering place. Its flow is copious and its water the purest and best throughout the desolate region. Ten Years ago the desert spaces outspreading to the southward were covered with abundant grasses, affording rich pasturage to horses and cattle. To-day hardly a blade of grass is to be found within ten miles of the spring, unless upon the crags and mesas of the Vermilion Cliffs behind it. The horses and cattle have disappeared, and the bones of many of the latter are bleached on the plains in front of it. (Dutton, 1882 p.78-79)

The Kaibab Paiute population was estimated to be 1,700 people in 1863, but after Anglo settlement the Indian population had fallen to 81 people in 1909 (Keller and Turek, 1998). The Secretary of the Interior created the Kaibab Paiute Reservation on October 16, 1907. Existing homesteads at Pipe Spring and Moccasin Spring were included as inholdings.

To avoid conflict over water use at Pipe Spring, Woodrow Wilson declared by Proclamation of April 17, 1916, that all land within ¼-mile of the spring was withdrawn as Public Water Reserve Number 34 (Engle, 1924). Secretary of the Interior Albert Hall adjusted the boundaries of the water reserve on May 31, 1922, exactly one year before Harding created the Monument. (Keller and Turek, 1998)

When tourism was first becoming popular in the area, travelers from Zion National Park to Grand Canyon, including Director of the National Park Service Stephen Mather, could not help but notice that Pipe Spring was a welcome oasis along a very long otherwise waterless journey. Stephen Mather visited Pipe Spring in 1920 and again in 1921, and on the latter trip had car troubles that added to the adventure. The owner at the time, Charles Heaton expressed an interest in selling the land for $5,000. At Mather’s encouragement, President Warren G. Harding issued Proclamation 1663 creating Pipe Spring National Monument on May 31, 1923. That proclamation specifically mentions the rarity and utility of the springs, and in recognition of their importance, prescribes that the waters be available for use by the Kaibab Paiute Indians. (full text of the Proclamation is included in Appendix A.)

> …provided, that in the administration of this Monument, the Indians of the Kaibab Reservation, shall have the privilege of utilizing waters from Pipe Spring of irrigation, stock watering and other purposes, under regulations to be prescribed by the Secretary of the Interior. (Presidential Proclamation 1663)

Non-Indian livestock users also made claim to the water based on their history of water use for livestock watering, which began several decades before the Kaibab Paiute Band acquired livestock and pastured them in the vicinity. When the Federal government gained title to the land from Charles Heaton on April 28, 1924, Stephen Mather was in negotiations with Heaton to provide continued access. On October 30, 1924, the director wrote that prior rights would be "fully recognized" by Interior. If the Commissioner of Indian Affairs did not renew non-Indian grazing permits on the reservation, he promised Charles Heaton water could be piped off the reserve: "there should be no reason to worry about this as at the proper time it will be taken care of." (Keller and Turek, 1998)

The Commissioner of Indian Affairs and Tribe opposed Mather's idea of retaining the water reserve that would allow access to all. In the past this had meant that the ranchers claimed an associated right to pasture livestock on tribal lands where they could gain easy access to the water. Commissioner of Indian Affairs' representatives felt that local whites had exploited the Indians in their use of the water and range. A Hydraulic Engineer from Commissioner of Indian Affairs suggested that water could be sold to the livestock users but only if it were piped off of the reservation (Keller and Turek, 1998). Representatives of the NPS recognized the rancher's use of the springs for livestock water pre-dated similar use by tribal cattle. Further they suggested that the inclusion of the clause in the Proclamation establishing an Indian "privilege" to use the water indicated that the Tribes legal claims to water were otherwise weak (McCoy, 2000).

A Memorandum of Agreement between the parties was signed June 9, 1924 that provided for the flow of Pipe Spring to be divided into three equal portions, but had no provision for approval by the Secretary of the Interior which is required for a binding agreement between the agencies. This agreement was given recognition on November 2, 1933 in regulations issued, but never promulgated by the Department of the Interior (text in Appendix A). Water use was divided in three shares – 1/3 to the Tribe, 1/3 to the NPS, and 1/3 to the ranchers (referred to in this report as the Cattleman's Association).

In April 1972, the NPS and the Kaibab Paiute Tribe entered into a renewable 25-year agreement wherein the NPS was to drill a well and provide delivery of water to the Tribe in exchange for use of the Tribe's one-third share of the spring flow. This jointly used well, called the NPS well, was put into service under the terms of the agreement. It remained in use until 2007 when it was replaced with a new NPS well at a location about 200 feet northwest. The agreement expired in 1997. An extension of the agreement for another 25 years has been drafted by the Monument, and awaits further negotiation and approval. In the interim, water use has continued as before under 1-year interim agreements, or, at times, informal continuance

Water for the Cattleman's Association has been piped from Tunnel Spring south off of the reservation to several stock-watering troughs. Prior to the 2001 stabilization of Tunnel Spring, the total flow of the spring was available to the association, however the cessation of flow from Main and Spring Room Springs left Tunnel Spring as the majority of spring flow. The 2001 Tunnel Spring Project included installation of a large weir box that permits all of the flow from Tunnel Spring to be divided into three equal portions, which, with minor adjustments to compensate for flow from West Cabin Spring, constitutes all of the remaining spring flow in the Monument. Currently, one third of the flow is directed into the pipeline for the Cattleman's Association. The remaining two-thirds of the flow (one-third NPS, and one-third Tribal used by NPS under the aforementioned agreement) is piped to the fort, Main Spring pool and ponds for use on the Monument.

Water Rights

The water rights setting at Pipe Spring National Monument is rife with possibility and uncertainty. The existence, nature, and ownership of water rights to Pipe Spring are integrally related to the history of land ownership, but understanding the history of land ownership does not necessarily equate to understanding the water rights. Substantial time and energy has been devoted to understanding the land ownership history of the Pipe Spring area. With an understanding of land ownership, reasonable inferences may be drawn regarding water development and use, but such inferences do not rise to the level of a resolution of water rights issues, particularly given the contentious history in the area. Short of adjudication, the parties' willingness to allocate water pursuant to agreement, without addressing water rights, may represent the best course available at present. (from Eric Lord, NPS-WRD)

Surface Water and Hydrography

Watersheds and Hydrologic Setting

For most of the lands within the Monument the surface watershed originates locally and is thus very small, with 1 to at most 5 acres draining to a given point. The higher part of the Monument land is a ridge that drains to the east and south. A small ephemeral wash flows across the eastern 1/3 of the Monument from north to south. It originates in Heart Canyon on adjacent Tribal lands drains 290 acres and constitutes a flood hazard described below.

The Monument and surrounding lands are in the watershed of Kanab Creek a tributary to the Colorado River in Grand Canyon. Surface drainage is to the south via small ephemeral channels joining Bitter Seeps Wash about 6 miles southeast, which flows into Kanab Creek within two miles. Bitter Seeps Wash has some pockets of seasonal water, but the nearest perennial water is in the lower reaches of Kanab Creek about 40 miles downstream.

Floodplains

The small dry wash that runs north-to-south through the east side of the Monument drains approximately 290 acres of land including Heart Canyon and the rocky slopes above it. Reports are that the park began to direct this runoff into a defined channel in the 1930s. The current straight and well defined channel was constructed after a large flood in 1971 that spread across the current garden, corrals, orchard and into the residential area. Park employees have observed cloudburst floods in the current drainage when the water rose to the bottom of the wooden pedestrian bridge by the Visitor Center and washed over the paved road to the residential area. The low-water road crossing at this point performed as designed where water in excess of capacity of small culverts flows over a dip in the road.

Though the upper watershed includes areas of slickrock slopes and shallow soils, where runoff is rapid and abundant, the channel and much of the watershed consists of very sandy soils with a high infiltration rate. As a result, surface runoff will occur in the channel only after high intensity rainfall.

Given the very short length of the watershed, one mile, the onset of flooding will occur quickly (5 to 15 minutes) after heavy rainfall occurs and will recede similarly quickly after rainfall diminishes. Based on the area drained and elevation, regression equations provided for Region 8 by Thomas and others (1994) give an estimated magnitude of runoff of:

Recurrence interval, in years	Discharge cubic feet/second
2	75
5	220
10	380
25	650
50	930
100	1,300

Other portions of the Monument grounds are subject to sheet wash during heavy precipitation, particularly where the soil is bare and/or compacted.

Springs and Wetlands as Surface Water Features
Until recently four points of discharge from the springs existed at Pipe Spring NM, though only two discharge water today. They are described in this section as surface water features, while their groundwater characteristics and history of discharge are described in the next Groundwater section. West Cabin Spring remains in a relatively natural condition, but the other springs have been greatly modified to suit human purposes. The general location of the springs is depicted in Figure 1, and each is described below. Of these, the wet areas around West Cabin and Main Springs, and the ponds constitute regulatory wetlands under executive Order 11990. Actions that impair their function would require a NPS wetlands statement of findings. Under current interpretations of what constitutes waters of the United States, these independent wetland areas would not be covered by section 404 of the Clean Water Act.

Spring Room Spring and Main Spring (Figure 14 and 15): Spring Room Spring was most attractive to the Mormon Settlers so they built Winsor Castle over the spring so that its valuable water could be controlled and protected. It originally discharged under and between sandstone blocks that are now beneath the north building of the fort where the parlor and kitchen are located (Figure 14). Water was directed across the courtyard (the means of conveyance is uncertain) to the Spring Room where it flowed through a trough, cooling the room making it possible to make cheese. During the 1930's or 1950's, when Superintendent Leonard Heaton made changes to the water system, a concrete cistern was constructed in the courtyard to collect the emerging spring water. A path between the cistern and a point of discharge under the parlor was filled with gravel. It is said that the flow pathway and gravel needed to be periodically excavated and cleaned out. Water was then piped from the cistern to the Spring Room. When it discharges from the spring

Figure 14. The Spring Room Spring cistern (left) and point of discharge under the parlor door. These were exposed during flow studies in 1999. At other times the cistern has a metal lid, the spring is filled with gravel and both are typically covered with soil.

Figure 15. Main Spring as it appears today with water piped to it from Tunnel Spring.

Room it flows to the exterior where small channels convey it to the ponds where it is used for irrigation.

Main Spring consists of a small pool about 10 square feet in size located just west of the west gate of the fort (Figure 15). Whether Main Spring is a natural point of spring discharge is uncertain. It is connected to the Spring Room Spring through a historic buried bark-lined channel that passes under the gate, but it may also be a natural point of discharge. Sharrow (1999) showed that when the Main Spring Pool or Spring Room Spring cistern were filled above a certain elevation water moved freely between the two. Main Spring is most likely a man-made feature, but may also have been a wet area or seep prior to construction of the bark-lined channel in the 1880's. Overflow from the pool flows down a small channel, into a watering trough and on to the ponds. When the spring was flowing, the slope between the pool and the trough was saturated with diffuse discharge.

In the late 1990s discharge from these two springs declined and in 1999 they ceased to flow. A discussion of this occurrence is included in the Groundwater Section that follows. Today, in order to maintain the historic scene, water is piped from Tunnel Spring to the Spring Room and the Main Spring Pool.

West Cabin Spring (Figure 16)**:** West Cabin Spring is located a short distance west and up slope from the historic West Cabin. Discharge from the spring flows directly downslope and a short distance onto the flats at the base of the slope. This is the least altered of the four springs, probably because it has a very small discharge, and is on a much steeper slope than the other springs. It has a short pipe driven into a small dry-stacked stone dam about 1/3 of the way down the slope, and flow measurements are taken at the discharge from this pipe. A swath of wetland vegetation exists along the surface flow consisting of willow, sedges and other members of the sedge family (Cyperaceae). Measurements of the discharge from West Cabin Spring show that since 1976 the flow has been consistently small, about ½ to 1 gallon per minute and it has been relatively constant over time. There is some indication that the discharge may be greater than in historic time because it now flows to and just across the historic road at the bottom of the slope. There was no culvert or bridge constructed in the road to allow for water passage, and, in this soil, a persistent muddy spot in the road would not have been tolerated, so it appears that surface water is extending farther down the slope than when the road was in use, or is the result of additional seepage emanating near the base of the slope.

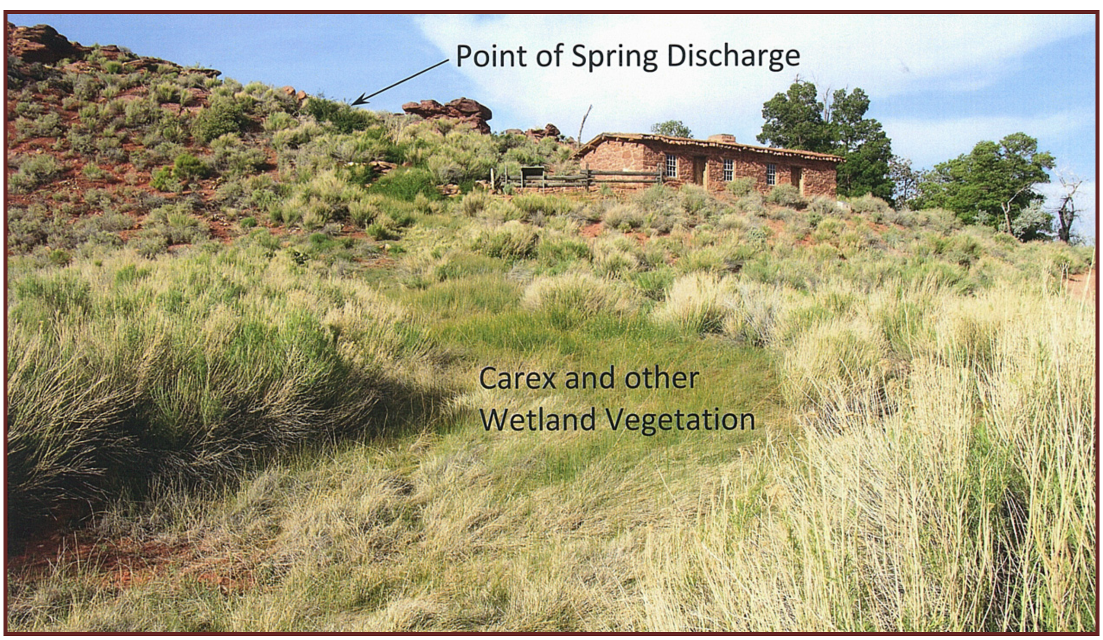

Figure 16. West Cabin Spring and West Cabin from the base of the slope looking up. The spring discharges from the steep slope above and to the west of the West Cabin, flows straight down slope and disperses near the location of the photographer.

Tunnel Spring (Figure 17 and 18)**:** Tunnel Spring exists only marginally as a surface water feature. In prehistoric times it existed as a wet or marshy area at the base of the slope on the northernmost part of the projection of Winsor Point. A layer of organic peat exists in the soil at this location that has been dated to 210 ± 40 years ago indicating a wetland was present for a period of time long enough for several inches of organic soil to accumulate. In an effort to develop this as a better-defined water source, the ranchers dug an adit (or qanat) into the hillside sometime between 1902 and 1907 to collect the spring flow. The tunnel was reported to be 200 feet long when originally constructed and when it was inspected and repaired in 1933 (Heaton, 1933). It probably extended a short distance into the current pasture, but this thin mantle of soil collapsed repeatedly, so in 1987 the entrance was stabilized with a vertical access and the length of the remaining adit was only 140 feet (Figure 17).

Continued instability, combined with the cessation of flow from Main and Spring Room Spring and the desire to have at least one reliable point of discharge, caused the NPS to undertake a major reconstruction of the outer part of the adit in 2000 and 2001 (Figure 18). Initially, the intention was to enlarge the adit working underground and line unstable

Figure 17. Historic Tunnel Spring. The vertical entrance that was in place from 1987 to 2000 (left photo), and a view inside the unstable hand-dug adit as it appeard in 1999 (right photo). The tunnel was found to clearly be in poor condition with abundant breakdown and roots.

Figure 18. Tunnel Spring during the 2000-2001 stabilization (left) and as the entrance appears today (right). Water discharges under the gate and is captured in a subsurface weir box to the left of the opening. The shrubs growing around the opening are Coyote willow (Salix exigua var. stenophylla) indicating shallow groundwater, and in the drier foreground Fourwing saltbush (Atriplex canescens).

portions with concrete. However, repeated caving of the soft fractured rock made this approach impossible, and excavation proceeded as an ever-deepening trench. The first 94 feet of the adit was excavated and concrete walls and ceiling were poured. Caving and collapse of the tunnel prevented entry or stabilization in the remaining, uppermost 56 feet of the adit, where most of the water enters. A PVC culvert was driven through the rubble pile at the end of the stabilized section of the adit to provide a conduit for water to flow from the back end of the tunnel into the reconstructed part of the tunnel. This water flows down the floor of the tunnel under the entrance gate and into a stainless steel collection box buried outside the tunnel entrance (Figure 18). Some water also surfaces outside the entrance and flows through gravel into the collection box.

Inside the collection box a set of adjustable weirs separates the flow into 3 equal portions representing the Tribal, NPS and Stockman's Association shares. One third of the flow is delivered to the Stockman's Association via a pipeline through the corrals, across tribal lands and to stockwatering troughs on range lands to the south. The remaining two-thirds of the flow is captured in a sump and pumped to Winsor Castle, Main Spring and the Ponds.

Ponds (Figure 19)**:** Historic accounts indicate that the ponds east of Winsor Castle have been present in some form since early in the period of Mormon settlement. Traditionally, discharge from the springs was stored in the ponds and distributed to various parts of the ranch for livestock watering, irrigation of the garden, orchard, grape vines and windbreaks. They have also been used by domestic waterfowl, native Tiger Salamanders and several species of bats and birds. The ponds have proven to be an excellent location for monitoring of bats during the warmer seasons.

As currently configured, the ponds are excavated into the hillslope on their northwest side below the fort, and impounded with low earthen dams on the downslope south, east and west sides (Figure 19). There are two ponds of 3,262 ft sq and 1901 sq ft in surface area, that maintain water depths of roughly 3 to 4 feet, and have exterior walls extending above the water surface 1 to 3 feet. Parts of the dam and west wall were lined with stone masonry in the 1880s. The ponds have been routinely lined with bentonite clay to reduce leakage.

Figure 19. One of two masonry lined ponds adjacent to Winsor Castle.

The availability of water has caused several white poplar and cottonwood trees to grow to large size surrounding the ponds in the dams and walls. The shade and windbreak they provide creates an idyllic setting at the ponds, very attractive to visitors and wildlife. Unfortunately, the trees also cause the dams to leak and the historic masonry to crack. As a result, the ponds have to be drained and dried about every 5 years so leaks can be fixed and masonry repointed. This process takes several months because the ponds must be drained and the clay bottom allowed to dry out before work can begin. Monument staff are currently working with NPS engineers to resolve this chronic problem of leakage.

Use of the ponds as refugia for rare native fish has been considered. Recovery teams for both the Colorado River fishes and the Virgin River fishes have expressed an interest. The Pipe Spring location is attractive due to its great distance from any other fish-bearing waters and the controlled access. There is also a potential that the fish could help reduce the abundant algal growth in the ponds during the summer. A decision regarding stocking fish in the ponds is being deferred until the leakage problem can be solved because of the difficulty in capturing the fish and holding them elsewhere for several months each time the ponds are drained; a problem that would be more difficult if the fish were listed as threatened or endangered.

Regulatory Status of Wetlands

West Cabin Spring and the wetted area downslope are a natural wetland as indicated by vegetation and hydrology. As such it is protected under Executive Order 11990 as implemented through NPS Directors Order 77-1 (NPS, 2008b). Actions considered adverse to this wetland should be avoided, and if necessary, will require preparation of a Wetlands Statement of Findings in addition to NEPA and cultural compliance. No such actions are currently planned in this area. Some conflict exists between maintaining the current extent of the wetlands and the historic road trace.

The remaining wetlands in the Monument are artificial in that they have been greatly modified from the natural setting, exist due to artificial impoundments and channels, are subject to routine maintenance and control of the water supply, and are part of a historic landscape. Areas included in this description are Main Spring (including the channel draining the pool, the watering trough, and channel to the ponds), the Ponds (including the channel from Winsor Castle and irrigation ditches downslope), and Tunnel Spring (including the diffuse infiltration into the weir box at the mouth of the tunnel). These areas fall under section 4.2.3 of NPS Procedural Manual #77-1 for Wetland Protection (revised February, 2008) for "artificial" wetlands, and are considered "intentional" and small (less than 5 acres). The Monument is encouraged to preserve wetland values and function, but may undertake actions that have adverse impacts when needed to "maintain the closest approximation of the natural condition when a truly natural system is no longer attainable, for the benefit of threatened or endangered species, or for cultural resources management purposes". Specifically:

> *… actions impacting these types of artificial wetlands **may** be excepted from the Statement of Findings requirements of Sections 5.3.4 and 5.3.5 and the compensation requirements of Section 5.2.3 of these procedures if, after evaluation of impacts on wetland functions and values, the anticipated wetland loss or degradation is determined to be minimal.*
> (NPS, 2008b, Sec 4.2.3)

This exception does not reduce compliance requirements for NEPA, NHPA, etc. Routine maintenance activities for the artificial wetlands, and their impacts, should be described in the GMP with an assessment of the need for a Statement of Findings.

All of the waters at the Monument are considered non-jurisdictional for compliance with section 404 of the Clean Water Act because they have only ephemeral connection with the waters of the Colorado River. (Pat McQueary, Corps of Engineers, pers. Comm., 2008)

Groundwater

Groundwater and its discharge at springs in the Monument is the most important and troubled natural resource feature. This section will include a description of the geohydrologic setting that supports the springs, a history of the declining spring flow, and a description of the likely cause of the decline in spring flow.

Hydrogeologic Setting

Groundwater collection, storage and movement, and ultimately its discharge at springs is controlled by the relative permeability of the rocks it flows through, the geologic structures that shape the rock, and ultimately determine the amount of water moving into and out of the system. Studies of spring flow and the groundwater system at Pipe Spring have been underway since the decline in spring flow became a concern in the 1970s. The decline became more apparent by 1990, and a series of studies was undertaken to better understand the groundwater system feeding the springs and the cause for their decline. These will not be described here in detail because Martin (2007) provides an excellent summary; rather this description will present the cumulative conclusions of the investigators that constitutes our current state of knowledge.

The groundwater system feeding Pipe Spring shares certain characteristics with all spring systems. First, it begins with water from rain or snowfall that percolated into the ground. This is a relatively small portion of the total precipitation that falls because most either runs off of the surface, evaporates from the land, or is captured by plants and evaporates from the leaves (called evapotranspiration). Because this is an arid environment, all of these surface losses are relatively large compared to the small amount of water that gets beyond the rooting zone and becomes groundwater. Secondly, water moves through spaces in the rock that are either the tiny spaces between the grains (primary porosity) or cracks in the rock where it is broken (secondary porosity). Because these spaces are small, and water is a sticky fluid, movement through the rock is slow.

The third thing needed is something to block the water from flowing ever deeper into the earth, which in this case are rock layers that are relatively impermeable so the water remains "perched" above it. Finally the groundwater must have a reason to come to the surface, or more commonly, the ground surface reaches a point where it is low enough to intersect the water table.

The aspects that make the groundwater system at Pipe Spring unusual are:

1. The springs are in an arid land where surface- and ground-water are always scarce,
2. The rock layers are bent and broken in such a way that forms an elongated trough that controls water storage and movement, and
3. That erosion of the land surface coincides with this geologic structure so that water comes to the surface and discharges at Pipe Spring on a ridge that overlooks hundreds of square miles of dry land.

Stratigraphy
The key rock layers for water infiltration and movement near Pipe Spring are the Navajo Sandstone and uppermost layers of the Kayenta Formation (see Table 2 and Figure 10). Both are sandstones made of sand grains cemented together where tiny voids (called pores) remain between the grains that can be filled with air or water. Of the two layers here, the Navajo Sandstone is an exceptionally good aquifer because its grains are uniform in size, well rounded, have very little cementing, and are pure quartz. The result is an abundant amount of pore space in the rock (20 to 30%), and because the quartz does not dissolve, the water remains low in dissolved minerals. In the Kayenta the grains are smaller, more mixed in size, and more angular so the pores are much smaller. This would typically mean that the Kayenta would be an effective barrier to water flow, but in key areas along the Pipe Spring aquifer the uppermost layers of sandstone in the Kayenta have been bent and fractured so groundwater can flow relatively freely through the large fractures.

Beneath these porous layers, the main Kayenta Formation has layers of mudstones where the grains are even finer and contain enough silt and clay sized particles that they bend rather than break. As a result they are very resistant to groundwater movement even when bent, and form an effective seal on the bottom side of the aquifer. The next layers down, Moenave Formation and the Petrified Forest Member of the Chinle Formation behave in a similar manner. The Moenkopi is also a significant layer because east of the Sevier Fault the rock layers are shifted upward so that the Moenkopi Formation is near the surface and forms an effective barrier to movement of groundwater east across the fault. This offset is best depicted in Figure 10.

Geologic Structures that Influence Groundwater
Geologic structures such as faults and folds have a strong influence on groundwater movement in the area. The most important are described in the description of geology above and include:

Moccasin Monocline - located on Winsor Point and Moccasin Mountain, this downward bending of the rock layers parallels the Sevier Fault and the West Branch of the Sevier Fault (see Figures 7 and 10). Flat-lying rock layers that cap the plateaus, specifically the Lamb Point Tongue of Navajo Sandstone, are bent downward along the east slopes of the plateau so they tip up to 10º down to the east or northeast (Figure 20). The significance of this structure for groundwater movement is (1) that the porous Navajo Sandstone forms a continuous layer that permits groundwater movement for the entire distance off of the east side of the plateau, and (2) fractures in the sandstone associated with the monocline (and some older deformation events) enhance groundwater movement through the rock.

Sevier Fault and West Branch of the Sevier Fault - The main Sevier Fault passes directly under Pipe Spring National Monument on a north-south alignment. The West Branch separates from the main fault about 2 miles north of the Monument and bends to the north west passing directly under the community of Moccasin and continuing for at least another two miles north (see Figures 7 and 10). Along both of these faults the rock layers are raised on the east of the fault and dropped on the west. Displacement along the main Sevier Fault in the vicinity of Pipe Spring is about 1,300 feet and a similar amount of displacement is found along the West Branch near the community of Moccasin (Billingsley and others 2004). The influence of these faults on groundwater is that water movement is effectively blocked from crossing the faults and therefore accumulates on the west side.

Syncline - A syncline, or U-shaped bend in the rock exists roughly paralleling the west side of the Sevier Fault near Pipe Spring and following the West Branch of the Sevier Fault through Moccasin and beyond (Figures 7, 10 and 20). This forms a trough or gutter-shaped structure roughly 500-1,000 feet wide and 5-6 miles long with a core of fractured Navajo and upper Kayenta Sandstones, surrounded by impermeable middle layers of Kayenta Formation. This trough forms the primary area for groundwater storage and movement to Moccasin and Pipe Springs (Figures 20 and 21).

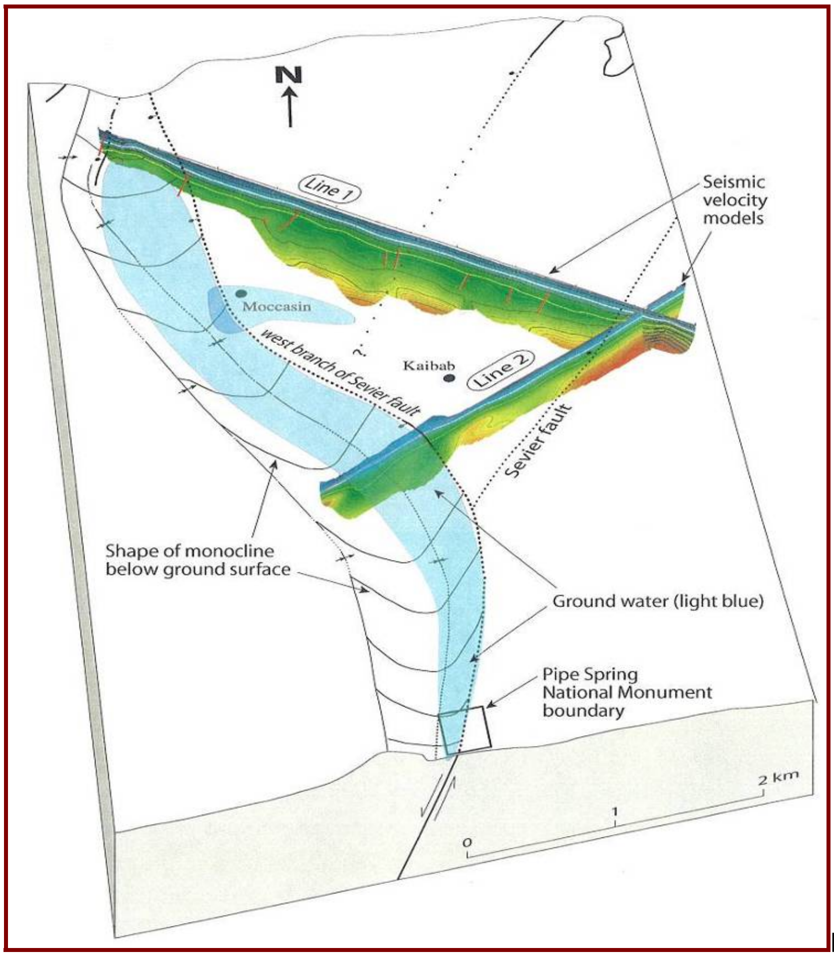

Figure 20. Geologic structure and hydrology, as determined from seismic profiling by Rymer and others, 2007. The general shape of the syncline and its capacity to hold groundwater is indicated by the blue shading.

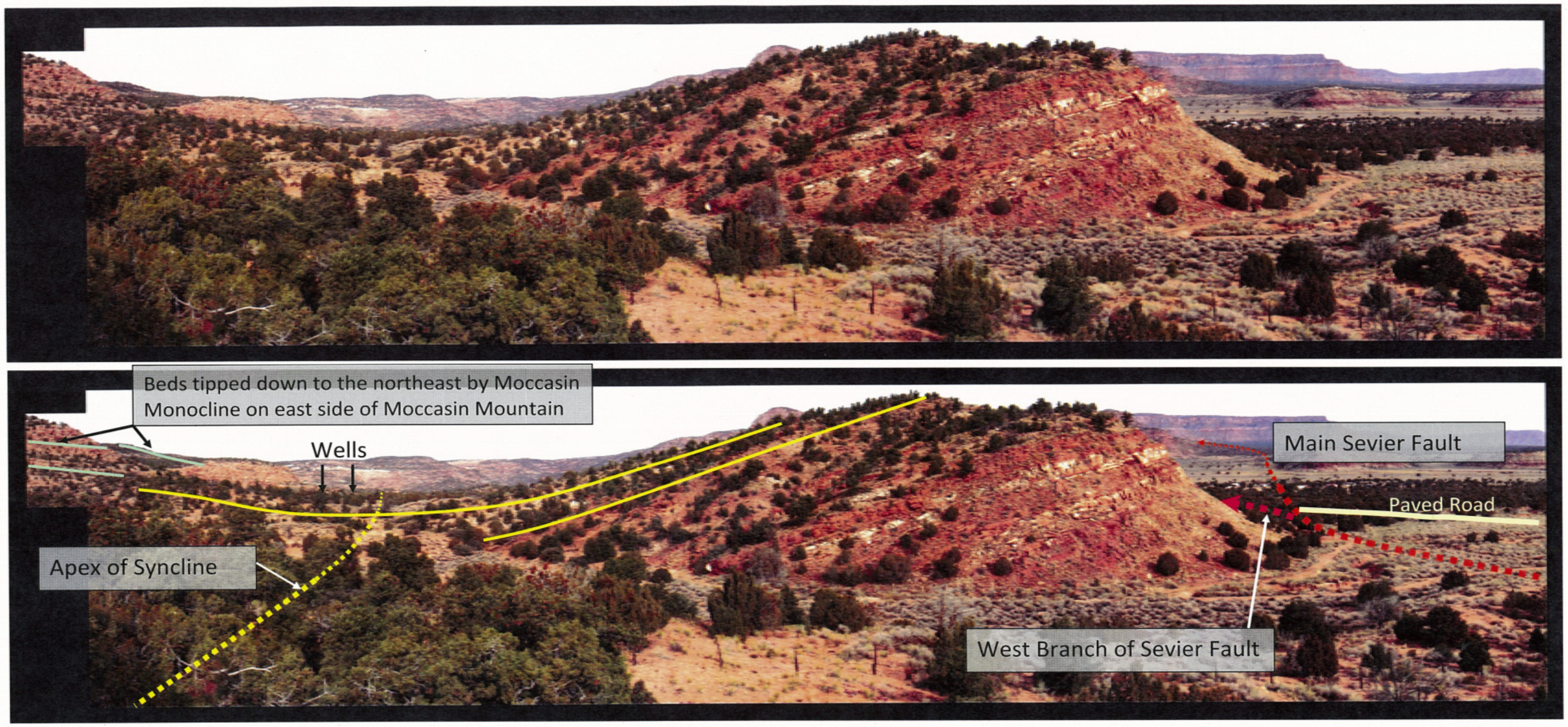

Figure 21. Composite photograph showing downward tipping beds of the Moccasin monocline and the reverse bending of the beds by the syncline. Photograph is from the hill behind the Kaibab Paiute Tribe Gymnasium facing north. Significant geologic features are labeled in the lower image. The downward tipping beds of the Moccasin Monocline are visible to the northwest (left). The syncline is left of center and the upward dipping beds of the Kayenta Formation forming the east side of the syncline are prominent in the butte in the center of the photograph. The main Sevier Fault passes just east (right) of the base of the butte and crosses the valley in the distance to the north-northeast, while the West Branch of the Sevier Fault is mostly hidden behind the butte. The NPS and Tribal domestic supply wells are just out of view about 0.7 miles northwest, and Pipe Spring is one mile south behind the photographer.

Moccasin Wash and Spring - Moccasin Spring is another very important water source in this area. It is located at the mouth of Moccasin Canyon, just north of Moccasin Wash and on the west side of the Community of Moccasin (Figure 22). Discharge is estimated to be about 100 gallons per minute and a portion of this is captured and shared between the community and the Kaibab Paiute Band. It at least partly shares the same groundwater system that supplies Pipe Spring (Truini, 1998). At Moccasin Spring, Moccasin Canyon exits Moccasin Mountain eastward cutting perpendicular to the West Branch of the Sevier Fault and the syncline. The surface wash flows out into the flat alluvium-filled valley to the east. The wash appears to have cut through some of the confining rock layers bounding the syncline and is filled with sandy alluvium. In conducting groundwater modeling for the Kaibab Paiute Band, Sabol (2005) suggests that groundwater flowing from the north to south encounters this alluvium, which happens to be more resistive to water movement than fractured rock, and is forced to the surface at Moccasin Spring. An unknown amount might also be exiting the syncline in the subsurface flowing east into the mantle of alluvium. Specific studies of this question remain to be conducted.

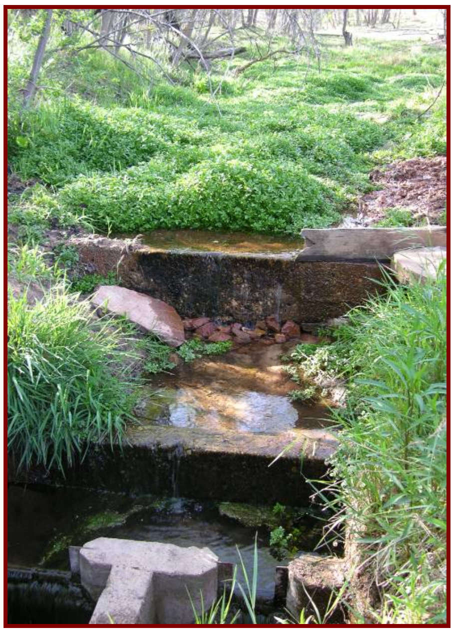

Figure 22. Moccasin Spring.

Moccasin Wash is a significant factor for Pipe Spring because groundwater might be exiting the syncline system at this location. If that is the case, then water taken from the system north of this point would have little influence on the flow of Pipe Spring so long as the amount pumped was less than the amount of water leaving the aquifer at Moccasin Wash. However, and such withdrawals of water could impact the flow of Moccasin Spring.

Direction and Timing of Groundwater Flow

Truini (1999) used a survey of water surface elevations, water chemistry, isotope characteristics, and geology to draw the following conclusions about groundwater flow:

- Ground-water movement is north to south along the syncline, through fractured consolidated rock. This is indicated by lower water-surface elevations in several springs and wells as one moves north to south, and also increasing sulfate concentrations indicating greater contact with Kayenta Formation.
- Two sets of springs (at Pipe Springs NM and Moccasin) and at least 15 wells share a common aquifer.

- The elevation drop along the aquifer (beginning at the Tribal Irrigation Well 1.4 miles north of Moccasin Spring), varies between 20 and 70 feet per mile.
- Water through the system appears to share a common recharge area as indicated by similarities in oxygen/deuterium isotopic concentrations.
- The estimated travel time for ground water from north to south is roughly 800 years. (Carbon dating showed a very wide range of water age between 50-9,000 years. 800 years is used as a reasonable value.)

It is important to note that even though water takes several hundred years to move through the system, changes in discharge from the springs in response to overdraft of ground water can happen much more quickly. This is because the volume of discharge from the springs is a result of the slope of the water table surface, and changes in this due to pumping can propagate through the ground-water system much more rapidly than the time it takes for water to transit the entire system.

A comparison of precipitation patterns, as indicated by the Palmer Hydrological Drought Index, with discharge from the springs shows little correlation (Martin 2007). So it must be concluded that, even though long-term discharge from the springs must be related to precipitation patterns, the response is very slow, on the order of decades.

NPS Domestic Water Supply, other Groundwater Uses and Declines in Spring Flow

For many years water supplied by Pipe and Moccasin springs was adequate to meet the needs of the park, the Kaibab Paiute Band and residents of Moccasin for a limited amount of irrigation, stock watering and domestic needs. This water supply was never abundant, but was sufficient for irrigation of gardens, some small pastures, a few residences who used water frugally, and a few park visitors. The number of park visitors and economic opportunities for the Kaibab Paiute Band was greatly limited by the long dirt road that provided the only access to the area.

Groundwater Development North of Pipe Spring

In the mid-1960s, reconstruction and rerouting of Highway 389 past Pipe Spring was completed. Shortly thereafter, the Kaibab Paiute Band began to make plans for various developments on the reservation (campground, housing, offices, etc.). It quickly became apparent that the Kaibab Paiute Band's one-third share of the water from the springs was insufficient for their existing needs and planned development. Furthermore, up to that time, the Tribe (and probably NPS) had used untreated water from the spring for irrigation and stock watering; while the band's development plans required a source of potable water. Thus it was not only the increased amount of water, but the kind of water that necessitated a major change in the water supply and distribution system that was shared by the Monument and the Kaibab Paiute Band (McKoy, 2000).

In 1969 it was decided mutual accord (as a temporary solution only) that the Tribe would tap into the pipeline that transported water from the springs to the Tribe's reservoir (the "Indian pond"). The water would require treatment before it could be used for potable purposes. The agreement bought the NPS additional time to wrestle with the problem and to work with the Tribe to find a permanent solution (McKoy, 2000).

NPS Water Development

The NPS in cooperation with the Tribe initiated a program of water exploration on the Reservation and construction of one or more wells to meet the needs of both the Monument and the Tribe. In 1969, NPS requested the USGS to conduct a study to identify potential alternative sources and locations for a well to supply groundwater for a joint NPS-Tribal water system. Southwest Regional Office officials gave the project top priority. The goal was to locate an alternate water source that would supply the Tribe's entire planned complex as well as potable water supply for the Park Service. Water flowing from Pipe Spring then could be used for "natural development of the oasis like quality of the area" (Geerdes, 1970). Basic considerations were that the well needed to be as close to the Monument as possible, it needed to yield at least 50 gallons per minute, and no reduction in flow of Pipe Spring would be tolerated (i.e., it could not tap the same water source from which Pipe Spring flowed). Consultation by Bill Fields with Geologist William F. Mildner of the Soil Conservation Service confirmed his (Geerdes') suspicions that a well drilled along the Sevier fault in the vicinity of the Monument would most likely affect the flow from Pipe Spring. Mildner thought that water could be obtained from the alluvial fill adjacent to Two Mile Wash (northeast of the Monument) without impacting Pipe Spring.

In the spring of 1971 the USGS, under the direction of the Park Service drilled 5 test wells in the alluvium along Twomile and South Moccasin washes. These test wells were either dry or produced poor-quality water (McGavock, 1974). Lack of success and knowledge of local hydrogeologic conditions left them with no alternative but to construct a well in the fault zone. A sixth test well was then constructed to test the Navajo Sandstone along the Sevier Fault that was a good producer of water. This well (aka NPS Well) produced abundant water and was completed as the joint water supply well for both the Monument and much of the reservation. It appears that the NPS well was constructed in the fault zone in spite of the knowledge that pumping groundwater from that area would likely cause spring flow to decline because, even after an extensive search, no viable alternatives were apparent.

The NPS well was the sole source of potable water for the Monument since the water system was completed in June 1973 through 2007 when a replacement well was put in service. The new well was drilled about 200 feet north west of the old well, because a sandy wash near the old well threatened to erode into the old well's casing. Drilling a new well was less expensive than stabilizing the sandy channel.

Tribal Water Development

By 1975, the Tribe had determined that the well at Kaibab Village, which had failed a year earlier, was no longer adequate (McKoy, 2000). After two unsuccessful attempts, in 1980 they drilled a successful well 700 feet southwest of the NPS well. This well has provided water to the tribal communities of Kaibab and Juniper since that time.

In 1975, the BIA constructed two test wells. One of the test wells is located about ½ mile south of Moccasin. Although it produced a good amount of water, it apparently has never been utilized. The second test well was located about a mile north of Moccasin and produced several hundred gpm. It has been used as an irrigation supply well by the Tribe. At some later time, a second irrigation well was constructed in the same general area, about a mile north of Moccasin.

Although the NPS and Tribal culinary wells are located only about 700 feet apart, they supply two independent storage and distribution systems. (The systems can be interconnected if either well is inoperative, but under ordinary circumstances the two systems are operated independently.) The NPS well pumps water to a buried 500,000-gallon reservoir located about a half mile south of the NPS well. Water from the NPS well is then distributed to the NPS facilities at the Monument, the Tribal-NPS partnership visitation center, and Tribal facilities including; the multi-purpose building, the NPS-leased admin building, campground, Red Hills Village, Tribal Court building, Red Cliffs gas station and convenience store, and the Tribal administration building. The Tribal well pumps water to storage tanks with a combined capacity of about 100,000 gallons on the hilltop about 1000 feet northeast of the NPS well. Water from the Tribal well is used primarily to supply the water needs at Kaibab Village, Juniper Village, and the tribal park and community center near Kaibab.

Other Wells in the Area

Several other wells exist in the vicinity, but for rural Arizona a database is lacking of well locations or water pumping. Martin (2007) made an attempt to identify all the wells by comparing databases from USGS and the Arizona Department of Water Resources (ADWR). Of 30 wells on the two lists, only four were on both. Despite this uncertainty, the combined lists are probably a fair representation of the wells that exist. The lists include:

- NPS domestic water supply well
- Tribal domestic water supply well
- 2 Tribal Irrigation Wells (high capacity, used intermittently)
- Kaibab Village Well (unused)
- NPS Monitoring Well
- USGS Monitoring Well
- Old NPS domestic Well (used for monitoring only)
- 13 Wells in Moccasin (with capacities of 20 - 450 gpm)
- 7 Test Wells (NPS and Tribal, never developed as water supply sources)

As indicated, the Tribe has two irrigation wells along the Sevier Fault about a mile north of Moccasin. These have been used on an intermittent basis, pumped heavily in some years and not pumped at all in other years. No data is available for the amount of water pumped in Moccasin. Assuming 70 acres of irrigated land, and roughly 20 residences and 100 head of livestock, consumptive water use could be about 300 acre-feet/year, or a constant diversion of 185 gallons per minute. A portion of this would be met by water diverted from Moccasin Spring, the rest from wells.

Water Monitoring

NPS and USGS Monitoring Wells
Water levels in the Pipe Spring aquifer in the vicinity of the Tribal and NPS potable supply wells have been monitored regularly for many years. The USGS monitoring well is located about 1 mile northwest of the supply wells and about ½ mile south of the Community of Moccasin (Figure 23). Water levels have been measured at the USGS monitoring well since 1976. The NPS monitoring well was constructed by the NPS in 1989. It is located about a mile south of the supply wells and a mile north of the Monument. Both of these wells are far enough from any of the pumped wells that water levels do not show any influence from those pumps turning on and off.

Spring Flow Measurements
In July 1976, a routine spring flow monitoring program was initiated. Discharge measurements were made at each of the springs (Main and Spring Room Spring, Tunnel Spring, and West Cabin Spring) at approximately the same time each month.

Declining Spring Flow and Groundwater Levels
Prior to 1977, there were very few measurements of the flow from the springs and it is unclear for all of these early measurements if the combined discharge from all the springs is being reported, or if it is a single spring. The following is a list of the measurements that have been found:

Date	Discharge (gpm)	
September 1933	42	
May 1934	43	
Prior to 1939	56	(Gregory, 1950)
March 12, 1959	35	
July 2, 1969	38	
August 6, 1976	32	
July 27, 1976	35	

Measurements in spring flow from 1977 to date are shown in Figure 24 with the pink, green and red lines showing flow from each spring and the blue line a combined total. For a clearer picture of flows refer to Figure 25 where only the total discharge is shown and it has been smoothed by showing three-month running averages. These data show an annual pattern with highest flow in late winter to early spring and the lowest flow in summer to early autumn. Several years of above average precipitation (and therefore greater recharge to the aquifer system) may partially explain the slowing of the rate of decline during the 1990s.

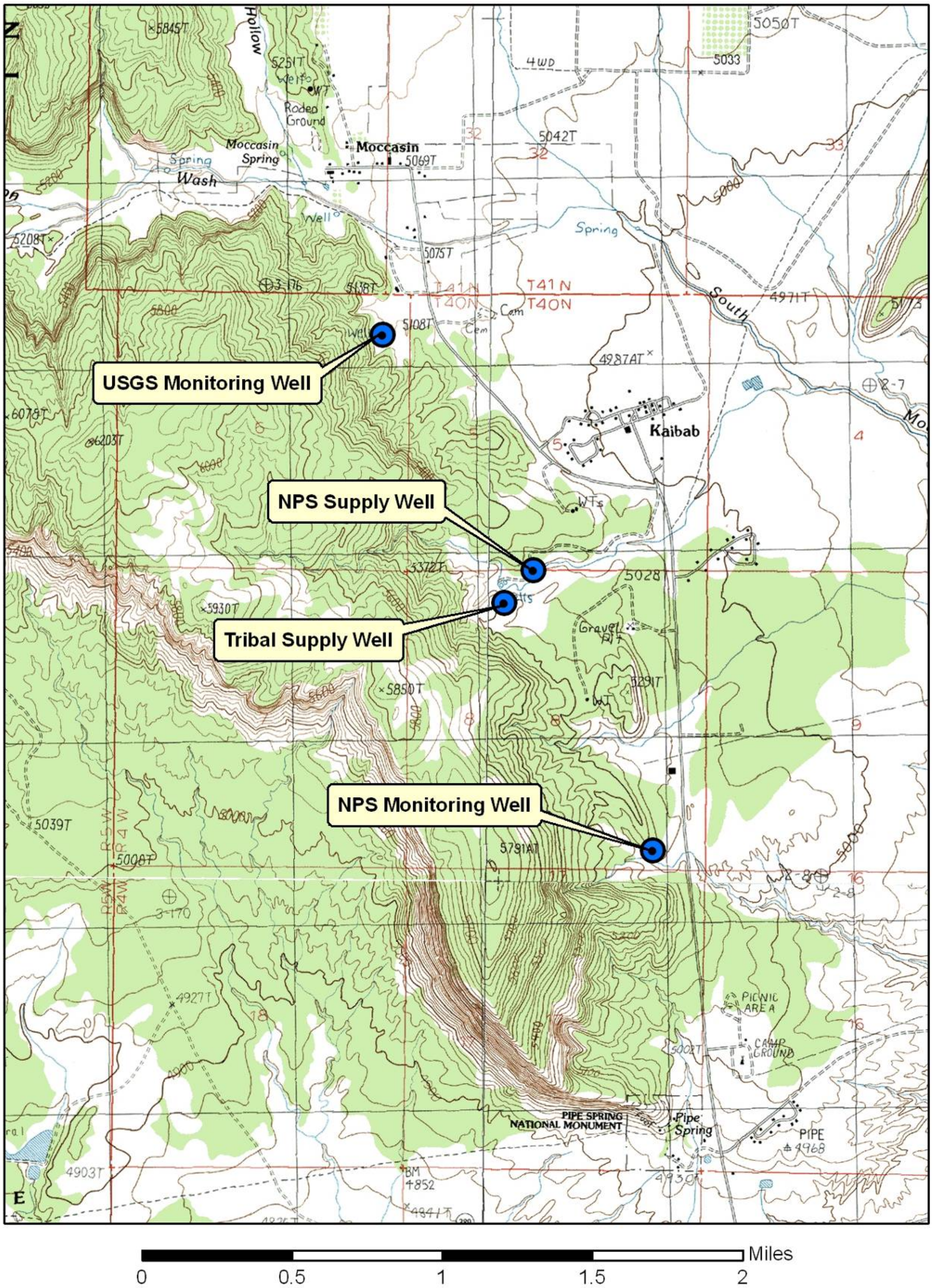

Figure 23. Location of water level monitoring wells and water supply wells near Pipe Spring. (from Martin 2007)

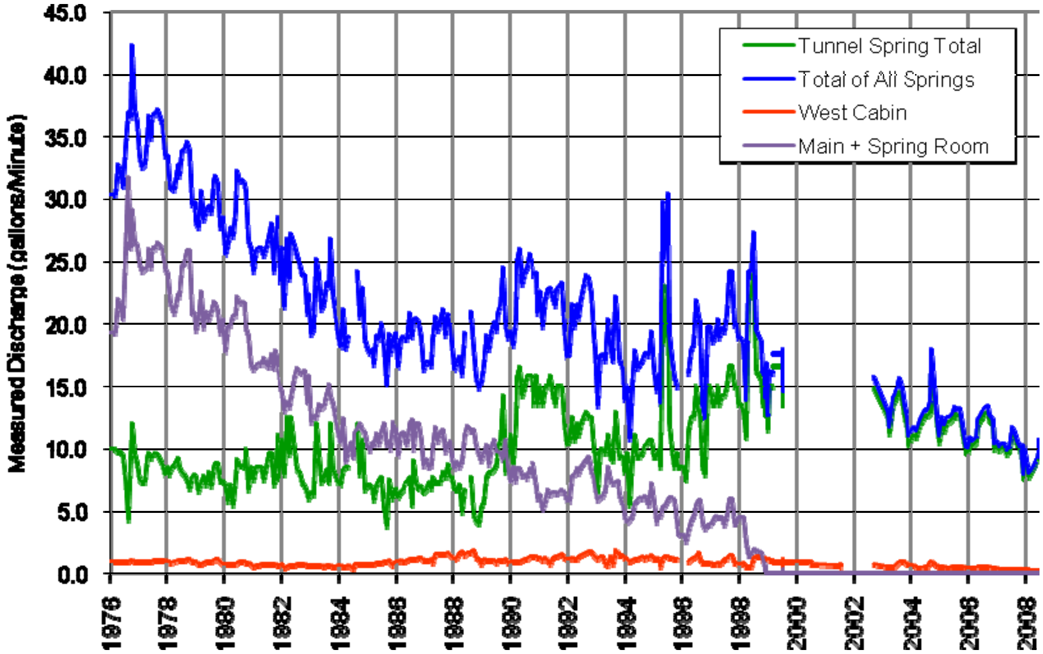

Figure 24. Measured discharge from springs at Pipe Spring National Monument between 1977 and 2009, with the total indicated by the blue line. (updated from Martin , 2007)

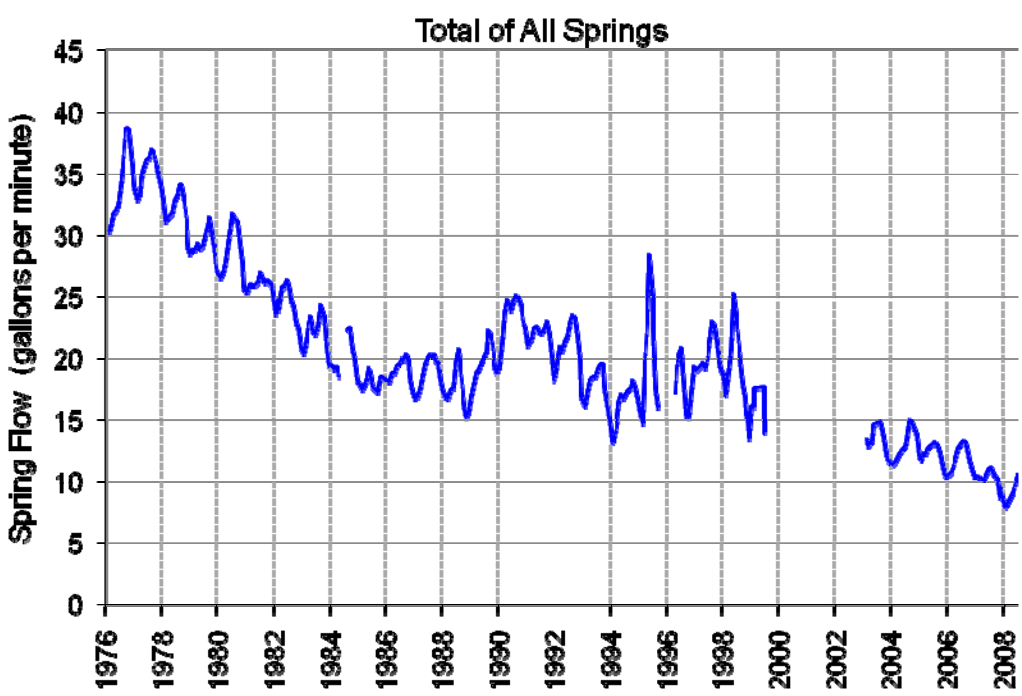

Figure 25. Total spring flow at Pipe Spring National Monument, three month running average from 1976 through 2009. (updated from Martin , 2007)

Total spring flow has shown a steady decrease of about 2 gpm per year for the period from July 1976 through June 1986. Spring flow stabilized at approximately 15- 20 gpm from 1985 to 1999. Measurements from September 1999 to September 2003 are omitted because few were available while Tunnel Spring was being rebuilt, and the measured flows are quite variable due to the changes in the spring and difficulty in getting accurate measurements. Since September 2003, total spring flow at the Monument has averaged around 11.5 gpm.

Most of the decreased outflow from the springs from 1976-1985 was a result of declining flow from the courtyard cistern to Main Spring and Spring Room Spring. Total flow was fairly steady from 1986-1990. After 1990, flow from Tunnel Spring increased and flow from the courtyard cistern decreased. In mid-1999, flow from the courtyard cistern ceased and there has been no natural flow at Main Spring or Spring Room Spring since then. One possibility suspected is that a local opening of fractures permitted water that was flowing to Spring Room and Main Springs to flow instead to Tunnel Spring which is 20 feet lower in elevation. Thus the cessation of flow from the upper springs was caused by a local event superimposed on a more general, but slower, decline in the larger aquifer. It appears from observations of ancient organic layers and deposits of evaporate minerals around the Monument, that the actual locations of discharge from the springs have shifted over time. Now a system of pumps and pipes has been constructed to pump water from Tunnel Spring to Main Spring and Spring Room Spring to artificially recreate the historical scene.

About 90% of the total spring flow at Pipe Spring now occurs from Tunnel Spring. Flow from West Cabin Spring has remained fairly steady between about ½ and 1½ gpm throughout the monitoring period. This pattern, where flow changes or ceases in some springs, but does not in others nearby, indicates that while there is a general path of groundwater flow to the springs, there is a great deal of local complexity within that pathway. This is supported by geophysical studies conducted in and near the Monument by the USGS, and is not unexpected in a fracture-flow aquifer located on an active fault.

The two monitoring wells provide a measure of the water table that is much more precisely measured than spring discharge. Figure 26 shows the depth to water in each of the wells over time, along with spring flow. Water levels in both monitoring wells show a general decline of about a third of a foot per year. The observed water table decline at the two monitoring wells, both about a mile from the supply wells, indicates a general decline of the water level in the aquifer encompassing a large area. It is reasonable to conclude that this decline is the cause of spring flow decline at Pipe Spring.

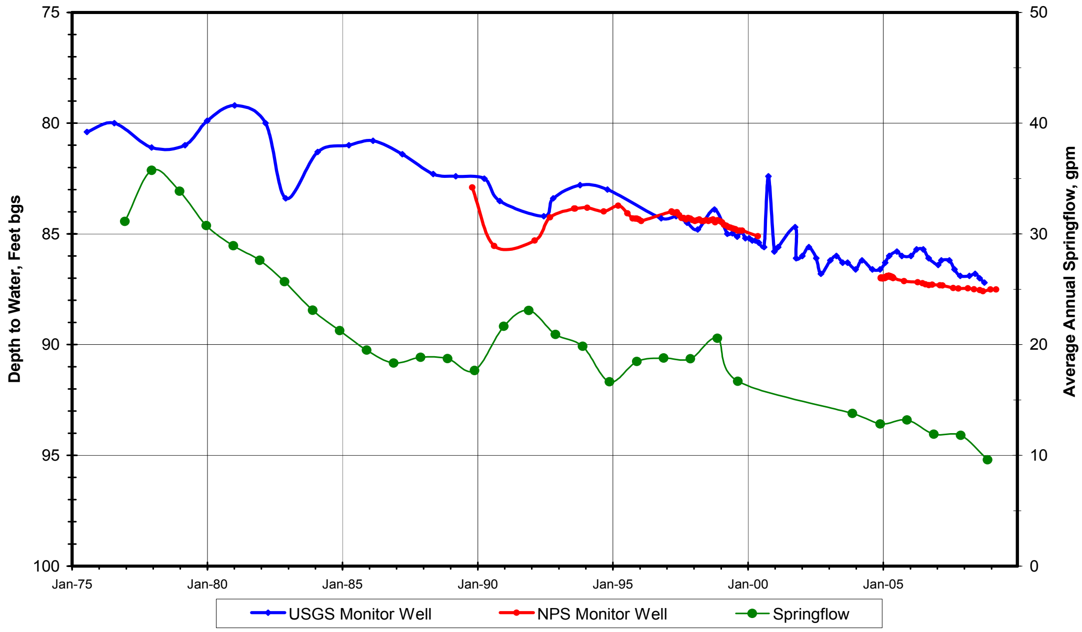

Figure 26. Water levels in the NPS and USGS monitoring wells and total spring flow measured at Pipe Spring National Monument. (updated from Martin , 2007)

Conclusions for Groundwater, Spring Flow and its Decline

The following conclusions can be drawn from the numerous studies of the geohydrology and patterns revealed by the monitoring of springs and groundwater levels.

- Essentially all of the water consumption in the local area, and the discharge from Pipe and Moccasin Springs, is from a single small aquifer system.
- Water levels in this aquifer and discharge from the springs are declining, indicating that the system is over utilized.
- The largest man-caused drain on the groundwater system affecting Pipe Spring is probably the NPS and Tribal domestic water supply wells.
- Other pumping in Moccasin and the Tribal irrigation wells are probably also contributors, but to a lesser degree, by virtue of their greater distance from Pipe Spring.
- If year-to-year climate variability is affecting discharge from the springs, the response is very slow - on the order of several years or decades.
- The drying of Spring Room Spring and Main Spring in 1999 was probably the result of both (1) a local shift in flow pathways, where more water flows to Tunnel Spring causing a temporary increase in flow, and (2) the general decline of water levels in the aquifer that continues today.

A very rough water budget was developed by Martin (2007) for the southern portion of the aquifer. It is based on the logical assumption that prior to the drilling of wells, the amount of water entering the aquifer from recharge, moving through the system, and discharging is roughly equal to the combined discharge of the springs.

		Average Discharge gallons/minute
Pre-Development Discharge from Aquifer		
	Pipe Spring	40
	Total	40
Present Discharge from Aquifer		
	Pipe Spring	10
	NPS Well	25
	Tribal Well	60
	Total	95

From this it is concluded that any water taken from wells must be eventually reflected in a reduction of spring flow. This concept holds even if the amount of water use from some of the wells, and the amount of water diverging from the aquifer at Moccasin Wash are not known with certainty. It serves to show that current discharge from the aquifer far exceeds what is naturally available. The difference is made up by a reduction in water stored in the aquifer which leads to the observed decline in the water table, and discharge at Pipe Spring. If the combined pumping from the NPS and Tribal wells continues to exceed the pre-development flow of Pipe Spring, then spring flow at Pipe Spring will continue to decline until it ceases entirely (Martin, 2007). This will be followed by an accelerating decline in the water table and eventual exhaustion of the aquifer.

Recommended approaches to Mitigate or Reverse Declines in Spring Flow

Any action to reduce the total amount of water removed from the aquifer would slow or reverse the decline in spring flow. The most straightforward of these is improving water conservation through installing water conserving fixtures, using water conserving landscaping and high efficiency irrigation, reducing the area of irrigated lands. Education of water users is also an important component of a water conservation effort, though it should be noted that most people in the vicinity are well aware of the scarcity of water. Other measures include installing meters and tracking water use, and using this information to find leaks and waste in the system. Some conservation measures have been implemented, but additional gains in efficiency can always be made. Tribal members and Government are aware of the need to conserve and have expressed support for such measures.

A longer-term solution would be to find an alternative water source to supplement or replace the current NPS/Tribal water supply wells. Unfortunately, in this arid land alternatives are few. To the south of Pipe Spring and the Vermillion Cliffs, and the east of the Sevier Fault, the geology is not conducive to successful wells. The rock layers near the surface either have little ability to hold water, or pass water so freely that it accumulates only at extreme depth. Limited drilling to the north and south of Grand Canyon indicated that reliable water can be found in the redwall/mauve aquifer, but that the depth near Pipe Spring would be over 3,000 feet. Wells to this depth are exceptionally expensive to drill, and operate and quality of any water found is uncertain.

To the north the search is bounded by the Arizona/Utah state line which is 9 miles north of the Monument and forms the north boundary of the Kaibab Paiute Indian Reservation. The administrators of Utah water law would look negatively on the export of water from the state.

Two alternatives for new wells have been identified.

1. **Moccasin/Pipe Spring aquifer in the vicinity of the tribal irrigation well.** This location is west of the West Branch of the Sevier Fault and about 1.5 miles north of Moccasin. It would be tapping the aquifer feeding the springs, but by virtue of greater distance from the springs and being north of Moccasin Wash, the impact would probably be less. How much less is dependent on (1) the amount of additional groundwater recharge occurring south of Moccasin Wash, and (2) the amount of water naturally lost from the aquifer through the sandy alluvium at the mouth of Moccasin Wash. Neither of these values has been quantified. However, modeling by Sabol (2005) indicates that there might be a fair degree of isolation between the north and south portions of the aquifer. There is a high degree of certainty that a successful well could be drilled at this location, or the existing Tribal Irrigation well could be used.

   The distance from the tribal irrigation well to the existing storage tanks near Kaibab is about 17,700 feet, elevation along this route drops from 5,220' at the well, to the low point of the valley at 5,000 feet, then rises to the tanks at 5,130 feet.

2. **Sandy Canyon Wash near the state line about 7 miles north of Kaibab.** This area is just west of the main Sevier Fault where it separates Moccasin Mountain from Moquith Mountain. There are no wells in this area, but the mapped geology suggests that groundwater may be flowing south from the area of Coral Pink Sand Dunes in Utah. Moderate to thick beds of Navajo Sandstone exist along the entire pathway, and eastward movement is blocked by the fault. A well at this location would have the advantage of being completely isolated from the aquifer that feeds Pipe Spring. Funding is being sought for additional geophysical studies to evaluate the groundwater potential in this area.

   The distance from the existing water tanks is 8.03 miles or 42,500 feet. Elevation of the well would be about 5,400 feet. The low point of a pipeline would be about 4,980 feet and rise to the tanks at 5, 130 feet.

Water Quality

The one water quality problem that has recently cropped up as an issue in the Monument lead. Recent samples of the Tribal and NPS water supply wells have shown levels of lead that exceed the drinking water standard of 15 ppb. The source of this lead is uncertain and an investigation is underway. Possible sources include (1) natural or anthropogenic contamination of the groundwater, though the rock strata in this area are not known to contain high levels of lead or other heavy metals, nor are industrial sources of contamination known, (2) contamination in the well, pump or plumbing at the well site, or (3) contamination in the storage or distribution system. It is also possible that samples could have been inadvertently contaminated at the time of sampling, or due to errors in the laboratory. Truini (1999) reports single samples with relatively high concentrations of lead in Spring Room Spring (20 ppb), Moccasin Culinary Well (20 ppb), NPS Culinary Well (12 ppb), West Cabin Spring (10 ppb), and Moccasin Spring (10 ppb). Lead was undetectable (<10 ppb) in samples from Tunnel Spring, the NPS Monitoring Well, and the Tribal Irrigation Well. Some later samples had lead levels significantly lower, so the source or persistence of the high levels is uncertain. Resampling of Spring Room Spring today is impossible because the spring has dried up.

Other than for lead, the few water quality samples from the springs have met Arizona Water Quality Standards. Water from the springs is moderate in dissolved minerals (total dissolved solids 300-350 mg/l and specific conductance 500-600 µS/cm), a slightly basic pH (7.8-8.3) and moderately hard (200-250 mg/l). Major ions are calcium, magnesium, carbonate, and sulfate. Ions found in relatively low concentrations are sodium, chloride, and potassium. Few water quality problems have been noted, however, this is based on very few samples. The Monument is exploring a cooperative arrangement with the Kaibab Paiute Tribe for the Tribe's water quality staff to routinely monitor park springs and the ponds.

Drinking Water and Wastewater Systems

By virtue of being located on an Indian Reservation, regulatory responsibility for drinking water supplies is through the EPA directly rather than the state. The NPS system is classified as a **Transient Non-Community Water System** (a public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time). The tribal system is classified as a **Community Water System** (a public water system that supplies water to the same population year-round), and as a **Very Small** water system that serves 25-500 people.

The NPS and Tribal drinking water wells have been monitored and neither have exceedances of maximum contaminant levels for inorganic, organic, nutrients or radionuclides. At the NPS well samples for bacteria are collected monthly, and quarterly for nutrients.

A Source Water Protection Plan has been completed for the Tribal well (Sabol, 2005). One is not required for the NPS well due to its classification as a Transient Non-Community Water System.

Wastewater disposal is almost entirely east of the Sevier Fault, so has no potential to contaminate the aquifer feeding the springs. It also does not contribute to recharge of the aquifer, so undertaking tertiary treatment and moving the discharge to the area of the syncline has some potential to partly mitigate the decline in groundwater levels.

Water-dependent Biological Resources

As might be expected the waters at the Monument, while small in volume and area, are a center of biological activity. Monitoring of bat use at the ponds has been conducted for several years. As of 2005, an astonishing fifteen species of bats have been recorded and are listed below. That amounts to 54% of the bat species known from the state of Arizona. Some of the bats apparently travel great distances to forage and drink at the open water of the small ponds at the Monument.

Myotis ciliolabrum	Western small-footed myotis
Myotis californicus	California myotis
Myotis thysanodes	Fringed myotis
Myotis volans	Long-legged myotis
Myotis yumanensis	Yuma myotis
Myotis evotis	Long-eared myotis
Myotis lucifugus occultus	Little brown bat
Pipistrellus hesperus	Western pipistrelle
Antrozous pallidus	Pallid bat
Eptesicus fuscus	Big brown bat
Idionycteris phyllotis	Allen's big-eared
Talarida brasiliensis	Mexican free-tailed
Plecotus townsendii	Townsend's big-eared
Lasionycteris noctivagen	Silver-haired bat
Lasiurus cinereus	Hoary bat

The aquatic invertebrates of Pipe Spring National Monument were sampled by Oberlin (1998) in 1997-1998. The non-insect fauna included: nematodes, oligochaetes, planariid turbellarian flatworms, *Pisidium* sphaeriid clams, *Physa virgata* physid snails, *Hyalella azteca* (a widely distributed amphipod), *Daphnia* cyclopid cyclopods, ostacods, water mites (Hydracarina), and isotomid Collembola. Numerous Diptera were reported, including: ceratopogonids, simuliids, chironomids, *Dixella* dixiids, *Trichoclinocera* empidids, *Oxycera* stratiomyids, *Chrysops* tabanids, and *Pseudolimnophila* and *Holorusia* tipulids. Other aquatic insects included: *Microvelia* veliids, *Argia* damselflies, and Gumaga sericostomatid caddisflies. (Reproduced from Grand Canyon Wildlands Council, 2001)

A survey of herpitofauna in 2000 and 2001 identified 15 species. Of these the Tiger Salamander (*Ambystoma tigrinum),* Woodhouse's Toad (*Bufo woodhousii), and* Great Basin Spadefoot *(Spea intermontana)* are water dependent species.

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APPENDIX A. PROCLAMATION AND WATER-RELATED REGULATION AND AGREEMENTS

BY PRESIDENT OF THE UNITED STATES OF AMERICA

A PROCLAMATION

[No. 1663 - May 31, 1923 - 43 Stat. 1913]

Whereas, there is in northwestern Arizona on the road between Zion National Park and the North Rim of the Grand Canyon National Park a spring, known as Pipe Spring, which affords the only water along the road between Hurricane, Utah and Fredonia, Arizona, a distance of sixty-two miles; and

Whereas, a settlement was made at Pipe Spring in 1863 and there was built a large dwelling place, called "Winsor Castle," with portholes in its walls, which was used as a place of refuge from hostile Indians by the early settlers, and it was also the first station of the Deseret Telegraph in Arizona; and

Whereas, it appears that the public good would be promoted by reserving the land on which Pipe Spring and the early dwelling place are located as a National Monument, with as much land as may be necessary for the proper protection thereof, to serve as a memorial of western pioneer life,

Now, therefore, I, Warren G. Harding, President of the United States of America, by virtue of the power in me vested by section two of the act of Congress entitled, "An Act for the Preservation of American Antiquities," approved June 8, 1906 (34 Stat., 225) do proclaim that there is hereby reserved, subject to all prior valid claims, and set apart as a National Monument to be known as Pipe Spring National Monument the lands shown upon the diagram hereto annexed and made part hereof and more particularly described as follows:

The southeast quarter of the southeast quarter of section seventeen, township forth north, range four west, Gila and Salt River Meridian.

Warning is hereby expressly given to all unauthorized persons not to appropriate, injure, destroy, or remove any of the features or objects included within the boundaries of this Monument and not to locate or settle upon any of the lands thereof.

The Director of the National Park Service under the direction of the Secretary of the Interior, shall have the supervision, management and control of this Monument, as provided in the act of Congress entitled, "An Act to establish a National Park Service, and for other purposes," approved August 25, 1916 (39 Stat, 535), as amended June 2, 1920 (41 Stat., 732): Provided, that in the administration of this Monument, the Indians of the Kaibab Reservation, shall have the privilege of utilizing waters from Pipe Spring of irrigation, stock watering and other purposes, under regulations to be prescribed by the Secretary of the Interior.

In witness whereof, I have hereto set my hand and caused seal of the United States to be affixed.

Done at the City of Washington this thirty-first day of May, in the year of our Lord one thousand nine hundred and twenty-three, and of the Independence of the United States of America the one hundred and forty-seventh.

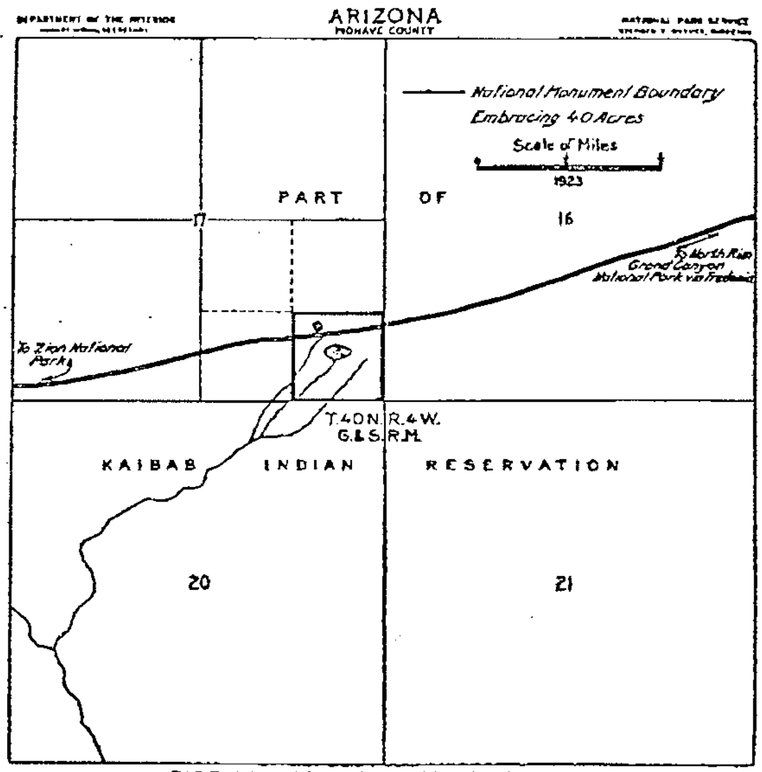
[SEAL]

Warren G. Harding

By the President:

Charles E. Hughes,

Secretary of State.



PIPE SPRING NATIONAL MONUMENT

REGULATIONS FOR THE DIVISION OF THE
WATERS OF PIPE SPRINGS

November 2, 1933

Pursuant to authority vested in me by the Presidential Proclamation of May 21, 1933, the following regulations are prescribed governing the distribution of the waters of Pipe Springs for irrigation, stock watering, and other purposes:

1. The waters of the Springs shall be divided equally, one-third to the Pipe Springs National Monument, one-third to the Indians of the Kaibab Indian Reservation, and one-third to the stockmen represented by a memorandum of agreement signed June 9, 1924, by representatives of the respective interests.

2. In order to accurately divide the waters, there shall be installed recognized recording water meters at each of the three springs, from which the water supply for the respective parties is derived, and of the combined flow of such springs each of the respective parties shall be entitled to receive for their respective uses one-third of such quantity of water. The diversion and use of water before it empties into reservoirs now constructed on the Monument shall be charged against the one-third share of the total flow to the party receiving such quantity of water. In order to prevent dispute among the respective interests relative to their not receiving their total share of the water, there shall be installed similar water meters at the respective points of outlets through which water to the respective parties is being carried to their points of use.

3. The cost, including installation, maintenance repairs and replacement of the meters shall be borne equally by the respective interests.

4. Failure on the part of the respective interests to pay for their share of the cost of the meters, their maintenance, repairs and replacement, shall be grounds for refusal of delivery of water to the parties so delinquent.

5. The respective interests involved shall have the right to inspect at any time the records of the division of the waters, but no tampering or interference with the meters shall be permitted. Should it appear at any time that any or all such meters after having been installed are not properly functioning, the meter, through proper channels, shall be submitted to the Director of the Park Service and the Commissioner of Indian Affairs, which Services shall have the meters inspected and if such inspection warrants, appropriate adjustments shall be made promptly.

6. Nothing herein shall be construed as in any way affecting or determining the respective water rights of the parties herein referred to. The right is reserved to modify, amend or change these regulations as conditions may warrant.

(SGD) Oscar L. Chapman
Assistant Secretary

AGREEMENT

THIS AGREEMENT, made and executed on this 13th day of April 1972, between the Kaibab Band of Paiute Indians of the Kaibab Reservation, Arizona, originated pursuant to section 16 of the Indian Reorganization Act of June 18, 1934 (*48 Stat. 984), as amended, hereafter referred to as the “Tribe,” and the United States National Park Service, hereafter referred to as the “Service.”

WITNESSETH :

WHEREAS, the waters of Pipe Springs within the boundary of Pipe Springs National Monument are now being used by both of the parties hereto under previous agreement; and

WHEREAS, increased needs of both parties have been given consideration, and with the permission of the Tribe and Service has drilled a well on tribal lands two miles north of Pipe Springs National Monument;

WHEREAS, it is deemed advisable to enter into an agreement for the use of the water from Pipe Springs and from the well so drilled in a manner to meet the needs of both parties.

NOW, THEREFORE, in consideration of the premises and of the mutual covenants and agreements hereafter contained, and the performance thereof by the parties hereto, the parties do hereby mutually covenant and agree as follows:

1. It is mutually understood and agreed that this contract shall become effective on execution thereof and shall extend for a period of twenty-five years (25) and, at the option of the Tribe, may be extended for an additional period of twenty-five (25) years, upon giving notice to that effect to the other party to this agreement at least thirty (30) days prior to the date of such aspiration.

2. The Service agrees to construct a water system which shall include a pump station, approved water treatment plant, an adequate water storage tank and a six inch water line or larger from the tank to Pipe Springs National Monument; the Service further agrees to provide Ts and water meters at five locations for service to tribal facilities. The locations of such Ts shall be determined by further agreement of the parties hereto. The Tribe agrees that the Service may have a right of way with full rights of ingress and egress during the terms of this agreement for the construction, maintenance and use of the water system as described on the attached plat which is marked Exhibit “A” and by reference made a part of this agreement.

3. The Service agrees to operate, maintain and repair the water system constructed as aforesaid at its sole cost and expense.

4. The Tribe agrees that the Service may use the present one-third of the output of water of Pipe Springs now being used by the Tribe so long as this agreement shall remain in force, except as hereinafter provided in paragraph No. 12 and 14.

5. The Service agrees that in lieu of the waters of Pipe Springs to which the Tribe has hereby granted exclusive use to the Service, the Service will furnish to the Tribe 7,884,000 gallons of water per year from the water system constructed pursuant to the terms of this agreement at the sole cost and expense of the Service and without and charge to the Tribe.

6. The Tribe agrees to pay the actual cost of production rate for all the water used by the Tribe during any one year in excess of the amount to be furnished to the Tribe without cost as stated in the preceding paragraph. Cost of production shall be determined by prorating the cost of (a) electricity, (b) chemicals, (c) maintenance of pump, plant and main line with appurtenances,

and (d) seven year amortization of the pump. The cost of production will be re-evaluated at the end of each two year period.

7. The Service retains the ownership in the water system as constructed by it, but in the event of termination of this agreement, the Tribe shall be given the right of purchase of the equipment at the then appraised market value before the Service shall have the right to remove the same from tribal property.

8. It is mutually agreed that the waters of both the well and Pipe Springs will be economically used with the objective of conserving the same, and obtaining the most feasible use therefrom. Water from the well shall not be used for commercial agriculture. In the event rated production of the well becomes less than 15 gallons per minutes (sic), the deficit of the amount agreed to be furnished by the Service to the Tribe shall be made available to the Tribe from Pipe Springs.

9. The Service agrees to meter all water and annually bill the Tribe for water in excess of the specified amount as heretofore provided.

10. The Service agrees to pay a rental charge for the use of water from the well by the Service at the rate of $33 per acre foot, payable annually. The rental charge does not apply to any water used by the Tribe from the well.

11. The parties each agree to make prompt payment upon receipt of billing from the other party.

12. The Service agrees that it will maintain the pool now constituting a part of the Pipe Springs Monument attraction and in the event water used by the Service from Pipe Springs is less than the output of said Springs, the Service agrees to make the excess water available to the Tribe through the Tribe's present line and storage system.

13. The Tribe at its own cost and expense may install a pipeline connecting the water well lines with the Kaibab Village system for emergency purposes only.

14. The Tribe would like to retain one gallon per minute flow from Pipe Springs for Livestock purposes which the Tribe will install at their own expenses.

KAIBAB BAND OF PAIUTE INDIAN S
OF THE KAIBAB RESERVATION, ARIZONA

BY Bill Tom
Tribal Chairperson

NATIONAL PARK SERVICE, PIPE SPRING

By Frank F. Kowski
Regional Director

APPROVED:

(name not legible)
Acting Superintendent, Hopi Indian Agency
Bureau of Indian Affairs

SUPPLEMENTAL AGREEMENT
BETWEEN THE UNITED STATES NATIONAL PARK SERVICE AND THE KAIBAB BAND OF PAIUTE INDIANS

THIS SUPPLEMENTAL AGREEMENT, made and entered into this 16 day of February, 1996, between the Kaibab Band of Paiute Indians of the Kaibab Reservation, Arizona, organized pursuant to Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended, hereinafter referred to as the "Tribe," and the United States National Park Service, hereinafter referred to as the "Service," amends the agreement entered into by said parties on the 13th day of April, 1972.

WITNESSETH :

WHEREAS, under the proclamation establishing Pipe Spring National Monument (43 Stat. 1913) the National Park Service, in its administration of the Monument was, among other things, to assure the Tribe of "the privilege of utilizing waters from Pipe Springs for irrigation, stock watering and other purposes, under regulations to be prescribed by the Secretary of the Interior;" and,

WHEREAS, the Service has continued to operate the water system described in the agreement of April 13, 1972 to the benefit of the Service and the Tribe; and,

WHEREAS, the Tribe, with the assistance of the Natural Resources *Conservation Service of the United States Department of Agriculture,* hereinafter referred to as the NRCS, has been granted funding to build a water line to a stock watering trough west of the Monument, in North Calf Pasture; and,

WHEREAS, the closest and only feasible sources of water for said project are either water from Pipe Springs or water from the water system on the Kaibab Reservation operated by the Service under the agreement of April 13, 1972; and,

WHEREAS, the Tribe, the Service, the NRCS, the Bureau of Indian Affairs, and the Arizona State Historic Preservation Officer agree that connecting the new water line to the joint NPS tribal water system within the Monument and laying said water line from the connection point to the Monument boundary, and ultimately to the water trough in North Calf Pasture, along a route following the old highway (see Appendix B - route map), can be achieved without any lasting damage to cultural resources as opposed to the alternative of laying the line around the boundaries of the Monument and across sensitive archeological resources on the Reservation. Furthermore, these parties have entered into a Memorandum of Agreement (Appendix A) regarding the protection of cultural resources during the installation of the water line; and,

THEREFORE, the Agreement of April 13, 1972 is hereby amended to allow for the installation and maintenance of a water line from a connection point on the joint NPS/tribal water system line approximately located southwest of the ponds, south of Winsor Castle, and running to the west boundary of the Monument beneath the surface of the old highway, pursuant to the terms of the Memorandum of Understanding among and between the NRCS, Tribe, Service, Bureau of Indian Affairs, Arizona State Historic Preservation Office, and Advisory Council on Historic Preservation, and in accordance with design and specifications developed by the NRCS, and approved by the Service, the Tribe, and the Bureau of Indian Affairs, and the following agreed provisions:

(1) The Tribe agrees to install a water meter, backflow prevention device, and shut-off valve, designed and specified by the NRCS and approved by the Service, at the point of connection to the water system, and a dependable float valve, designed and specified by the NRCS, at the water trough destination, which will provide for health

and safety requirements and water conservation goals.

(2) The Tribe agrees to conduct routine and emergency maintenance on the subject water line and its components, at its cost and expense, to assure its adequate operation and economic use with the objective of conserving water.

(3) The Tribe agrees to notify the Service of any necessary maintenance work on the line within Pipe Spring National Monument, and to proceed with said maintenance only after obtaining approval from the Service, which approval shall not be unreasonably denied.

(4) The Tribe agrees to conduct any necessary maintenance pursuant to the same considerations for protection of cultural resources, including Service participation and approvals, agreed to by all parties, including the Arizona State Historic Preservation Office, and Advisory Council on Historic Preservation, in the aforementioned Memorandum of Understanding concerning installation.

(5) The Tribe agrees to notify the Service of any secondary connections to the North Calf Pasture water line proposed in the future, and to ensure that any such connections and supplementary water lines meet the same, or equivalent, applicable NRCS specifications as the primary line which is the principle subject of this agreement, including, but not limited to, design and specifications for pipeline and float valves.

(6) The Service agrees to conduct any necessary maintenance on the subject water line and its components within the Monument which is a result of actions of the Service or its invitees.

(7) The Service agrees to respond to requests from the Tribe to conduct maintenance work by the Tribe or its representatives within the Monument as expeditiously as possible.

(8) The Service agrees to regularly record water meter readings on the subject water line and share said information with the Tribe as requested or necessary.

(9) The Service agrees to immediately inform the Tribe of any necessary maintenance it discovers a need for on the subject water line and its components.

(10) The Service and the Tribe agree that the Service may shut off the subject water line in the event of a water line break, leak, or failure of component which threatens health and safety or results in loss of water from the joint water system compromising other water needs of both parties, especially culinary and fire needs and requirements. In the event the Service finds it necessary to so shut off the line, the Service will immediately notify the Tribe so the necessary repairs and alternative arrangements for watering of livestock can be made.

(11) This Supplemental Agreement shall become effective upon execution and shall remain in effect over the present or extended term of the principle Agreement of April 13, 1972.

KAIBAB BAND OF PAIUTE INDIANS OF THE KAIBAB RESERVATION, ARIZONA

BY Gloria Bulletts Benson Date 2/16/1996
Tribal Chairperson

NATIONAL PARK SERVICE, PIPE SPRING

BY John W. Hiscock Date 3/8/1996
Superintendent

BUREAU OF INDIAN AFFAIRS, SOUTHERN PAIUTE FIELD STATION

BY Flossie I. Girty Date 3/8/1996
Field Representative

APPENDIX B. SUPPLEMENTAL INFORMATION ON CLIMATE

Climate Summary

Location: **Pipe Spring National Monument**

County: Mojave   Latitude: 36.8586   Longitude: -112.739   Elevation: 4,920 feet

Period of Record: 1963-2005

Pipe Spring National Monument

Monthly Data Summary

Maximum Temperature in °F

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Normal		48.1	53.5	61.3	69.6	78.9	90.1	94.7	91.8	84.8	72.9	58.1	49.1	71.1
Standard Deviation		8.2	9.2	8.7	9.5	8.3	6.7	5.2	5.7	6.5	9.4	9.4	8.2	18.1
Average Monthly		47.7	53.5	61.0	68.7	79.0	89.6	94.7	91.7	84.7	73.1	58.2	48.7	71.0
Standard Deviation		8.7	9.0	9.2	9.6	8.4	7.0	5.2	5.6	6.5	9.5	9.4	8.4	18.3
High Monthly Average		59.0	63.3	71.6	78.0	87.2	94.8	99.6	96.3	90.5	81.6	66.7	58.9	99.6
Year of Occurrence		1986	1995	1972	1989	1984	1994	2003	1994	1979	1964	1999	1980	2003
Low Monthly Average		34.8	44.2	51.5	60.8	72.3	82.9	89.8	86.2	79.0	66.0	50.8	40.1	34.8
Year of Occurrence		1973	1979	1973	1975	1995	1965	1999	1968	1986	1972	2000	1978	1973
Record High Daily		79	78	85	89	99	110	108	105	100	93	79	69	110
Day of Occurrence		18	26	21	27	31	26	7	4	1	1	9	1	June 26
Year of Occurrence		1971	1986	2004	2000†	2002	1970	1985†	1994†	1995†	1980†	1973	1969†	1970
Record Low Daily		20	22	32	39	45	59	68	67	56	36	30	17	17
Day of Occurrence		31	7	10	10	7	17	8	30	25	29	19	22	Dec 22
Year of Occurrence		1979†	1989	1969	1965	1964	1995	1992	2000	1986	1971	1985	1990	1990
Days max ≥ 100	Avg. #/ month or year	0	0	0	0	0	1.5	4.9	2.1	0.05	0	0	0	8.6
Days max ≥ 90		0	0	0	0	2.3	15.8	24.4	20.0	6.6	0.5	0	0	69.6
Days max ≤ 32		0.8	0.4	0	0	0	0	0	0	0	0	0.1	0.8	2.1

†Also Occurred on Earlier Date(s).

Pipe Spring National Monument

Monthly Data Summary

Minimum Temperature in °F

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Normal		22.6	26.3	30.1	35.8	43.4	51.5	58.9	58.1	50.2	39.1	28.6	22.5	38.9
Standard Deviation		8.1	8.0	7.2	7.1	6.9	6.3	5.6	5.0	6.4	7.2	8.2	8.1	14.6
Average monthly		21.7	25.5	29.8	34.9	42.9	51.1	58.7	57.7	49.6	38.8	28.8	22.0	38.5
Standard Deviation		8.5	8.0	7.2	7.2	6.9	6.2	5.3	5.0	6.8	7.5	7.9	8.3	14.7
High Monthly Average		29.5	32.0	35.0	40.3	48.3	56.0	63.5	62.5	56.1	45.7	34.2	28.2	63.5
Year of Occurrence		2005	1968	1978	1992	2000	1981	1996	2003	1963	1963	1965	1980	Jul 1996
Low Monthly Average		11.9	15.3	23.6	26.5	38.0	46.5	53.0	53.9	43.6	31.5	23.7	13.2	11.9
Year of Occurrence		1973	1964	2002	1970	1983	1995	1987	1975	1970	1970	1994	1968	Jan 1973
Record High Daily		45	47	53	59	66	78	77	74	72	62	56	46	78
Day of Occurrence		14	20	23	15	29	30	6	1	4	1	10	6	Jun 30
Year of Occurrence		1980†	1996	2004†	2002	2000†	1996	1996	2002	1990	1976	2005	1966	1996
Record Low Daily		-12	-8	4	8	20	33	41	38	28	10	0	-13	-13
Day of Occurrence		30	4	2	2	1	14	1	23	20	30	19	23	Dec 23
Year of Occurrence		1979	1979	1971	1975	1967	2001	1970	1968	1978†	1971	1985	1990	1990
Days min ≤ 32	Avg. #/ month or year	25.5	21.5	18.9	10.7	2.1	0	0	0	0.3	5.4	19.7	26.0	130.1
Days min ≤ 0		0.4	0.1	0	0	0	0	0	0	0	0	0.02	0.4	0.9
Days min ≤ -20		0	0	0	0	0	0	0	0	0	0	0	0	0

†Also Occurred on Earlier Date(s).

Pipe Spring National Monument

Monthly Data Summary

Mean Temperature in °F

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Normal	35.4	39.9	45.7	52.7	61.1	70.7	76.8	75.0	67.4	55.9	43.4	35.8	51.0
Standard Deviation	6.8	7.1	6.6	7.3	6.7	5.8	4.2	4.2	5.4	7.2	7.7	6.9	15.8
Average monthly	34.7	39.5	45.4	51.8	60.9	70.3	76.7	74.7	67.2	55.9	43.5	35.3	50.8
Standard Deviation	7.3	7.0	6.9	7.4	6.8	5.8	4.0	4.2	5.6	7.3	7.5	7.2	15.9
High Monthly Average	43.4	46.6	51.8	59.0	66.7	74.6	80.6	78.1	71.1	62.6	49.0	43.6	80.6
Year of Occurrence	1986	1995	2004	1989	1984	1981	2003	1994	1963	2003	1981	1980	Jul 2003
Low Monthly Average	23.4	31.9	39.8	45.3	56.7	64.9	73.3	70.1	62.5	50.3	37.2	28.1	23.4
Year of Occurrence	1973	1979	1964	1970	1965	1965	1987	1968	1986	1984	2000	1967	Jan 1973

Location: **Pipe spring National Monument**

County: Mojave Latitude: 36.8586 Longitude: -112.739 Elevation: 4,920 feet

Period of Record: 1963-2005

Pipe Spring National Monument

Monthly Data Summary

Precipitation in Inches

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Normal	1.42	1.44	1.17	0.79	0.53	0.29	0.90	1.43	0.97	1.03	0.87	0.63	11.46
Standard Deviation	1.4	1.0	1.0	0.7	0.5	0.4	0.7	1.0	0.9	1.0	0.8	0.7	2.6
Average monthly	1.23	1.26	1.08	0.76	0.53	0.34	0.92	1.40	0.90	0.96	0.89	0.75	10.91
Standard Deviation	1.4	1.0	1.0	0.7	0.5	0.4	0.7	1.0	1.0	1.0	0.8	0.7	3.5
High Monthly Total	6.00	3.52	4.28	3.14	2.00	1.45	2.99	4.15	3.99	4.02	3.50	2.70	19.46
Year of Occurrence	1993	2005	1992	1988	1995	1968	1989	1963	1990	2000	1978	1966	1995
Low Monthly Total	0.01	0.01	0	0	0	0	0	0.06	0	0	0	0	5.33
Year of Occurrence	1972	1972	2004[†]	1989[†]	2004[†]	2003[†]	1993	1998	1989	1995[†]	1994[†]	1989[†]	2002
Record High Daily	1.50	1.57	1.14	1.09	0.95	1.38	1.50	1.86	1.95	1.89	1.91	1.00	1.95
Day of Occurrence	16	15	3	21	25	8	10	16	4	22	5	27	Sep.4
Year of Occurrence	2001	1986	1992	1988	1995	1968	1989	1990	1990	2004	1987	1984	1990
Days pcp ≥ .01 (Avg. #/ month or year)	5.0	5.6	5.5	4.1	3.6	2.2	5.2	6.7	4.0	4.2	3.8	4.1	54
Days pcp ≥ .10 (Avg. #/ month or year)	3.4	3.6	3.5	2.2	1.7	0.9	2.4	3.5	2.3	2.5	2.4	2.3	30.7
Days pcp ≤ .50 (Avg. #/ month or year)	0.7	0.8	0.4	0.3	0.1	0.2	0.4	0.8	0.5	0.5	0.5	0.4	5.6
% of months with No pcp	0%	0%	5%	5%	5%	10%	3%	0%	2%	5%	5%	7%	4%

[†]Also Occurred on Earlier Date(s).

Pipe Spring National Monument

Monthly Data Summary

Snow and Sleet in Inches

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Normal	*	*	*	*	0	0	0	0	0	0	*	*	*
Standard Deviation	*	*	*	*	0	0	0	0	0	0	*	*	*
Average monthly	*	*	*	*	0	0	0	0	0	0	*	*	*
Standard Deviation	*	*	*	*	0	0	0	0	0	0	*	*	*
High Monthly Total	*	*	*	*	0	0	0	0	0	0	*	*	*
Year of Occurrence	*	*	*	*	0	0	0	0	0	0	*	*	*
Low Monthly Total	*	*	*	*	0	0	0	0	0	0	*	*	*
Year of Occurrence	*	*	*	*	-	-	-	-	-	-	*	*	*
Record High Daily	16	10	7.5	4.5	0	0	0	0	0	0	8	6	16
Day of Occurrence	4	27	22	4	-	-	-	-	-	-	12	25	Jan 4
Year of Occurrence	1973	1997	1973	1999	-	-	-	-	-	-	1985	1966	1973
Days snow ≤ .1 (Avg. #/ month or year)	*	*	*	*	0	0	0	0	0	0	*	*	*
Days snow ≤ 5 (Avg. #/ month or year)	*	*	*	*	0	0	0	0	0	0	*	*	*
Days snow ≤ 10 (Avg. #/ month or year)	*	*	*	*	0	0	0	0	0	0	*	*	*

[†]Also Occurred on Earlier Date(s).

* The record of snowfall measurements is too erratic to report this data.

Pipe Spring National Monument

Monthly Data Summary

Degree Days

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Heating Normal	920	710	600	370	152	17	0	3	35	287	649	907	4650
Heating Average	941	721	608	396	157	20	0	2	40	286	644	921	4736
Cooling Normal	0	0	0	1	32	190	381	311	109	6	0	0	1030
Cooling Average	0	0	0	1	30	184	372	303	105	6	0	0	1001
Growing 40 Normal	25	76	198	387	657	924	1186	1085	825	498	153	29	6043
Growing 40 Average	24	69	195	361	649	933	1167	1077	816	499	155	28	5973

[†]Also Occurred on Earlier Date(s).

Glossary

Average vs. Normal – reported averages are the mean of all values for the period of record (in this case 1963 through 2005), while "normal" values are the mean over the most recent 30 years (1976-2005). At PISP there is generally little difference between average and normal because the total period of record is not much longer than 30 years.

Data Quality – While the overall period-of-record is 43 years, there are several data gaps. Where whole months of data are missing, a reduced "n" is used in calculating monthly means.

Month	Months Reported over Period-of-Record	Months Reported over "Normal" Period
JAN	43	29
FEB	43	29
MAR	44	30
APR	44	30
MAY	44	30
JUN	43	29
JUL	42	27
AUG	44	30
SEP	44	29
OCT	44	29
NOV	44	30
DEC	45	29
Annual	44	30

Degree Days

Heating Degree Days – An indicator of the energy required for home heating. Calculated as the sum of the number of degrees that each day's daily mean temperature is below 65ºF.

Cooling Degree Days – An indicator of the energy required for home cooling. Calculated as the sum of the number of degrees that each day's daily mean temperature is above 65ºF.

Growing Degree Days – A measure of the length and intensity of the growing season for crops. It is calculated as the sum of the number of degrees that each day's daily mean temperature exceeds 40ºF. (This can also be calculated for corn based on a 50ºF, with the daily tally capped at 86ºF.)

Number of Occurrences per Year – Where the number of days above or below a given temperature (≥100º or ≤32º) is reported, the number represents the average number of occurrences for that month or year.

Precipitation - Where a significant amount precipitation data is missing (often an entire month) those months are omitted when calculating monthly averages and extremes. For annual totals, however, an estimation of monthly precipitation is calculated based on adjusting the monthly for Pipe Spring based on the actual precipitation recorded at Kanab as compared to the Kanab average for that month.

Snowfall – Much of the snowfall data is suspect in that snowfall was not reported. There are frequent instances where a significant amount of precipitation is recorded, and temperatures are near freezing or below all day, but now snowfall is recorded. Therefore, only some extreme events are reported in the snowfall table.

Precipitation Summary for Pipe Spring National Monument

STATION AT PIPE SPRING NATIONAL MONUMENT (Station ID 26616)
Located at Park Headquarters/Visitor Center (Lat. 36.8586, Long. -112.739, Elevation 4920')
Record begins 6/1/1963. Total period of record 43 years

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
1963	z	z	z	z	z	z	0.11	4.15	2.26	1.49	1.36	0.01	9.36
1964	0.14	0.01	1.16	1.34	0.30	0.01	0.98	0.44	0.20	0.01	0.40	0.76	5.72
1965	0.36	0.29	1.67	2.62	1.13	0.31	0.47	0.36	0.45	0.35	2.54	2.64	13.17
1966	0.12	1.22	0.24	0.25	0.70	0.14	0.35	0.63	0.63	0.56	0.80	2.70	8.33
1967	0.68	0.02	0.51	0.74	0.70	0.58	0.89	1.71	2.85	0.02	0.22	1.45	10.36
1968	0.21	0.93	0.71	0.77	0.40	1.45	2.13	0.63	0.11	0.14	0.16	0.53	8.16
1969	2.64 d	2.66	0.17	0.04	0.78	0.54	0.69	2.25 z	1.01	0.39	0.79	0.01	11.96
1970	0.40	1.31	0.51	0.07	0.01	0.22	1.95	2.28	0.25	0.10	0.85	1.04	8.97
1971	0.10	1.03	0.15	0.36	0.84	0.10	0.57	2.74	0.02	1.88	1.36	1.58	10.70
1972	0.01	0.01	0.00	0.47	0.34	0.62	0.12	1.42	1.07	3.58	1.40	0.87	9.88
1973	1.69	1.47	2.95	0.49	0.33	0.69	0.42	0.82	0.01	0.02	0.79	0.20	9.85
1974	2.48	0.05	0.62	0.23	0.04	0.01	1.22	0.17	0.25	1.93	1.13	0.88	9.00
1975	0.40	0.91	1.65	0.76	0.62	0.64	2.67	0.67	0.56	0.17	0.43	0.49	9.94
1976	0.02	1.70	0.47	1.56	0.96	0.01	0.55	0.30	1.02 z	0.46	0.01	0.10	7.13
1977	0.83	0.08	0.51	0.10	1.52	0.94	0.27	0.89	0.29	0.33	0.25	1.06	7.05
1978	4.06	2.32	2.25	0.79	0.80	0.00	0.87	0.26	0.38	0.95	3.50	2.05	18.21
1979	3.20	1.03	2.07	0.00	0.63	0.01	0.01	1.95	0.03	0.03	0.65	0.66	10.26
1980	3.25	3.31 a	2.80	0.34	0.84	0.26	1.20 z	1.45	0.63	1.23	0.17	0.40	15.86
1981	0.34	0.74	2.26	0.65	1.49	0.23	1.60	2.33	0.71	2.14	1.13	0.13	13.74
1982	1.27	0.80	1.22 a	0.26	0.59	0.06	0.78	2.90	1.17	0.51	2.27	0.69	12.51
1983	1.19	1.20	1.83	0.98	0.13	0.00	1.28	1.61	1.60	0.43	1.39	0.00	11.64
1984	0.18	0.28	0.46	0.13	0.01	0.21	0.94	1.64	0.06	0.15	0.40	2.61	7.07
1985	1.42	0.33	0.94	1.44	0.37	0.58	0.66	0.28	1.33	0.84	2.61	0.77	11.56
1986	0.20	2.12	1.68	0.28	0.02	0.17	0.36	1.12	2.18	1.88	0.88	0.00	10.89
1987	0.87	1.26 z	0.59	0.29	0.70	0.10	0.53	1.31	0.01	1.75	2.45	0.26	10.11
1988	0.87	0.72	0.06	3.14	0.38	1.14	0.35	2.05	0.01	0.23	0.48	1.31	10.73
1989	1.12	0.32	0.70	0.00	0.92	0.01	2.99	1.75	0.00	0.22	0.01	0.00	8.04
1990	0.53	0.82	0.15	0.90	0.03 a	0.75	0.45 z	1.86 a	3.99 a	0.00	0.55	0.13	10.15
1991	1.10 a	0.37	2.20	0.04	0.01	0.15	1.04	0.98	1.18	0.58	0.24	0.53	8.40
1992	0.56	2.72	4.28	0.14	1.54	0.09	1.59	3.22	1.93	1.24	0.00	1.40	18.69
1993	6.00 a	2.99	1.87	0.03	0.61	0.77	0.00	2.89	0.03	1.80	0.55 a	0.86	18.39
1994	0.25	1.37	0.53	1.70 a	0.53	0.05	0.09	0.99	0.13	1.02	0.00 e	0.65 a	7.30
1995	4.31	2.24	3.22	1.70	2.00	0.62	1.02 a	0.80	1.05	0.00	1.83	0.69 a	19.46
1996	0.43 e	1.91	0.02 a	0.26	0.15	0.01	1.47	0.21	0.68	1.06	0.81	0.56	7.54
1997	2.07	1.08	0.01	1.36	0.32	0.40	1.73	2.95	2.79	0.87	0.57	0.37	14.48
1998	0.84	2.32	1.01	0.71	0.24	0.43 z	1.57 z	0.06	2.57	0.86	1.28	0.01	11.88
1999	0.23 a	0.84	0.01	1.55	0.36	0.48	1.19	1.35	1.19	0.01	0.01	0.09	7.29
2000	0.77 z	0.74	0.92	0.18 a	0.12	0.25	1.03 a	1.52 a	0.38	4.02	0.32	0.18	10.41
2001	2.37 a	0.90 a	1.06 a	0.83	0.17	0.47	1.44	0.46	0.16	0.24 z	0.02	1.20 z	9.29

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
2002	0.20	0.02	0.04	0.02 a	0.00	0.00	0.48	0.19	1.90	1.22 a	0.45 a	0.84 d	5.33
2003	0.21	3.05	0.97	1.13	0.25	0.00	1.36	1.25 a	0.60	0.42	1.19 b	0.75 b	11.17
2004	0.34 a	1.85 a	0.00 a	1.28	0.00	0.02	0.66 a	2.60	0.92 e	3.41 a	1.72	0.98 a	13.77
2005	3.06 a	3.52	1.07	1.91	0.29	0.78	0.02	1.87	0.25	2.23	0.30	0.35	15.63
2006	0.46	0.09 b	3.19 b	0.48	0.07	0.16	1.93	1.79	0.69	1.80	0.06	0.30 a	11.02
2007	0.04 b	0.18	0.50 a	0.56	0.00	0.00	1.22	0.41	1.56	0.00	0.04	2.31	6.82
2008													
2009													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Mean	1.19	1.20	1.12	0.75	0.50	0.32	0.95	1.39	0.91	0.96	0.85	0.78	10.82
Minimum	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	5.33
Maximum	6.00	3.52	4.28	3.14	2.00	1.45	2.99	4.15	3.99	4.02	3.50	2.70	19.46
N	43	43	44	44	44	43	42	44	44	44	45	44	45
Std. Dev.	1.36	0.99	1.04	0.72	0.47	0.35	0.70	0.97	0.93	1.00	0.82	0.74	3.44

Notes on Missing Data

a = 1 day missing, b = 2 days missing, c = 3 days, ..etc..,
z = 26 or more days missing

Individual Months are not used for calculating monthly statistics if more than 5 days are missing. However, Annual totals are calculated using estimated monthly totals (indicated by blue shaded cells) based on a ratio of the total for that month and year to the overall mean for that month at a nearby station (Kanab, Utah) and applying that ratio to the overall mean for that month for this station. For Example:

$$EstimatedPISP = Kanab\left(\frac{Actual\ \mathrm{Pr}\ ecip.forAUG}{MeanAUG}\right)xPISP(MeanAUG)$$

Long-term means are calculated from monthly columns; thus, the sum of the monthly means may not exactly equal the annual values.

Summer Monsoon Precipitation for Pipe Spring National Monument

YEAR	JUN	JUL	AUG	SEP	Total
1963	m	0.11	4.15	2.26	6.51
1964	0.01	0.98	0.44	0.20	1.62
1965	0.31	0.47	0.36	0.45	1.59
1966	0.14	0.35	0.63	0.63	1.75
1967	0.58	0.89	1.71	2.85	6.02
1968	1.45	2.13	0.63	0.11	4.32
1969	0.54	0.69	2.25	1.01	4.49
1970	0.22	1.95	2.28	0.25	4.69
1971	0.10	0.57	2.74	0.02	3.42
1972	0.62	0.12	1.42	1.07	3.22
1973	0.69	0.42	0.82	0.01	1.92
1974	0.01	1.22	0.17	0.25	1.65
1975	0.64	2.67	0.67	0.56	4.53
1976	0.01	0.55	0.30	1.02	1.88
1977	0.94	0.27	0.89	0.29	2.39
1978	0.00	0.87	0.26	0.38	1.50
1979	0.01	0.01	1.95	0.03	1.99
1980	0.26	1.20	1.45	0.63	3.54
1981	0.23	1.60	2.33	0.71	4.87
1982	0.06	0.78	2.90	1.17	4.90
1983	0.00	1.28	1.61	1.60	4.49
1984	0.21	0.94	1.64	0.06	2.85
1985	0.58	0.66	0.28	1.33	2.85
1986	0.17	0.36	1.12	2.18	3.83
1987	0.10	0.53	1.31	0.01	1.95
1988	1.14	0.35	2.05	0.01	3.55
1989	0.01	2.99	1.75	0.00	4.75
1990	0.75	0.45	1.86	3.99	7.05
1991	0.15	1.04	0.98	1.18	3.34
1992	0.09	1.59	3.22	1.93	6.82
1993	0.77	0.00	2.89	0.03	3.69
1994	0.05	0.09	0.99	0.13	1.26
1995	0.62	1.02	0.80	1.05	3.48
1996	0.01	1.47	0.21	0.68	2.36
1997	0.40	1.73	2.95	2.79	7.86
1998	0.43	1.57	0.06	2.57	4.63
1999	0.48	1.19	1.35	1.19	4.21
2000	0.25	1.03	1.52	0.38	3.17
2001	0.47	1.44	0.46	0.16	2.52
2002	0.00	0.48	0.19	1.90	2.56
2003	0.00	1.36	1.25	0.60	3.21
2004	0.02	0.66	2.60	0.92	4.20
2005	0.78	0.02	1.87	0.25	2.91
Mean	0.34	0.93	1.42	0.90	3.59
Minimum	0	0	0.06	0	1.26
Maximum	1.45	2.99	4.145	3.99	7.86
N	42	43	43	43	43
Std Dev	0.35	0.69	0.97	0.93	0.93

Values in Blue cells are estimated where data is missing based on patterns from nearby Kanab

Winter Season Precipitation for Pipe Spring National Monument								
Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	Total
1964	1.49	1.36	0.01	0.14	0.01	1.16	1.34	5.51
1965	0.01	0.40	0.76	0.36	0.29	1.67	2.62	6.09
1966	0.35	2.54	2.64	0.12	1.22	0.24	0.25	7.35
1967	0.56	0.80	2.70	0.68	0.02	0.51	0.74	6.01
1968	0.02	0.22	1.45	0.21	0.93	0.71	0.77	4.31
1969	0.14	0.16	0.53	2.64	2.66	0.17	0.04	6.34
1970	0.39	0.79	0.01	0.40	1.31	0.51	0.07	3.47
1971	0.10	0.85	1.04	0.10	1.03	0.15	0.36	3.62
1972	1.88	1.36	1.58	0.01	0.01	0.00	0.47	5.30
1973	3.58	1.40	0.87	1.69	1.47	2.95	0.49	12.43
1974	0.02	0.79	0.20	2.48	0.05	0.62	0.23	4.39
1975	1.93	1.13	0.88	0.40	0.91	1.65	0.76	7.65
1976	0.17	0.43	0.49	0.02	1.70	0.47	1.56	4.82
1977	0.46	0.01	0.10	0.83	0.08	0.51	0.10	2.07
1978	0.33	0.25	1.06	4.06	2.32	2.25	0.79	11.05
1979	0.95	3.50	2.05	3.20	1.03	2.07	0.00	12.79
1980	0.03	0.65	0.66	3.25	3.31	2.80	0.34	11.03
1981	1.23	0.17	0.40	0.34	0.74	2.26	0.65	5.78
1982	2.14	1.13	0.13	1.27	0.80	1.22	0.26	6.95
1983	0.51	2.27	0.69	1.19	1.20	1.83	0.98	8.67
1984	0.43	1.39	0.00	0.18	0.28	0.46	0.13	2.87
1985	0.15	0.40	2.61	1.42	0.33	0.94	1.44	7.29
1986	0.84	2.61	0.77	0.20	2.12	1.68	0.28	8.50
1987	1.88	0.88	0.00	0.87	1.26	0.59	0.29	5.77
1988	1.75	2.45	0.26	0.87	0.72	0.06	3.14	9.25
1989	0.23	0.48	1.31	1.12	0.32	0.70	0.00	4.16
1990	0.22	0.01	0.00	0.53	0.82	0.15	0.90	2.62
1991	0.00	0.55	0.13	1.10	0.37	2.20	0.04	4.38
1992	0.58	0.24	0.53	0.56	2.72	4.28	0.14	9.04
1993	1.24	0.00	1.40	6.00	2.99	1.87	0.03	13.53
1994	1.80	0.55	0.86	0.25	1.37	0.53	1.70	7.05
1995	1.02	0.00	0.65	4.31	2.24	3.22	1.70	13.13
1996	0.00	1.83	0.69	0.43	1.91	0.02	0.26	5.13
1997	1.06	0.81	0.56	2.07	1.08	0.01	1.36	6.92
1998	0.87	0.57	0.37	0.84	2.32	1.01	0.71	6.67
1999	0.86	1.28	0.01	0.23	0.84	0.01	1.55	4.78
2000	0.01	0.01	0.09	0.77	0.74	0.92	0.18	2.70
2001	4.02	0.32	0.18	2.37	0.90	1.06	0.83	9.67
2002	0.24	0.02	1.20	0.20	0.02	0.04	0.02	1.73
2003	1.22	0.45	0.84	0.21	3.05	0.97	1.13	7.86
2004	0.42	1.19	0.75	0.34	1.85	0.00	1.28	5.82
2005	3.41	1.72	0.98	3.06	3.52	1.07	1.91	15.66
Mean	0.92	0.90	0.77	1.22	1.26	1.08	0.76	6.91
Minimum	0	0	0	0.01	0.01	0	0	1.73
Maximum	4.02	3.5	2.7	6	3.52	4.28	3.14	15.66
N	42	42	42	42	42	42	42	42
Std Dev	1.00	0.82	0.71	1.38	0.97	1.00	0.73	0.73

Values in Blue cells are estimated where data is missing based on patterns from nearby Kanab

Temperature Summary for Pipe Spring National Monument

STATION AT PIPE SPRING NATIONAL MONUMENT (Station ID 26616)
Located at Park Headquarters/Visitor Center (Lat. 36.8586, Long. -112.739, Elevation 4920')
Record begins 6/1/1963. Total period of record 42 years

Low Temperatures

Average Lowest Temperature for the year:	2.5°	
Lowest Recorded Temperature:	-13°	December 23, 1991
Highest Low Temperature for the year:	13°	November 212, 1980
Average Number of Days 32° or below in a year:	138	
Greatest Number of Days 32° or below:	113	1986, 2004
Least Number of Days 32° or below:	159	1971
Average Number of Days 20° or below in a year:	41	
Greatest Number of Days 20° or below:	76	1964
Least Number of Days 20° or below:	15	1978, 2005
Average Number of Days 10° or below in a year:	6.8	
Greatest Number of Days 10° or below:	21	1989
Least Number of Days 10° or below:	0	many
Typical Day of First Frost:	October 16	
Earliest First Frost:	September 15, 1970	
Latest First Frost:	November 11, 1988	
Typical Day of Last Frost:	May 9	
Earliest Last Frost:	April 10, 2004	
Latest Last Frost:	May 26, 1980	
Typical Frost Free Period:	157 days	
Shortest Frost Free Period:	117 Days	2006
Longest Frost free Period:	201 days	1987

High Temperatures

Average Annual High Temperature for the Year:	103.4°	
Highest Recorded Temperature:	110°	June 26, 1970
Lowest High Temperature for the year:	99°	July 16, 1965
Average First Day over 100°:	July 2	
Earliest First 100° day:	June 7, 1985	
Latest First 100° day:	August 9, 1980	
Average Last Day Over 100°:	August 4	
Earliest Last 100° day:	June 22, 1968	
Latest Last 100° day:	September 13, 1963	
Average Number of Days over 100° in a year:	9.3	
Greatest Number of Days over 100° in a year:	30	1994
Least Number of Days over 100° in a year:	0	1995
Average Number of Days in a year over 110°:	0.02	
Greatest Number of Days in a year over 110°:	1	1970
Least Number of Days in a year over 110°:	0	(many years)

Year	N (# of Days of Data)	Pattern of Missing Data	Day over 100° (Julian Day)		Highest Temperature for the Calendar Year		Number of Days over 100°	Number of Days over 110°	Frost (Julian Day)		Frost Free Period (Days)	Lowest Temperature for the Water Year[1]		Number of Days ≤ Temp[1] (Based on Water Year, Oct-Sep)		
			First 100°	Last 100°	Date	Max. Temp			First Frost	Last Frost		Date	Min. temp	32°	20°	10°
1963	178	Begin at 6/21	182	256	24-JUL[2]	102°	10	0	310	☼	☼	☼	☼	☼	☼	☼
1964	355		189	222	19-JUL	103°	6	0	295	130	165	15-JAN	2°	**145**	**76**	**17**
1965	361		-	-	16-JUL[2]	99°	0	0	261	130	131	12-FEB	5°	**155**	**49**	**5**
1966	363		200	229	7-AUG	103°	10	0	287	117	170	9-FEB	0°	**119**	**43**	**9**
1967	364		182	207	1-JUL[2]	103°	9	0	282	134	148	28-DEC	-4°	**148**	**40**	**11**
1968	357		172	174	22-JUN	101°	3	0	265	138	127	21-DEC	-7°	**151**	**41**	**12**
1969	282	Aug & Winter	182	185	2-JUL	102°	4[3]	0[3]	277	119	158	23-DEC[3]	2°	**97**[3]	**30**[3]	**10**[3]
1970	313	Scattered	173	225	26-JUN	110°	21	1	258	122	136	3-JAN[2]	-3°	**150**[3]	**35**[3]	**11**[3]
1971	345	Scattered	172	222	15-JUL	105°	16	0	262	143	119	5-JAN	-9°	**159**	**54**	**14**
1972	362		182	224	29-JUL	107°	15	0	295	132	163	14-DEC	-1°	**151**	**52**	**11**
1973	355		178	186	5-JUL	102°	5	0	283	122	161	7-JAN	-8°	**157**	**52**	**18**
1974	351		163	210	15-JUN	105°	8	0	303	140	163	2-JAN	-5°	**143**	**39**	**3**
1975	344		181	216	7-JUL	104°	4	0	281	141	140	24-DEC	4°	**157**	**43**	**4**
1976	323	Sep	188	205	7-JUL[2]	101°	7	0	294	119	175	2-JAN	0°	**147**	**40**	**6**
1977	354		179	214	31-JUL[2]	**102°**	7	0	305	138	167	27-NOV	4°	**158**	**65**	**8**
1978	362		204	220	30-JUL[2]	102°	6	0	262	138	124	24-JAN	12°	**119**	**15**	**0**
1979	359		178	216	17-JUL[2]	102°	12	0	294	131	163	30-JAN	-12°	**145**	**47**	**17**
1980	335	July	221	225	11-AUG	102°	4[3]	0[3]	289	147	142	21-NOV	13°	**128**	**22**	**0**
1981	348		172	220	25-JUN[2]	104°	11	0	287	135	152	26-JAN	11°	**122**	**21**	**0**

Year	N (# of Days of Data)	Pattern of Missing Data	Day over 100° (Julian Day)		Highest Temperature for the Calendar Year		Number of Days over 100°	Number of Days over 110°	Frost (Julian Day)		Frost Free Period (Days)	Lowest Temperature for the Water Year[1]		Number of Days ≤ Temp[1] (Based on Water Year, Oct-Sep)		
			First 100°	Last 100°	Date	Max. Temp			First Frost	Last Frost		Date	Min. temp	32°	20°	10°
1982	365		193	203	12-JUL	107°	4	0	281	126	155	5-FEB	1°	**127**	**31**	**6**
1983	365		186	186	5-JUL	100°	1	0	295	140	155	31-DEC	12°	**155**	**26**	**0**
1984	366		180	222	28-JUN[2]	102°	4	0	289	120	169	18-JAN	4°	**147**	**61**	**1**
1985	365		158	238	5-JUL[2]	108°	22	0	287	134	153	5-FEB[2]	0°	**139**	**43**	**6**
1986	365		176	215	25-JUN[2]	102°	8	0	286	129	157	19-NOV	0°	**113**	**24**	**7**
1987	337	Feb	163	206	12-JUN[2]	100°	5	0	312	111	201	9-JAN[2]	6°	**113**[3]	**44**[3]	**7**[3]
1988	366		199	202	17-JUL	101°	3	0	316	129	187	20-JAN	1°	**138**	**53**	**11**
1989	365		166	221	7-JUL	106°	15	0	278	133	145	27-DEC	-7°	**118**	**56**	**21**
1990	363		173	222	25-JUN[2]	103°	15	0	281	121	160	4-JAN	2°	**130**	**56**	**11**
1991	365		183	210	5-JUL	104°	6	0	298	132	166	23-DEC	-13°	**144**	**44**	**9**
1992	366		215	232	19-AUG	103°	4	0	306	112	194	1-DEC	7°	**117**	**24**	**4**
1993	365		209	215	2-AUG	103°	5	0	292	125	167	19-DEC	2°	**119**	**32**	**5**
1994	365		175	228	4-AUG	105°	30	0	289	137	152	26-NOV	7°	**146**	**43**	**5**
1995	365		191	244	28-JUL	103°	13	0	278	127	151	20-NOV[2]	6°	**129**	**36**	**2**
1996	366		183	242	6-JUL[2]	103°	15	0	294	121	173	26-JAN	7°	**138**	**25**	**2**
1997	365		186	198	15-JUL[2]	101°	5	0	285	122	163	15-JAN	1°	**136**	**40**	**4**
1998	304	June & July	☼	☼	☼	☼	☼	☼	278	142	136	26-DEC[2]	7°	**151**	**39**	**6**
1999	365		182	187	1-JUL	102°	3	0	290	121	169	24-DEC	5°	**154**	**50**	**3**
2000	335	Jan	204	215	30-JUL	103°	5	0	287	133	154	23-NOV	7°	**99**[3]	**29**[3]	**2**[3]

Year	N (# of Days of Data)	Pattern of Missing Data	Day over 100° (Julian Day)		Highest Temperature for the Calendar Year		Number of Days over 100°	Number of Days over 110°	Frost (Julian Day)		Frost Free Period (Days)	Lowest Temperature for the Water Year[1]		Number of Days ≤ Temp[1] (Based on Water Year, Oct-Sep)		
			First 100°	Last 100°	Date	Max. Temp			First Frost	Last Frost		Date	Min. temp	32°	20°	10°
2001	302	Oct & Dec	182	241	2-JUL[2]	103°	8	0	306	125	181	19-NOV[2]	11°	**136**	**40**	**0**
2002	365		177	228	14-JUL	105°	14	0	292	143	149	31-JAN[3]	3°	☼	☼	☼
2003	205	Jan & June	187	224	11-JUL[2]	106°	19 [3]	0 [3]	308	☼	☼	☼	☼	☼	☼	☼
2004	319	July & Sep	☼	☼	☼	☼	☼	☼	297	103	194	5-JAN	2°	**113**	**39**	**6**
2005	358		194	204	14-JUL	104°	9	0	297	132	165	30-NOV[2]	11°	**122**	**15**	**0**
2006	358		158	206	28-Jun	106	11	0	297	115	117	28-Nov	7	**133**	**38**	**1**
2007	362		174	227	5-Jul	106	18	0	292	128	152	1-Dec	-2	**135**	**45**	**8**
2008																
Max or Earliest	366		158 7-JUN-1985	174 22-JUN-1968	15-JUN-1974 105°	110° (1970)	0 (1965)	0 (Many)	258 15-SEP-1970	103 10-APR-2004	201 1987	5-FEB-1982 1°	13° (1980)	159 (1971)	76 (1964)	21 (1989)
Min or Latest	178		221 9-AUG-1980	256 13-SEP-1963	19-AUG-1992 103°	99° (1965)	30 (1994)	1 (1970)	316 11-Nov-1988	147 26-May-1980	117 2006	12-FEB-1965 5°	-13° (1991)	113 (1986, 2004)	15 (1978, 2005)	0 (many)
Mean	344		183	216	195	103.4°	9.3	0.0	289	129	157	90	2.5°	138	41.0	6.8
Equivalent Day	-		July 2	Aug 4	July 14				16OCT	9MAY		29 DEC				

[1] The Water Year (October to September) is used to compare winters so that low temperature occurrences for an entire winter season are combined in a single year. As a result the winter of 1996 is tallied from October 1995 through spring of 1996, and low temperature occurrences in the fall of 1996 will be tallied with the winter of 1997. The tallies for single days of missing data are counted when temperatures on both adjacent days meet the criteria.

[2] Maximum or minimum temperatures for the year occur on two or more days in these years. The date of the first occurrence is listed, but an average Julian day is calculated, shown in the table and used for calculating average occurrences.

[3] The period if interest for these statistics includes some missing data, which is not used for calculating averages, maximums or minimums.

☼ A substantial amount of data is missing during these periods.

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

PIPE SPRINGS NATL MONUME, ARIZONA (02-6616) 36.8586 N 112.7386 W 4950 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 4
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2006
Extracted: Tue Sep 30 2008

Precipitation Frequency Estimates (inches)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.14	0.21	0.26	0.35	0.44	0.53	0.59	0.73	0.91	1.03	1.15	1.31	1.57	1.75	2.28	2.74	3.28	3.74
2	0.18	0.27	0.34	0.46	0.56	0.67	0.74	0.92	1.14	1.28	1.43	1.64	1.97	2.21	2.86	3.43	4.12	4.71
5	0.25	0.38	0.47	0.63	0.78	0.89	0.97	1.16	1.43	1.60	1.78	2.05	2.48	2.81	3.58	4.28	5.19	5.95
10	0.31	0.47	0.58	0.78	0.97	1.09	1.16	1.37	1.67	1.86	2.08	2.38	2.89	3.30	4.14	4.92	6.03	6.93
25	0.40	0.61	0.76	1.02	1.27	1.39	1.46	1.68	1.99	2.22	2.48	2.85	3.46	3.99	4.90	5.77	7.16	8.26
50	0.49	0.74	0.92	1.24	1.53	1.66	1.71	1.93	2.24	2.50	2.79	3.22	3.90	4.53	5.49	6.42	8.04	9.30
100	0.58	0.89	1.10	1.48	1.83	1.98	2.02	2.21	2.51	2.81	3.12	3.61	4.37	5.11	6.09	7.06	8.93	10.36
200	0.70	1.06	1.31	1.77	2.19	2.35	2.38	2.56	2.81	3.11	3.46	4.01	4.84	5.70	6.70	7.69	9.85	11.44
500	0.87	1.33	1.65	2.22	2.74	2.93	2.95	3.14	3.28	3.53	3.92	4.56	5.50	6.54	7.52	8.52	11.07	12.91
1000	1.03	1.57	1.95	2.62	3.24	3.44	3.46	3.65	3.76	3.86	4.28	5.00	6.01	7.20	8.15	9.15	12.01	14.04

* These precipitation frequency estimates are based on a partial duration series. **ARI** is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting forces estimates near zero to appear as zero.

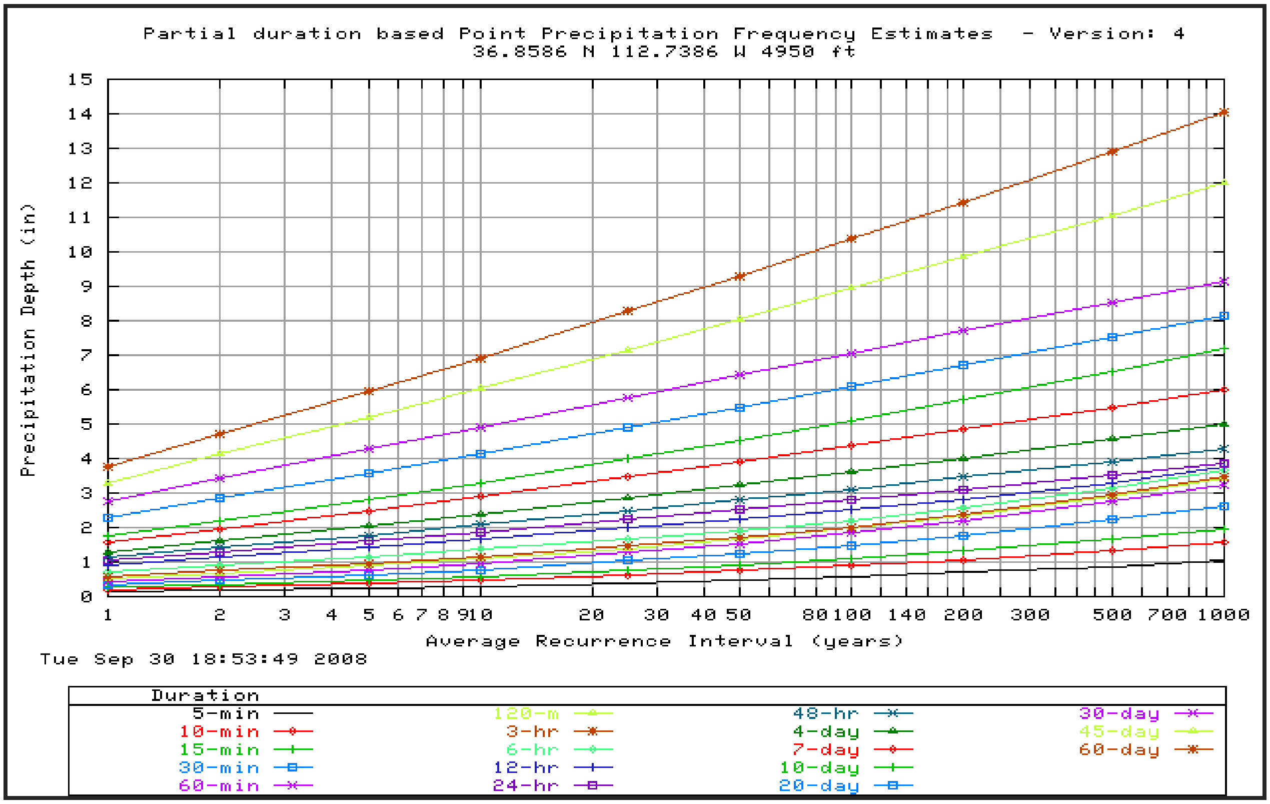
* Upper bound of the 90% confidence interval Precipitation Frequency Estimates (inches)

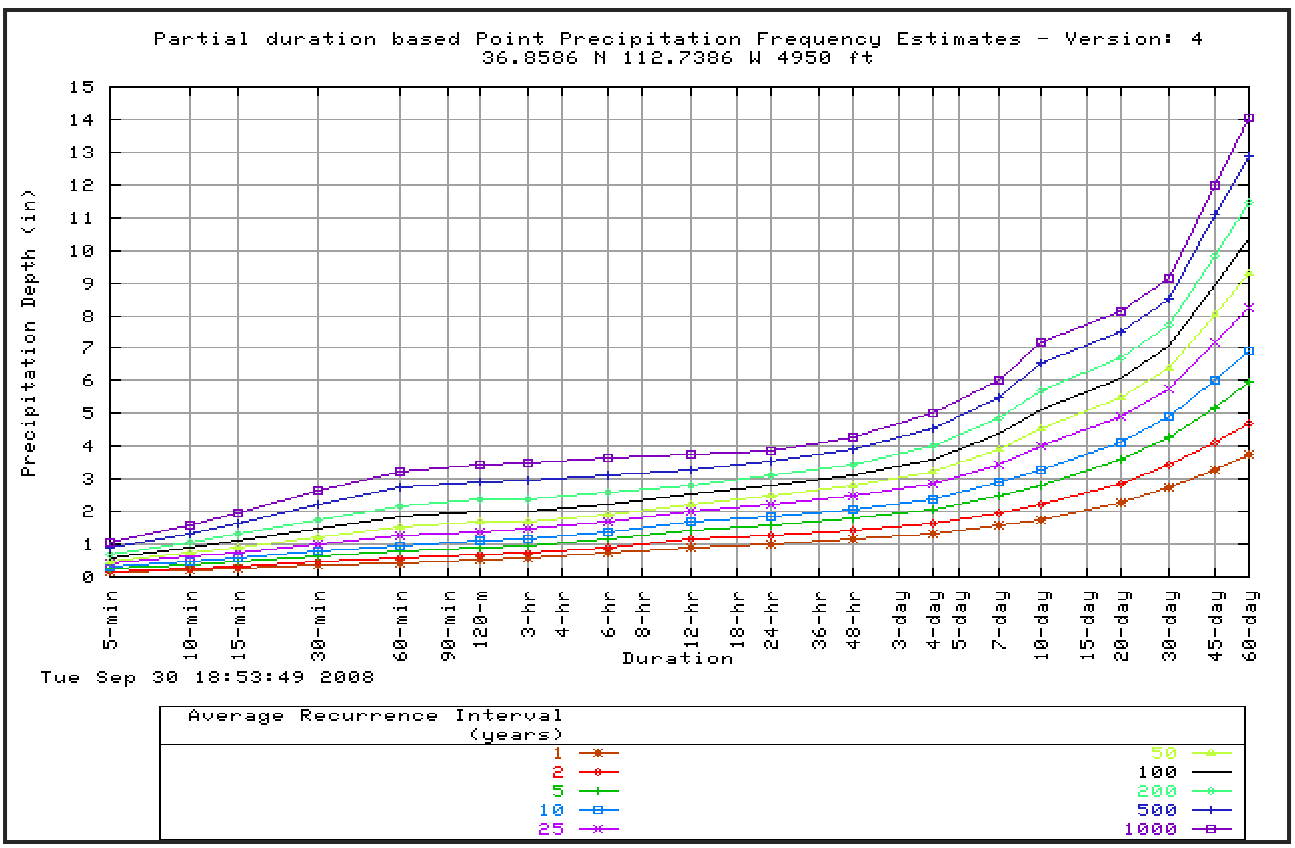
ARI** (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.17	0.25	0.31	0.42	0.52	0.61	0.68	0.83	1.02	1.13	1.25	1.41	1.70	1.92	2.50	2.99	3.63	4.16
2	0.21	0.33	0.40	0.54	0.67	0.77	0.85	1.04	1.28	1.41	1.55	1.76	2.13	2.43	3.13	3.75	4.56	5.22
5	0.29	0.45	0.56	0.75	0.93	1.03	1.11	1.32	1.61	1.76	1.94	2.20	2.68	3.08	3.90	4.66	5.72	6.61
10	0.37	0.56	0.69	0.93	1.15	1.26	1.34	1.55	1.87	2.04	2.25	2.55	3.11	3.60	4.50	5.35	6.64	7.69
25	0.48	0.73	0.91	1.22	1.51	1.62	1.68	1.90	2.24	2.43	2.70	3.06	3.74	4.35	5.32	6.28	7.91	9.19
50	0.58	0.88	1.09	1.47	1.82	1.94	1.98	2.19	2.53	2.76	3.04	3.47	4.22	4.96	5.97	6.98	8.88	10.35
100	0.70	1.06	1.32	1.78	2.20	2.33	2.35	2.53	2.85	3.09	3.42	3.90	4.75	5.61	6.65	7.71	9.90	11.56
200	0.84	1.28	1.59	2.14	2.65	2.78	2.80	2.97	3.21	3.43	3.81	4.37	5.30	6.30	7.37	8.45	10.94	12.82
500	1.07	1.63	2.02	2.72	3.37	3.52	3.56	3.69	3.79	3.93	4.36	5.02	6.07	7.30	8.34	9.39	12.43	14.57
1000	1.28	1.95	2.42	3.26	4.04	4.21	4.25	4.36	4.41	4.45	4.81	5.54	6.71	8.09	9.12	10.16	13.55	16.01

* The **upper** bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are **greater** than.
** These precipitation frequency estimates are based on a partial duration series. **ARI** is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

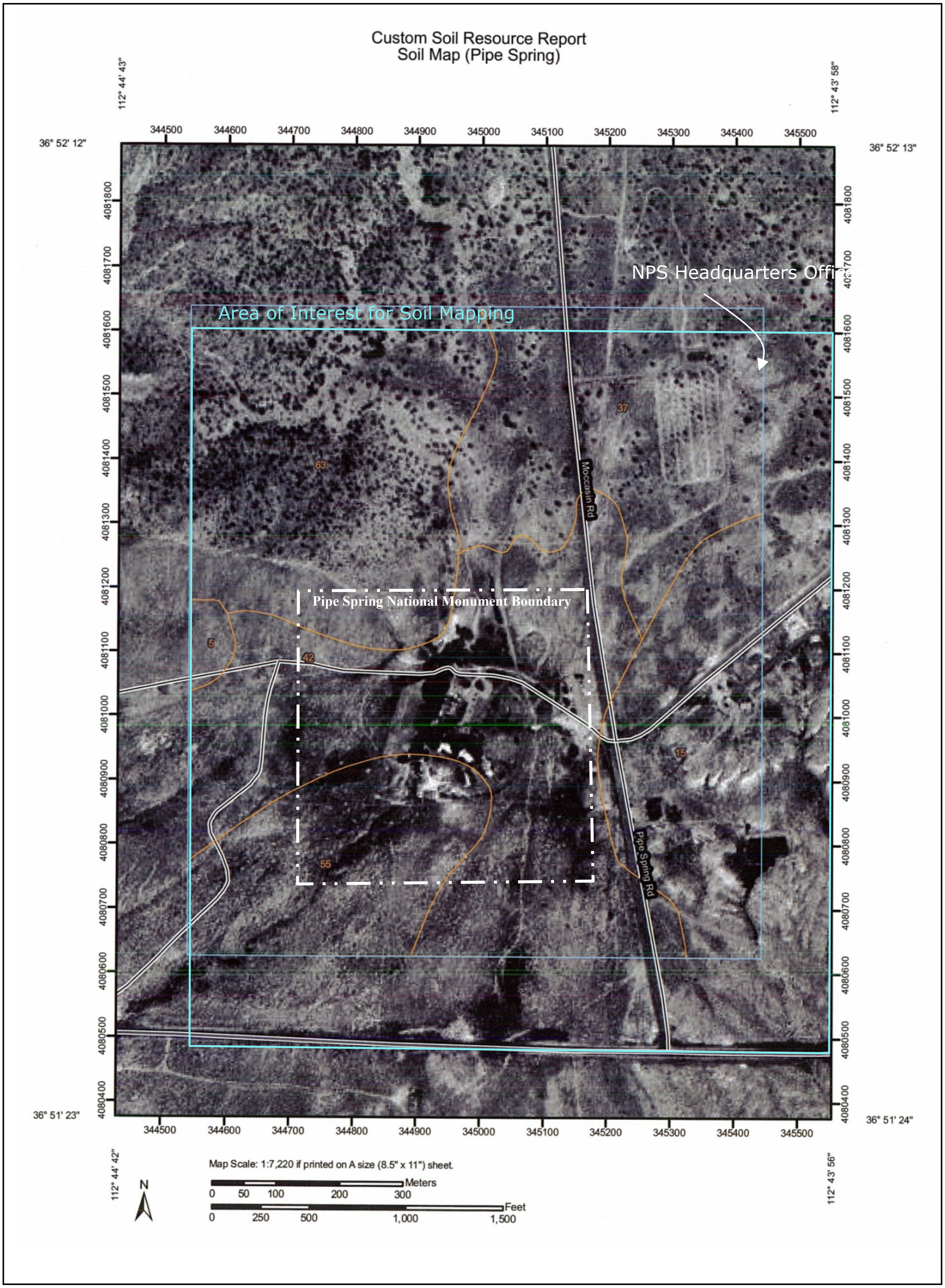
* Lower bound of the 90% confidence interval Precipitation Frequency Estimates (inches)																		
ARI (years)**	**5 min**	**10 min**	**15 min**	**30 min**	**60 min**	**120 min**	**3 hr**	**6 hr**	**12 hr**	**24 hr**	**48 hr**	**4 day**	**7 day**	**10 day**	**20 day**	**30 day**	**45 day**	**60 day**
1	0.12	0.18	0.22	0.30	0.37	0.46	0.52	0.65	0.82	0.93	1.06	1.21	1.44	1.61	2.09	2.50	2.99	3.39
2	0.15	0.23	0.29	0.39	0.48	0.57	0.66	0.82	1.02	1.16	1.32	1.52	1.81	2.02	2.62	3.13	3.77	4.26
5	0.21	0.32	0.39	0.53	0.66	0.77	0.85	1.04	1.28	1.45	1.64	1.91	2.28	2.56	3.26	3.90	4.74	5.38
10	0.26	0.39	0.48	0.65	0.81	0.93	1.01	1.22	1.49	1.68	1.91	2.21	2.65	3.01	3.77	4.49	5.50	6.26
25	0.33	0.50	0.62	0.84	1.04	1.17	1.25	1.47	1.76	2.00	2.26	2.63	3.15	3.63	4.45	5.25	6.50	7.43
50	0.39	0.59	0.74	0.99	1.23	1.37	1.45	1.66	1.96	2.24	2.54	2.96	3.54	4.09	4.97	5.81	7.26	8.31
100	0.46	0.70	0.86	1.17	1.44	1.59	1.68	1.88	2.17	2.50	2.82	3.29	3.94	4.57	5.48	6.34	8.02	9.20
200	0.53	0.81	1.00	1.35	1.67	1.84	1.93	2.14	2.40	2.75	3.11	3.62	4.35	5.04	5.99	6.86	8.77	10.05
500	0.64	0.97	1.21	1.63	2.01	2.20	2.31	2.55	2.74	3.08	3.49	4.07	4.87	5.70	6.64	7.53	9.75	11.20
1000	0.73	1.11	1.38	1.86	2.30	2.51	2.64	2.90	3.10	3.33	3.77	4.40	5.27	6.21	7.11	8.02	10.48	12.05

* The **lower** bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are **less** than.
** These precipitation frequency estimates are based on a partial duration maxima series. **ARI** is the Average Recurrence Interval.
Please refer to NOAA Atlas 14 Document for more information. NOTE: Formatting prevents estimates near zero to appear as zero.


Partial duration based Point Precipitation Frequency Estimates - Version: 4
36.8586 N 112.7386 W 4950 ft
Precipitation Depth (in)
Average Recurrence Interval (years)
Tue Sep 30 18:53:49 2008
Duration
5-min
10-min
15-min
30-min
60-min
120-m
3-hr
6-hr
12-hr
24-hr
48-hr
4-day
7-day
10-day
20-day
30-day
45-day
60-day


Partial duration based Point Precipitation Frequency Estimates - Version: 4
36.8586 N 112.7386 W 4950 ft
Precipitation Depth (in)
Duration
Tue Sep 30 18:53:49 2008
Average Recurrence Interval (years)
1
2
5
10
25
50
100
200
500
1000

APPENDIX C. SUPPLEMENTAL INFORMATION ON SOILS


Custom Soil Resource Report
Soil Map (Pipe Spring)
112° 44' 43"
112° 43' 58"
36° 52' 12"
36° 52' 13"
36° 51' 23"
36° 51' 24"
112° 44' 42"
112° 43' 56"
344500
344600
344700
344800
344900
345000
345100
345200
345300
345400
345500
4081800
4081700
4081600
4081500
4081400
4081300
4081200
4081100
4081000
4080900
4080800
4080700
4080600
4080500
4080400
NPS Headquarters Offi
Area of Interest for Soil Mapping
Moccasin Rd
Pipe Spring Rd
Pipe Spring National Monument Boundary
63
37
5
42
15
55
Map Scale: 1:7,220 if printed on A size (8.5" x 11") sheet.
N
Meters
0 50 100 200 300
Feet
0 250 500 1,000 1,500

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Units

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other

Special Line Features
- Gully
- Short Steep Slope
- Other

Political Features
- Cities

Federal Land
- National Park Service

Water Features
- Oceans
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

MAP INFORMATION

Map Scale: 1:7,220 if printed on A size (8.5" × 11") sheet.

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 12N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County
Survey Area Data: Version 8, Sep 10, 2008

Date(s) aerial images were photographed: 9/9/1992

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Soil Map Unit Coverage

Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County (AZ625)				
Map Unit Symbol	Map Unit Name	Acres in Map Area of Interest	Percent of Mapped Area of Interest	Percent of Pipe Spring NM
5	Begay fine sandy loam, 3 to 12 percent slopes	2.0	0.9%	0%
15	Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 percent slopes	32.2	14.2%	0%
37	Mido fine sand, 1 to 10 percent slopes	42.5	18.8%	0.6%
42	Monue fine sandy loam, 1 to 5 percent slopes	67.9	30.0%	66.0%
55	Sheppard fine sand, 1 to 7 percent slopes	27.5	12.2%	8.8%
63	Torriorthents-Rock outcrop complex, 30 to 70 percent slopes	54.1	23.9%	24.6%
Totals for Area of Interest		**226.1**	**100.0%**	**100.0%**

All materials in this appendix are from:

U.S. Department of Agriculture, Natural Resources Conservation Service, 2008. **Soil Survey Geographic (SSURGO) database for Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County**, USDA-NRCS, Fort Worth, Texas, Survey Area Symbol az625. NRCS Soil Data Mart at http://soildatamart.nrcs.usda.gov/Survey.aspx?County=AZ015

Soil Property tables have been adapted to a more convenient format.

Map Unit Descriptions (Brief, Generated)

Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County

[Minor map unit components are excluded from this report]

Map unit: 5 - Begay fine sandy loam, 3 to 12 percent slopes

Component: Begay (85%)

The Begay component makes up 85 percent of the map unit. Slopes are 3 to 12 percent. This component is on fan terraces. The parent material consists of alluvium derived from sandstone. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is high. Available water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 2 percent. This component is in the F035XC323AZ Juniperus Osteosperma/artemisia Tridentata Ssp. Wyomingensis-Purshia Stansburiana/achnatherum Hymenoides-Hesperostipa Comata ecological site. Nonirrigated land capability classification is 6s. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches, typically, does not exceed 6 percent.

Map unit: 15 - Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 percent slopes

Component: Gypsiorthids (60%)

The Gypsiorthids component makes up 60 percent of the map unit. Slopes are 1 to 50 percent. This component is on fan terraces, hills. The parent material consists of gypsiferous alluvium derived from shale. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Available water to a depth of 60 inches is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. This component is in the R035XD405AZ Gypsum Upland 7-11" P.z. ecological site. Nonirrigated land capability classification is 7e. This soil does not meet hydric criteria.

Component: Gypsiorthids, shallow (35%)

The Gypsiorthids, shallow component makes up 35 percent of the map unit. Slopes are 1 to 50 percent. This component is on fan terraces, hills. The parent material consists of gypsiferous alluvium derived from shale. Depth to a root restrictive layer, bedrock, paralithic, is 4 to 20 inches. The natural drainage class is well drained. Available water to a depth of 60 inches is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. This component is in the R035XD404AZ Gypsum Hills 7-11" P.z. ecological site. Nonirrigated land capability classification is 7e. This soil does not meet hydric criteria.

Map unit: 37 - Mido fine sand, 1 to 10 percent slopes

Component: Mido (95%)

The Mido component makes up 95 percent of the map unit. Slopes are 1 to 10 percent. This component is on fan terraces. The parent material consists of alluvium and/or eolian sands derived from sandstone. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is excessively drained. Water movement in the most restrictive layer is high. Available water to a depth of 60 inches is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R035XC315AZ Sandy Upland 10-14" P.z. ecological site. Nonirrigated land capability classification is 7s. Irrigated land capability classification is 2s. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches, typically, does not exceed 6 percent.

Map unit: 42 - Monue fine sandy loam, 1 to 5 percent slopes

Component: Monue (85%)

The Monue component makes up 85 percent of the map unit. Slopes are 1 to 5 percent. This component is on fan terraces. The parent material consists of alluvium derived from sandstone. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is well drained. Water movement in the most restrictive layer is moderately high. Available water to a depth of 60 inches is moderate. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 1 percent. This component is in the R035XD413AZ Sandy Loam Upland 7-11" P.z. Calcareous ecological site. Nonirrigated land capability classification is 7s. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches, typically, does not

Map unit: 55 - Sheppard fine sand, 1 to 7 percent slopes

Component: Sheppard (90%)

The Sheppard component makes up 90 percent of the map unit. Slopes are 1 to 7 percent. This component is on fan terraces. The parent material consists of alluvium and/or eolian sands derived from sandstone. Depth to a root restrictive layer is greater than 60 inches. The natural drainage class is excessively drained. Water movement in the most restrictive layer is high. Available water to a depth of 60 inches is low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. Organic matter content in the surface horizon is about 0 percent. This component is in the R035XD412AZ Sandy Upland 7-11" P.z. ecological site. Nonirrigated land capability classification is 7e. Irrigated land capability classification is 4e. This soil does not meet hydric criteria. The calcium carbonate equivalent within 40 inches, typically, does not exceed 5 percent.

Map unit: 63 - Torriorthents-Rock outcrop complex, 30 to 70 percent slopes

Component: Torriorthents (50%)

The Torriorthents component makes up 50 percent of the map unit. Slopes are 30 to 70 percent. This component is on hills, escarpments. The parent material consists of colluvium and/or alluvium derived from limestone, sandstone, and shale. Depth to a root restrictive layer, bedrock, lithic, is 4 to 60 inches. The natural drainage class is well drained. Available water to a depth of 60 inches is very low. Shrink-swell potential is low. This soil is not flooded. It is not ponded. There is no zone of water saturation within a depth of 72 inches. This component is in the R035XC302AZ Sedimentary Cliffs 10-14" P.z. ecological site. Nonirrigated land capability classification is 7e. This soil does not meet hydric criteria.

Component: Rock outcrop (45%)

Generated brief soil descriptions are created for major soil components. The Rock outcrop is a miscellaneous area.

Physical Soil Properties - Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County

Map Symbol and Soil Name	Depth	Sand	Silt	Clay	Moist Bulk Density	Saturated Hydraulic Conductivity	Available Water Capacity	Linear Extensibility	Organic Matter	Erosion Factors			Wind Erodibility Group	Wind Erodibility Index
										Kw	Kf	T		
	in	Pct	Pct	Pct	g/cc	micro m/sec	in/in	Pct	Pct					
5 - Begay fine sandy loam, 3 to 12 % slopes	0-3	68	21	8-15	1.40-1.50	14-42	0.13-0.15	0.0-2.9	1.0-3.0	.28	.28	5	2	86
	3-35	68	21	8-15	1.40-1.50	14-42	0.13-0.15	0.0-2.9	1.0-3.0	.28	.28			
	35-55	80	17	2-5	1.50-1.60	42-141	0.06-0.08	0.0-2.9	0.5-1.0	.20	.20			
	55-60	68	21	8-15	1.40-1.50	14-42	0.13-0.15	0.0-2.9	0.5-1.0	.28	.28			
15 - Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 %														
Gypsiorthids	—	—	—	—	—	—	—	—	—					
Gypsiorthids, shallow	—	—	—	—	—	—	—	—	—					
37 - Mido fine sand, 1 to 10 percent slopes	0-2	96	1	1-5	1.50-1.60	42-141	0.05-0.07	0.0-2.9	0.5-1.0	.17	.17	5	1	220
	2-60	93	1	3-8	1.40-1.50	42-141	0.05-0.09	0.0-2.9	0.5-1.0	.17	.17			
42 - Monue fine sandy loam, 1 to 5 percent slopes	0-5	70	16	10-18	1.35-1.40	14-42	0.13-0.15	0.0-2.9	0.5-1.0	.28	.28	5	3	86
	5-40	70	16	10-17	1.35-1.40	14-42	0.13-0.15	0.0-2.9	0.4-0.6	.28	.28			
	40-46	18	51	27-35	1.20-1.25	1.4-4	0.19-0.21	3.0-5.9	0.4-0.6	.37	.37			
	46-60	45	42	7-20	1.25-1.40	4-14	0.12-0.18	0.0-2.9	0.4-0.6	.28	.32			
55 - Sheppard fine sand, 1 to 7 percent slopes	0-2	96	1	2-5	1.50-1.60	42-141	0.05-0.07	0.0-2.9	0.0-0.5	.17	.17	5	1	220
	2-60	78	16	3-8	1.50-1.60	42-141	0.06-0.08	0.0-2.9	0.0-0.5	.20	.20			
63 - Torriorthents-Rock outcrop complex, 30 to 70 percent slopes														
Torriorthents-	—	—	—	—	—	—	—	—	—			2		
Rock Outcrop	—	—	—	—	—	—	—	—	—					

Chemical and other Soil Properties - Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County

Map Symbol and Soil Name	Depth	Cation Exchange Capacity	Soil Reaction	Calcium Carbonate	Gypsum	Salinity	Sodium Adsorption Ratio	Depth to restrictive Layer	Subsidence Initial	Subsidence Total	Potential for Frost Action	Risk of Corrosion Uncoated Steel	Risk of Corrosion Concrete
	in	meq/100g	pH	Pct	Pct	mmhos/cm		in.	in.	in.			
5 - Begay fine sandy loam, 3 to 12 % slopes	0-3	5.0-15	7.4-9.0	0-10	0	0.0-2.0	0	—	0	—	Low	High	Low
	3-35	5.0-15	7.4-9.0	1-10	0	0.0-2.0	0						
	35-55	0.0-5.0	7.4-9.0	1-10	0	0.0-2.0	0						
	55-60	5.0-15	7.4-9.0	1-10	0	0.0-2.0	0						
15 - Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 %									2-10	10-36	Moderate	High	High
Gypsiorthids	—	—	—	—	—	—	—	—					
Gypsiorthids, shallow	—	—	—	—	—	—	—	4-20 bedrock					
37 - Mido fine sand, 1 to 10 percent slopes	0-2	1.0-5.0	7.4-7.8	0-2	0	0.0-2.0	0	—	0	—	Low	High	Low
	2-60	1.0-5.0	7.4-8.4	2-10	0	0.0-2.0	0						
42 - Monue fine sandy loam, 1 to 5 percent slopes	0-5	2.0-10	7.4-8.4	1-5	0	0.0-2.0	0	—	0	—	Low	High	Low
	5-40	2.0-10	7.9-8.4	1-5	0	0.0-2.0	0						
	40-46	10-20	8.5-9.9	3-10	0	0.0-2.0	0						
	46-60	2.0-10	7.9-8.4	3-10	0	0.0-2.0	0						
55 - Sheppard fine sand, 1 to 7 percent slopes	0-2	0.0-5.0	7.4-8.4	0-5	0	0	0	—	0	—	Low	High	Low
	2-60	0.0-10	7.4-9.0	0-10	0	0.0-2.0	0						
63 - Torriorthents-Rock outcrop complex, 30 to 70 percent slopes													
Torriorthents-	—	—	—	—	—	—	—	4-60 bedrock	0	—	Low		
Rock Outcrop	—	—	—	—	—	—	—	—	—	—			

Soil Properties for Sewage Disposal, Ponds and Embankments - Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County									
Map Symbol and Soil Name	% of Map Unit made up of Described Soil	Septic Tank Absorption Fields		Sewage Lagoons		Pond Reservoir Areas		Embankments, Dikes and Levees	
		Rating Class and Limiting Features	Value[1]	Rating Class and Limiting Features	Value[1]	Rating Class and Limiting Features	Value[1]	Rating Class and Limiting Features	Value[1]
5 - Begay fine sandy loam, 3 to 12 % slopes	85	Somewhat Limited		Very Limited		Very Limited		Not Limited	
		Slope	0.01	Seepage Slope	1.00 1.00	Seepage Slope	1.00 1.00		
15 - Gypsiorthids-Gypsiorthids, shallow complex, 1 to 50 %									
Gypsiorthids	60	Not Rated		Not Rated		Very Limited		Not Rated	
						Slope	1.00		
Gypsiorthids, shallow	35	Not Rated		Not Rated		Very Limited		Not Rated	
						Slope Depth to Bedrock	1.00 0.92		
37 - Mido fine sand, 1 to 10 percent slopes	95	Very Limited		Very Limited		Very Limited		Somewhat Limited	
		Filtering Capacity	1.00	Seepage Slope	1.00 0.92	Seepage Slope	1.00 0.68	Seepage	0.31
42 - Monue fine sandy loam, 1 to 5 percent slopes	85	Very Limited		Very Limited		Very Limited		Very Limited	
		Slow Water movement	1.00	Seepage Slope	1.00 0.08	Seepage	1.00	Piping Seepage	1.00 0.01
55 - Sheppard fine sand, 1 to 7 percent slopes	90	Very Limited		Very Limited		Very Limited		Somewhat Limited	
		Filtering Capacity	1.00	Seepage Slope	1.00 0.32	Seepage Slope	1.00 0.08	Seepage	0.30
63 - Torriorthents-Rock outcrop complex, 30 to 70 percent slopes									
Torriorthents-	50	Not Rated	—	Not Rated	—	Very Limited	—	Not Rated	
Rock Outcrop	45	Not Rated	—	Not Rated	—	Not Rated	—	Not Rated	

[1]Numerical rating values indicate the severity of the individual limitations. The ratings are shown as decimal fractions ranging from 0.01 to 1.00 with the higher value indicating a greater degree of limitation.

Rangeland Productivity and Plant Composition- Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County						
[Only the soils that support rangeland vegetation suitable for grazing are rated]						
Map Symbol and Soil Name	Ecological site	Total dry-weight production			Characteristic vegetation	Rangeland composition percent
		Favorable Year lb/ac	Normal Year lb/ac	Unfavorable Year lb/ac		
5: Begay		—	—	—		—
15: Gypsiorthids	Gypsum Upland 7-11" p.z	650	550	450	Pleuraphis jamesii Indian ricegrass Shadscale saltbush Fourwing saltbush Gyp dropseed Other perennial grasses Black grama Elymus elymoides ssp. elymoides Ephedra	25 15 15 10 10 10 5 5 5
15. Shallow Gypsiorthids,	Shallow Gypsum Hills 7-11" p.z.	450	350	250	Gyp dropseed Shadscale saltbush Bigelow sagebrush Ericameria nauseosa ssp. nauseosa var. nauseosa Indian ricegrass Other perennial forbs Pleuraphis jamesii Stansbury cliffrose Utah serviceberry	15 15 10 5 5 5 5 5 5
37: Mido	Sandy Upland 10-14" p.z.	900	650	400	Sand sagebrush Indian ricegrass Blue grama Dropseed Hesperostipa comata ssp. comata Ephedra Fourwing saltbush Other perennial forbs Other perennial grasses Sand buckwheat	50 20 15 10 10 5 5 5 5 2

Rangeland Productivity and Plant Composition- Mohave County Area, Arizona, Northeastern Part, and Part of Coconino County

[Only the soils that support rangeland vegetation suitable for grazing are rated]

Map Symbol and Soil Name	Ecological site	Total dry-weight production			Characteristic vegetation	Rangeland composition percent
		Favorable Year lb/ac	Normal Year lb/ac	Unfavorable Year lb/ac		
42: Monue	Sandy Loam Upland 7-11" p.z. Calcareous	900	800	650	Other perennial grasses Black grama Ephedra Indian ricegrass Other perennial forbs Other shrubs Fourwing saltbush Globemallow Mesa dropseed Pleuraphis jamesii Sand dropseed Spike dropseed Winterfat	15 10 10 10 10 10 5 5 5 5 5 5 5
55: Sheppard	Sandy Upland 7-11" p.z.	700	500	300	Indian ricegrass Fourwing saltbush Hesperostipa comata ssp. comata Pleuraphis jamesii Sand dropseed Sand sagebrush Black grama Ephedra	25 10 10 10 10 10 5 5
63: Torriorthents	Sedimentary Cliffs 10-14" p.z	800	600	400	Hesperostipa comata ssp. comata Big sagebrush Blue grama Indian ricegrass Utah juniper Ephedra Muttongrass Pleuraphis jamesii	15 10 10 10 10 5 5 5
Rock Outcrop		—	—	—		—

APPENDIX D. SUPPLEMENTAL INFORMATION ON GEOLOGY

Description of Geologic Map Units

For units exposed in and near Pipe Spring National Monument.

Excerpted from:
Billingsley, George H., Susan S. Priest, and Tracey J. Felger, 2004, ***Geologic Map of Pipe Spring National Monument and the Western Kaibab Paiute Indian Reservation, Mohave County, Arizona,***, U.S. Geological Survey Scientific Investigations Map 2863.

MAP SYMBOL	UNIT DESCRIPTION
	SURFICIAL DEPOSITS Surficial deposits are differentiated from one another chiefly on the basis of difference in morphologic character and physiographic position observed on 1976 aerial photographs and field observations. Older alluvial and eolian deposits generally exhibit extensive erosion, whereas younger deposits are actively accumulating material or are lightly eroded. Salt is a common constituent in all alluvial deposits derived from the Chinle and Moenkopi Formations in the south and east part of the map area.
Qaf	**Artificial fill and quarries (Holocene)**—Alluvium and bedrock material removed from quarries and trench excavations to build stock tanks, drainage diversion dams, roads, or other manmade construction projects other than modern highways. No map distinctions between cut or fill excavations. Agricultural fields are not shown.
Qs	**Stream-channel alluvium (Holocene)**—White to light-red interbedded silt, sand, gravel, and pebbles; unconsolidated and poorly sorted. Pebbles and some cobbles are mostly sandstone above the topographic position of the Shinarump Member of the Chinle Formation; below the Chinle, clasts are dominated by black, well-rounded pebbles of quartzite or chert of volcanic origin. Locally overlaps or is deposited adjacent to young and intermediate alluvial terrace-gravel deposits (Qg1, Qg2) and commonly overlaps young and intermediate alluvial fan (Qa1, Qa2) deposits. Gradational and arbitrary contacts with other surficial alluvial or eolian deposits are approximate and subject to change. Stream channels are subject to intermittent high-energy flash floods that can produce local sediment accumulation on floodplain (Qfp) and young terrace alluvial (Qg1) deposits and widespread sediment accumulations on young alluvial fan (Qa1) deposits. Stream-channel alluvium is a common source for local sand dune or sand sheet accumulations in Pipe Valley and Sandy Canyon Wash areas. Little or no vegetation in stream channels except for occasional tamarisk trees or willow trees and grass. Thickness, 3 to 12 ft.
Qes	**Eolian sand sheet deposits (Holocene)**—On Moccasin and Moquith Mountains above Vermilion Cliffs, light-red to white silt and fine- to

coarse-grained eolian sand derived from the Navajo Sandstone (⅃). Forms thick deposits over gently sloping terrain of Navajo Sandstone where sand fills large cracks and joints on the surface of Navajo allowing deep-rooted vegetation to develop linear growths on sand sheet or sand dune (Qd) deposits. Only most extensive and thickest deposits on Moccasin Mountain are shown; map contacts are arbitrary and gradational between sand sheet (Qes), sand dune (Qd), and mixed eolian and fluvial (Qae) deposits and are based on morphologic interpretation on aerial photos. Below Vermilion Cliffs, deposits accumulate along local stream drainages and on gentle slopes of young and intermediate alluvial fan (Qa1, Qa2) deposits. Unit forms coarse-grained sand ramps on gentle slopes of the Shinarump Member of the Chinle Formation where the Shinarump is the sand source. Deposit often leads to fine-grained climbing or falling sand dune (Qd) accumulations on steep bedrock or landslide (Ql) deposits along Vermilion Cliffs and other small isolated mesas and buttes where wind speed is reduced to allow sand accumulation. In Pipe Valley south of State Highway 389, sand sheet deposits are thin, widespread, and partly stabilized by grass and small high-desert shrubs during wet conditions on young alluvial fan (Qa1) deposits; also stabilized by lag gravel consisting mostly of black pebbles derived from the Shinarump Member of the Chinle Formation of Yellowstone Mesa. Sand sheet veneer deposits are widespread and common through the map area but most are too thin to show. Support moderate growths of grass, black brush, and other small high-desert shrubs above Vermilion Cliffs, mostly grass below Vermilion Cliffs. Thickness, 0.5 to 3 ft in south half of map; as much as 9 to 15 ft in large valleys on Moccasin Mountain and within tributary canyons eroded into Moccasin Mountain.

Qd — **Eolian sand dune deposits (Holocene)**—Light-red to white, fine- to coarse-grained sand. Form complex lumpy dune shapes and random dune accumulations on variable sloping topography. Include climbing or falling dunes on steep sloping topography along Vermilion Cliffs. Arbitrary and gradational contact with sand sheet (Qes) and mixed eolian and fluvial (Qae) deposits are based on aerial photography interpretation. Dune surfaces are commonly active in large open valley areas that support sparse growth of grass or small shrubs and on steep topography. Unit is partly stabilized by grassy vegetation or by crypto-organic soil growths in local canyon drainage areas below Vermilion Cliffs. Thickness, 12 to 35 ft.

Qae — **Mixed eolian and fluvial deposits (Holocene)**—Composed of gray, light-red, and white silt and fine- to coarse-grained eolian and fluvial sand lenses interbedded with red-brown and gray silt and clay. Include some coarse-grained gravel composed of angular chert fragments and red to white sub-rounded sandstone pebbles on Moccasin Mountain. Below Vermilion Cliffs, southeast half of map area, include multicolored, well-rounded quartzite pebbles derived from the Shinarump Member of the Chinle Formation. Commonly occupy upper slopes of young and intermediate alluvial fan (Qa1, Qa2) deposits. Below Vermilion Cliffs, northwest quarter of map area, mostly composed of white and light-red sandstone and red siltstone that forms young alluvial fan deposits but deposits are dominated by interbedded mixed fluvial and eolian deposits in Parashont and Woodberry Canyons. Often overlapped by surficial sand sheet (Qes) or sand dune (Qd) deposits with arbitrary or approximate map contacts based on aerial photo interpretations. Support thick to moderate growths of grass, cactus, and some sagebrush below Vermilion Cliffs; sagebrush, oak brush, cliffrose bush, pinion pine, oak, and juniper trees above Vermilion Cliffs. Thickness, 5 to 60 ft.

Qtr **Talus and rock fall deposits (Holocene)**—Include silt, sand, and large to small broken rocks and boulders that form talus debris slopes in steep-walled canyons and lower part of Vermilion Cliffs. Some boulders of Navajo Sandstone or sandstone of the Shinarump Member of the Chinle Formation are as large as vehicles and up to house size near landslide debris (Ql) deposits below Vermilion Cliffs. Arbitrary and gradational contact between landslide debris (Ql) deposits, talus and rock fall debris (Qtr), young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) deposits as determined by aerial photo interpretation. Unit grades downslope into young, intermediate, or old alluvial fan (Qa1, Qa2, Qa3) deposits. Thickness, 5 to 45 ft.

Qa1 **Young alluvial fan deposits (Holocene)**—Light-red, gray, and brown silt, fine- to coarse-grained interbedded sand and gravel; partly consolidated by gypsum, calcite, and clay. Contain light-red to brown silt, red and white chert fragments and small red and white sandstone pebbles locally derived from outcrops of the Kayenta Formation and Navajo Sandstone below the Vermilion Cliffs. Locally include boulders of the Shinarump Member of the Chinle Formation as much as 6 ft in diameter near outcrops of the Shinarump below Yellowstone Mesa and Bitter Seeps Wash areas. Clay content greatest near outcrops of Petrified Forest Member of the Chinle Formation in Sandy Canyon Wash, and Pipe Valley areas. Include numerous black, brown, yellow, red, and gray, very well rounded quartzite and chert pebbles 0.5 to 2 inches in diameter and rare, rounded, gray-white petrified wood fragments derived from Shinarump Member of the Chinle Formation. Locally covered by thin sand sheet (Qes) and mixed eolian and fluvial (Qae) or sand dune (Qd) deposits at distal ends of alluvial fan deposits. Commonly overlapped by or intertongue with stream (Qs) deposits. Subject to extensive sheet wash erosion or sediment accumulation during heavy storms. Support moderate growths of grass, sagebrush, and various small high-desert shrubs. All deposits below Vermilion Cliffs are composed of sediment derived locally from Triassic and Jurassic sedimentary strata. Thickness, 5 to 40 ft.

Qa2 **Intermediate alluvial fan deposits (Holocene and Pleistocene(?))**—Similar to young alluvial fan (Qa1) deposits; partly consolidated by calcite, clay, and gypsum cement below stratigraphic level of the Chinle Formation; mostly unconsolidated above Chinle Formation. Commonly overlapped by young alluvial fan (Qa1) and stream-channel (Qs) deposits. Intertongue with intermediate alluvial terrace-gravel (Qg2) deposits near distil ends of fans. Intertongue with landslide (Ql) deposits and talus and rock fall (Qtr) deposits at upper reaches of alluvial fans below Vermilion Cliffs where unit is heavily dissected by erosion. Support moderate growths of sagebrush, cactus, and grass. Thickness, 6 to 45 ft.

Ql **Landslide debris deposits (Holocene and Pleistocene)**—Unconsolidated masses of unsorted rock debris typically along lower slopes of Vermilion Cliffs. Include detached blocks of strata that have rotated backward and slid downslope as loose incoherent masses of broken rock and deformed strata, often surrounded by talus and rock fall (Qtr) debris. Often covered in part by sand sheet (Qes) and sand dune (Qd) deposits. Individual landslides may become unstable during wet conditions and creep downslope where unit overlies claystone or siltstone bedrock of Petrified Forest Member of the Chinle Formation or lower part of the Kayenta Formation. Support sparse growth of sagebrush, cactus, grass, juniper trees, and pinion trees. Thickness, 25 to 200 ft.

SEDIMENTARY ROCKS

Jn **Navajo Sandstone (Lower Jurassic)**—White to light-red and yellow-gray, cliff-forming, medium-crossbedded to thickly-crossbedded, well-sorted, fine- to coarse-grained eolian quartz sandstone interbedded with dark-red, coarse-grained sandstone and siltstone in lower part. Age determination by Peterson and Pipiringos (1979) and Biek and others (2000). Lower part is commonly red, upper part commonly white. Includes lenses of interbedded dark purple-gray, thin-bedded, calcareous sandstone beds that formed freshwater deposits within and between coastal sand dunes. High-angle, crossbedded sandstone sets interbedded with low-angle, crossbedded sandstone and thin flat-bedded sandstone sets. Unit commonly covered by thin to thick sand sheet (Qes), sand dune (Qd), or mixed eolian and fluvial (Qae) deposits. Unit is highly fractured by near vertical northeast-, northwest-, and north-south-oriented bedrock joints. Joints that parallel the Moccasin Monocline dip west or southwest as much as 82º and strata of the Navajo Sandstone and Kayenta Formation dip east 8º at Moccasin Canyon and just northwest of Pipe Spring National Monument. Joints are near vertical in upper Moccasin Canyon where strata are nearly horizontal verifying that the joints likely developed prior to development of the Moccasin Monocline. Gradational but sharp contact with underlying Tenney Canyon Tongue of the Kayenta Formation placed at base of Navajo Sandstone cliff at Moquith Mountains and the Kayenta Formation elsewhere. Supports moderate growth of pinion and juniper trees, cliff-rose bush; thick growths of sagebrush, various high-mountain shrubs and grasses on Moccasin and Moquith Mountains. Incomplete section due to removal of top part by modern erosion. Unit thickens north of map area to as much as 2,000 ft. Thickness, about 1,500 ft.

Jkt **Tenney Canyon Tongue of the Kayenta Formation (Lower Jurassic)**—Age as described by Biek and others (2000). Dark-red to light red-brown, slope-forming, very fine-grained, thin-bedded to laminated, fluvial siltstone and sandstone. Includes dark-red sandstone lenses that form ledges in upper part. Gradational southwesterly facies change from fine-grained, ledge- and slope- forming sequence to alternating slope-forming, fine- to coarse-grained, mudstone, siltstone, and sandstone sequence. Unit intertongues laterally with underlying Lamb Point Tongue (Jnl) of the Navajo Sandstone. Forms sharp local horizontal contact at top of Lamb Point Tongue cliff marked by color contrast of dark-red siltstone and sandstone of Tenney Canyon Tongue to white and light-red sandstone of Lamb Point Tongue at Moquith (Moki) Mountain area. Unit thickens from 120 ft at Kanab, Utah, to 220 ft at Ed Lamb Point, Moquith Mountains 8 miles northeast of Kaibab and Moccasin, Arizona. Tenney Canyon Tongue becomes upper part of Kayenta Formation where Lamb Point Tongue of Navajo Sandstone pinches out west and south of Moquith Mountains. Thickness at Moquith Mountain area, 220 ft.

Jnl **Lamb Point Tongue of the Navajo Sandstone (Lower Jurassic)**—Age as described by Biek and others (2000). Type locality is Ed Lamb Point on USGS 7.5' Kaibab quadrangle, Vermilion Cliffs of Moquith Mountains, 8 miles northeast of Moccasin and Kaibab, Arizona (Wilson, 1967). Gray-white to orange-brown, cliff-forming, very fine-grained to fine-grained, crossbedded quartz sandstone of eolian origin. Top 10 to 15 ft east of Ed Lamb Point locally shows penecontemporaneous deformed beds that are beveled by overlying Tenney Canyon Tongue (Jkt) of the Kayenta Formation. Forms gradational and sharp contact with underlying Kayenta Formation (Jk) marked at base of white and red sandstone cliff of the Lamb Point Tongue. Forms cliff of white and red cross-bedded Navajo Sandstone within upper part of Kayenta Formation along Vermilion Cliffs from Moquith Mountains east to Kanab, Utah. Unit is 400 ft thick near Kanab, Utah, thins south and west to 140 ft thick at Moquith Mountains; is mostly a red sandstone cliff about 100 ft thick near Point Spring of Vermilion Cliffs 2 mi north of Moccasin and Kaibab, Arizona. Unit forms an elongated 1-mi-wide tongue of sand that extends southwest from Ed Lamb Point to Moccasin Mountains 2 mi north of Kaibab, Arizona and pinches out as a red sandstone ledge in Vermilion Cliffs 1 mi west of Pipe Spring National Monument. Thickness, 0 to 140 ft.

Jk **Kayenta Formation (Lower Jurassic)**—Dark-red and light red-brown, slope-forming calcareous mudstone, siltstone, and sandstone. Unit deposited in river floodplains, river channels, playas, and shallow lake environments (Blakey, 1994; Peterson, 1994). Age of unit determined by Peterson and Pipiringoes (1979) and Biek and others (2000). Unit often covered by landslide debris (Ql) and talus and rockfall (Qtr) deposits along lower part of Vermilion Cliffs. Erosion of soft sediments of the Kayenta Formation undercuts the resistant overlying Navajo Sandstone causing large sections of Navajo and upper Kayenta units to fail as landslide blocks along Vermilion Cliffs, especially where local joints parallel Vermilion Cliffs. Thickness increases from 270 ft at Ed Lamb Point to nearly 400 ft at Potter Canyon at the expense and loss of the Lambs Point Tongue of the Navajo Sandstone southwest of Moccasin Mountain. Thickness, 270 to 400 ft.

Moenave Formation (Lower Jurassic)—Includes, in descending order, the Springdale Sandstone Member, Whitmore Point Member, and Dinosaur Canyon Member as defined by Averitt and others (1955); Stewart and others (1972); and Sargent and Philpott (1987). Age determination after Peterson and Pipiringos (1979) and Biek and others (2000)

Jms **Springdale Sandstone Member (Lower Jurassic)**—Light-red to red-brown, cliff-forming, thin- to thick-bedded sandstone and lenses of conglomerate. Includes low-angle trough crossbedded sets of fluvial sandstone that contain dark red mudstone and siltstone rip-up clasts and poorly preserved petrified and carbonized fossil plant remains within crossbedded sets (Peterson and Pipiringos, 1979; Biek and others, 2000). Crossbeds are separated by thin-bedded to laminated dark red siltstone and mudstone beds that locally contain mudstone pellets (Wilson, 1967). Gradational contact with underlying Whitmore Point Member. Unit deposited by northeast to southwest flowing streams based on crossbedding studies by Wilson (1967). Thickens north and east of map area to about 200 ft at Kanab, Utah, thins southward and intertongues with lower part of the Kayenta Formation. Thickness, 120 to 170 ft.

Jmw **Whitmore Point Member (Lower Jurassic)**—Type section is near Potter Canyon at southwest point of Moccasin Mountains (elev. 6,603 ft at Radio Towers, left end of cross section B-B'). Named for Whitmore Point by Wilson (1967) 3.5 mi west of Pipe Spring National Monument, but the name Whitmore Point is not on the current USGS 7.5' Moccasin quadrangle. Composed of red-brown sandstone and siltstone interbedded with red-purple to green-gray and blue mudstone and claystone and thin gray dolomitic limestone. Limestone contains small red-brown chert nodules and poorly preserved fossil algal structures and fish scales and bones near Zion National Park north of map area (Biek and others, 2000). Gradational contact with underlying Dinosaur Canyon Member (Jmd) marked by distinct color contrast of blue-green, green, and yellow mudstone and siltstone of Whitmore Point Member to red-brown siltstone and sandstone of underlying Dinosaur Canyon Member. Thickness, 60 to 80 ft.

Jmd **Dinosaur Canyon Member (Lower Jurassic)**—Red-brown, slope and ledge-forming, thin-bedded, very fine-grained sandstone and silty sandstone. Unconformable contact with underlying undivided Owl Rock and Petrified Forest Members of the Chinle Formation. Unit gradually thickens west to east and is about 200 ft thick at Kanab, Utah (Wilson, 1967). Thickness, 120 to 200 ft.

Chinle Formation (Upper Triassic)—Includes, in descending order, the Owl Rock Member, Petrified Forest Member, and Shinarump Member as used by Stewart and others (1972); Sargent and Philpott (1987); Biek and others (2000)

Ꞧcp **Owl Rock and Petrified Forest Members, undivided (Upper Triassic)**—The Owl Rock Member of the Chinle Formation, (not mapped separately) is present at the south end of the Moquith Mountains, northeast corner of the map area and gradually thins to the west and southwest and overlies the Petrified Forest Member. The Owl Rock is composed of light-red and white, coarse-grained sandstone, gray, fine-grained sandstone and siltstone interbedded with thin-bedded (5 in to 2 ft) gray-white siliceous limestone beds. Limestone contains red and white chert nodules. The Owl Rock is 40 ft thick at Kanab, Utah, and thins to less than 30 ft at Ed Lamb Point and grades into the upper part of the Petrified Forest Member throughout the map area. The Petrified Forest Member is composed of gray, light-purple, blue, light- to dark-red, slope-forming claystone, siltstone, and white, coarse-grained sandstone. Weathers to frothy popcorn surface. Includes petrified wood and calcite nodules at the Blue Knolls area. Unit is mostly covered by sand sheet (Qes) and sand dune (Qd) and mixed fluvial and eolian (Qae) deposits, and young, intermediate, and old alluvial fan (Qa1, Qa2, Qa3) deposits. Contact with underlying Shinarump Member is gradational in the vertical and lateral extent because multicolored mudstone and siltstone intertongue with white gritty sandstone and conglomerate of the Shinarump Member. Thickness, 600 to 700 ft.

Ꞧcs **Shinarump Member (Upper Triassic)**—White to yellow-brown, cliff-forming, thin- to thick-bedded, coarse-grained, low-angle crossbedded sandstone, gravel, and conglomeratic sandstone. Includes numerous small channel lenses and pockets of small pebble conglomerate composed of well rounded to subrounded, multicolored quartz, quartzite, and black chert pebbles in gravely sandstone matrix. Black chert pebbles are the dominant pebble. Pebbles average 1 to 2 inches in diameter and include some well-rounded quartzite cobbles as much as 10 inches in diameter and numerous petrified wood fragments and segments of petrified logs. Black pebbles eroded from the Yellowstone Mesa area form a desert pavement of lag gravel on all alluvial fan surfaces around Yellowstone Mesa, southwest quarter of map area. Unit is the common source for multicolored quartz, quartzite, and chert pebbles in all surficial units below outcrops of the Shinarump Member of the Chinle Formation. Weathered sand from the Shinarump Member is a source for local sand sheet (Qes) and sand dune (Qd) deposits that overlie the Petrified Forest Member east of the Vermilion Cliffs. Unit overlies and fills broad erosion channels that are as deep as 30 ft and ½ to 1 mi wide eroded into underlying Upper Red Member of the Moenkopi Formation. Thickness, 20 to 125 ft.

Moenkopi Formation (Middle(?) and Lower Triassic)—Includes, in descending order, Upper Red Member, Shnabkaib Member, Middle Red Member, Virgin Limestone Member, Lower Red Member and Timpoweap Member, undivided, as used by Stewart and others (1972). (Timpoweap Member is redefined for this map area due to facies changes of the Timpoweap Member from that defined by Stewart and others [1972])

Ћmu **Upper Red Member (Middle(?) and Lower Triassic)**—Light-red and dark-red, slope- and ledge-forming sequence of siltstone and Sandstone. Forms small cliffs in upper part. Gradational contact with underlying Shnabkaib Member placed arbitrarily at top of highest thick white siltstone and dolomite bed of Shnabkaib Member. Thickness, 160 ft.

Ћms **Shnabkaib Member (Lower Triassic)**—White to light-gray, laminated to thinly bedded, slope-forming, aphanitic dolomite interbedded with light-gray, calcareous silty gypsum. Includes some thin light red mudstone, siltstone, and sandstone beds in lower and upper part. Gradational contact with underlying Middle Red Member placed at lowest thick white or light-gray calcareous siltstone and dolomite bed of the Shnabkaib Member. Unit thickens northwest of map area, thins southeast. Thickness, 90 to 110 ft.

Ћmm **Middle Red Member (Lower Triassic)**—Red-brown, thin-bedded to laminated, slope-forming gypsiferous siltstone and sandstone. Includes thin veinlets and stringers of gypsum deposited in fractures and cracks throughout unit. Includes minor beds of white laminated dolomite, green siltstone, and gray-green to red gypsiferous mudstone. Mudcracks and ripple marks common throughout. Gradational lower contact with Virgin Limestone Member placed at top of highest gray limestone bed of Virgin Limestone Member. Thickness, 280 to 300 ft.

Ћmv **Virgin Limestone Member (Lower Triassic)**—Includes two light-gray, thin-bedded to laminated, ledge-forming limestone beds (1 to 3 ft thick), separated by pale-yellow, light-red, and bluish-gray, thin-bedded to massive, slope-forming gypsiferous siltstone that makes up the bulk of the unit. Lowest limestone bed contains star-shaped crinoid plates and poorly preserved Composita brachiopods in upper part 18 mi east of map area; locally, upper limestone bed contains fossil algae. Erosional unconformity separates lower gray limestone from underlying dark red siltstone and sandstone of Lower Red Member of the Moenkopi Formation with erosional relief as much as 4 ft. Lower limestone bed thickens and thins as shallow channel-fill deposit. Forms small mesas near Bitter Seeps Wash and Pipe Valley Wash. Thickness, 120 ft.

Ћml **Lower Red Member and Timpoweap Member, undivided (Lower Triassic)**—Dark-red, slope-forming, thin-bedded, fine-grained, gypsiferous, sandy siltstone, sandstone, and pale-yellow to gray laminated silty gypsum. Gypsum, siltstone, and sandstone in lower part are derived from erosion of Harrisburg Member of the Kaibab Formation. Includes a prominent ledge-forming red-gray to light purple-red, coarse-grained, low-angle crossbedded calcareous sandstone marker bed in lower part 3 to 7 ft thick that often forms resistant sandstone surface of Kanab Plateau near Bulrush Wash and Bitter Seeps Wash. Marker bed includes raindrop impressions and rare carbonaceous plant fossils 18 mi east of map area (Billingsley and others, 2002). Has unconformable contact with underlying gray limestone and red sandstone and siltstone of Harrisburg Member of the Kaibab Formation at southeast edge of map area. Thickness, 120 to 180 ft.

Kaibab Formation (Lower Permian)—Includes, in descending order, Harrisburg and Fossil Mountain Members as defined by Sorauf and Billingsley (1991)

Pkh **Harrisburg Member**—Red and gray, slope-forming, interbedded gypsiferous siltstone, sandstone, gypsum, and gray, cliff-forming, thin-bedded limestone. Yellow-gray to light-red alternating slope and ledge-forming calcareous sandstone and sandy limestone in upper part; contains calcite and gypsum cement. Upper part includes thin beds of low-angle crossbedded, calcareous sandstone, conglomerate, and minor siltstone that form small ledges in Burnt Canyon Point area, southeast corner of map area. Limestone beds are as much as 14 ft thick consisting of a gray, thin-bedded, cherty limestone that weathers dark brown or black and a light-gray, thin-bedded, sandy limestone. Limestone beds thicken and thin laterally and form small cliffs in the Bulrush and Sandy Canyon Wash areas. Dissolution of gypsum in lower part has locally distorted some limestone beds causing them to slump or bend into local drainages. Contact with underlying Fossil Mountain Member is gradational and marked at top of cherty limestone bed of the Fossil Mountain Member of the Kaibab Formation. Thickness, 160 ft.

Pkf **Fossil Mountain Member**—Light-gray, fine- to medium-grained, thin-bedded, fossiliferous, cliff-forming, sandy, cherty limestone. Unit characterized by thin bedded, white chert beds and nodules in sandy cliff-forming limestone. Contact with underlying Woods Ranch Member of the Toroweap Formation is not exposed in map area but is exposed 3 mi southeast of map area in Kanab Canyon where contact is an unconformity caused by a combination of dissolution of gypsum and channel erosion with relief as much as 6 to 15 ft. Thickness, 250 ft.

Geologic Formation Properties and Limitations for ZION and Pipe Spring.

Data is summarized from Biek and others (2000), Clyde (1987), and Gregory (1950). An explanation of the Property Categories follows the table.

Map Symbol[1]	Name	Lithology[2]	1. Erosion Potential	2. Aquifer Potential	3. Aquifer Yields	4. GW Quality	5. Contam. Potential	6. Landslide Potential	6.5 Cliff-forming & rockfall Potential
Qa	Alluvium	variable clastics	variable	unconsol.idated aquifer	mod. to v. large	fresh to saline	low	low	low
Ql	Lakebed Deposits	silt, clay	high	limited	low	fresh	low	low	low
Qe	Eolian Sand	eolian sand	very high	local	large to v. large	fresh	low	variable	low
Qb	Basalt Flows	basalt	low	local aquifer	large to v. large	fresh	low	variable	high
Qms	Landslides and Talus	variable clastics	variable	low	variable	fresh	low	very high	moderate
Tu	Old Boulder Gravel Deposits	igneous & sedimentary	variable	limited	small to large	fresh	low		
Kt	Tropic Shale	shale	high	low	low	saline	salt	very high	low
Kd	Dakota	conglom. & shale	high in shale	limited	small to moderate	fresh to saline	mod	very high	low
Jcw	Carmel-Winsor Mem.	sandst. & siltstone	high	limited	small to moderate	poor	mod	very high	low
Jcp	Carmel-Paria R. Member	lms., shale & gypsum	high	limited	small to moderate	poor	gypsum	variable	low
Jcx	Carmel-Crystal Cr. Member	sandst. & siltstone	high	limited	small to moderate	poor	mod	low	low
Jcc	Carmel-coop Creek. Mem.	limestone, shale	high	limited	small to moderate	poor	mod	low	moderate
Jtw	Temple Cap-White throne	sandstone	moderate	limited	moderate	fresh	low	low	high
Jts	Temple Cap-Sinawava	siltstone & sandstone	high	limited	small to moderate	fresh	mod	low	moderate
Jn	Navajo sandstone	sandstone	high at fractures	main aquifer	moderate to v. large	fresh	low	high if undercut	very high
Jk	Kayenta Fm.	siltst., shale sandstone	high	spring & seeps	small to moderate	fresh to saline	mod	high	moderate
Jms	Moenave – Springdale.	sandstone	high	limited	small to moderate	fresh to saline	low - mod.	high	high
Jmw	Moenave- Whitmore Pt.	siltstone	high	limited	small	poor	mod	high	moderate
Jmd	Moenave- Dinosaur Cyn.	siltstone, shale	high	limited	small	poor	mod	high	low
TRcp	Chinle- Petrified forest	siltst., shale, sandst lens	high	None	small to moderate	fresh to saline	high	very high	low
TRcs	Chinle – Shinarump	sandstone	low –mod.	limited	small to moderate	fresh to saline	mod – high	low	very high
Trmu	Moenkopi-Upper Red	shale, siltstone	high	limited	small	poor	mod – high	high	moderate
TRms	Moenkopi-Shnabkaib	siltst., shale gypsum	high	limited	small	poor	gypsum	high	moderate
TRmm	Moenkopi-Middle Red	shale, siltstone	high	limited	small	poor	gypsum	high	moderate
TRmv	Moenkopi-Virgin Limestone	limestone	low –mod.	limited	small to moderate	poor	mod – high	low	moderate
TRml	Moenkopi-Lower Red	shale, siltstone	high	limited	small	poor	mod – high	high	low
TRmt	Moenkopi-Timpoweap	limestone	low –mod.	local	small to moderate	poor	oil, sulfates	low	moderate
TRmr	Moenkopi-Rock Canyon	cherty conglom.	high	limited	small to moderate	poor	oil, sulfates	low	moderate
Pk	Kaibab Limestone	limestone	low	karst aquifer	moderate to high	poor	oil, sulfates	low	high

Map Symbol[1]	Name	Lithology[2]	7. Paleo Resources	7a.Paleo Sensitivity[3]	8. Cultural Resource Site*	9. Karst Potential	10. Economic Potential	11.Expanding or Collapsing Soils
Qa	Alluvium	variable clastics	bison bones	**1**	historic and prehistoric settlement, agriculture, pigment	very low	sand & gravel	--
Ql	Lakebed Deposits	silt, clay	bird and camel track & pollen	**2**	settlement and agriculture	very low	--	--
Qe	Eolian Sand	eolian sand	--	**0**	--	very low	--	yes
Qb	Basalt Flows	Basalt	--	**0**	tool material, rock art	moderate	Cinders	--
Qms	Landslides and Talus	Variable clastics	trace fossils on blocks--	**1**	--	very low	--	--
Tu	Old Boulder Gravel Deposits	igneous & sedimentary	--	**1**	--	very low	--	--
Kt	Tropic Shale	marine shale	ammonites, marine	**2**	--	very low	--	yes
Kd	Dakota	conglom. & shale	bone & plants	**2**	tool material	very low	coal, U	yes
Jcw	Carmel-Winsor Mem.	sandst. & siltstone	--		alcoves beneath Kd cliffs	very low	--	--
Jcp	Carmel-Paria R. Member	lms., shale & gypsum	small pelecypods	**2**	--	low	gypsum	yes
Jcx	Carmel-Crystal Cr. Member	sandst. & siltstone	--		--	very low	--	--
Jcc	Carmel-coop Creek. mem.	limestone, shale	marine inverts.		--	low	Limestone	--
Jtw	Temple Cap-White throne	sandstone	--	**0**	--	very low	--	--
Jts	Temple Cap-Sinawava	siltstone & sandstone	--		--	very low	--	--
Jn	Navajo sandstone	sandstone	poor, dino track	**1**	alcoves in cliff, rock art, pigment, tool material	very low	Cu, oil, glass sand	
Jk	Kayenta Fm.	siltst., shale sandstone	many dino tracks, fish scales, inverts.	**5**	alcoves beneath Jn cliff	very low	--	--
Jms	Moenave – Springdale.	sandstone	dino. track	**2**	tool source material	very low	--	--
Jmw	Moenave- Whitmore Pt.	siltstone	dino track, fish	**3**	--	very low	--	--
Jmd	Moenave- Dinosaur Cyn.	siltstone, shale	burrows, tracks	**2**	--	very low		yes
Ŧcp	Chinle- Petrified forest	siltst., shale sandst lens	bone and teeth from fish, metoposaurs, phytosaurs, ornithischian and aetosaurs, coprolites, wood, plant s, and invert. burrows.	**5**	tool material	very low	Pb, Zn, Ag, Au, Mn, U, bentonite, petrified wood	yes
Ŧcs	Chinle – Shinarump	sandstone	wood		rock art, tool material	very low	Pb, Zn, Ag, Au, Mn, U, oil	--
Ŧmu	Moenkopi-Upper Red	shale, siltstone	vertebrate tracks,		alcoves beneath Ŧcs cliffs	very low	--	--
Ŧms	Moenkopi-Shnabkaib	siltst., shale gypsum	marine inverts.		pigment	very low	gypsum	yes
Ŧmm	Moenkopi-Middle Red	shale, siltstone	wood & bone?		--	very low	--	--
Ŧmv	Moenkopi-Virgin Limestone	limestone	marine inverts.	**2**	--	very low	--	--
Ŧml	Moenkopi-Lower Red	shale siltstone	vertebrate tracks, wood & bone?		--	very low	--	--
Ŧmt	Moenkopi-Timpoweap	limestone	marine inverts.		--	moderate	Oil	--
Ŧmr	Moenkopi-Rock Canyon	cherty conglom.	wood & bone?		tool material	low	--	--
Pk	Kaibab Limestone	limestone	marine inverts.	**2**	--	high	Cu, oil, limestone	--

* other possibilities for cultural uses that may be associated with specific strata: clay, pigments. Tools of many types (grinding, pounding) are derived from many of the stony strata

[1]Geologic Period Symbols
Q: Quaternary
T: Tertiary
K: Cretaceous
J: Jurassic
TR: Triassic, P: Permian

[2]Rock Type Abbreviations
conglom. = conglomerate
sandst. = sandstone
siltst. = siltstone
lms. = limestone
inverts. = invertebrates

[3] Paleontological Sensitivity Codes
0 Fossils absent
1 Fossils Rare
2 Fossils Present
3 Significant Sites Known
4 Very Sensitive, 5 Extremely Sensitive

Formation Properties and Limitations

For Geologic Formations found in and near Zion National Park and Pipe Spring National Monument

Explanation of Properties described in Tables

1. Erosion Potential:

In general, erosion potential is highest in those formations that contain abundant siltstone and shale or unconsolidated Quaternary material. Erosion of this less resistant bedrock or unconsolidated sediment tends to generate steep slopes or unstable banks along rivers in this semi-arid environment in which vegetation is scarce. The intensity of erosion processes is increased after a thunderstorm due to the lack of vegetation although the duration of summer thunderstorms is generally short.

The erosion potential in sandstones will depend on the porosity and permeability of the sandstone and the natural cement that binds the grains together. Calcite cement will dissolve more readily in meteoric water than will silica or iron cement. Friable sandstones are those in which the grains of quartz are not firmly cemented together. Erosion of friable sandstones form the rounded knobs and temples of ZION. Fractures in sandstones also tend to promote rapid erosion and tend to create features such as spires and needles. The Navajo Sandstone is a relatively friable sandstone containing abundant joints and thus, has a high erosion potential along fractures and joints. Many of the sandstones in ZION are underlain by shale or siltstone and are prone to undercutting which may lead to erosion through landsliding and rockfall.

2. Aquifer Potential:

Generally, most precipitation in the semi-arid ZION region generally runs off the hard poorly vegetated surface, or if it wets the soil, it is captured by plants and evaporates from the leaves. Such conditions are usually not favorable for the accumulation of groundwater, but about 10% of rain and snowmelt seeps downward into underground groundwater aquifers. Several beds have the necessary porosity and permeability to accommodate this percolating groundwater. The space between the individual grains of the rock is referred to **primary porosity**, while **secondary porosity** occurs where space is provided by fractures or solution cavities.

The Navajo Sandstone is the principal consolidated aquifer in the region. Large recoverable reserves of excellent groundwater quality are present in the Navajo Sandstone (Gregory, 1950; Cordova, 1978; Clyde, 1987). Porosity of the Navajo Sandstone ranges from 32% on neutron logs run in groundwater wells to 17% from rock samples analyzed in the laboratory. Because the Navajo Sandstone is exposed at the surface, the aquifer is considered to be an unconfined aquifer. Sandstones in the Carmel, Kayenta, Moenave, Chinle, and Moenkopi Formations and the Kaibab Limestone also contain recoverable quantities of groundwater but these aquifers may be confined between impermeable strata.

Where impervious shales, limestones, and mudstones inhibit upward or downward flow of groundwater in the more porous sandstones, the water escapes laterally and if the aquifer is exposed at the surface by a deeply trenched stream, springs or seeps develop. Consequently, the contact between the Navajo Sandstone and underlying, less permeable Kayenta Formation is often marked by springs or seeps. Clyde (1987) provides location maps for both springs and wells in the Virgin River basin.

Alluvial aquifers located in unconsolidated, narrow valley-fill sediment along major drainages are a primary source of water for irrigation in the area (Gregory, 1950; Clyde, 1987). Loose unconsolidated material ranges from near zero to 61 m (200 ft) in depth. The water table is usually high and groundwater is easily recovered through shallow wells. Deeper, more extensive alluvial aquifers are also found in the Virgin River basin that may extend to 152 m (500 ft). Local aquifers have been defined also in Quaternary basalts and thin sandstone units in the Cretaceous Dakota Sandstone and the sandstone lenses in the Chinle Formation.

Contour maps of groundwater flow are presented in Cordova (1978) and Clyde (1987). The general pattern of groundwater flow follows the surface topography and surface water runoff downward from higher country towards the drainage network of the Virgin River and its tributaries. Both gaining and losing streams are present. A gaining stream is one in which the aquifer drains into a surface body of water. Conversely, a losing stream is one in which the groundwater levels are below the stream bed so that water from the stream is “lost” to recharge of the groundwater. Of course, groundwater movement may be extremely variable, especially with regard to confined aquifers. Some groundwater will move vertically through porous and semi-pervious layers while some groundwater will move horizontally due to an impervious barrier and emerge as a spring or seep. Faults can also complicate groundwater flow. Some faults act as barriers to groundwater flow; some act as conduits (Cordova, 1978; Clyde, 1987).

Groundwater aquifers are naturally recharged in the Upper Virgin River Basin by infiltration of precipitation (some directly and most from melting snow) and seepage from streams passing over recharge areas of the aquifer outcrops. Much of the recharge takes place at higher elevations where precipitation is greater. Development of recharge areas may impact groundwater levels. A more thorough description of groundwater recharge and discharge properties in the Navajo Sandstone is presented in Cordova (1978) and Clyde (1987).

The above is a very brief summary of the hydrogeology of ZION. For a more complete coverage of the water/rock interactions, groundwater and surface water quality, and surface and groundwater properties, please refer to the following references:

Clyde, C. G., 1987, Groundwater Resources of the Virgin River Basin in Utah: Utah Division of Water Resources, 104 p.

Cordova, R. M., 1978, Ground-Water Conditions in the Navajo Sandstone in the Central Virgin River Basin, Utah: U.S.G.S. Technical Publication No. 61, 66 p.

Gregory, H. E., 1950, Geology and Geography of the Zion Park Region Utah and Arizona: U.S.G.S. Professional Paper 220, 200 p.

Hereford, R., Jacoby, G.C., and McCord, V.A.S., 1995, Geomorphic History of the Virgin River in the Zion National Park Area, Southwest Utah: U.S.G.S. Open-File Report 95-515, 75 p.

Water Resources Division, National Park Service, Fort Collins, Colorado.

3. Aquifer Yields:

Most of the deliverable water is in the cross-bedded Navajo Sandstone, Quaternary basalt/sedimentary rock, and unconsolidated alluvial deposits. Other aquifers have limited value because they either lack porosity and permeability or they are limited in lateral and vertical extent.

4. Groundwater (GW) Quality:

Most of the springs in the Zion Park region yield water that is relatively low in mineral content. Generally, the longer groundwater is in contact with its surrounding rock medium, the higher will be the mineral content. Springs that feed Oil Seeps Wash and Alkali Wash are also gypsiferous and may even taste of oil (Gregory, 1950). Otherwise, groundwater is generally fresh while some is fresh to slightly saline.

5. Contamination Potential:

Gypsum is the primary potential contaminant to groundwater and is found in the Petrified Forest Member of the Chinle Formation and the Shinabkaib Member of the Moenkopi Formation. Blebs of oil in the cherty conglomerate of the basal Rock Canyon Conglomerate Member of the Moenkopi Formation may also impact groundwater.

6. Landslide Potential:

Landslides and subsequent canyon widening are primary processes in canyon development at ZION and throughout the Colorado Plateau. They are also potential hazards in the park. As previously mentioned, the soft Kayenta Formation is easily eroded from beneath the Navajo Sandstone. When the Navajo is undercut, slabs of sandstone collapse and cascade downslope. Fractures in the Navajo help facilitate movement. Landslides and old landslide deposits are common features throughout ZION and have been responsible for damming rivers and creating lakes in the past. Not only is the Navajo undercut, but also when the slabs collapse, they tend to slide on the weak, underlying shale beds.

Widespread landslides often occur where the Petrified Forest Member of the Chinle Formation is exposed below thick layers of overlying deposits. This is particularly apparent in the vicinity of Springdale. These slides have all occurred where overlying strata have slid on the weaker, more plastic Petrified Forest Member of the Chinle Formation. The chinle first outcrops near the ZION south entrance, and landslides begin at that point and can be recognized by tipped and broken strata and irregular hummocky terrain.

If located on steep slopes, unconsolidated Quaternary deposits present landslide potential especially during and after high-intensity rainfall. If the toe of these old landslide deposits should be disturbed, from road-building for example, the landslide will reactivate and flow to another position of relative stability. The velocity of the flow will depend on several factors such as the size of the material to be moved, the amount of water, the degree of slope, and vegetation.

7. Paleontological Resources:

The Geologic Resources Division of the National Park Service is conducting a separate paleontological inventory of the National Parks and Monuments, so a detailed description of the paleontology and biostratigraphy of Zion National Park is beyond the scope of this report. Table 4 summarizes data from Santucci (2000), but a more comprehensive list of fossils discovered by 1950 may be found in Gregory (1950).

The Utah Geological Survey completed a Survey of the paleontological resources of Zion National Park in 2005 (De Blieux and others, 2005). Among the paleontological resources found in the park are bones, plant materials and imprints, tracks, burrows and other trace fossils, wood invertebrates fish and Quaternary tracks and bones. The abundance of fossils varies considerably by strata from absent to abundant. The UGS established the following sensitivity classes for each strata in the park representing the presence of fossil resources and their vulnerability to human and natural degradation.

0) *Fossils absent* – Formations with rock types, such as igneous or metamorphic rocks, that are very unlikely to contain fossils of any kind.
1) *Fossils rare* – Formations that contain fossils only in rare instances such that intensive survey is unlikely to uncover noteworthy occurrences of fossils. Additionally, significant sites are known from Quaternary alluvium, but we place it in this category because of the vast areal extent of these surficial deposits and the low probability of encountering fossils at any particular location.
2) *Fossils present* – Formations known to contain fossils, but these fossils are unlikely to be of unique scientific importance. For example, formations with abundant marine invertebrate fossils in which disturbance of small areas are unlikely to impact scientifically significant fossils.
3) *Significant sites known* – Formations from which scientifically important fossil sites are known, but many areas of the formation will not contain significant fossil resources because of either the large areal extent of the formation or rarity of these sites.
4) *Very sensitive* – Formations known to contain abundant and significant vertebrate, invertebrate, and/or plant fossils in which a field survey is likely to result in the discovery of scientifically significant fossils.
5) *Extremely sensitive* – Formations that can be considered "world-famous" because of the scientifically important fossils they contain. Formations in which unique and scientifically important fossils are very likely to be discovered during field survey and in which there is a good possibility that any disturbance will impact critical fossil resources.

8. Cultural Resources:

Cultural resources may be expected in caves carved into the less resistant shales and siltstones beneath sandstone cliffs. Primary contacts where caves occur are at the Dakota Sandstone/Carmel Formation, Navajo Sandstone/Kayenta Formation, and Shinarump Conglomerate Member of the Chinle Formation/Upper Red Member of the Moenkopi Formation.

Two types of caves have been etched by erosion: flat-roofed structures at the base of flat-lying, regularly bedded, and resistant sandstones and arched roof structures at the base of massive cross-bedded friable sandstones. Flat-roofed caves are found in the Moenkopi shales beneath flat-lying Shinarump conglomerate and in the shales beneath Cretaceous sandstones. Caves with arched roofs and generally flat floors are found in the Navajo.

9. Karst Potential:

The sole formation with significant karst potential is the Kaibab Limestone. Karst features are common in the formation.

10. Economic Potential:

Interest in exploiting mineral resources in southwest Utah has been active since 1851 when large deposits of iron and coal were found near Cedar City (Gregory, 1950). Most of the prospect holes and milling tests, however, have not been encouraging with regards to commercial amounts of ore. Widely scattered, small, impure deposits of copper have been discovered in the Kaibab Limestone and the Navajo Sandstone. Lead, zinc, silver, gold, manganese, and uranium are present in the Chinle shales. Building stone is also present.

Pioneer settlers and Paiutes knew about the oil seeps in Oil Seeps Wash and on North Creek and the cavities filled with "oily tar" in rocks in the La Verkin, Virgin, and Short Creek Valleys (Gregory, 1950). Oil exploration began in 1907 with the Virgin Oil field located approximately 3 miles west of Zion National Park. The Virgin Oil field is Utah's oldest (but noncommercial) oil field. The reservoir for the oil was determined to be thin beds of sandy limestone in the Timpoweap Member of the Moenkopi Formation. Production depths rarely exceeded 600 feet (Driscoll, 1978). Seeps of crude oil and dark sulfurous water have been found in some areas where fractures extend from the surface to the producing horizon. The producing beds lie 10 to 30 feet above fossiliferous limestone that has cavities filled with asphalt (Gregory, 1950).

Porosity and permeability in the producing sandy limestones was never measured (Driscoll, 1978). The average net pay thickness is 1 to 12 feet and while production history is suspect, approximately 206,225 barrels of oil had been produced by 1976. No wells were drilled in 1977 and the shallowness of the producing formation precludes any commercial production today. However, the deepest well drilled in the field, the Bardwell No. 1 Venton, bottomed out at 4,538 feet in the Mississippian and had several good shows in the base of the Permian at 3,410 to 3,490 feet. The RM may wish to explore the reservoir potential of these deeper formations before an exploration company seeks permission to drill in the park.

Oil accumulated in the Moenkopi Formation in the Virgin Oil field on a broad synclinal nose that plunges gently towards the northeast (Driscoll, 1978). Structural features that favor the accumulation of hydrocarbons include both folds and faults, primarily west of the

Hurricane Cliffs. In this region, Harrisburg dome, Washington dome, and Bloomington dome are folds associated with the long Virgin anticline. Many of the folds are difficult to define without detailed field mapping because the dip of the beds is only 2º to 6 º (Gregory, 1950). The Hurricane fault might also serve as a trap for upward-migrating oil. No wells drilled into the Moenkopi in these structures have proved to be commercially profitable. However, advanced drilling techniques developed within the last fifteen years and our growing emphasis on domestic oil production may make previously unprofitable sites attractive again.

In the ZION region, North Creek Valley, the site of the only producing wells drilled in the area, seems to offer the most favorable conditions for the accumulation of oil (Gregory, 1950). Perhaps it would behoove the Resource Manager to identify the anticlines in the park, the amount of closure under these anticlines, the number and types of faults associated with the folds, the depth to the Moenkopi, and the potential for any other source and reservoir rocks in the park. Also helpful would be data on any oil fields drilled in southwest Utah. Such information was determined to be beyond the scope of this report.

Coal was also found by the Mormon pioneers in Coal Creek Canyon and on Cedar Mountain north of ZION. The coal is contained in the Cretaceous formations in the ZION region. The deposits that are thick enough to mine are found in the Tropic Formation, a Cretaceous formation that is not exposed in the park, but are exposed on the slopes of the watershed above the park.. Although not exposed in ZION, coal development in southwest Utah may impact the viewscape of the park and thus, the visitor's experience. Acidic precipitation, over time, would also impact the geological features of the landscape.

Sand and gravel in various amounts are also available in alluvial deposits. Potential sand and gravel mining operations would target the more abundant deposits and the RM may wish to have a map of these deposits on hand if one is not already available.

11. Expandable and Collapsible Soils:

As noted in the GRI workshop (1999), the Triassic Chinle Formation contains bentonite, a clay formed from altered volcanic ash. Bentonite has the unique property of being able to incorporate water molecules into its chemical structure and expand. Upon drying, the structure collapses. This shrink-swell property can cause maintenance and construction problems due to unstable soils.

Collapsible soils have structural integrity when dry but settle dramatically when wetted. They are therefore unsuitable for building. They have been encountered in ZION on terraces with soils derived from sheet flow off of the Moenave Formation.

TABLE OF CONTENTS FROM PIPE SPRING NATIONAL MONUMENT, GEOLOGIC RESOURCES EVALUATION REPORT (DRAFT)

The Geological Resources Evaluation Report for Pipe Spring National Monument provides an overview of the Geological History of Monument and surrounding region at a greater level of detail than is possible in this Physical Resources Information and Issues Overview Report. Some readers may find it a useful reference. A copy of the Table of Contents is included here to identify the topics that are included. It should be published in 2009 by the NPS Geological Resources Division. The final full document is nearing completion and will be available obtained at http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

Graham, John, 2007. ***Pipe Spring National Monument, Geologic Resources Evaluation Report.*** Draft of November 27, 2007. Colorado State University and National Park Service, Geological Resources Division. 40p.

I. Table of Contents

I. List of Figures

Appendix E. Stakeholder Contact Information

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