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Water-Quality Data Collected to Determine the Presence, Source, and Concentration of Lead in the Drinking Water Supply at Pipe Spring National Monument, Northern Arizona

Open-File Report 2013–1029

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Kaibab Paiute Tribe drinking water storage tank near Pipe Spring National Monument. Photograph taken by National Park Service Resource Manager Amber Van Alfen.

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By Jamie P. Macy, U.S. Geological Survey; David Sharrow, National Park Service; and Joel Unema, U.S. Geological Survey

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U.S. Geological Survey
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Conversion Factors and Datums

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

SI to Inch/Pound

Multiply	By	To obtain
	Volume	
milliliter (mL)	0.03381402	ounce, fluid (fl. oz)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

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Abstract

Pipe Spring National Monument in northern Arizona contains historically significant springs. The groundwater source of these springs is the same aquifer that presently is an important source of drinking water for the Pipe Spring National Monument facilities, the Kaibab Paiute Tribe, and the community of Moccasin. The Kaibab Paiute Tribe monitored lead concentrations from 2004 to 2009; some of the analytical results exceeded the U.S. Environmental Protection Agency action level for treatment technique for lead of 15 parts per billion. The National Park Service and the Kaibab Paiute Tribe were concerned that the local groundwater system that provides the domestic water supply might be contaminated with lead. Lead concentrations in water samples collected by the U.S. Geological Survey from three springs, five wells, two water storage tanks, and one faucet were less than the U.S. Environmental Protection Agency action level for treatment technique. Lead concentrations of rock samples representative of the rock units in which the local groundwater resides were less than 22 parts per million.

Introduction

Pipe Spring National Monument (PISP) is a 40-acre tract of land within the Kaibab Paiute Indian Reservation in northern Arizona at the base of the Vermillion Cliffs north of Grand Canyon (fig. 1). Several springs, such as West Cabin, Tunnel, and Spring Room Springs, discharge from a local aquifer within the Navajo Sandstone and upper facies of the Kayenta Formation, and are known collectively as PISP (Sharrow, 2009). The springs have historically provided water for Native American settlement and farming, and later ranching and settlement. PISP was established in 1923 to preserve the remote historic ranching site that developed around the springs (Sharrow, 2009). The area around PISP has remained rural, where communities are small and widely separated. Water from the local aquifer is used by the National Park Service (NPS), the Kaibab Paiute Tribe (KPT), the Cattleman's Association, and the non-tribal community of Moccasin. Discharge from the springs within PISP is shared by the NPS, the KPT, and the Cattlemen's Association under a historical agreement. These three parties also maintain water-supply wells that withdraw groundwater from the local aquifer. Routine water analysis of lead concentrations in tap water between 2004 and 2009 by the KPT indicated elevated concentrations of lead that exceeded the U.S. Environmental Protection Agency action level for treatment technique (USEPA TT) for lead of 15 µg/L. In response to these findings, groundwater samples were collected in 2009 from the KPT water-supply well. Lead concentrations exceeded the USEPA TT before purging the well, but were less than the USEPA TT after purging the well. Groundwater geochemical results from a previous investigation by the U.S. Geological Survey (USGS) of groundwater recharge, age, flowpaths, and water and rock interaction also indicated concentrations of lead near or greater than the current USEPA TT (Truini, 1999).

Lead is a toxic metal that was used for many years in products used in and around homes. Lead is a soft, malleable metal and is considered a heavy metal. Lead is used in paints, building construction, lead-acid batteries, bullets, weights, and plumbing materials. Lead is often used in the solder or flux used in water service lines. A prohibition on lead in plumbing supplies has been in effect since 1986, and "lead free" pipe, solder, and flux are used to install or repair public and residential water systems (U.S. Environmental Protection Agency, 2009). Lead, however, does get into drinking-water systems and can cause health issues. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink water containing lead over many years could develop kidney problems or high blood pressure (U.S. Environmental Protection Agency, 2009).

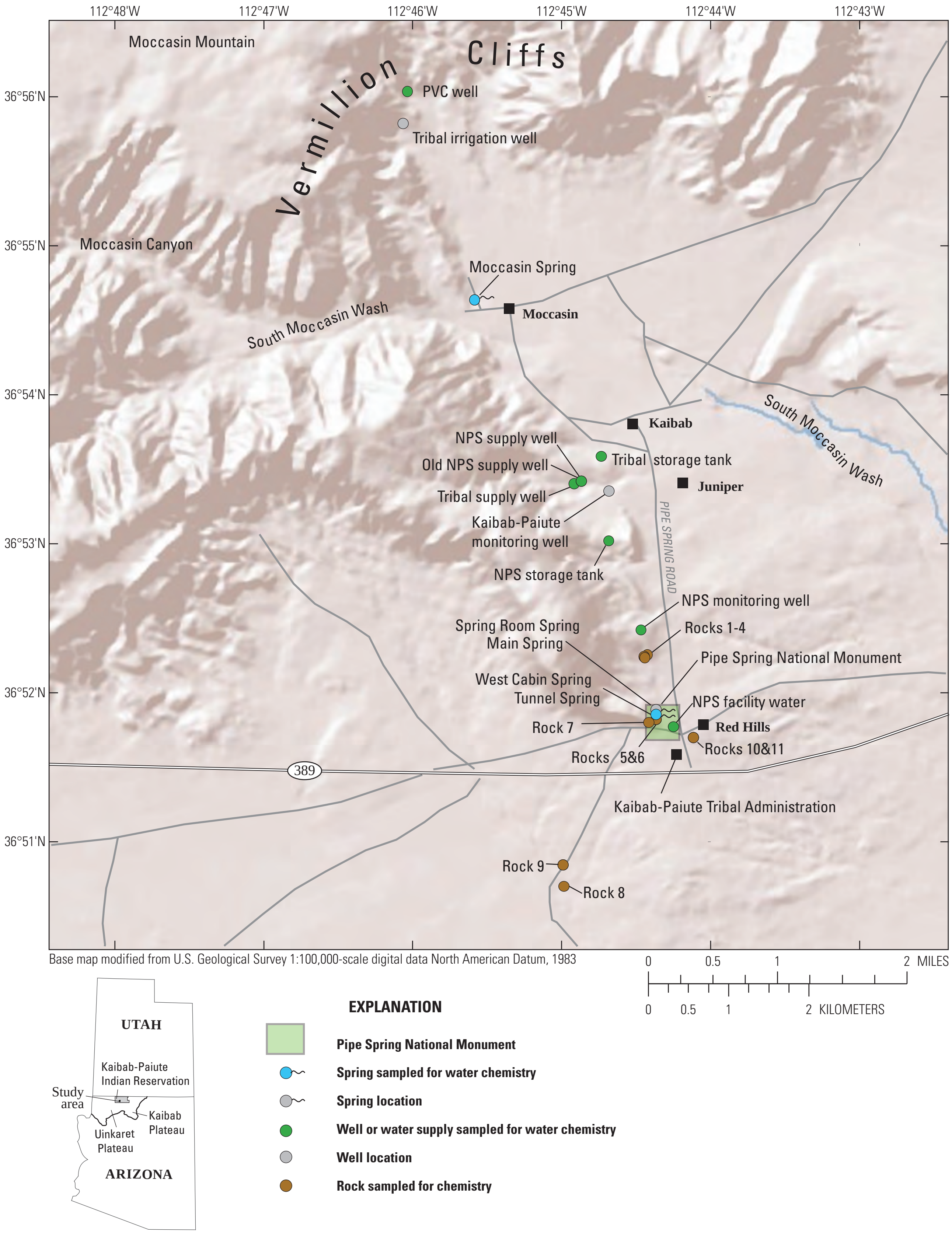

Figure 1. Study area and wells, springs, and rock sample locations, Pipe Spring National Monument area, northern Arizona. (NPS, National Park Service.)

For most contaminants, U.S. Environmental Protection Agency (USEPA) sets an enforceable regulation called a maximum contaminant level (MCL). However, because lead contamination of drinking water often results from corrosion of the plumbing materials belonging to water system customers, USEPA established a treatment technique rather than an MCL for lead. The treatment technique regulation for lead (referred to as the Lead and Copper rule) requires water system managers to control the corrosivity of the water (U.S. Environmental Protection Agency, 2009). The regulation also requires water systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead. If more than 10 percent of tap water samples exceed the lead action level of 15 parts per billion, then water system managers are required to take additional actions including: (1) taking further steps to optimize the corrosion control treatment (for water systems serving 50,000 people that have not fully optimized corrosion control); (2) educating the public about lead in drinking water and actions consumers can take to reduce their exposure to lead; (3) replacing the portions of lead service lines (lines that connect distribution mains to customers) under the water system's control (U.S. Environmental Protection Agency, 2009).

This investigation was undertaken to address concerns that the groundwater system that supports Pipe Spring and provides the domestic water supply for PISP, and adjacent communities on the Kaibab Paiute Indian Reservation could have elevated levels of lead. The USGS in cooperation with the NPS developed a study to determine the presence, source, and concentrations of lead in the local water supply for PISP, the KPT, the Cattleman's Association, and the community of Moccasin. Water-quality data results from this study will provide the NPS, the KPT, the Cattleman's Association, and the community of Moccasin with information to determine if the source and presence of the elevated lead concentrations are from the infrastructure and water supply wells, and (or) are naturally occurring within the rocks of the local aquifer. The results from this study will complement a study by the Indian Health Services for the KPT, which also focused on the presence and concentration of lead in the wells and infrastructure of the Tribal water-supply distribution system.

Purpose and Scope

The purpose of this report is to (1) describe the water-quality analysis results that were collected and analyzed for lead and other constituents, (2) determine the presence of lead in the water-supply wells, (3) determine if the source of lead is from the infrastructure and water-supply wells and (or) is naturally occurring within the rocks of the local aquifer, and (4) confirm if the concentrations of lead from water samples from wells and springs exceed the USEPA TT.

This report presents water-quality analysis results from sampling of wells, springs, and selected distribution points from the water-supply infrastructure. Lead chemistry analysis of rock samples that are associated with the local aquifer also are presented in this report.

Previous Investigations

In a USGS groundwater study (Truini, 1999), geochemical analytical results yielded lead concentrations from Spring Room Spring at 20 µg/L, Moccasin Community well at 20 µg/L, NPS Culinary well at 12 µg/L, West Cabin Spring at 10 µg/L, and Moccasin Spring at 10 µg/L. Lead was undetectable at concentrations less than 10 µg/L in samples from Tunnel Spring, the NPS Monitoring well, and the Tribal Irrigation well. The USGS National Water Quality Laboratory detection limit, at the time of this study (Truini, 1999), was 10 µg/L, which is only slightly less than the current USEPA TT.

Routine monitoring of lead concentrations between 2004 and 2009 by the KPT determined that 10.4 percent of 77 tap-water samples exceeded the USEPA TT of 15 µg/L (Olsen, Water Program Manager, Kaibab Paiute Tribe, written commun., 2009). In response to these findings, groundwater-quality samples were collected by the KPT at the well heads from the NPS supply well, the Tribal supply well, and the Moccasin Community Well on July 22, 2009. Lead concentrations in water-quality analytical results, collected before purging the wells, exceeded the USEPA TT and were 16 (NPS supply well), 21 (Tribal supply well), and 22 µg/L (Moccasin Community Well) (U.S. Department of Health and Human Services, Indian Health Services, 2010). After the wells were purged, the lead concentrations decreased to 6.8 (NPS supply well), 12 (Tribal supply well), and 5.6 (Moccasin Community Well) µg/L (U.S. Department of Health and Human Services, Indian Health Services, 2010). Possible sources of the elevated lead concentrations that were considered included (1) natural or anthropogenic contamination of the groundwater, (2) contamination in the well, pump, or plumbing at the well site, and (3) contamination in the storage or distribution system (U.S. Department of Health and Human Services, Indian Health Services, 2010). Contamination in the plumbing system is possible because lead is commonly a component of the metal used to solder together pipes from the infrastructure. Natural contamination is considered to be a source of contamination, but the geologic strata in the study area are not known to contain high concentrations of lead or other heavy metals. Additionally, industrial sources of lead contamination are not present in the area. Besides the sources previously listed, it is possible that water samples could have been inadvertently contaminated at the time of collection or may have been subject to laboratory errors.

Description of Study Area

Geology

The existence of the springs at PISP is the result of local stratigraphy, geologic structure, and landforms that control the movement, direction, and discharge of groundwater in the study area (Levings, 1974; Ingles, 1990, 1997; Truini, 1999; Billingsley and others, 2004; Truini and others, 2004). PISP is located west of the Sevier Fault and lies at the intersection of the northern parts of the Uinkaret and Kaibab Plateaus on the southwestern part of the Colorado Plateau physiographic province. Although the region is dominated by nearly flat Paleozoic and Mesozoic sedimentary strata, there are notable faults and folding in the vicinity of PISP (fig. 2; Billingsley and others, 2004).

Stratigraphy

Stratigraphic layers exposed in the vicinity of PISP are shown in a stratigraphic column in figure 3 and are described by Billingsley and others (2004). These layers constitute a thick sequence of Triassic and Jurassic age sediments that can cover an interval ranging from 980 to 1,970 ft thick. Given the relatively small range of land-surface elevation in the park of 200 ft, the number of strata of interest would be limited; however, the 1,500-ft offset of the Sevier Fault exposes several more stratigraphic layers in and near the park.

The oldest exposed layer near PISP is the Shnabkaib Member of the Moenkopi Formation, which is widely exposed on the eastern side of the Sevier Fault and is considered to be a barrier to groundwater movement (figs. 2 and 3; Levings, 1974; Ingles, 1990, 1997; Truini, 1999; Truini and others, 2004). The Chinle and Moenave Formations overlie the Shnabkaib Member in places to the east of the Sevier Fault (figs. 2 and 3; Billingsley and others, 2004).

The most prominent rock layer at PISP is the red sandstone and mudstone of the Kayenta Formation (fig. 3). At PISP, the Navajo Sandstone is exposed as a thin, light-colored remnant that caps the top of the upper sandstone beds of the Kayenta Formation (fig. 3). Groundwater in the local aquifer resides in the Navajo Sandstone and Kayenta Formation. Bedding planes, faults, and fractures within the rocks provide primary and secondary groundwater porosity (Levings, 1974; Ingles, 1990, 1997; Truini and others, 2004).

Geologic Structure

The Sevier Fault is the dominant structure within the study area, extending for more than 100 mi to the north and south. Displacement on the normal Sevier Fault in the study area is 1,500–2,000 ft down and to the west (Billingsley and others, 2004). It is believed that the Sevier Fault has been active for 12–15 million years coincident with the initiation of the extension of the Basin and Range Province to the west (Lund and others, 2008). The west segment of the Sevier Fault branches from the main segment just north of PISP. Groundwater movement in the local aquifer is bounded by the west segment of the Sevier Fault (referred to as the West Branch by Truini, 1999) in the north and central parts of the study area, and the Sevier Fault in the southern part of the study area (Truini and others, 2004). The Sevier Fault influences the movement of groundwater in the local aquifer in the three ways:

1. Associated with the west segment of the Sevier Fault is an east dipping monocline named the Moccasin Monocline (figs. 2 and 4). The Moccasin Monocline descends the eastern side of Moccasin Mountain providing a continuous connection of permeable Navajo Sandstone for groundwater movement from the higher terrain down to the valley (Truini, 1999; Billingsley and others, 2004; Truini and others, 2004).

2. At the base of the Moccasin Monocline is a small syncline that parallels the strike of the monocline (fig. 2). The syncline forms a trough-shaped local aquifer roughly 6 mi long and 6 mi or less wide, with PISP at its southern terminus (Billingsley and others, 2004). Along the syncline is the location of many of the springs and productive wells in the area. Erosion has exposed the southern terminus permeable rock in this syncline at PISP (figs. 2 and 4; Sharrow, 2009).

3. The offset of the Sevier Fault brings relatively impermeable Moenkopi Formation to the surface as a barrier to eastward movement of groundwater across the fault (fig. 4; Truini, 1999; Truini and others, 2004; Martin, 2007).

Hydrogeology

Studies of the relation between spring discharge and the local aquifer near PISP have been conducted because of concerns about decreasing spring discharges. In the mid-1970s the NPS began to measure the discharge from the springs at PISP on a regular basis and began to notice a steady decrease (Sharrow, 2009). The decrease in spring discharge became more apparent by 1990, and a series of investigations were undertaken to better understand the groundwater system feeding the springs and to determine the cause for the decrease in spring discharge (Ingles, 1990, 1997; Truini, 1999; Truini and others, 2004; Martin, 2007; Sharrow, 2009). Truini (1999) used a survey of water-surface elevations, water chemistry, isotope characteristics, and geology to draw the following conclusions about groundwater flow:

1. Groundwater movement is north to south through fractured and consolidated rock on the western side of the Sevier Fault and the west segment ("Branch") of the Sevier Fault. This is indicated by low water-surface elevations in springs and wells from north to south, and also by increasing sulfate concentrations, which indicates greater contact with the underlying Kayenta Formation.

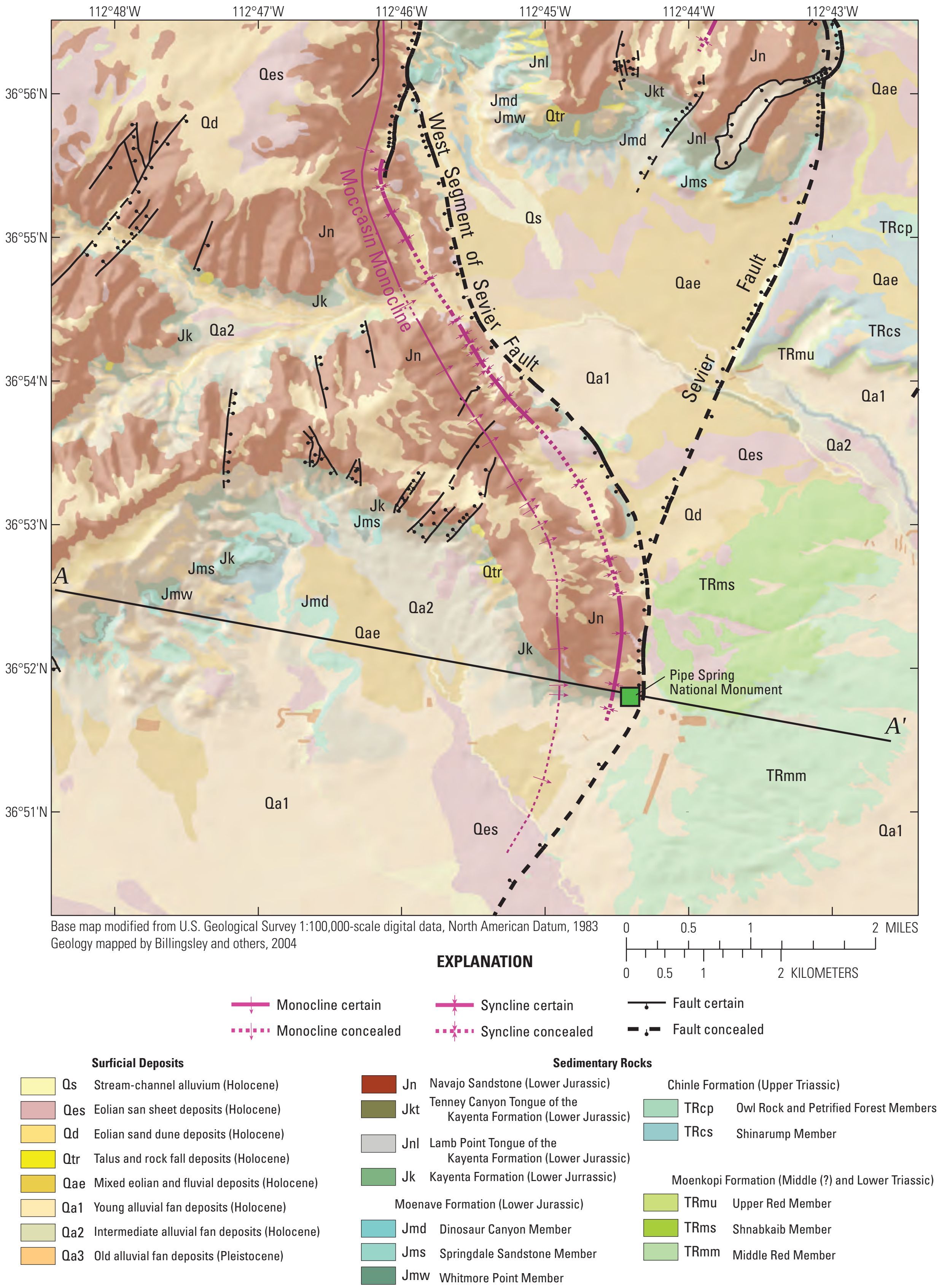

Figure 2. Surface geology and geologic structure, Pipe Spring National Monument area, northern Arizona (modified from Billingsley and others, 2004).

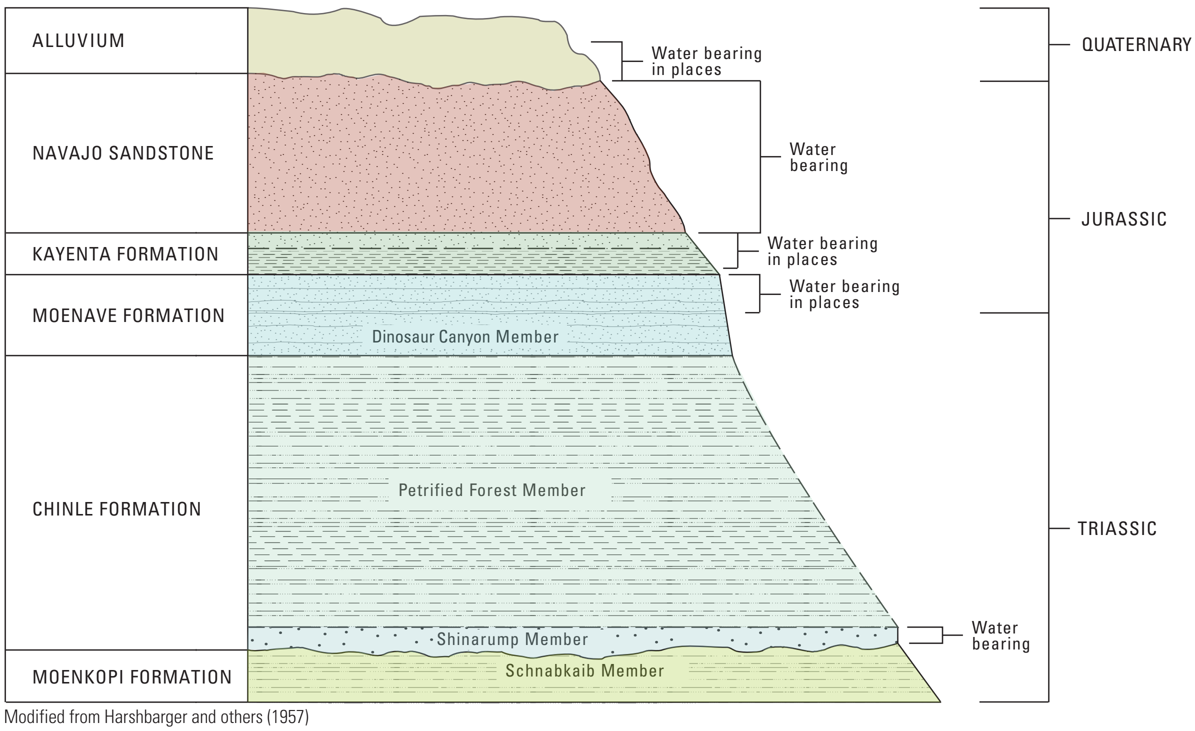

Figure 3. Stratigraphic columnar section, Pipe Spring National Monument area, northern Arizona.

2. Two sets of springs (at PISP and the community of Moccasin, fig. 1) and at least 15 wells share this common aquifer.

3. The elevation gradient along the aquifer (measured from the Tribal Irrigation Well, 4 mi north of Moccasin Spring, fig. 1) ranges from 20 to 70 ft/mi.

4. Water throughout the groundwater system appears to share a common recharge area as indicated by similarities in oxygen/deuterium isotopic concentrations.

5. The estimated travel time for groundwater from north to south is about 800 years. (Carbon dating produced a wide range of water ages between 50 and 9,000 years, and 800 years was selected as a reasonable estimated value.)

Five springs were identified by Truini (1999) as discharging from the Pipe Spring aquifer, with four of the springs located within PISP (figs. 1 and 2). Tunnel Spring has the highest discharge of the five springs, which varies seasonally between 8 and 12 gal/min and has been decreasing for the past decade. West Cabin Spring is on the slope above and to the northwest of Tunnel Spring and has had a relatively constant discharge of 0.5–1.0 gal/min since 1976. Spring Room and Main Springs are located in or near Winsor Castle, but these springs dried up in 1999 and were not available for sampling during this study.

The other spring discharging from the local aquifer is Moccasin Spring, which is within the small community of Moccasin, 2.5 mi north-northwest of Pipe Spring (fig. 1). The spring discharges where Moccasin Wash cuts across the syncline at a right angle, and water flowing in fractures up gradient is pooled behind the sandy alluvium of the wash (Sabol, 2005). Water from this spring is used jointly by the residents of Moccasin and the KPT.

Water-Supply Systems

The KPT and NPS have community water-supply wells about 1.6 mi north of PISP (fig. 1). The NPS well was originally drilled in 1975 and replaced in 2007 with a new well 200 ft to the south. The old well is used for monitoring. The KPT drilled their well in 1980 about 700 ft southwest of the NPS well. Although the NPS and Tribal supply wells are only about 700 ft apart, they supply two independent storage and distribution systems (Sharrow, 2009). 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-gal metal storage tank located about 0.5 mi south of the NPS well. Water from the NPS well is then distributed to the south to NPS facilities at PISP, the Tribal-NPS partnership visitation center, and Tribal facilities. The Tribal facilities include

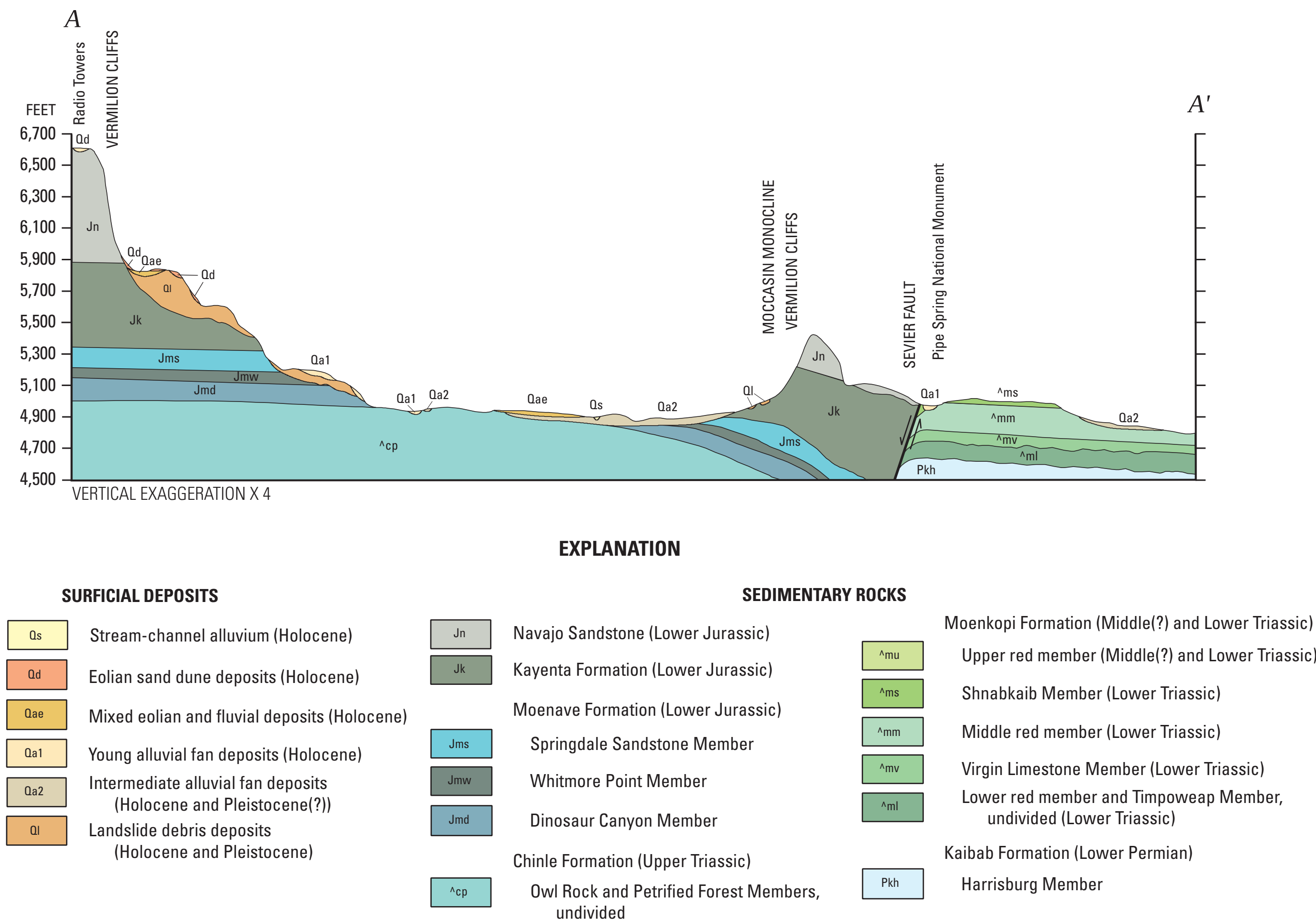

Figure 4. West-east section showing stratigraphy of the Vermilion Cliffs, the Moccasin Monocline, and the west branch of the Sevier Fault, northern Arizona (Billingsley and others, 2004).

the multipurpose building, the NPS-leased office building, the 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 two metal storage tanks with a combined capacity of 100,000 gal on the hilltop about 1,000 ft northeast of the well (fig. 1). Water from the Tribal well primarily is used to supply the water needs at Kaibab and Juniper villages, totaling 47 homes, and the Tribal park and community center near Kaibab.

By virtue of the water supply system being located on an Indian Reservation, regulatory responsibility for drinking-water supplies is through the USEPA directly rather than through the State. The NPS system is classified as a Transient Non-Community Water System, a public water system that provides water to a place such as a gas station or campground where people do not remain for long periods of time (Sharrow, 2009). The Tribal system is classified as a Very Small Community Water System, a public water system that supplies water to the same population year-round and that serves 25–500 people (Sharrow, 2009).

The USGS operates three real-time monitoring wells in the vicinity of PISP (fig. 2). The longest period of record dating from 1976 is available for the Kaibab-Paiute monitoring well (station No. 365403112452801), which is 1 mi northwest of the water-supply wells. This well was equipped for real-time monitoring in 2010. The NPS monitoring well (station No. 365236112442501) was drilled in 1989 and manually monitored until 2004 when the real-time telemetry was installed, and is located about 1 mi south of the water-supply well. Real-time monitoring was installed in the PVC well (station No. 365602112460201) in 2010 to provide information from the aquifer 1.5 mi north of the community of Moccasin near the northern end of the local aquifer.

Methods

Collection and analysis of water-quality data and rock composition were designed to help identify the presence, source, and concentrations of lead in the water-supply systems for PISP, the KPT, the Cattleman's Association, and the community of Moccasin. From February 7 to 9, 2011, water-quality samples were collected from 10 sites. A single water-quality sample was collected on June 3, 2010, as part of a separate USGS investigation (Bills and others, 2010), and results from the analysis were included as part of this study. Counting the sample from one site collected by Bills and others (2010) plus samples collected from 10 sites for this study, 11 sites were sampled including 5 wells, 3 springs, 2 storage tanks, and 1 faucet at the NPS facilities at PISP. Of the five wells sampled, two wells were the water-supply wells for for PISP and the KPT, one well was an old NPS supply well, and two wells were observation wells. The two water storage tanks were part of the infrastructure in connection to the NPS and Kaibab Paiute water-supply systems. A single faucet was sampled at PISP, which was part of the infrastructure connected to the NPS supply well and the NPS storage tank. The source of the three springs that were sampled is the same local aquifer as the source of drinking supply at PISP.

All analytical results were compared to the USEPA drinking-water standards. Maximum contaminant levels (MCLs) are the primary regulations, and are legally enforceable standards that apply to public water systems (U.S. Environmental Protection Agency, 2009). MCLs protect drinking-water quality by limiting the concentrations of specific contaminants that can adversely affect public health. Secondary maximum contaminant levels (SMCLs) provide guidelines for the control of contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (U.S. Environmental Protection Agency, 2009). The USEPA recommends compliance with SMCLs for public water systems; however, compliance is not enforced. Treatment technique (TT) is a required process intended to reduce the level of contaminant in drinking water and the action level at which that treatment technique is required is the action level treatment technique (U.S. Environmental Protection Agency, 2009).

Water-chemistry samples were collected and analyzed for major ions, nutrients, and trace elements. Field measurements were done in accordance with standard USGS protocols documented in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated). Field measurements include pH, specific conductance, temperature, barometric pressure, dissolved oxygen, alkalinity, and discharge rates at springs. Field alkalinities were determined using incremental equivalence (Rounds, 2006). Major ion, nutrient, trace element, and alkalinity samples were filtered through a 0.45-µm pore size filter and preserved with 2.0 mL of 7.7N HNO_3 according to sampling and analytical protocol. Laboratory analyses for samples were done at the USGS National Water Quality Laboratory (NWQL) according to techniques described in Fishman and Friedman (1989), Fishman (1993), Struzeski and others (1996), American Public Health Association (1998), Garbarino (1999), Garbarino and others (2006), and Patton and Kryskalla (2011).

Water-quality samples from water-supply wells were collected from a hose spicket near the wellhead prior to any water treatment, such as disinfection, softening, or filtration. Polyethylene tubing connected the hose spicket of a well to a splitter that directed water to a flow-through chamber, a sample line, and an overflow line. A Hydrolab minisonde multi-parameter probe was used in conjunction with a closed flow-through chamber to determine field parameters for pH, water temperature, specific conductance, and dissolved oxygen. All wells, except the PVC well, were purged using a portable pump or existing pumps in the water-supply wells for at least three well casing volumes and until field parameter readings stabilized for two readings at 15 min intervals: pH within ±0.1 units, temperature ±0.2°C, specific conductance ±5 percent, and dissolved oxygen ±0.3 mg/L. Once the well was purged and the field parameters stabilized, water samples were collected from the sample line using USGS protocols for the specific types of analysis (U.S. Geological Survey, 2006). The PVC well could not be purged for three well casing volumes because of the slow recovery of the well after one purge volume and therefore the well was only purged for one well casing volume.

Water samples collected from water tanks were collected as depth-integrated samples. A peristaltic pump with 1/8-in. silicone tubing was used to pump water from the bottom, middle, and top of the tank into a 4-L high-density polyethylene (HDPE) sample bottle. The silicone tubing was weighted at the end with a large rubber stopper and lowered into the water tanks from the access port on the top of the tank. Water was pumped through the tubing into a 4-L HDPE bottle from which water-chemistry samples were processed for shipment to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. The water-chemistry sample from the faucet at PISP was collected directly from the faucet into a 4-L HDPE sample bottle and processed out of the 4-L HDPE bottle into smaller polyethylene bottles for shipment to NWQL (U.S. Geological Survey, 2006).

Water samples from springs were collected as close to the source as possible. Water was collected directly into a 4-L HDPE sampling bottle and then processed into smaller bottles for shipment to NWQL. Field parameters were measured at each site using individual probes for pH, water temperature, specific conductance, and dissolved oxygen. When no flow was present, but water was pooled, a peristaltic pump was used to pump water into a 4-L HDPE sampling bottle, and then samples were processed from that 4-L HDPE bottle for shipment to NWQL (U.S. Geological Survey, 2006).

Lead isotope water-chemistry samples were collected and planned for analysis in this study, but it was determined that the total lead concentrations in water samples was too low for accurate isotopic analysis (Thomas Bullen, Research Geochemist, U.S. Geological Survey, oral commun., 2011). Metals analyses were used to determine if the concentration of lead and other metals associated with the presence of lead might be from the plumbing system at PISP. Metals that were analyzed include barium, beryllium, cadmium, chromium, cobalt, copper, iron, lithium, manganese, molybdenum, nickel, silver, strontium, thallium, tungsten, vanadium, and zinc.

Rock samples were collected as part of this study to determine the lead concentration within the rocks associated with the local aquifer near PISP. Eleven rock samples were collected during the same time period as the water-quality samples from February 7 to 9, 2011 (fig. 1; table 1). Seven samples of the Navajo Sandstone and Kayenta Formation, which form the local aquifer, were analyzed. Rocks from the local aquifer are in continual contact with water from the local aquifer and the potential exists for lead to dissolve out of aquifer rocks and into the aquifer water. Other analyzed samples include three samples from the Moenkopi Formation, two of which were from the Shnabkaib Member and one from the middle red member. One sample of the Moenave Formation (fig. 5) also was collected. The Moenkopi and Moenave Formations are in continual contact with the local aquifer because they have been faulted near the surface by the west segment of the Sevier Fault. Because these formations are in contact with the local aquifer, lead could dissolve out of the rocks and potentially impact the local aquifer. Lead isotopic ratios were analyzed from rock samples in an attempt to characterize the type of lead present in the stratigraphic units. Lead isotopic ratios would have been compared to lead isotopic ratios in water-chemistry samples as an indicator of source rock, but the water chemistry samples were not analyzed for lead isotopes for the reasons previously described. Rock samples were prepared and analyzed for total lead concentration and lead isotopic ratios at Northern Arizona University (Ketterer and others, 1991; Halliday and others, 1998).

Lead isotopic ratios of 206Pb/205Pb, 207Pb/204Pb, 208Pb/204Pb, 207Pb/204Pb, and 208Pb/206Pb were analyzed by inductively coupled plasma mass spectrometry (ICPMS) using a VG Axiom MC instrument following procedures outlined in Ketterer and others (1991) and Halliday and others (1998). Isotopic ratios were corrected for instrument bias using the National Institute of Standards and Technology (NIST) 981 as a standard and the analysis accuracy was evaluated using a NIST 2711 control sample and compared to control values from Unruh and others (2000). Analysis of NIST 2711 indicated that the isotopic ratios of the average of five analyses to be very close to control values, within 0.015 for 206Pb/204Pb, 0.01 for 207Pb/204Pb, 0.02 for 208Pb/204Pb, 0.0005 for 207Pb/206Pb, and 0.0015 for 208Pb/206Pb. Lead concentration was determined using quadropole ICPMS and a Thermo X Series II instrument. The detection limit is 0.8 µg/g lead.

Quality Assurance

Quality assurance for this study was maintained through the use of proper training of field personnel, use of standard USGS field and laboratory protocols, collection of a sample blank, and a thorough review of the analytical results. All USGS scientists involved with this study have participated in the USGS National Field Quality Assurance Program, which requires participants to successfully determine pH, specific conductance, and alkalinity of reference samples supplied by the USGS Branch of Quality Systems. Field crews were trained in water-quality field methods by USGS personnel or through formal instruction at the USGS water-quality field methods class.

Laboratory analyses were completed at the NWQL using methods approved by the USGS or the USEPA. The detection level used by the NWQL for most analytes is the laboratory reporting level (LRL; Childress and others, 1999). The LRL is determined through a statistical procedure designed to yield a false positive or false negative rate of less than 1 percent at the LRL (Childress and others, 1999), and is twice the long-term method detection level (LT-MDL). For more discussion of LRLs and LT-MDLs, see Childress and others (1999).

One field blank was collected during the sampling effort. The blank was collected at the NPS supply well by pumping certified blank water from the USGS NWQL. This sample was analyzed to determine if bias existed in the data from contamination during sample collection and (or) analysis. Cobalt and manganese were detected in the field-blank sample, at 0.17 and 0.3 µg/L, respectively. In order to further investigate these detections, analytical results for all field blank samples were compiled for samples analyzed for cobalt and manganese collected during 2010–11 by the same personnel using the same equipment as this study. The results for four cobalt blank samples indicate that potential cobalt contamination is estimated with 76 percent confidence to be no greater than 0.18 µg/L in at least 70 percent of the blank samples since 2010. The six manganese blank samples indicate that potential manganese contamination is estimated with 74 percent confidence to be no greater than 0.3 µg/L in at least 80 percent of the samples since 2010.

Table 1. Physical properties and chemical analyses of water samples from selected municipal wells, springs, and water distribution checkpoints around Pipe Spring National Monument, northern Arizona.

[°C, degrees Celsius; µS/cm, microsiemen per centimeter at 25°C; mg/L, milligram per liter; E, estimated; µg/L, microgram per liter; <, less than.; –, no data]

Site name	U.S. Geological Survey identification number	Latitude (decimal degrees)	Longitude (decimal degrees)	Screened/open Interval (feet below land surface)	Geologic unit at screened/open interval	Date of samples	Temperature field (°C)	Specific conductance field (µS/cm)	pH field (units)	Alkalinity, field, dissolved (mg/L as $CaCO_3$)	Dissolved solids residue at 180°C (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
NPS Facility Water	365146112441500	36.862778	112.7375	–	–	02-07-2011	9.5	618	7.7	190	360	50.1	25.2
Tunnel Spring	365149112442202	36.863611	112.739444	–	–	06-03-2010	14.4	545	7.7	205	–	54.2	23.9
Cabin Spring	365149112442203	36.863611	112.739444	–	–	02-08-2011	14.6	489	7.0	180	325	45.6	19.6
NPS Monitoring Well	365236112442501	36.876667	112.740278	115–125	Navajo Sandstone	02-09-2011	16.0	509	–	185	332	48.2	21.2
NPS Storage Tank	365301112444100	36.883611	112.744722	–	–	02-09-2011	10.1	617	7.5	189	350	47.2	24.1
Tribal Well	365324112445501	36.89	112.748611	–	–	02-07-2011	14.7	561	7.4	180	338	52.7	23.5
Old NPS Well	365325112445201	36.890278	112.747778	175–205	Navajo Sandstone	02-08-2011	15.0	587	7.4	200	349	48.1	24.2
NPS Supply Well	365325112445202	36.890278	112.747778	–	–	02-08-2011	14.4	588	7.3	206	354	48.6	24.5
Tribal Storage Tank	365335112444400	36.893056	112.745556	–	–	02-07-2011	9.1	583	7.4	181	355	48.8	22.3
Moccasin Spring	365438112453501	36.910556	112.759722	–	–	02-09-2011	14.3	195	7.7	83.1	113	19.8	8.51
PVC Well	365602112460201	36.933889	112.767222	82–90	Alluvium	02-08-2011	15.0	634	7.7	230	415	72.0	30.9

Site name	U.S. Geological Survey identification number	Latitude (decimal degrees)	Longitude (decimal degrees)	Date of samples	Potassium, dissolved (mg/L as K)	Sodium, dissolved (mg/L as Na)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Sulfate, dissolved (mg/L as SO_4)	Ammonia, dissolved (mg/L as NH_3)	Nitrate + nitrite, dissolved (mg/L as N)	Ortho-phosphate, dissolved (mg/L as P)
NPS Facility Water	365146112441500	36.862778	112.7375	02-07-2011	4.12	40.1	34.4	0.19	11.6	56.3	<0.013	5.83	0.038
Tunnel Spring	365149112442202	36.863611	112.739444	06-03-2010	2.63	30.9	25.0	.32	12.0	46.2	<.026	2.18	.009
Cabin Spring	365149112442203	36.863611	112.739444	02-08-2011	3.06	28.5	24.4	.24	12.5	44.9	<.013	3.69	.016
NPS Monitoring Well	365236112442501	36.876667	112.740278	02-09-2011	3.30	28.7	24.4	.22	12.9	44.7	<.013	3.73	.024
NPS Storage Tank	365301112444100	36.883611	112.744722	02-09-2011	3.96	38.0	33.7	.20	11.9	55.2	<.013	5.70	.041
Tribal Well	365324112445501	36.89	112.748611	02-07-2011	3.51	34.4	29.4	.21	12.2	49.5	<.013	6.44	.039
Old NPS Well	365325112445201	36.890278	112.747778	02-08-2011	3.96	37.6	33.7	.20	11.9	54.8	<.013	5.51	.041
NPS Supply Well	365325112445202	36.890278	112.747778	02-08-2011	3.87	38.3	34.1	.20	11.8	56.9	<.013	5.75	.041
Tribal Storage Tank	365335112444400	36.893056	112.745556	02-07-2011	3.49	33.3	29.1	.20	12.2	48.7	<.013	6.52	.036
Moccasin Spring	365438112453501	36.910556	112.759722	02-09-2011	3.43	4.22	4.05	.05	11.6	4.59	<.013	1.90	.017
PVC Well	365602112460201	36.933889	112.767222	02-08-2011	5.65	15.7	4.70	.21	22.1	52.6	.015	17.3	.023

Table 1. Physical properties and chemical analyses of water samples from selected municipal wells, springs, and water distribution checkpoints around Pipe Spring National Monument, northern Arizona.—Continued

[°C, degrees Celsius; µS/cm, microsiemen per centimeter at 25°C; mg/L, milligram per liter; E, estimated; µg/L, microgram per liter; <, less than.; –, no data]

Site name	U.S. Geological Survey identification number	Latitude (decimal degrees)	Longitude (decimal degrees)	Date of samples	Aluminum, dissolved (µg/L as Al)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)
NPS Facility Water	365146112441500	36.862778	112.7375	02-07-2011	6.0	53.6	<0.006	<0.016	0.32	[1]0.068	64.0	7.3	0.181
Tunnel Spring	365149112442202	36.863611	112.739444	06-03-2010	E3.0	60.5	E.007	<.020	.36	.214	<1.0	<6.0	<.030
Cabin Spring	365149112442203	36.863611	112.739444	02-08-2011	2.4	51.9	<.006	<.016	.49	[1].023	<.50	<3.2	.019
NPS Monitoring Well	365236112442501	36.876667	112.740278	02-09-2011	3.3	51.7	<.006	<.016	.58	[1].025	<.50	<3.2	.019
NPS Storage Tank	365301112444100	36.883611	112.744722	02-09-2011	<1.7	56.1	<.006	<.016	.31	[1].055	<.50	<3.2	.027
Tribal Well	365324112445501	36.89	112.748611	02-07-2011	<1.7	52.7	<.006	<.016	.51	[1].023	1.1	<3.2	.148
Old NPS Well	365325112445201	36.890278	112.747778	02-08-2011	<1.7	53.2	<.006	<.016	.32	[1].072	64.0	<3.2	.176
NPS Supply Well	365325112445202	36.890278	112.747778	02-08-2011	<1.7	56.1	.007	<.016	.31	[1].024	2.2	<3.2	.369
Tribal Storage Tank	365335112444400	36.893056	112.745556	02-07-2011	<1.7	53.3	<.006	<.016	.51	[1].023	<.50	<3.2	<.015
Moccasin Spring	365438112453501	36.910556	112.759722	02-09-2011	<1.7	31.9	<.006	<.016	.36	[1]<.020	<.50	<3.2	<.015
PVC Well	365602112460201	36.933889	112.767222	02-08-2011	<1.7	84.0	<.006	<.016	.72	.361	.55	<3.2	<.015

Site name	U.S. Geological Survey identification number	Latitude (decimal degrees)	Longitude (decimal degrees)	Date of samples	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Thallium, dissolved (µg/L as Tl)	Tungsten, dissolved (µg/L as W)	Vanadium, dissolved (µg/L as V)
NPS Facility Water	365146112441500	36.862778	112.7375	02-07-2011	31.3	0.29	2.22	0.32	<0.005	373	<0.010	<0.010	0.97
Tunnel Spring	365149112442202	36.863611	112.739444	06-03-2010	37.6	.36	.817	1.5	<.010	339	<.020	<.020	1.2
Cabin Spring	365149112442203	36.863611	112.739444	02-08-2011	31.3	.29	1.13	.17	<.005	306	<.010	<.010	1.4
NPS Monitoring Well	365236112442501	36.876667	112.740278	02-09-2011	30.9	[1]<.13	1.10	.16	<.005	315	<.010	.023	1.1
NPS Storage Tank	365301112444100	36.883611	112.744722	02-09-2011	31.2	[1]<.13	2.21	.14	<.005	374	<.010	<.010	1.1
Tribal Well	365324112445501	36.89	112.748611	02-07-2011	27.9	[1].20	1.67	.20	<.005	332	<.010	<.010	1.5
Old NPS Well	365325112445201	36.890278	112.747778	02-08-2011	30.9	.28	2.21	.30	<.005	365	<.010	<.010	.96
NPS Supply Well	365325112445202	36.890278	112.747778	02-08-2011	33.9	[1]<.13	2.33	.15	<.005	377	<.010	<.010	1.1
Tribal Storage Tank	365335112444400	36.893056	112.745556	02-07-2011	28.0	.26	1.66	.18	<.005	328	<.010	.017	1.5
Moccasin Spring	365438112453501	36.910556	112.759722	02-09-2011	2.32	.66	.080	<.09	<.005	71.9	<.010	<.010	.34
PVC Well	365602112460201	36.933889	112.767222	02-08-2011	15.5	3.26	1.02	2.2	<.005	441	<.010	1.08	.67

Site name	U.S. Geological Survey identification number	Latitude (decimal degrees)	Longitude (decimal degrees)	Date of samples	Zinc, dissolved (µg/L as Zn)	Antimony, dissolved (µg/L as Sb)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)	Selenium, dissolved (µg/L as Se)	Uranium, dissolved (µg/L as U)
NPS Facility Water	365146112441500	36.862778	112.7375	02-07-2011	25.5	<.027	4.0	170	4.9	11.4
Tunnel Spring	365149112442202	36.863611	112.739444	06-03-2010	<2.8	<.054	2.5	165	3.3	6.28
Cabin Spring	365149112442203	36.863611	112.739444	02-08-2011	1.7	<.027	3.1	156	3.2	6.64
NPS Monitoring Well	365236112442501	36.876667	112.740278	02-09-2011	<1.4	<.027	2.8	155	3.0	6.39
NPS Storage Tank	365301112444100	36.883611	112.744722	02-09-2011	11.5	<.027	4.1	172	4.9	11.5
Tribal Well	365324112445501	36.89	112.748611	02-07-2011	13.1	<.027	3.5	158	4.3	7.64
Old NPS Well	365325112445201	36.890278	112.747778	02-08-2011	25.3	<.027	3.9	174	4.9	11.3
NPS Supply Well	365325112445202	36.890278	112.747778	02-08-2011	13.5	<.027	4.1	172	5.1	12.3
Tribal Storage Tank	365335112444400	36.893056	112.745556	02-07-2011	9.4	<.027	3.4	156	4.2	7.39
Moccasin Spring	365438112453501	36.910556	112.759722	02-09-2011	2.8	<.027	.95	23	.47	.257
PVC Well	365602112460201	36.933889	112.767222	02-08-2011	3.1	.084	1.7	202	2.8	2.56

[1]Possibly contains contamination.

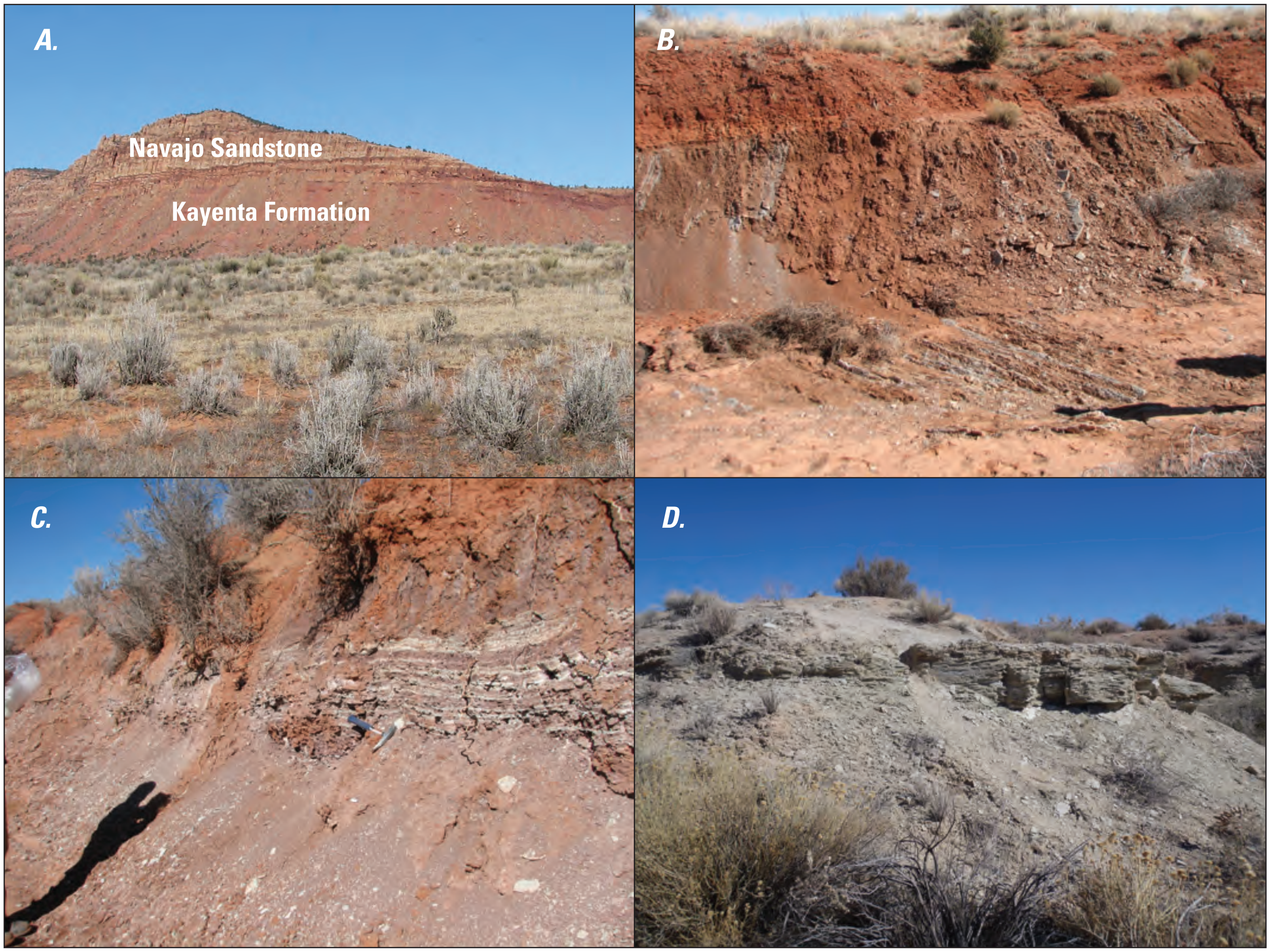

Figure 5. Stratigraphic units and outcrops where rock composition samples were collected. (*A*) Windsor Mountain, cliffs composed of Navajo Sandstone and Kayenta Formation. (*B*) Outcrop of Moenkopi Formation where rock sample 8 was collected. (*C*) Outcrop of Dinosaur Canyon Member of the Moenave Formation where rock sample 9 was collected. (*D*) Outcrop of Shnabkaib Member of the Moenkopi Formation where rock samples 10 and 11 were collected. USGS photographs taken by Jamie P. Macy.

Water-Quality Results

Water-quality analytical results from the 11 samples were similar in composition for all sites except for Moccasin Spring and the PVC well (table 1). Lead concentrations ranged from less than the reporting limit (0.025 µg/L) at Tunnel Spring, Tribal Storage Tank, Moccasin Spring, Cabin Spring, PISP monitoring well, and the PVC well to a maximum of 0.369 µg/L at the NPS supply well. Lead concentrations in the remaining four sites were 0.027 µg/L at the NPS storage tank, 0.148 µg/L at the Tribal supply well, 0.176 µg/L at the old NPS supply well, and 0.181 µg/L at the NPS facility water at the faucet. Dissolved-solids concentrations ranged from 113 mg/L at Moccasin Spring to 415 mg/L at the PVC well with all other sites ranging from 325 to 350 mg/L. Chloride concentrations were 4.05 mg/L at Moccasin Spring and 4.70 mg/L at the PVC well. Chloride concentrations in the remaining nine samples ranged from 24.4 to 34.4 mg/L. Concentrations of calcium, magnesium, and sodium in water samples from Moccasin Spring were substantially lower than samples from all other sites (table 1). Nitrate + nitrite as nitrogen concentration was 17.3 mg/L at the PVC well and concentrations for the remaining 10 samples were less than 7 mg/L.

The concentrations of chemical constituents in samples from 10 sites were compared to the USEPA TTs, MCLs, and SMCLs for drinking-water standards (U.S. Environmental Protection Agency, 2009). The USEPA TT for lead in drinking water is 15 µg/L, and all analytical results for lead were less than the USEPA TT, with the highest concentration of 0.369 µg/L. Low concentrations of lead in water from storage tanks and faucets indicate that the water-supply system does not contribute significantly to lead concentrations in drinking water. The MCLs and SMCLs for all other analyzed chemical constituents were not exceeded at any site, except at the PVC well where the concentration of dissolved nitrate + nitrite as nitrogen was 17.3 mg/L. Nitrogen is measured as the sum of nitrite and nitrate. The nitrite concentration in the sample from the PVC well was less than 0.001 mg/L, making the concentration of nitrate in the sample about equal to the total concentration of nitrogen, 17.3 mg/L; therefore, the sample exceeded the USEPA MCL of 10 mg/L for nitrate. However, this result is viewed with caution because this sample did not meet the requirement for purging three well volumes before sample collection because of the extremely slow recovery of the well after one pumping. Residual nitrate could have remained in the well after one casing volume was purged and therefore influenced the results.

Rock Composition Results

Rock sample analytical results indicated that naturally occurring lead concentrations were low. Rock samples were analyzed from 11 sites in and around PISP (figs. 1 and 5). Rock samples were collected from areas where it was determined that the rocks would be representative to those rocks associated with the local aquifer (fig. 5). Results of lead isotopic ratio and lead concentration analysis are presented in table 2. Lead concentrations in rock samples ranged from 2.8 to 21.1 µg/g. Concentrations of lead were highest (20.7 and 21.1 µg/g) from rock samples 5 and 6 (fig. 1) of the Kayenta Formation collected near the back of the tunnel at Tunnel Spring. Concentrations of lead were lowest (3.7 and 4.9 µg/g) from rock samples from the Moenkopi Formation. Measured concentrations of lead in rock samples collected at PISP were average or low when compared to average rock compositions for the Western United States (Connor and Shacklette, 1975). Average lead concentrations in sandstones, limestones, and shales for the Western United States range from about less than 3 to less than 20 µg/g (Connor and Shacklette, 1975). A low concentration of lead in Pipe Spring aquifer rocks would indicate that total dissolved lead in water samples also would be low. Water-chemistry samples and rock samples from PISP indicate that naturally occurring lead concentrations are low and water from the local aquifer would be expected to have low concentrations of lead.

Table 2. Sample locations, stratigraphic reference, lead isotopic ratios, and lead concentration analysis from rock samples around Pipe Spring National Monument area, northern Arizona.

[**Sample ID:** Reference to rock sample number on figure 1. **Abbreviations:** Pb, lead; µg/g, microgram per gram]

Sample ID	Latitude (decimal degrees)	Longitude (decimal degrees)	Stratigraphic unit	206/204 Pb	207/204 Pb	208/204 Pb	207/206 Pb	208/206 Pb	Total Pb concentration (µg/g)
Rock 1	36.870861	112.740389	Navajo Sandstone	18.778	15.643	38.462	0.83295	2.0482	9.0
Rock 2	36.870639	112.740778	Navajo Sandstone	18.513	15.615	38.233	0.84336	2.0650	6.1
Rock 3	36.870694	112.74075	Navajo Sandstone	18.419	15.612	38.189	0.84755	2.0732	7.3
Rock 4	36.870528	112.740667	Navajo Sandstone	18.669	15.621	38.335	0.83718	2.0533	8.0
Rock 5	36.863611	112.739444	Kayenta Formation	19.688	15.712	39.128	0.79794	1.9871	21.1
Rock 6	36.863611	112.739444	Kayenta Formation	19.586	15.705	39.092	0.80176	1.9956	20.7
Rock 7	36.86325	112.740222	Kayenta Formation	18.408	15.605	38.156	0.84763	2.0726	14.8
Rock 8	36.845306	112.750806	Middle red member of Moenkopi Formation	19.199	15.667	38.954	0.81598	2.0288	4.9
Rock 9	36.847556	112.750833	Dinosaur Canyon Member of Moenave	19.527	15.690	38.984	0.80344	1.9963	8.8
Rock 10	36.861611	112.73525	Schnabkaib Member of Moenkopi	18.547	15.601	38.199	0.84115	2.0595	2.8
Rock 11	36.861611	112.73525	Schnabkaib Member of Moenkopi	19.425	15.678	39.211	0.80703	2.0185	3.7

Summary

Water-quality and rock sample analytical results yielded undetectable to low concentrations of dissolved lead in water samples and low concentrations of lead in rock samples. Water-quality analysis from five wells, three springs, two storage tanks, and one water faucet was completed to determine the presence, source, and concentration of lead in the water-supply system for the PISP, the Kaibab Paiute Tribe, the Cattleman's Association, and the town of Moccasin. Water-quality analytical results from water samples from the 11 sites that were evaluated in this study indicated low concentrations of lead in water from any of the sites. Concentrations of lead and all other chemical constituents in sampled water were less than U.S. Environmental Protection Agency maximum contaminant level, secondary maximum contaminant level, and treatment technique action level. Analytical results for nitrate + nitrite as dissolved nitrogen in the PVC well (17.3 milligrams per liter) exceeded the MCL of 11 milligrams per liter. Concentrations of lead in water from the two storage tanks (<0.01 and 0.18 micrograms per liter) and the facility water at the faucet (0.18 micrograms per liter) indicate that the water-supply system does not contribute significantly to lead concentrations in drinking water. The lead concentration of samples from rock units representative of the rocks within the local aquifer are less than 22 micrograms per gram. Lead concentrations in water samples were too low for isotopic analysis, so differentiation between sources of lead was not possible by the techniques of this study. Lead isotope data from rock samples were measured, and are included in this report.

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