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Natural Resource Stewardship and Science

Fourteen Years of Springflow Data at Arches National Park

Natural Resource Report NPS/NCPN/NRR—2015/1018

ON THE COVER

Temporary weir plate that enables flow measurements at Sleepy Hollow Spring, Arches National Park.
NPS/M. Moran

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Executive Summary

Monthly springflow monitoring began at four springs in the Courthouse Wash–Sevenmile Canyon complex of Arches National Park in December 2000, to support water rights negotiations with the State of Utah. Sites were selected to represent three sections of a dissected local aquifer in the Moab Member of the Curtis Formation. One spring, Sleepy Hollow, emerges from the eastern section of the aquifer, which is entirely protected within the park. Two springs, Poison Ivy and Sevenmile Boundary, flow from the western section of the aquifer, which includes lands not protected by the park. The fourth spring, Courthouse Boundary, has a more complex flow path fed by the northern section of the aquifer and wash-bottom alluvium, both of which extend beyond park boundaries. This report presents the results of 14 years of springs monitoring at those sites.

Sleepy Hollow Spring, emerging from the eastern sector, had stable springflow from 2001 to 2014. Both springs emerging from the western sector showed significant declines in springflow. Courthouse Boundary Spring also had a statistically significant decline in flow, but its record is complicated by multiple changes in measurement locations and methods and increasing sedimentation. Springflow measurements were discontinued at Courthouse Boundary Spring in 2011, due to increasing instability at the site.

The cause of declining springflow at Poison Ivy and Sevenmile Boundary springs is unknown, and additional analyses of climate relationships are necessary. Existing groundwater withdrawals are unlikely to affect recharge in the western sector due to geologic controls on the recharge area. The water-rights agreement signed in May 2015 between Arches National Park and the State of Utah protects the Moab Member of the Curtis Formation aquifer from additional groundwater withdrawals in the future.

Acknowledgements

This project was initiated by Charlie Schelz, former Southeast Utah Group (SEUG) ecologist, and Jim Harte, hydrologist for the National Park Service (NPS) Water Resources Division (WRD). Schelz supervised the project and occasionally did field monitoring before leaving his position in 2007. Harte has provided advice through the years, while also advancing a water-rights agreement for Arches National Park and participating in related research projects. Brad Gillies, formerly of the WRD, also assisted during the early years of the project. Many SEUG staff and volunteers have helped with monitoring over the years. Biological science technicians Sarah Finkbeiner (2008–2012) and Patricia Ortiz (2013–2014) led some of the monthly monitoring runs. Aneth Wight (Northern Colorado Plateau Network) created map figures. Mark Miller (SEUG) and Jim Harte provided thoughtful reviews of this report.

1 Introduction

Aridland springs are considered to be among the most complex, diverse, productive, and threatened ecosystems on earth (Stevens and Meretsky 2008). Though scarce in arid landscapes, springs and riparian ecosystems provide essential habitat for diverse plant and animal communities and are disproportionate contributors to biological diversity and productivity. In Arches National Park (NP), springs and seeps are concentrated in a few areas. They are particularly notable in Courthouse Wash Canyon and its largest tributary, Sevenmile Canyon (Figure 1-1), in the southwestern part of the park. Many springs and seeps support rare hanging-garden communities, and springflow provides most of the base flow for riparian systems associated with Courthouse Wash and Sevenmile Canyon (Hurlow and Bishop 2003).

Figure 1-1. Sevenmile Canyon, December 21, 2009.

Beginning in December 2000, springflow (discharge) was monitored on a monthly basis at four spring sites in the Courthouse–Sevenmile area (Figure 1-2). This long-term monitoring project was initiated primarily because of management concerns regarding the potential impacts of groundwater withdrawals outside the park on spring-dependent ecosystems within the park. The springs and seeps of the Courthouse–Sevenmile area are fed by a shallow aquifer with a recharge area only a few kilometers wide, surrounding the core canyon area (Hurlow and Bishop 2003).

To the east of the canyons, the recharge area is within the park. To the north, west, and southwest, most lands adjacent to the park boundary are owned by the State of Utah under the School and Institutional Trust Lands Administration (SITLA) or as State Sovereign Lands, with the remainder held privately or by the Bureau of Land Management (BLM). SITLA leases or sells its lands for a variety of uses, including developments that, in some situations, apply for and receive water rights for groundwater withdrawals (http://trustlands.utah.gov, accessed Feb. 3, 2011). A few groundwater wells already exist in the area near the park boundary.

This project was also motivated by concern over the potential for climate change to impact springflows and possibly result in greater sensitivity of springs to the effects of groundwater withdrawals. Long-term monitoring data may enable detection of climate-related trends in springflow that have implications for mitigation planning.

National Park Service (NPS) Management Policies direct the NPS to perpetuate surface and groundwater resources as integral components of park ecosystems (NPS 2006, Section 4.6). In May 2015, the NPS and State of Utah signed a water-rights agreement that protects flows within the park and creates a groundwater protection zone around the park boundary. Data acquired by this monitoring project provide important information to support the agreement.

Specific objectives of this project are to:

- Measure springflow monthly (at least 10 times each year) at monitoring sites to quantify seasonal and annual variability in springflow under baseflow conditions;
- Examine results for potential differences among distinct sections of the dissected aquifer;
- Provide springflow data to park managers and the Utah Division of Water Rights, to assist them in protecting NPS groundwater resources; and
- Demonstrate due diligence in monitoring park springflows to the Utah Division of Water Rights.

Purposes of this report are to summarize field methods, describe activities conducted

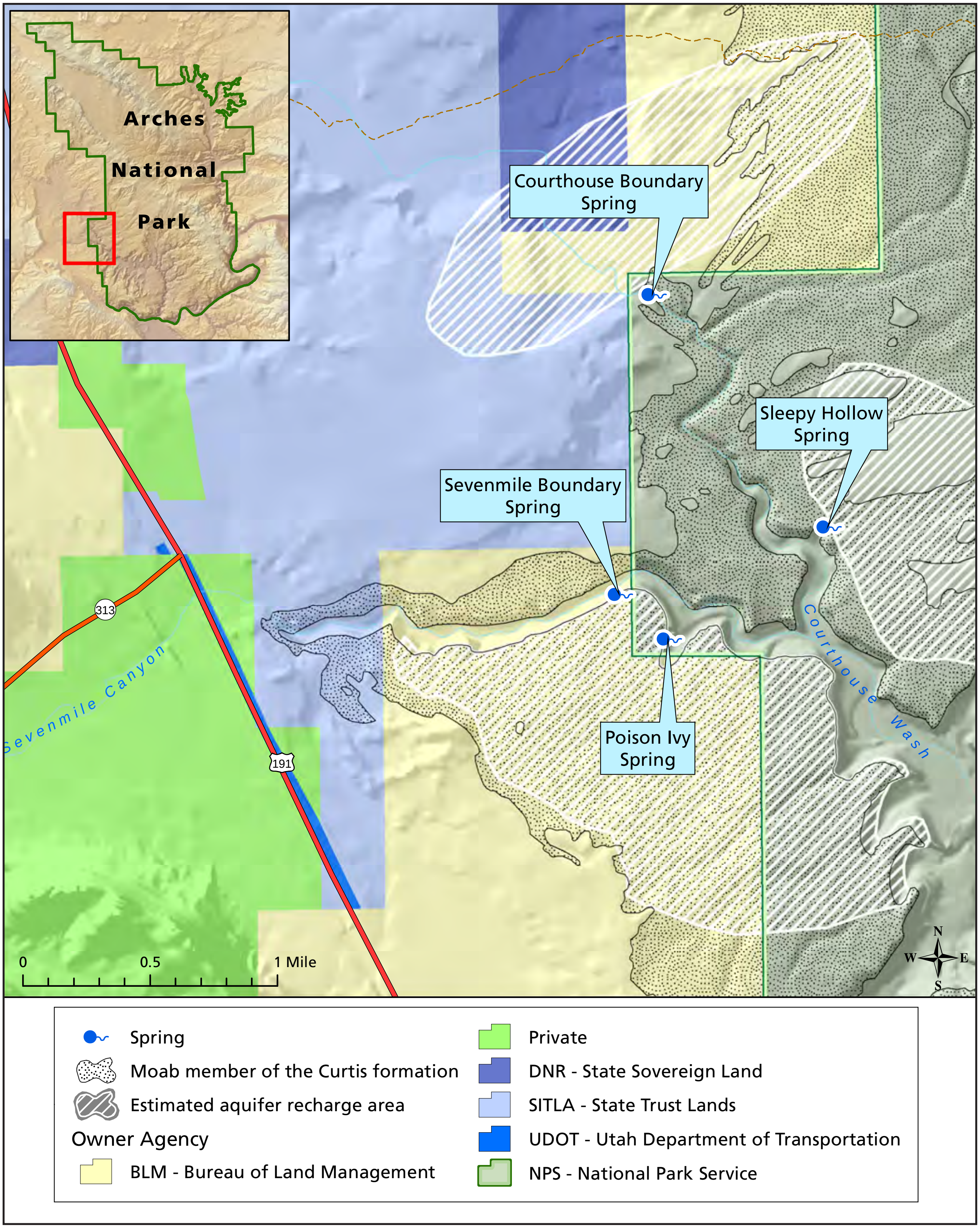


Figure 1-2. The four springs in and adjacent to Arches National Park selected for long-term flow monitoring. Springs are primarily recharged through local outcrops of the Moab Member of the Curtis Formation, some of which lie outside park boundaries.
DNR = Department of Natural Resources; SITLA = School and Institutional Trust Lands Administration

during the 2001–2014 field seasons, present the dataset, and describe overall trends in the data for each site.

1.1 Setting

1.1.1 Hydrogeology and landscape context

One shallow, dissected aquifer feeds most of the springs and provides most of the water flow in the Courthouse–Sevenmile Canyon region of this project. The aquifer is in the well-sorted, fine sandstone of the Moab Member of the Curtis Formation (Doelling 2001; formerly called Moab Tongue of the Entrada Sandstone in Doelling 1985). Recharge of the aquifer is from precipitation directly onto the highly jointed Moab Member outcrop area. Discharge is, in most cases, from the lower Moab Member contact and within eight meters above the contact with the Slick Rock Member of the Entrada Sandstone. Sedimentary layers above and below the Moab Member are relatively impervious, limiting the aquifer to this one stratigraphic unit (Hurlow and Bishop 2003).

The aquifer is limited in size geographically by the outcrop area of the Moab Member. The Moab Fault system truncates the Member at the southwest edge of the study area, roughly paralleling U.S. Highway 191. Younger, relatively impervious sedimentary rocks overlie the Moab Member immediately to the north and northwest of the Courthouse Canyon intersection with the park boundary. The Moab Member is absent within two miles east and northeast of the canyon system, where it has been eroded away (Doelling 2001).

Within the project area, the Moab Member aquifer has been dissected by canyons that divide the aquifer into three geographic areas with distinct recharge and discharge areas. In the southwest, water recharging the aquifer south of Sevenmile Canyon is discharged in springs or seeps on the south side of Sevenmile Canyon, or on the west side of Courthouse Wash south of its confluence with Sevenmile. In the northern sector, water recharging the aquifer north of Sevenmile Canyon is discharged on the north side of Sevenmile Canyon and west side of Courthouse Wash Canyon. On the east side of the study area, water recharging the aquifer east of Courthouse Wash discharges on the east side of Courthouse Wash Canyon (Hurlow and Bishop 2003).

From a management perspective, the dissected nature of the aquifer is important because impacts from potential groundwater withdrawal exist for the southwest and northern sectors, but not for the eastern sector, where the entire recharge area lies within Arches NP. From a study-design perspective, the eastern sector acts as a control, reflecting flow fluctuations due to weather and climate but without potential impacts from groundwater withdrawals.

1.1.2 Ecological importance of springs

Springs are oases in semi-arid systems. They provide essential habitat for flora and fauna and are the basis for surface flow in perennial and intermittent reaches at Arches NP. Many of the plants found at hanging gardens in and near the park, including alcove columbine (*Aquilegia micrantha*), maidenhair fern (*Adiantum capillus-veneris*), cave primrose (*Primula specuicola*), alcove death camas (*Zigadenus vaginatus*), and alcove bog-orchid (*Habenaria zothecina*), are endemic to hanging gardens of the Colorado Plateau (Welsh 1989).

The spring sites, and the canyons between them, provide habitat for a diversity of wildlife. Common wildlife sightings include red-tailed hawks (*Buteo jamaicensis*), Cooper's hawks (*Accipiter cooperii*), great-horned owls (*Bubo virginianus*), common ravens (*Corvus corax*), innumerable songbirds, and the tracks of coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), and bobcat (*Lynx rufus*). Rarer sightings include golden eagles (*Aquila chrysaetos*), wild turkeys (*Meleagris gallopavo*), and the tracks of mountain lion (*Puma concolor*) and elk (*Cervus elaphus*). On one summer monitoring day, a black phoebe (*Sayornis nigricans*), not previously recorded in the park, was seen hunting insects over the pool at Sleepy Hollow Spring.

1.2 Study sites

During reconnaissance trips conducted in winter 2000–2001, four springs were determined suitable for flow monitoring (see Figure 1-2). Three of the springs are hanging gardens that emerge in protected alcoves. The fourth spring (Courthouse Boundary Spring) is in a wash-bottom setting subject to surface flows.

The hanging gardens associated with three of the springs in this monitoring program are relatively rare and isolated communities. One of them, Sleepy Hollow Spring, is in the eastern sector of the aquifer, which lies within park boundaries. The other two hanging gardens, Sevenmile Boundary Spring and Poison Ivy Spring, are in the southwest sector of the dissected aquifer, which is potentially subject to groundwater depletion from outside the park.

The fourth spring, Courthouse Boundary Spring, located in the channel of Courthouse Wash, is considered to be in the northwest sector of the dissected aquifer. The recharge area for this spring is complex and is subject to groundwater depletions from outside the park.

1.2.1 Sleepy Hollow Spring

Sleepy Hollow Spring is located in the back of a large alcove on the east side of Courthouse Wash Canyon, roughly 0.8 kilometers upstream of Courthouse's confluence with Sevenmile Canyon. Multi-tiered seeps emerge from near the base of the Moab Member along a hanging-garden backwall. A perennial pool, roughly 10 meters in diameter, lies at the base of the backwall (Figure 1-3). Some seeps may emerge under the waters of the pool. A single outflow channel carries surface flow from the large pool. Flow is measured within the outflow channel, 2–5 meters downstream of the large pool.

A significant pouroff feature exists above the Sleepy Hollow pool. Though the drainage above the pouroff is a small one, it is a few miles long and collects enough runoff during large precipitation events to send a substantial waterfall into the pool. Because of this, hanging-garden and flood-intolerant plant species crowd the pool's backwall, but riparian species dominate the downstream side of the pool, where occasional floodwaters roar through. In August 2014, a flood event deposited a substantial amount of sediment in the pool area, resulting in a significantly smaller and shallower pool with a wide, sand beach. These conditions have persisted through March 2015.

1.2.2 Sevenmile Boundary Spring

Sevenmile Boundary Spring is located in a small, north-facing alcove on the south side of Sevenmile Canyon, just outside the park boundary on BLM land. It emerges as multiple seeps from several seeplines at and above the base of the Moab Member, along a hanging-garden backwall (Figure 1-4). A small pool or pools are present near the base of the wall and two small channels converge into one channel downslope of the pools. No obvious pouroff site exists at the top of the backwall, and in 14 years of monitoring, evidence of only a few small flood events has been observed in the stream channel. Flow is measured in the combined channel at a designated location roughly 15 meters downstream of the base of the wall. Hanging-garden and riparian vegetation are diverse and dense at this site, and liverworts grow on the colluvial boulders at the base of the wall.

1.2.3 Poison Ivy Spring

Poison Ivy Spring is located within a short side canyon on the southwest side of Sevenmile Canyon, roughly one kilometer upstream of its confluence with Courthouse Wash and approximately 1,200 feet aerially from Sevenmile Boundary Spring. Measurements capture outflow from the largest alcove within this side canyon, on the west side of the side canyon. Like Sevenmile Boundary Spring, Poison Ivy Spring emerges from multiple seeps from several locations at and above the base of the Moab Member, along a hanging-garden backwall (Figure 1-5). At this site, a colluvial (detritus) slope lies at the base of much of the backwall. There are a few pools at the base of the slope, and a small, defined channel forms downslope of the pools. There is no significant pouroff site at the top of the backwall, and the only evidence of flood events observed has been some leaves and organic detritus accumulation on several occasions. Flow is measured in a merged channel roughly 30 meters downslope of the

Figure 1-3. Sleepy Hollow Spring pool and lower part of backwall, October 2010.

Figure 1-4. Sevenmile Boundary Spring seeplines and pool, January 2013.

Figure 1-5. Poison Ivy Spring seeplines and colluvial slope, June 2010. The trees in the foreground line a channel where springflow coalesces.

base of the backwall/colluvial slope. Riparian and spring vegetation is dense in the measurement area, including multiple tree species and a dense undergrowth of horsetail (*Equisetum hyemale*) and poison ivy (*Toxicodendron rydbergii*).

1.2.4 Courthouse Boundary Spring

Courthouse Boundary Spring has a different setting and source than the other three monitored springs. It emerges from the bottom of Courthouse Wash, in an open area several hundred meters upstream of where the wash enters Courthouse Wash Canyon (Figure 1-6). The spring emergence area appears to be at least 75 meters long along the wash bottom. The upper end of this reach is defined by a perennial pool bounded on its upstream edge by exposed, sloping bedrock, and a smaller pool just one or two meters upstream, on the bedrock surface. Stratigraphically, the springs emerge not from the bottom of the Moab Member, but from joints and cross-bed surfaces near the top of the unit (Hurlow and Bishop 2003). The layers of the overlying Summerville and Morrison formations can be seen in the low hills to the west of the site. Shifting alluvial sediments cover the wide wash bottom, and the retreating edge of an alluvial terrace forms a vertical cliff roughly ten meters high along the eastern margin of the wash in this area.

Hurlow and Bishop (2003) consider Courthouse Boundary Spring to be within the northern recharge area, though it is transitional geographically to the eastern recharge area. Their studies indicated chemical differences between these spring waters and those of the other three springs. They conjectured that the water from these springs was at least in part from a localized alluvial aquifer composed of sediments from the overlying Jurassic Summerville and Morrison formations, or from limited recharge through these layers into the top of the Moab Member (Hurlow and Bishop 2003). Later age-dating and chemistry studies confirmed that these spring waters are complicated, with inputs from the Moab Member as well as overlying rock layers, mixed with younger alluvial water sourc-

Figure 1-6. Alluvial setting of Courthouse Boundary Spring, September 2007.

es. These later results indicate a substantially larger recharge area than the extent of Moab Member outcrops for this spring area (Kirby 2007; Masbruch et al. 2010).

Courthouse Boundary Spring is the sole source of perennial streamflow in this reach of Courthouse Wash, and the stream above the site is usually dry. However, the drainage basin of Courthouse Wash upstream is significant, and large flood events periodically pass through the system. Between 2001 and 2014, floods deposited over one meter of sediment, burying bedrock outcrops in the channel. They also caused the adjacent alluvial terrace to collapse and briefly dam flow from the spring. Even minor flood events can cause shifts in the main channel, deposit sediment, flatten riparian vegetation, and form new secondary channels. The flow measurement area for this site has been less stable than at the other spring sites because of all these geomorphic changes, but it remained within a single 30-meter reach downstream of the spring emergence area until August 2011. By that time, the various deposition and channel-shifting events made accurate flow measurement impossible at this site. We continue to visit this site frequently to monitor water quality, but flow measurements have not been possible since 2011.

2 Methods

Monthly springflow measurements were initiated in March 2001, and continue to be collected (with the exception of Courthouse Boundary Spring, where measurements were suspended in fall 2011). At each site, a long-term measurement location was selected downstream of the point where flow coalesced into a channel.

From March 2001 until October 2005, the measurement site for Courthouse Boundary Spring was located on a rock ledge where the springflow could be captured and channelized using plumber's putty and a pipe or downspout extension (Figure 2-1). A 30-centimeter drop from the edge of the rock ledge to the channel bottom below allowed for placement of a five-gallon plastic bucket in which the entire flow through the pipe could be captured.

Springflow measurements were made by placing the measuring bucket under the downstream end of the pipe and noting the time required to fill the bucket. On each site visit, six measurements were made and averaged to calculate the final flow in gallons per minute.

The measurement-site location and measurement method at Courthouse Boundary Spring changed after a flood event in October 2005 deposited sediments that buried all exposed bedrock at the spring. From November 2005 through November 2009, a portable Parshall flume and associated staff gage were used to measure springflow at this site (see Figure 1-6). The measurement-site location and measurement method were again changed after surface flow decreased due to additional sediment deposition at the measurement site, and a timed filling of a plastic bag was used to measure flow in 2010 and 2011, until measurements were discontinued in fall 2011.

Springflow at Sleepy Hollow Spring, Sevenmile Boundary Spring, and Poison Ivy Spring was measured using the same "bucket and stopwatch" technique used at Courthouse Boundary Spring, except the flow was captured and channelized using a steel weir plate. The weir plate was fabricated using a 1-foot-high by 2-feet-wide piece of 3/8-inch plate steel. A hole three inches in diameter was cut from the center of the plate and a length of steel pipe three inches in diameter was welded into the hole (Figure 2-2).

Figure 2-1. Original flow-measurement location at Courthouse Boundary Spring, showing a bedrock ledge subsequently buried in flood events.

To block the flow, the weir plate is hammered into the channel bottom and streambanks perpendicular to the flow path, and any leaks around the perimeter of the plate are blocked with soil found onsite. A staff gage is installed in the pool upstream of the weir plate and the water level in the pool is allowed to stabilize before a flow measurement is made. Springflow measurements are made by placing a

Figure 2-2. Example of constructed weir plate and installation at Sleepy Hollow Spring, October 2014.

measuring bucket under the downstream end of the pipe and noting the time required to fill the bucket.

On each site visit, six measurements were made and averaged to calculate the final flow in gallons per minute. Most field monitoring runs were conducted during one day each calendar month by a lead NPS staffperson and an assistant. Occasionally, monitoring of Courthouse Boundary Spring was completed on a different day than that of the other three springs.

The project protocol calls for avoiding monitoring soon after significant rain events, in an attempt to measure baseflow rather than flows supplemented by direct precipitation runoff. Generally, monitoring was delayed 1–3 days after precipitation events, depending on the size of the event and scheduling constraints. Weather of the previous week was recorded on each site visit, largely to document any precipitation events that may have impacted baseflow.

Because the flow measurement sites at all four springs are located at some distance downslope of actual spring emergence, freezing and thawing in the areas between the emergence and measurement sites could influence flow measurements. Previous weather and air temperatures during visits were noted on the datasheets to document these potential influences.

Figure 2-3. Sleepy Hollow Spring flow-measurement location and weir, December 2002.

After the first few months of adjusting measurement methods during 2001, datasheets were developed for each of the four spring sites. Each datasheet included a gear list and protocol steps for that site, as well as space for entering flow and other relevant data. The datasheets were slightly modified between 2001 and 2012 to reflect changes in flow-measurement methods at the various sites (Appendix A). In February 2013, a more general datasheet was adopted, as we initiated springflow measurements in locations outside the scope of this report (Weissinger et al. in review).

2.1 Flow measurement locations and quality

Channel changes caused by floods and other natural events have required adjustments in flow-measurement methods and/or locations at all of the monitoring sites through the years, though the changes have been quite minor except at Courthouse Boundary Spring. A site visit to Sleepy Hollow, Sevenmile Boundary, and Poison Ivy springs in December 2014 confirmed that changes in measurement locations at these three sites have not been large enough to significantly affect the amount of flow captured at each location.

2.1.1 Sleepy Hollow Spring

At Sleepy Hollow Spring, measurements were initially made in a small pool just a couple of meters downstream from the outlet of the site's notable large pool. A steel weir plate, as described previously, with an extension pipe attached to the one-foot outlet pipe, projected the entire flow out over the small pool (Figure 2-3). Standing in the small pool and submerging the bottom of a 19-liter bucket into this pool, it was possible to capture the tube's outflow in a timed measurement. This small pool partially filled in with sediment a few times during the first few years of monitoring, and was repeatedly shoveled out in order to allow measurements to be taken. Finally, the small pool area became a downcut channel and the site was moved approximately five meters downstream, to a slightly larger and deeper pool in November 2005 (Table 2-1; Figure 2-4). A flow event in August 2010 deposited sediment in the new

Table 2-1. Weir placement and stability notes at Sleepy Hollow Spring, 2001–2014.

Date	Description	Reason/Notes
3/1/2001	Original weir plate placement 1–2 m downstream of cottonwood trunk at big pool outlet. Weir plate removed and stashed each month between visits.	There was a drop in the channel with a pool downstream of it approximately 0.5 m deep, providing enough drop to level a 5-gallon (19-L) bucket at the outlet tube.
2001–2005		Flooding occasionally added sediment to the pool, but it was always possible to dig enough to fit the 19-L bucket.
11/16/2005	Moved appx. 5 m downstream, to just above the small pool that is adjacent to a large boulder.	Slow sedimentation and gradual disappearance of the measurement pool, culminating in a flood event eliminating the former measurement pool completely.
2/24/2010	Moved weir plate "a few feet" (appx. 1 m) upstream.	Channel headward eroded from small pool.
9/2/2010	Tried temporary weir plate move but sediment too unstable so data discarded.	Flooding previous month.
10/24/2012	Moved weir plate appx. 1 m upstream in channel	Channel headward erosion and downcutting, and higher water surface in pool below weir.
9/27/2013	Sediment too unstable to measure flow this month.	Major flood events in Aug–Sept.
10/23/2013	Channel has widened, weir plate in about the same place.	Fall flooding widened channel, and it dammed the channel far downstream. We breached dam.
11/18/2013	Started using 12-L capture bucket instead of 19-L.	Fall flooding filled pool below weir with sediment; much digging required to fit 12-L bucket.
1/16/2014	Weir moved appx. 1 m downstream in channel.	Sediment deposition has extended appx. 3 m downstream since last visit.
3/25/2014	Managed to use 19-L bucket.	This took significant digging.
4/21/2014	Back to 12-L bucket.	This month much digging was required just to use the 12-L bucket.
5/28/2014	Weir plate moved additional 1 foot (0.5 m) downstream (now appx. 1.5 m downstream of Oct 2013 photo location, 0.5 m upstream of 11/2005–1/2010 location).	More sediment deposition downstream.
9/25/2014	Significant re-placement of weir plate upstream, to appx. 5 feet (1.5 m) downstream of cottonwood trunk near big pool outlet.	More drop in outlet channel than we have seen in recent years allows move; former site becoming too mobile and problematic.

Figure 2-4. Flow measurement location and method at Sleepy Hollow Spring from November 2005 to early 2014, approximately 5 m downstream from original location.

measurement pool, but once this had settled it was possible to dig out enough sediment to allow continued measurements at the same location, missing only one month's flow measurement. The weir was moved upstream approximately one meter in October 2012, due to additional channel downcutting. The weir was moved several times after flood events in 2014, with the final location being within 0.5 meters of the original 2005 location. In November 2013, the capture bucket was changed to a 12-liter bucket.

2.1.2 Sevenmile Boundary Spring

A steel weir plate, as described previously, was placed at Sevenmile Boundary Spring each month at a set location in a small channel approximately 15 meters downstream of the large hanging-garden backwall (Figure 2-5). Water was captured in a four-liter bucket. In October 2009, the flow measurement site was moved less than two meters upstream from the original weir plate placement site, due to cumulative changes in the channel morphology through time and eventual loss of any gradient at the original measurement site. The location was moved upstream approximately two meters in July 2011 and downstream 1.5 meters in October 2012. The monitoring location was moved several times from 2013 to 2014, although the most consistent location was approximately 0.5 meters downstream of the original weir location (Table 2-2).

2.1.3 Poison Ivy Spring

At the Poison Ivy Spring measurement site, flow was measured about 30 m downslope of the colluvial slope where the water coalesces into a flowing channel (Figure 2-6). Initially, the weir plate was left in place for several years, rather than being installed and then removed for each monthly measurement, because of the amount of poison ivy at the site. Leaving the weir in place caused a mossy, spongy channel bottom substrate to form behind the weir, and in August 2006, some water was flowing through this substrate under the weir. We moved the weir upstream 0.7 meters in September 2006, and continued capturing water in a four-liter bucket, while continually monitoring the situation.

Figure 2-5. Flow measurement location and weir placement at Sevenmile Boundary Spring, October 2012.

Table 2-2. Weir placement and stability notes at Sevenmile Boundary Spring, 2001–2014.

Date	Description	Reason/Notes
12/9/2000	Placement of weir plate adjacent to red-osier dogwood or slightly upstream of it. Weir plate removed and stashed each month between visits.	Rebar placed at ends of weir plate on bank within a couple months after this date.
10/30/2009	Moved weir plate appx. 1.5 m upstream; first move since Dec 2000 installation.	Flooding approximately 10/20/2009 flattened former measurement area so there is no longer any drop in the channel there.
7/25/2011	Moved weir plate upstream 2 m.	Recent flooding widened channel at former location.
10/24/2012	Moved weir plate downstream 1.5 m.	Changes in relative drop along stream; needed to move to area with sufficient drop.
8/20/2013	Moved weir plate appx. 2.5 m downstream, appx. 0.5 m downstream of original Dec 2000–Sept 2009 location.	Flood changes made upstream area wider with very little drop.
3/25/2014	This month only: moved weir plate 0.5 m upstream.	
4/21/2014	Moved back to location of 8/2013–2/2014 (and 0.5 m downstream of 12/2000– 9/2009 location).	
7/14/2014	This month only: moved weir plate appx. 0.3 m upstream.	
8/25/2014	Moved weir plate back to 8/2013– 6/2014 (except 3/2014) location.	Attempt to use natural channel constriction.

Figure 2-6. Flow measurement location and weir placement at Poison Ivy Spring, December 2002.

The same problem developed in June 2009. The weir plate was moved another 0.5 meters upstream in November 2009 and another one meter upstream in February 2012. In August 2013, the weir location was moved downstream approximately three meters, and observers began removing the weir each month, as at the other monitoring locations (Table 2-3).

2.1.3 Courthouse Boundary Spring

Courthouse Boundary Spring is a wash-bottom spring in a very dynamic location with frequent geomorphic changes. In October 2005, an alluvial deposit buried a 30-cm rock ledge that had provided a convenient measurement site since 2001. When this first happened, we changed methods from using a device that captured and projected the flow out over the waterfall lip for a timed capture in a bucket, to using a Parshall flume (Rantz et al. 1982). The exact placement site for the Parshall flume had to be adjusted frequently due to multiple collapses of high vertical sediment banks adjacent to the site, as well as flood flows that resulted in sediment reconfiguration. All of the placement sites were downstream of the wash-bottom spring emergence, in a reach roughly 30 meters long. Sometime between November 2009 and March 2010 (a frigid and inaccessible winter), sediment aggradation in this reach led to a low-gradient, braided channel, in which there is no longer enough gradient to use a Parshall flume. Beginning in December 2010, flow was captured in a plastic bag and then poured into a container marked with volumetric increments. Flow sampling was suspended in September 2011, due to continued geomorphic change in the channel and its potential effects on subsurface and surface flow. In all methods used at this site, any percentage of the surface flow that could not be captured was estimated, and calculated flows were adjusted for flow not captured. The amount of flow not captured was always estimated to be small, usually from 0 to 2 percent.

2.2 Data gaps

Overall, this dataset is notable for its length and continuity, but occasional gaps occur (Appendix B). Courthouse Boundary Spring, located near a dirt four-wheel-drive road, was occasionally inaccessible during winter months as the road was impassable. The winter of 2009–2010 was extreme enough that Sleepy Hollow Spring, near the Courthouse–Sevenmile confluence, was also inaccessible for one month. Winter conditions at Sleepy Hollow in December 2005 resulted in such a slow set-up and stabilization time that it left no time for visits to Sevenmile Boundary and Poison Ivy springs that day. During a couple of winter monitoring runs, ice prohibited safe travel on Sevenmile Boundary Spring's steep access trail, and once, a giant ice block sat precisely where the weir was usually placed at Sleepy Hollow.

Occasionally, a few months of measurements were missed at one spring because of a change in geomorphology at the site and reconfiguration of the details or setup of the methods for the site, as noted above. This happened most frequently at Poison Ivy Spring and Courthouse Boundary Spring.

Table 2-3. Weir placement and stability notes at Poison Ivy Spring, 2001–2014.

Date	Description	Reason
3/1/2001	First measurement; weir plate installed and left in place.	
4/17/2006	First evidence of water leaking through porous sediment under weir. Began compressing sediment behind weir and waiting for stabilization before each month's measurement.	
9/20/2006	Removed weir plate for first time since 3/2001, and re-placed it 2 feet (0.6 m) upstream. Compressed spongy soil substrate as much as possible. Did not take measurement this month in order to allow system to settle.	Leakage around weir plate did not allow reliable data collection previous month.
3/15/2007	Water flowing under weir upon arrival; sealed with sand and compression. Soil compressed behind weir in order to seal in future months.	
7/22/2009	Moved weir 0.5 m upstream; did not take measurement this month or next few in order to allow system to settle and assess situation.	
11/19/2009	Weir plate finally stabilized and measurements resumed.	
6/23/2011	Recorded 2% loss under weir plate and drip under pipe.	
2/23/2012	Moved weir plate 1 m upstream in channel. Used extension pipes to drain area below plate and check for leaks; no leaks seen after this move. Continued in future months to compress substrate behind weir plate and wait for stabilization.	Two holes developed since last month behind weir plate.
5/16/2013	Suspected leakage around weir plate as observed on 8/20/13; rejected data.	
6/11/2013	Suspected leakage around weir plate as observed on 8/20/13; rejected data.	
7/23/2013	Suspected leakage around weir plate as observed on 8/20/13; rejected data.	
8/20/2013	Moved weir plate appx. 3 m downstream adjacent to the closer of 2 box elder trees; started practice of removing it each month between visits, as at other sites.	Placed extension pipe on weir and found leakage around weir plate, as suspected the last 3 months.
5/28/2014	Cut a root exposed in substrate under weir since last month, so that weir could have contact with soil.	
7/14/2014	Drained area to check for leaks under weir plate but found none after compressing substrate behind plate.	Just a periodic check since the pool on downstream edge of the weir plate makes it difficult to detect leaks without draining the area.

Sometimes flood events had liquefied sediments at a site enough that the measurement setup would not stabilize within the time of the site visit. Once or twice, other work constraints caused an entire month's run to be missed.

2.3 Statistical methods

Prior to analysis, datapoints that were flagged as unrepresentative of springflow due to runoff events, icy conditions, or leaking weirs were removed from the dataset. Data were evaluated for unidirectional trends using a seasonal Mann-Kendall test. The seasonal Mann-Kendall test adjusts for expected seasonal variation in flow by comparing data within user-defined seasons and then aggregating the results for each season into an overall test for trend at a site (Hirsch and Helsel 2002). For example, samples collected during May are always compared to other samples from May, while August lowflow samples are always compared to August samples. The data trend for May is then combined with the data trend for August (and any other seasons used) to determine whether there is an overall trend for the site. Months with conflicting upward and downward trends are cancelled out in this analysis and would result in an overall evaluation of no trend. A consistent trend across seasons would result in an overall upward or downward trend for the site.

Trend analyses were evaluated at $\alpha=0.05$ for statistical significance. This indicates that there is a less than 5% chance that a random sample from a spring with no trend in flow would produce a similar result. A non-parametric slope of the magnitude of the trend, called a Sen slope, was calculated and represents the median annual change in flow. We calculated a median rate of change as (Sen slope/median value) * 100. The total magnitude of change was calculated as (Sen intercept – median value) * 2, and the total percent change was calculated as (Total change/Sen intercept) * 100. Data summary and analysis was completed using the freeware R v.3.1.2 (R Core Team 2013). Seasonal Mann-Kendall tests and Sen slopes were calculated using the EnvStats package v.1.0.3 for R (Millard 2013).

3 Results and Discussion

Results are presented here in the form of a graph displaying all of the flow data for the four spring sites from December 2000 to December 2014 (Figure 3-1; figures begin on page 19). Supporting data are presented in tabular form in Appendix B.

3.1 Seasonal patterns

All four sites showed a clear seasonal pattern of higher flows in the winter to early spring, and lower flows during the growing season of May–October (Figures 3-2 to 3-5).

In those figures, the boxes represent the median value using a bolded black line and the interquartile range (IQR; the middle 50% of the data, or the 25–75th percentile of measurements) for each month. The whiskers represent the variability around the median that includes most of the measurements (1.5 * IQR). Unusual values that are more than 1.5 * IQR are represented by circles.

3.2 Trends over time

3.2.1 Hanging gardens

Flow has remained stable over the period of record at Sleepy Hollow Spring (Figure 3-6, $p = 0.71$), with a median flow of 7.92 gallons per minute. This site is considered the control site because the eastern aquifer, which feeds it, is entirely protected within the boundaries of Arches NP. It is likely to reflect weather patterns and climate change, but not likely to see impacts of groundwater development or pumping.

The two springs in the southwestern portion of the aquifer, which is not protected within the park, both showed declines in springflow. Sevenmile Boundary Spring has declined significantly over the period of record (Figure 3-7, $p<0.001$) at a median annual rate of -5.9%. This corresponds to a median total decline of approximately 3.8 gallons per minute, or a 52% decline from the median flow measured in 2001. Poison Ivy Spring has also declined significantly over the period of record (Figure 3-8, $p<0.001$), although the decline was most noticeable from 2001 to 2006. The decline at Poison Ivy Spring is estimated at a median annual rate of -2.9%, for a median total decline of 2.0 gallons per minute (24.7%). Both springs show a possible abrupt change in flow that needs to be further investigated.

Groundwater wells located south of Sevenmile Canyon and east of the Moab Fault (generally in Sections 1 and 2, T25S, R20E, and Section 31, T24S, R21E, SLBM) that produce water from the Moab Member of the Curtis Formation could have the potential to divert water from the source aquifer for Sevenmile Boundary Spring and Poison Ivy Spring. The Utah Division of Water Rights online database (http://www.waterrights.utah.gov/wrinfo/default.asp) includes information for three water rights located in Section 2, T25S, R20E, SLBM that have the greatest probability of affecting springflows at Sevenmile Boundary and Poison Ivy springs (Figure 3-9).

Water Right Number 01-1194 is for a water well located east of the Moab Fault, west of State Highway 191, and approximately 700 feet north of the Sevenmile Canyon stream channel. As required by the conditions of approval for this water right, the well is completed in and draws its water from the Navajo Sandstone aquifer. The Moab Member of the Curtis Formation is sealed off from other rock units during the drilling process. As the Navajo Sandstone is separated from the Moab Member of the Curtis Formation by the Dewey Bridge Member of the Carmel Formation (Figure 3-10), a confining rock unit, this well should not affect the springflow of Sevenmile Boundary Spring and Poison Ivy Spring.

Water Right Number 01-1127 is for a water well located west of the Moab Fault, east of State Highway 191, and south of Sevenmile Canyon. The Driller's Report Well Log lists the well depth at approximately 260 feet (Utah Division of Water Rights online database, 2015) and geologic maps suggest the well is completed in the Permian Cutler Formation (Doelling 1985; Doelling and Morgan 2000). The Cutler Formation is separated from the Moab Member of the Curtis Formation to the east by the Moab Fault. Differences in water-level elevations in wells located on the east and west sides of the Moab Fault suggest the Moab Fault is a barrier to groundwater flow across the fault; therefore, this well should not affect the springflow of Sevenmile Boundary Spring and Poison Ivy Spring.

Water Right Number 01-1166, Change Application a37094, is for a water well located east of the Moab Fault, east of State Highway 191, and south of Sevenmile Canyon. There is no documentation in the Utah Division of Water Rights online database that a well has been drilled at this location to date. As required by the conditions of approval for this water right, any well would be completed in and draw its water from the Navajo Sandstone aquifer. The Moab Member of the Curtis Formation would be sealed off from other rock units during the drilling process. As the Navajo Sandstone is separated from the Moab Member of the Curtis Formation by the Dewey Bridge Member of the Carmel Formation, a confining rock unit, this well should not affect the springflow of Sevenmile Boundary Spring and Poison Ivy Spring.

As all three water rights are apparently isolated from the aquifer that is the source of water for Sevenmile Boundary Spring and Poison Ivy Spring, additional examination of weather and climate factors is needed to interpret decreased springflow at these sites.

3.2.2 Wash-bottom spring

Flow monitoring at Courthouse Boundary Spring showed a statistical decline from 2001 to 2011, when monitoring was suspended (Figure 3-11; $p<0.001$). Shifts in methods or exact measurement sites were obvious at the Courthouse Boundary Spring site on more than one occasion when the sample site was buried with sediment, especially in the year or two following the first complete burial of the site area with sediment in October 2005.

Flow at Courthouse Boundary Spring appears to have at least two sources: groundwater originating from the upper Moab Member of the Curtis Formation and release of stored surface water from the 10-m thick sediments in contact with the upper Moab Member at the spring source. Groundwater originating from the spring occurs in Courthouse Wash as both surface flow and subsurface flow.

From 2001 until October 2005, a rock shelf exposed in the channel 25 meters downstream from the source area concentrated surface flow and allowed the flow to be easily measured using a pipe, bucket, and stopwatch. Flood events after October 2005 have deposited enough sediment in the channel (and continue to rework existing sediments) to completely bury the rock shelf, eliminating the measurement site used from 2001 to 2005. Since October 2005, additional sediment deposition in the Courthouse Wash stream channel has led to a braided channel where much of the flow consists of subsurface flow (flowing through the deposited sediments), and it has become impractical to attempt to concentrate and measure surface flow. Because of these issues, monitoring at this site was suspended in 2011. There are no plans to resume monitoring here unless a stable flow monitoring location becomes available.

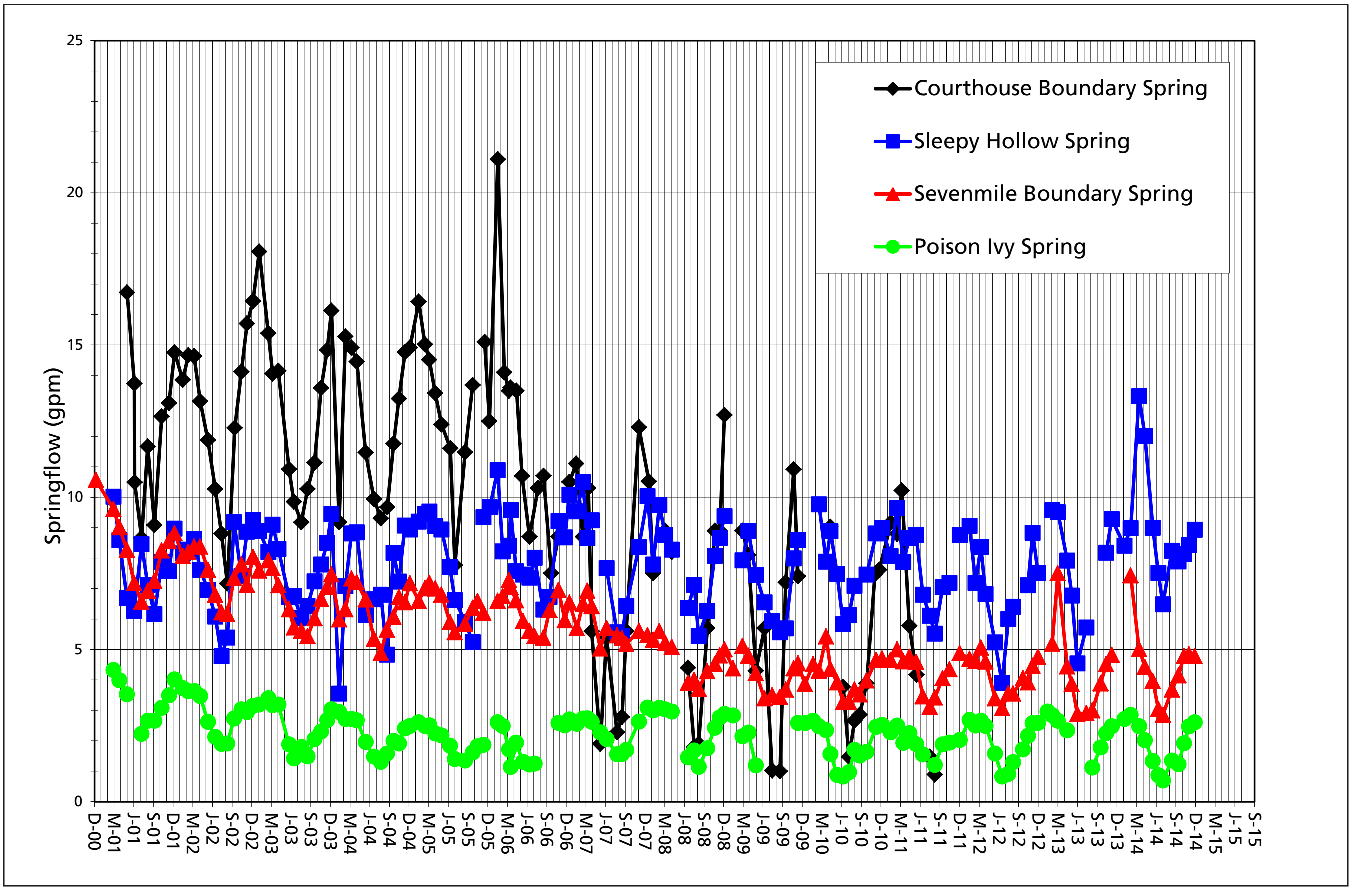


Figure 3-1. Springflow data for four springs included in the Courthouse Wash–Sevenmile Canyon springflow monitoring project, in and adjacent to Arches National Park, December 2000–December 2014. Month and year are indicated on x-axis; flow in gallons per minute (gpm) is indicated on y-axis.

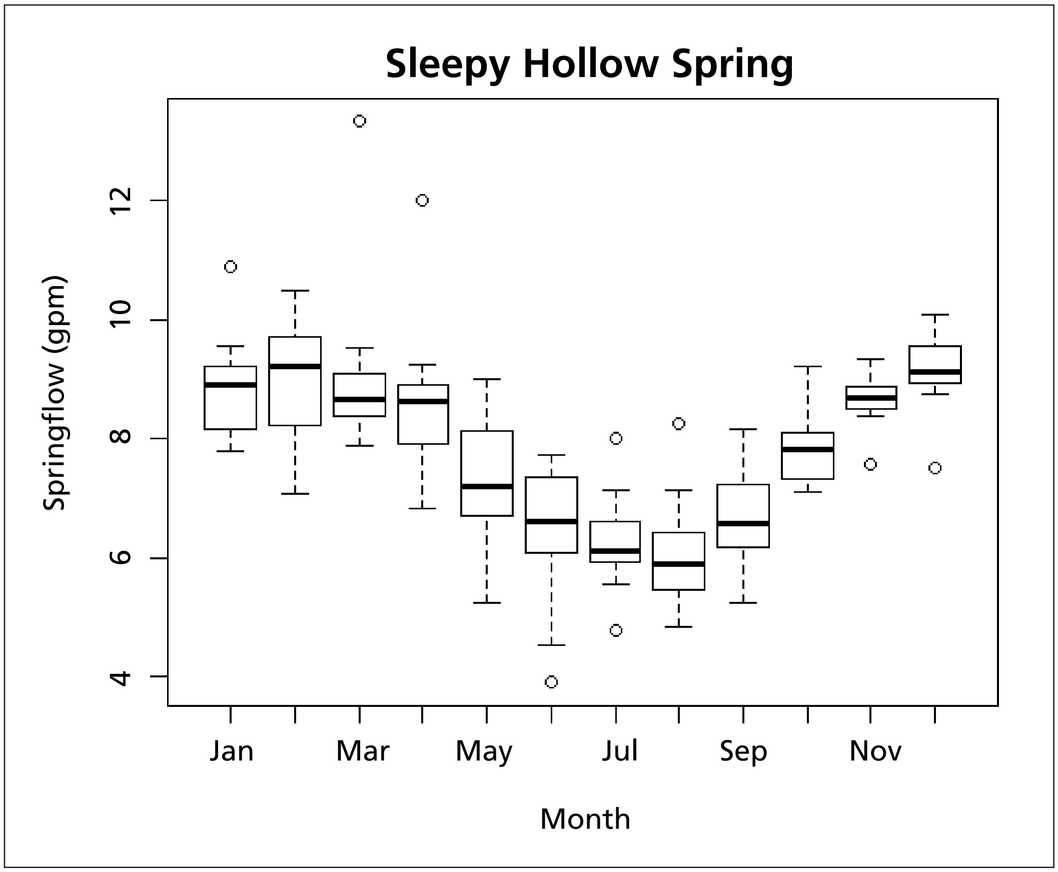


Figure 3-2. Seasonal variation in flow at Sleepy Hollow Spring, 2001–2014.

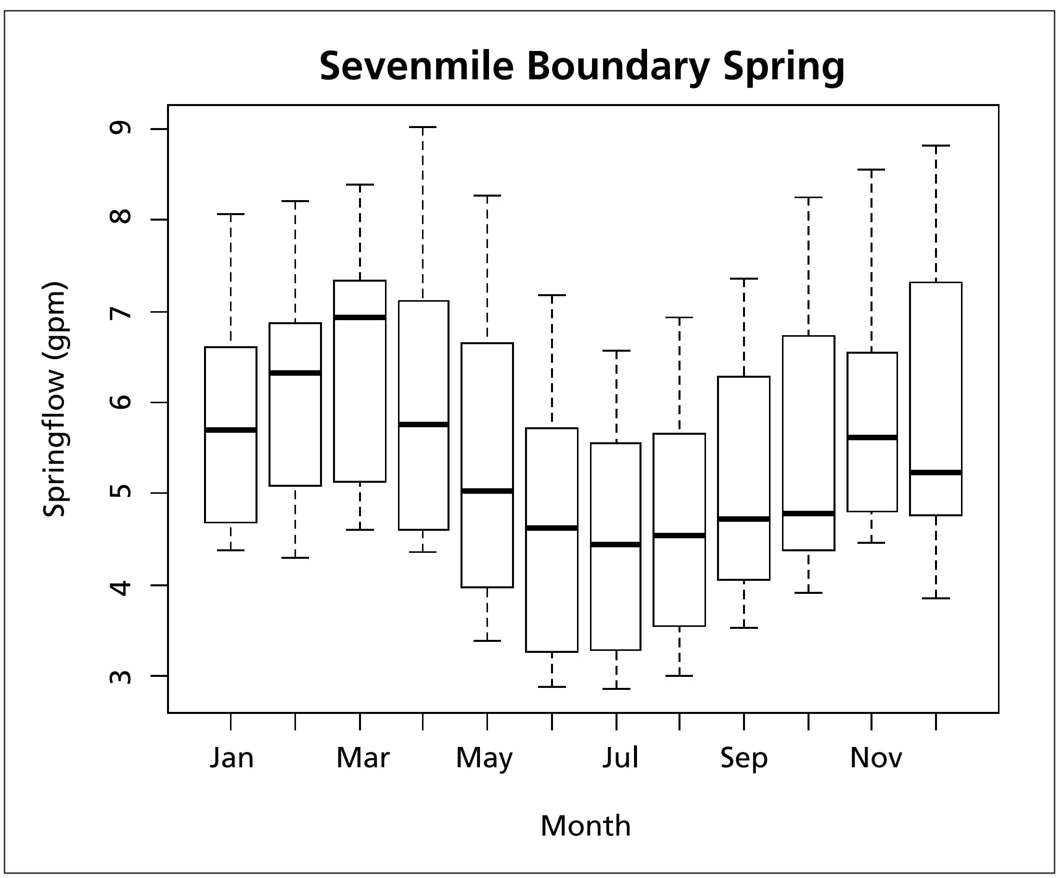


Figure 3-3. Seasonal variation in flow at Sevenmile Boundary Spring, 2001–2014.

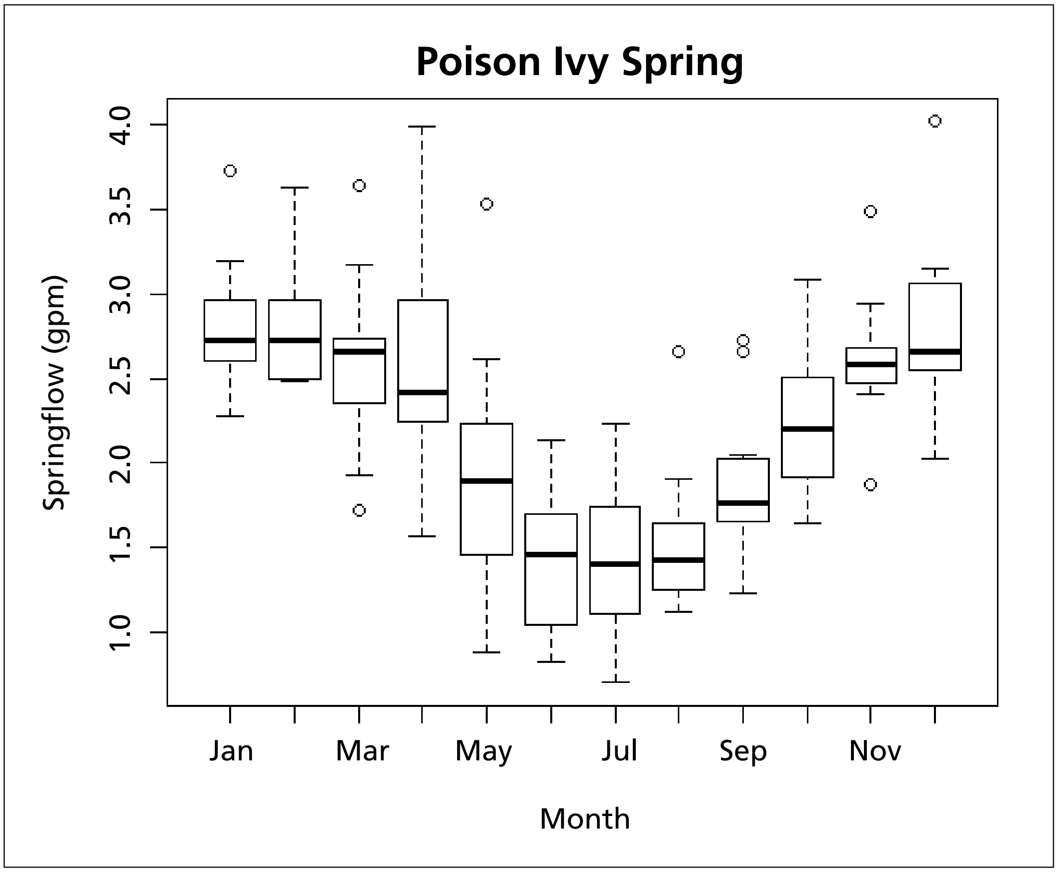


Figure 3-4. Seasonal variation in flow at Poison Ivy Spring, 2001–2014.

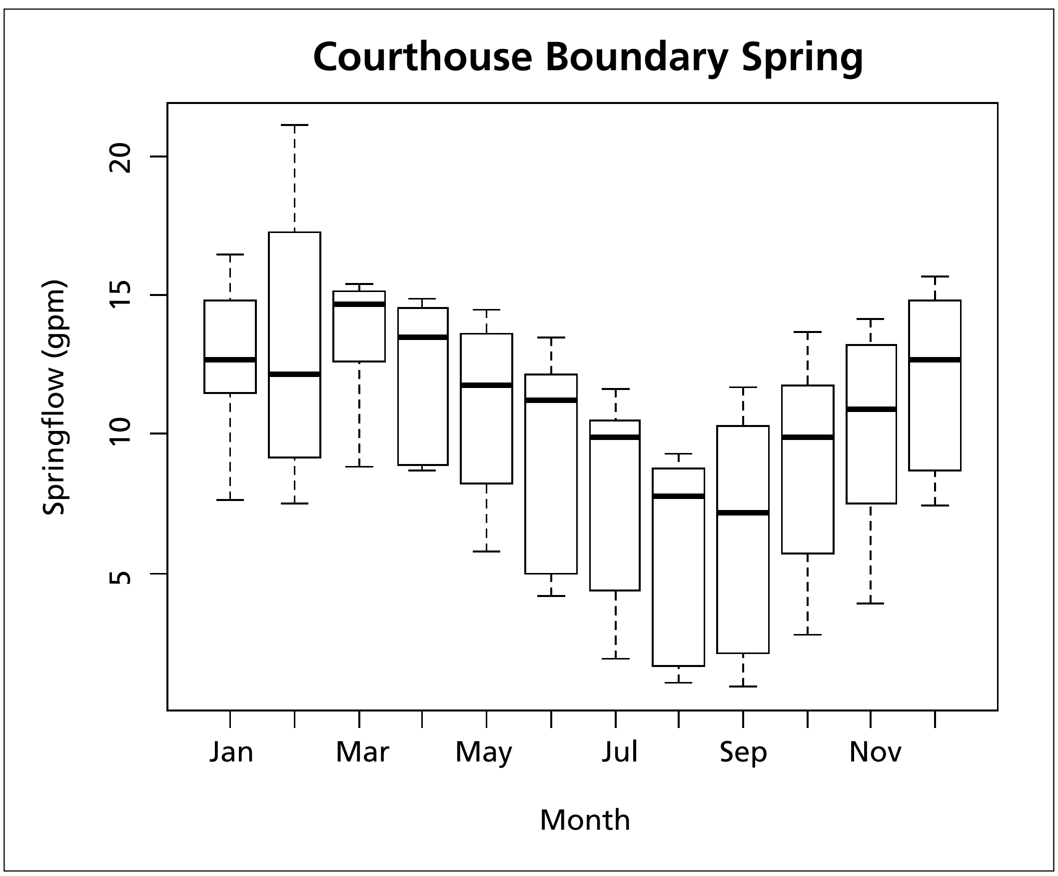


Figure 3-5. Seasonal variation in flow at Courthouse Boundary Spring, 2001–2011.

Figure 3-6. Sen slope with 95% confidence intervals shows no significant trend over time at Sleepy Hollow Spring.

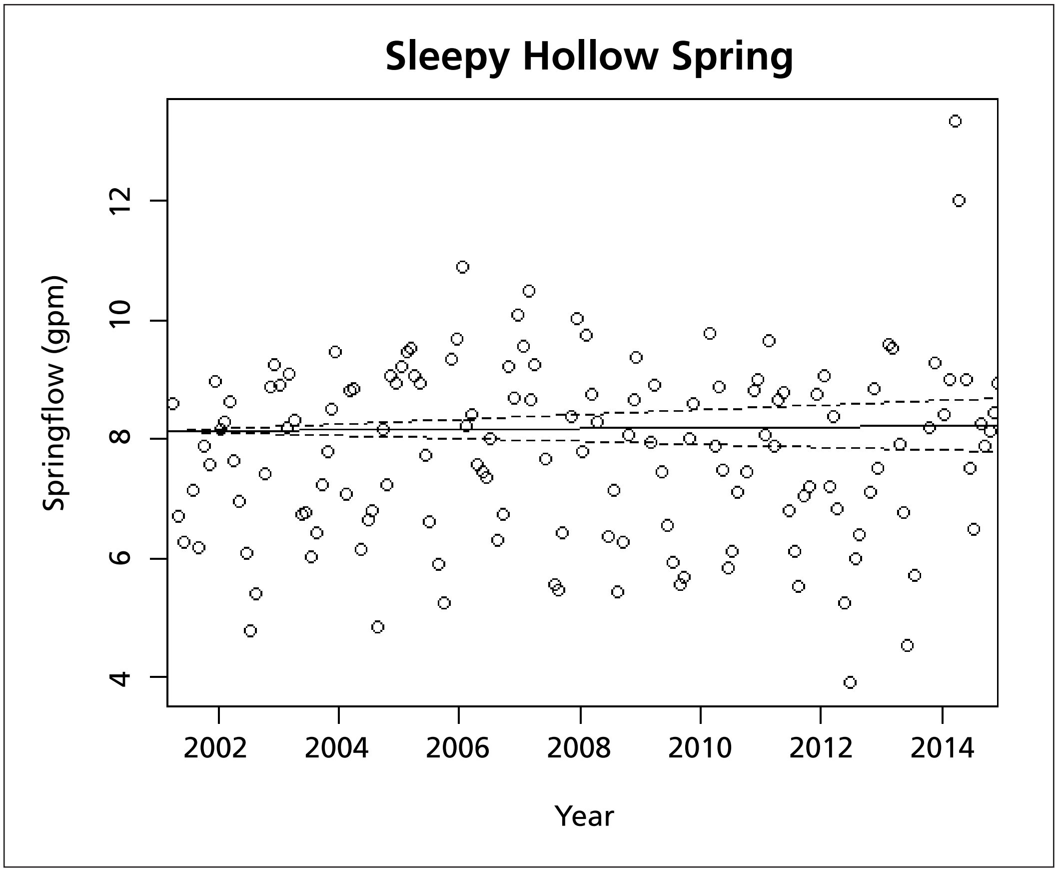
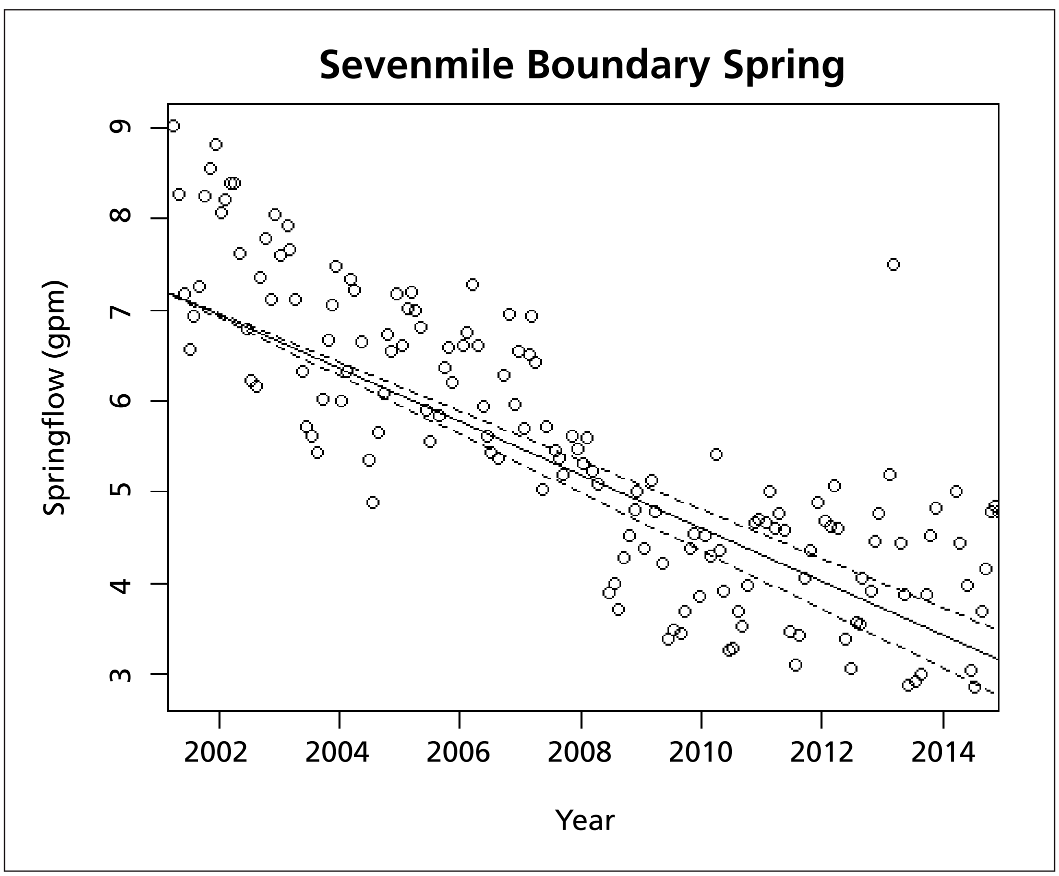


Figure 3-7. Sen slope with 95% confidence intervals shows a significant downward trend over time at Sevenmile Boundary Spring.



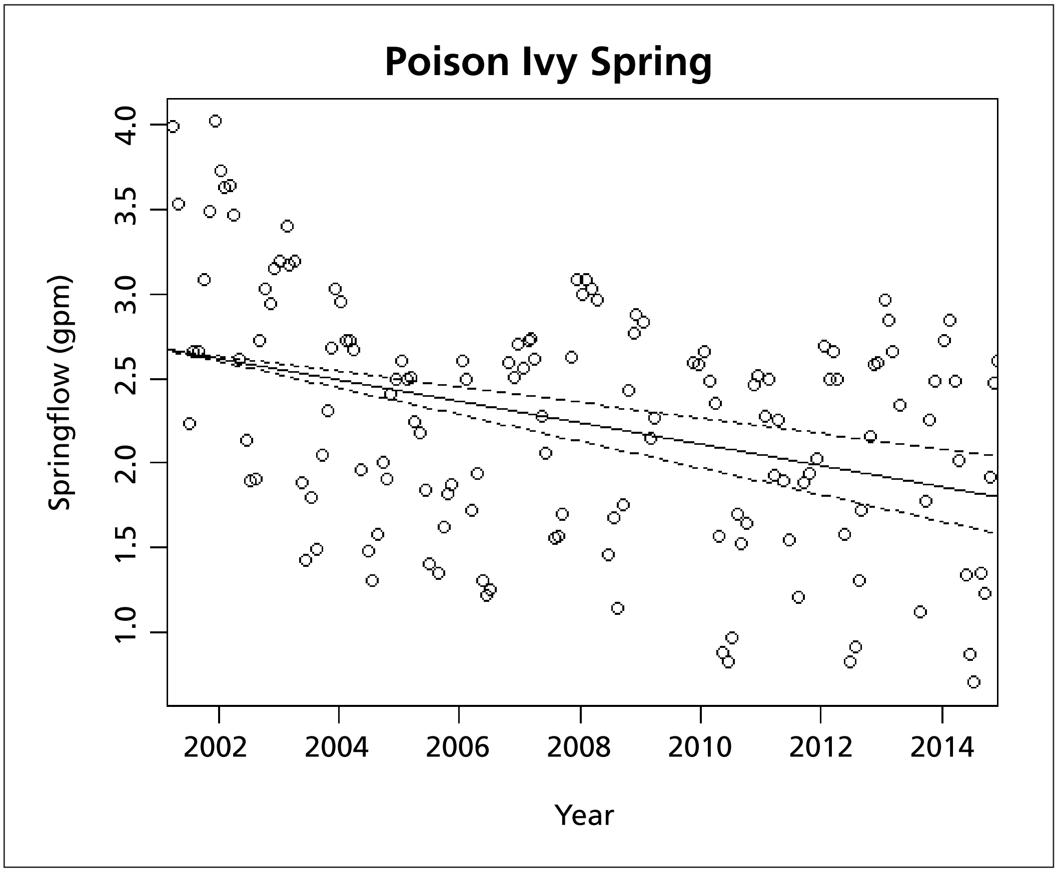


Figure 3-8. Sen slope with 95% confidence intervals shows a significant downward trend over time at Poison Ivy Spring.

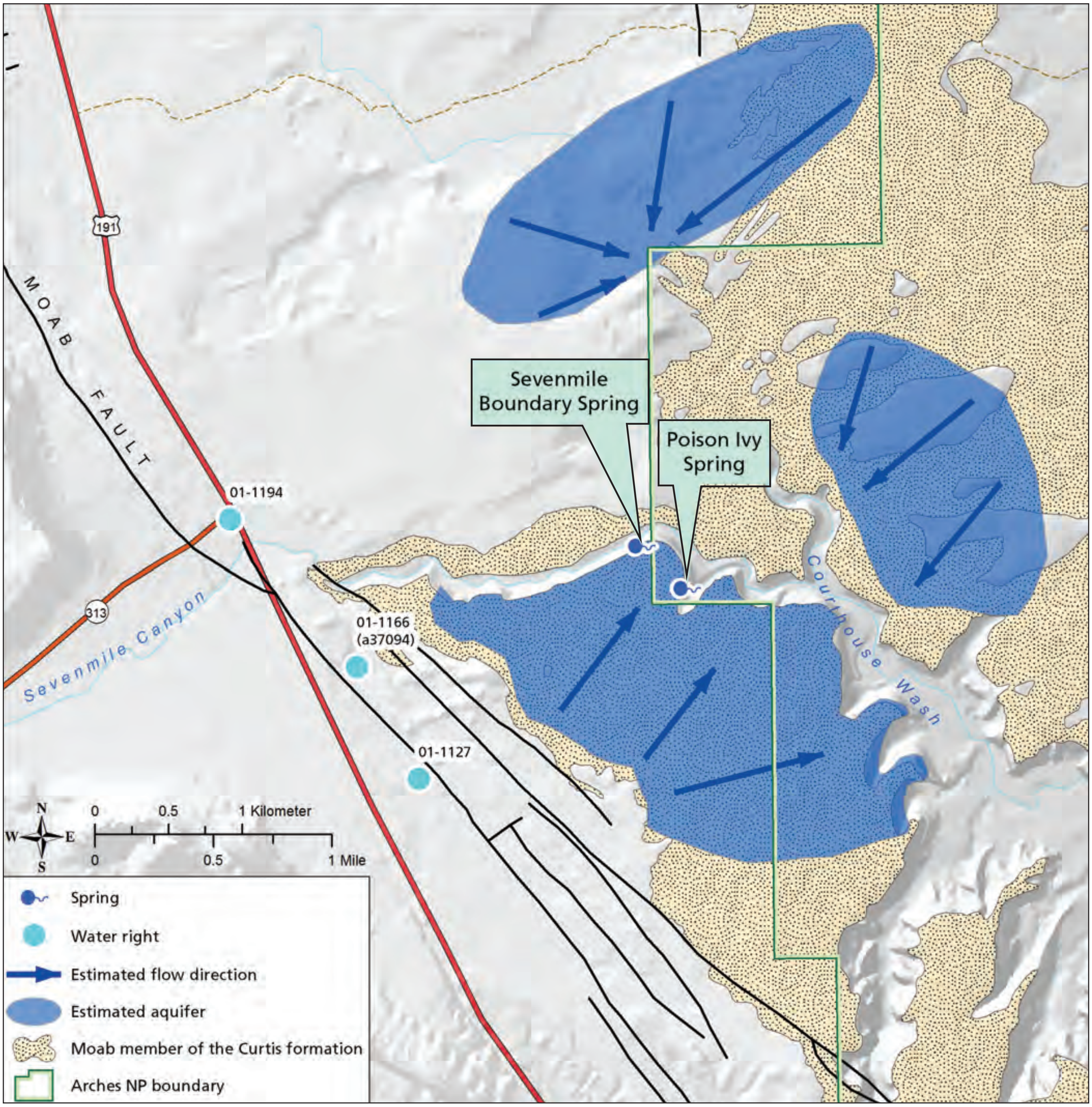


Figure 3-9. Existing water rights near Sevenmile Boundary Spring and Poison Ivy Spring relative to the Moab Member of the Curtis Formation and mapped faults. Estimated aquifers and flow directions taken from Hurlow and Bishop (2003).

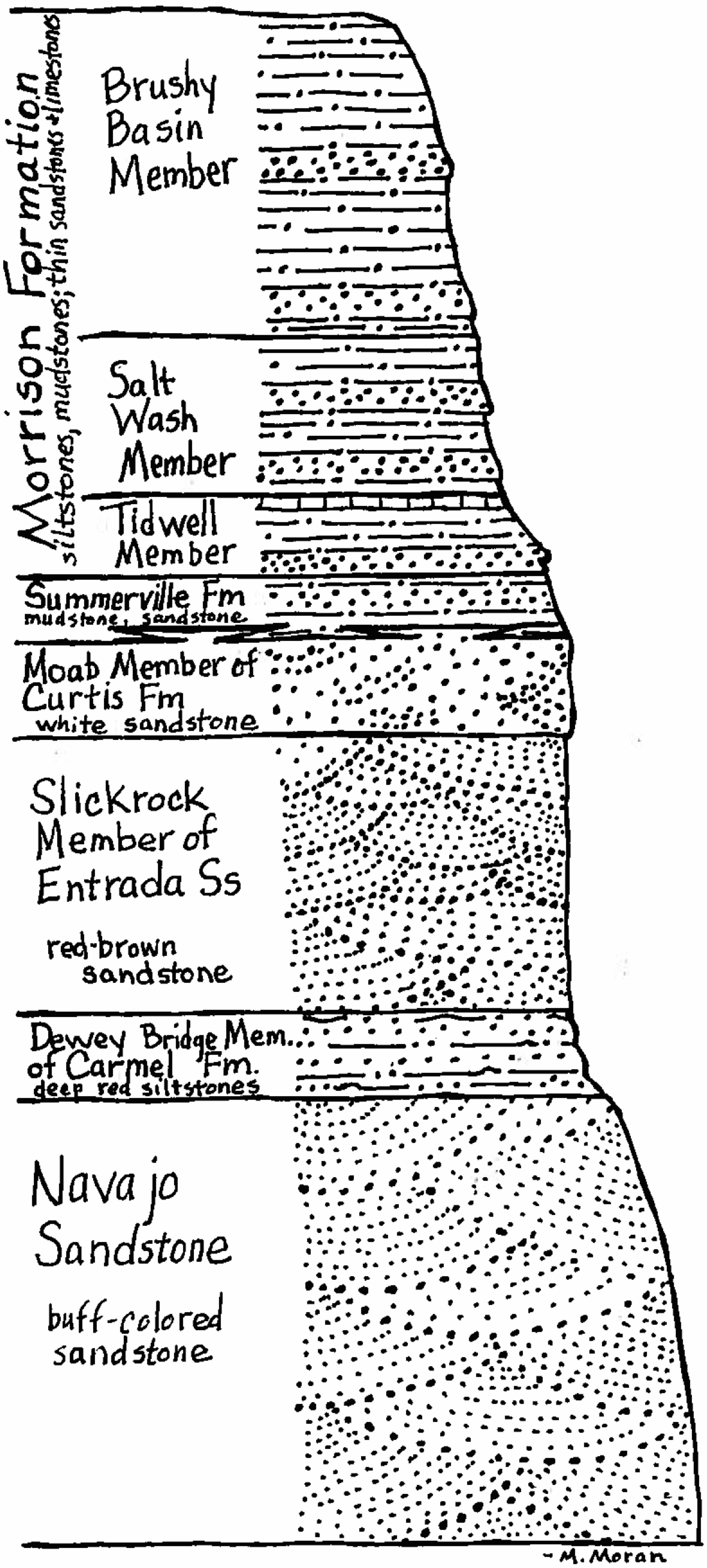


Figure 3-10. Stratigraphic section of the dominant rocks of Arches National Park. These rocks were deposited in the middle to upper Jurassic Period. The springs of Arches National Park are fed from an aquifer in the Moab Member of the Curtis Formation, and emerge from the lower part of this unit. The Navajo Sandstone holds a deeper, regional aquifer.

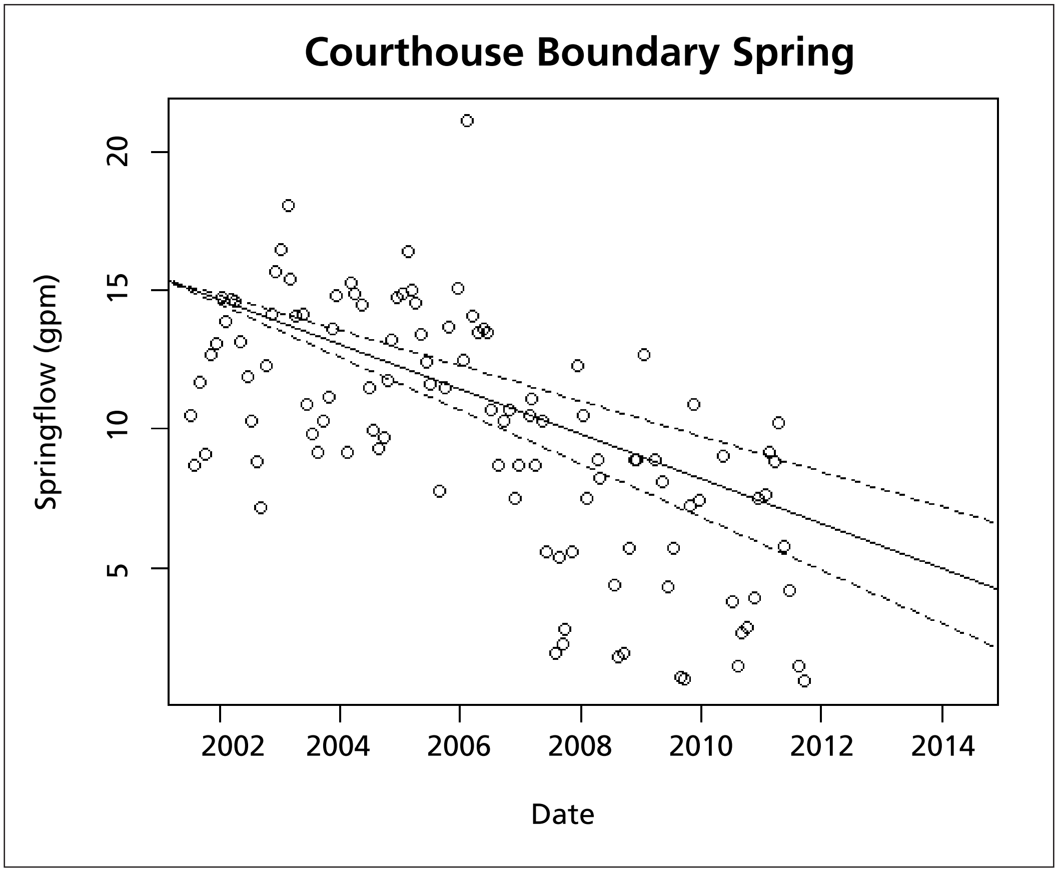


Figure 3-11. Sen slope with 95% confidence intervals shows a significant downward trend over time at Courthouse Boundary Spring.

4 Conclusions

An examination of monitoring data collected from December 2000 through December 2014 indicates that springflows have decreased at two sites in Sevenmile Canyon (Sevemile and Poison Ivy springs) while remaining stable at a site in Courthouse Wash Canyon (Sleepy Hollow Spring). The trends appear to include abrupt changes in flow, indicating a need for a more thorough examination of the data to evaluate potential relationships with precipitation and other climate variables during the monitoring period. The springs and estimated recharge areas are protected under a water-rights agreement with the State of Utah. Southeast Utah Group staff will continue to collect monitoring data on a monthly basis at the two Sevenmile Canyon sites and at Sleepy Hollow Spring. Monitoring has been suspended at Courthouse Boundary Spring until a stable flow-monitoring location emerges.

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Appendix A. Discharge Measurement Procedures and Datasheets

01. Spring ID Number/Name: SM200101/**Sevenmile Boundary Spring**
02. Spring Location: NENENE Section 1, T. 25 S., R. 20 E., SLBM
03. Date (mm/dd/yy): ___________ 04. Time (24 hr): __________
05. Weather: ___________________ 06. Air Temperature (°C): ________
07. Short description of the previous week's weather (if rain/snow, estimate quantity):

____

08. **Discharge Measurement Procedure:**

□Equipment: Weir plate, data sheet, pen, site photos, charged camera, stopwatch, thermometer, shovel, hammer, folding ruler, 4-liter bucket, poison ivy clothing/clippers, rubber gloves.

□ Install weir plate in steam channel at same location as used in previous months (aligned 90° to flow) with pipe on downstream side of plate. Seat plate firmly in stream bottom and seal any leaks around weir plate using available soil.

□ Clear weir plate and pipe of all debris and sediment as water behind the plate rises.

□ Install folding tape in stream channel approximately 1 foot upstream of weir plate. Folding ruler must be plumb. Record measurement on tape once it seems stable.

□ Verify there is sufficient space between the bottom of the pipe and the bottom of the stream channel to move the measuring bucket in and out easily. Clear space if necessary, stockpiling streambank and channel bottom material for later replacement. Bucket must be level.

□ Wait until the water depth on the ruler is stable for a minimum of 10 minutes. Record the time and depth of water on the ruler before measurements are taken.

□ Take 6 flow measurements, recording the time (to 100th's of seconds) it takes to fill the bucket to the 4 liter line. Record data.

□ Record the time and depth of water on the ruler after measurements are taken.

□ Every few months, or whenever there has been significant change since the previous month, take photographs of the weir plate setup.

□ Remove the weir plate and store in a secure location. Replace any soil, rock, or vegetation that was disturbed.

09. **Discharge Measurement:**

Time (24 hr) after tape placement: ________ Reading on ruler (inches): _________
Time (24 hr) before measurement: ________ Reading on ruler (inches): _________
Time (24 hr) after measurement: ________ Reading on ruler (inches): _________

Number	Liters	Seconds	L/S	GPM = (L/S * 15.85)
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
6	________	________	________	________

Average GPM ________
Average CFS = (Average GPM * .0022) ________

10. Photos taken? ___________
11. Name (and title) of persons making measurement: ____________________________________

01. Spring ID Number/Name: SM200102/**Poison Ivy Spring**

02. Spring Location: SESWSW Section 31, T. 24 S., R. 21 E., SLBM

03. Date (mm/dd/yy): ___________ 04. Time (24 hr): __________

05. Weather: _________________________________ 06. Air Temperature (°C): ________

07. Short description of the previous week's weather (if rain/snow, estimate quantity):

____

08. **Discharge Measurement Procedure:**

□Equipment: Weir plate, data sheet, pen, site photos, charged camera, stopwatch, thermometer, shovel, hammer, folding ruler, 4-liter bucket, poison ivy clothing/clippers, weir extension, duct tape, rubber gloves (winter).

□ Check weir plate (in place) for leaks or clogging, and adjust as needed, using or removing sediment or debris. Tamp down spongy soil substrate behind weir to limit leaking of water through substrate and under weir.

□ Add extension to weir outlet pipe. Check for leaking on underside of the pipe-extension junction. It may be necessary to remove the extension and re-wrap it with duct tape to stop leaking.

□ Install folding ruler in stream channel approximately 1 foot upstream of weir plate. Ruler must be plumb. Record measurement on ruler once it seems stable.

□ Verify that there is sufficient space between the end of the extension and the bottom of the stream channel to move the measuring bucket in and out easily. Clear space if necessary, stockpiling streambank and channel bottom material for later replacement. Bucket must be level.

□ Wait until the water depth on the ruler is stable for a minimum of 10 minutes. Record the time and depth of water on the ruler before measurements are taken.

□ Take 6 flow measurements, recording the time (to 100th's of seconds) it takes to fill the bucket to the 4 liter line. Record data.

□ Record the time and depth of water on the ruler after measurements are taken.

□ Every few months, or whenever there has been significant change since the previous month, take photographs of the weir plate setup.

09. Discharge Measurement:

Time (24 hr) after tape placement: ________ Reading on ruler (inches): _________

Time (24 hr) before measurement: ________ Reading on ruler (inches): __________

Time (24 hr) after measurement: ________ Reading on ruler (inches): __________

Number	Liters	Seconds	L/S	GPM = (L/S * 15.85)
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
6	________	________	________	________

Average GPM ________

Average CFS = (Average GPM * .0022) ________

10. Photos taken? _____________

11. Name (and title) of persons making measurement: ______________________________________

01. Spring ID Number/Name: CH200102/**Sleepy Hollow Spring**

02. Spring Location: NWNESE Section 31, T. 24 S., R. 21 E., SLBM

03. Date (mm/dd/yy): ___________ 04. Time (24 hr): __________
05. Weather: ___________________ 06. Air Temperature (°C): ________
07. Short description of the previous week's weather (if rain/snow, estimate quantity): ___________
08. **Discharge Measurement Procedure:** ____________________________________

- □ Equipment: Weir plate and extension tube, data sheet, pen, site photos, charged camera, stopwatch, thermometer, shovel, hammer, folding ruler, 19-liter bucket, duct tape, waders or shorts and sandals, rubber gloves (winter).
- □ Duct tape extension to weir plate, approximately perpendicular to plate (a two-person job).
- □ Install weir plate with extension in stream channel (aligned 90° to flow) so that extension extends out over small measurement pool, propping up extension with stick if needed and keeping extension outlet at least 1-2 inches above pool surface. Seat plate firmly in stream bottom and seal any leaks around weir plate using available soil. Install folding ruler in stream channel approximately 1 foot upstream of weir plate. Record measurement on ruler once it seems stable.
- □ Verify there is sufficient space between the bottom of the extension outlet and the bottom of the measurement pool to move the measuring bucket in and out easily. Dig out sediment if necessary, stockpiling streambank and channel bottom material for later replacement. Bucket must be level.
- □ Wait until the water depth on the ruler is stable for a minimum of 10 minutes. Record the time and depth of water on the ruler before measurements are taken. If outlet becomes clogged with debris, clear it and start ten-minute waiting period again.
- □ Take 6 flow measurements, recording the time (to 100th's of seconds) it takes to fill the bucket to the 19-liter line. Record data.
- □ Record the time and depth of water on the tape measure after measurements are taken.
- □ Every few months, or whenever there has been significant change since the previous month, take photographs of the weir plate setup.
- □ Remove the weir plate, remove duct tape and disconnect extension, and store in a secure location. Replace any soil, rock, or vegetation that was disturbed.

09. **Discharge Measurement:**

Time (24 hr) after tape placement: ________ Water Depth (inches): __________
Time (24 hr) before measurement: ________ Water Depth (inches): __________
Time (24 hr) after measurement: ________ Water Depth (inches): __________

Number	Liters	Seconds	L/S	GPM = (L/S * 15.85)
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
6	________	________	________	________

Average GPM ________
Average CFS = (Average GPM * .0022) ________

10. Photos taken? ___________

11. Name (and title) of persons making measurement: ____

01. Spring ID Number/Name: CH200101/**Courthouse Boundary Spring**
02. Spring Location: NWNWSW Section 30, T.24 S., R. 21 E., SLBM
03. Date (mm/dd/yy): ___________ 04. Time (24 hr): __________
05. Weather: ________________________________ 06. Air Temperature (°C): ________
07. Short description of the previous week's weather (if rain/snow, estimate quantity): ______________
____

08. Is the wash flowing above the spring discharge area? ________________

09. Discharge Measurement Procedure:

□Equipment: data sheet, pen, site photos, charged camera, stopwatch, thermometer, shovel, extra large plastic bag (giant ziplocks are best), volumetric containers, rubber gloves (winter).

□ Check previous month's measurement location. If suitable, use same location. If not, find a location with some stream gradient (drop) where stream is within a single channel, if possible. If not, consider a site with two channels and a volumetric split measurement.

□ If necessary, use shovel to move sediment in order to narrow channel so that it can be captured in the plastic bag. With plastic bag, check that there is enough drop to measure successfully.

□ Record time after moving sediment, and wait ten minutes for flow to stabilize in new configuration. (If sediment movement creates a large pool, place folding ruler in pool, and wait ten minutes after the pool depth has stabilized on ruler.)

□ Take timed measurement of flow, capturing all or as much of the flow as possible and maximizing capture time as much as possible. Avoid backflow or damming effect from water in bag. Pour capture into volumetric containers and record volume of capture, time (to hundredths of seconds), and estimated percent loss (uncaptured flow).

□ Repeat until you have 3-5 measurements. Take five measurements if possible, but if the setup erodes or breaks down after three or four, that is sufficient.

□ Every few months, or anytime there has been substantial change since the previous month, take a few photographs of the setup and site location.

□ Replace any soil, rock, or vegetation that was disturbed.

10. Discharge Measurement:

Time (24 hr) after sediment alterations: ________ Reading on ruler: __________
Time (24 hr) before measurement: ____________ Reading on ruler: __________

Number	Liters	Seconds	L/S	GPM = (L/S * 15.85)
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________

Average GPM ________
Average CFS = (Average GPM * .0022) _______

11. Photos taken? ___________
12. Name (and title) of persons making measurement: ____

Appendix B. Spring Discharge Measurements, December 2000–December 2014

Bolded measurements were not used for trend analysis. See footnotes for reason.

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	GPM	Estimated % of flow captured*	Estimated GPM*	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)
12/9/2000	-	-	-	-	-	-	**10.57** [a]	4	-	-
3/1/2001	-	-	-	-	**10.02** [b]	4	**9.61** [b]	4	**4.33** [b]	4
3/28/2001	-	-	-	-	8.59	4	9.01	4	3.99	4
5/2/2001	-	-	-	-	6.69	19	8.27	4	3.53	4
5/3/2001	**15.05** [b]	90%	**16.72** [a]	12	-	-	-	-	-	-
6/5/2001	-	-	-	-	6.26	19	7.18	4	-	-
6/6/2001	**13.60** [a]	99%	**13.74**	4	-	-	-	-	-	-
6/7/2001	10.39	99%	10.49	19	-	-	-	-	-	-
7/9/2001	8.23	95%	8.66	19	**8.46** [b]	19	6.57	4	2.23	4
8/7/2001	10.50	90%	11.67	19	7.12	19	6.93	4	2.66	4
9/7/2001	8.63	95%	9.08	19	6.16	19	7.25	4	2.66	4
10/11/2001	11.39	90%	12.66	19	7.87	19	8.25	4	3.08	4
11/14/2001	11.13	85%	13.09	19	7.58	19	8.55	4	3.49	4
12/10/2001	14.02	95%	14.76	19	8.97	19	8.82	4	4.02	4
1/17/2002	13.44	97%	13.86	19	8.16	19	8.07	4	3.73	4
2/12/2002	13.93	95%	14.66	19	8.28	19	8.20	4	3.63	4
3/11/2002	14.05	96%	14.64	19	8.63	19	8.38	4	3.64	4
4/8/2002	12.76	97%	13.15	19	7.62	19	8.38	4	3.47	4
5/14/2002	11.52	97%	11.88	19	6.95	19	7.62	4	2.62	4
6/17/2002	9.96	97%	10.27	19	6.08	19	6.79	4	2.13	4
7/16/2002	8.54	97%	8.80	19	4.78	19	6.22	4	1.90	4
8/12/2002	6.88	96%	7.17	19	5.39	19	6.16	4	1.91	4
9/13/2002	-	-	-	-	**9.18** [b]	4	7.35	4	2.73	4
9/16/2002	11.91	97%	12.27	4	-	-	-	-	-	-
10/17/2002	13.69	97%	14.12	12	7.41	19	7.79	4	3.03	4
11/12/2002	15.23	97%	15.70	12	8.87	19	7.12	4	2.94	4
12/10/2002	16.11	98%	16.44	12	9.25	19	8.04	4	3.15	4
1/8/2003	17.53	97%	18.07	12	8.89	19	7.59	4	3.19	4

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	GPM	Estimated % of flow captured*	Estimated GPM*	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)
2/19/2003	15.08	98%	15.39	12	8.20	19	7.93	4	3.40	4
3/11/2003	14.06	100%	14.06	12	9.10	19	7.67	4	3.17	4
4/7/2003	13.87	98%	14.15	12	8.30	19	7.11	4	3.19	4
5/27/2003	10.81	99%	10.92	12	6.72	19	6.32	4	1.88	4
6/18/2003	9.75	99%	9.85	12	6.75	19	5.72	4	1.42	4
7/23/2003	9.18	100%	9.18	12	6.03	19	5.61	4	1.80	4
8/21/2003	10.17	99%	10.27	12	6.43	19	5.43	4	1.49	4
9/22/2003	11.02	99%	11.13	12	7.24	19	6.02	4	2.05	4
10/23/2003	13.46	99%	13.59	12	7.79	19	6.66	4	2.31	4
11/20/2003	14.68	99%	14.83	12	8.50	19	7.05	4	2.68	4
12/10/2003	16.13	100%	16.13	12	9.45	19	7.47	4	3.03	4
1/15/2004	8.76	95%	**9.18** [c]	12	**3.55** [c]	19	5.99	4	2.95	4
2/13/2004	15.13	99%	15.28	12	7.08	19	6.32	4	2.72	4
3/12/2004	14.91	100%	14.91	12	8.81	19	7.33	4	2.72	4
4/6/2004	14.45	100%	14.45	12	8.85	19	7.21	4	2.67	4
5/17/2004	11.36	99%	11.47	12	6.13	19	6.64	4	1.96	4
6/25/2004	9.84	99%	9.94	12	6.65	19	5.35	4	1.48	4
7/27/2004	9.22	99%	9.31	12	6.80	19	4.89	4	1.31	4
8/24/2004	-	-	-	-	4.83	19	5.65	4	1.58	4
8/26/2004	9.38	97%	9.67	12	-	-	-	-	-	-
9/24/2004	11.64	99%	11.76	12	8.17	19	6.07	4	2.00	4
10/19/2004	13.17	100%	13.24	12	7.23	19	6.72	4	1.91	4
11/16/2004	14.61	99%	14.76	12	9.07	19	6.55	4	2.41	4
12/9/2004	14.91	100%	14.91	12	8.94	19	7.17	4	2.49	4
1/19/2005	16.10	98%	16.42	12	9.20	12	6.60	4	2.61	4
2/17/2005	14.87	99%	15.02	12	9.46	19	7.01	4	2.49	4
3/9/2005	14.52	100%	14.52	12	-	-	-	-	-	-
3/10/2005	-	-	-	-	9.53	19	7.19	4	2.51	4
4/6/2005	13.42	100%	13.42	12	9.05	19	7.00	4	2.24	4
5/5/2005	12.39	100%	12.39	12	8.94	19	6.80	4	2.18	4

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	GPM	Estimated % of flow captured*	Estimated GPM*	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)
6/13/2005	-	-	-	-	7.71	19	5.90	4	1.84	4
6/15/2005	11.49	99%	11.61	12	-	-	-	-	-	-
7/6/2005	7.77	100%	7.77	12	6.62	19	5.56	4	1.40	4
8/23/2005	11.36	99%	11.48	12	5.91	19	5.84	4	1.35	4
9/27/2005	13.54	99%	13.68	12	5.24	4	6.37	4	1.62	4
10/20/2005	-	-	-	-	-	-	6.59	4	1.82	4
11/16/2005	-	-	-	-	9.34	19	6.20	4	1.87	4
11/22/2005	15.10	100%	15.10	Parshall	-	-	-	-	-	-
12/14/2005	12.50	100%	12.50	Parshall	-	-	-	-	-	-
12/16/2005	-	-	-	-	9.67	19	-	-	-	-
1/21/2006	-	-	-	-	10.89	17	6.60	4	2.61	4
1/22/2006	21.10	100%	21.10	Parshall	-	-	-	-	-	-
2/14/2006	-	-	-	-	8.22	19	6.75	4	2.49	4
2/21/2006	14.10	100%	14.10	Parshall	-	-	-	-	-	-
3/15/2006	13.50	100%	13.50	Parshall	8.41	19	7.28	4	1.72	4
3/22/2006	13.60	100%	13.60	Parshall	-	-	-	-	-	-
3/23/2006	-	-	-	-	9.58	14	7.04	4	1.14	4
4/17/2006	-	-	-	-	7.57	19	6.61	4	1.94	4
4/19/2006	13.50	100%	13.50	Parshall	-	-	-	-	-	-
5/15/2006	10.70	100%	10.70	Parshall	-	-	-	-	-	-
5/19/2006	-	-	-	-	7.46	19	5.93	4	1.31	4
6/18/2006	-	-	-	-	7.36	19	5.61	4	1.22	4
6/19/2006	8.70	100%	8.70	Parshall	-	-	-	-	-	-
7/12/2006	-	-	-	-	8.01	19	5.43	4	1.25	4
7/28/2006	10.30	100%	10.30	Parshall	-	-	-	-	-	-
8/22/2006	-	-	-	-	6.31	19	5.38	4	-	-
8/23/2006	10.70	100%	10.70	Parshall	-	-	-	-	-	-
9/20/2006	-	-	-	-	6.73	19	6.29	4	-	-
9/28/2006	7.50	100%	7.50	Parshall	-	-	-	-	-	-
10/31/2006	8.70	100%	8.70	Parshall	9.21	19	6.96	4	2.59	4

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	GPM	Estimated % of flow captured*	Estimated GPM*	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)
11/30/2006	-	-	-	-	8.68	19	5.96	4	2.51	4
12/21/2006	10.50	100%	10.50	Parshall	10.08	19	6.54	4	2.70	4
1/22/2007	11.10	100%	11.10	Parshall	-	-	-	-	-	-
1/25/2007	-	-	-	-	9.54	19	5.70	4	2.56	4
2/22/2007	8.70	100%	8.70	Parshall	10.49	19	6.50	4	2.73	4
3/15/2007	-	-	-	-	8.66	19	6.93	4	2.74	4
3/19/2007	10.30	100%	10.30	Parshall	-	-	-	-	-	-
4/4/2007	5.60	100%	5.60	Parshall	9.24	19	6.42	4	2.62	4
5/14/2007	1.90	100%	1.90	Parshall	-	-	5.03	4	2.28	4
6/12/2007	5.40	100%	5.40	Parshall	7.67	19	5.71	4	2.06	4
7/31/2007	2.23	98%	2.28	Parshall	5.56	19	5.46	4	1.56	4
8/23/2007	2.78	100%	2.78	Parshall	5.45	19	5.37	4	1.57	4
9/12/2007	5.60	100%	5.60	Parshall	6.42	19	5.18	4	1.70	4
11/10/2007	12.30	100%	12.30	Parshall	8.36	19	5.61	4	2.63	4
12/20/2007	-	-	-	-	10.03	19	5.47	4	3.09	4
12/26/2007	10.52	100%	10.52	Parshall	-	-	-	-	-	-
1/15/2008	7.50	100%	7.50	Parshall	7.79	19	5.32	4	3.00	4
2/13/2008	wash flowing				9.74	19	5.60	4	3.08	4
3/11/2008	8.90	100%	8.90	Parshall	8.76	19	5.22	4	3.03	4
4/11/2008	8.20	100%	8.20	Parshall	8.28	19	5.08	4	2.96	4
6/25/2008	4.40	100%	4.40	Parshall	6.36	19	3.90	4	1.46	4
7/24/2008	1.80	100%	1.80	Parshall	7.12	19	4.00	4	1.68	4
8/14/2008	1.90	100%	1.90	Parshall	5.44	19	3.71	4	1.14	4
9/23/2008	5.70	100%	5.70	Parshall	6.27	19	4.28	4	1.75	4
10/28/2008	8.90	100%	8.90	Parshall	8.08	19	4.52	4	2.43	4
11/20/2008	8.90	100%	8.90	Parshall	8.66	19	4.80	4	2.77	4
12/12/2008	12.70	100%	12.70	Parshall	9.38	19	5.00	4	2.88	4
1/21/2009	no access				iced over		4.38	estimate	2.83	4
3/6/2009	8.90	100%	8.90	Parshall	7.93	19	5.12	4	2.15	4
4/2/2009	8.10	100%	8.10	Parshall	8.90	19	4.79	4	2.27	4

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	GPM	Estimated % of flow captured*	Estimated GPM*	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)	GPM	Volume of catch (L)
5/7/2009	4.30	100%	4.30	Parshall	7.45	19	4.22	4	**1.19**[a]	4
6/16/2009	5.70	100%	5.70	Parshall	6.55	19	3.39	4	-	-
7/22/2009	1.00	98%	1.02	Parshall	5.93	19	3.49	4	-	-
8/27/2009	1.00	100%	1.00	Parshall	5.56	19	3.44	4	-	-
9/23/2009	7.20	100%	7.20	Parshall	5.69	19	3.68	4	-	-
10/30/2009	10.70	98%	10.92	Parshall	7.99	19	4.38	4	-	-
11/19/2009	7.40	100%	7.40	Parshall	8.59	19	4.54	4	2.59	4
12/21/2009	no access				icy		3.86	4	2.58	4
1/29/2010	no access				no access		4.51	4	2.66	4
2/24/2010	no access				9.77	19	4.30	4	2.48	4
3/30/2010	no measure				7.89	19	5.42	4	2.35	4
4/19/2010	8.76	97%	9.03	bag	8.88	19	4.36	4	1.57	4
5/20/2010	no measure				7.48	19	3.92	4	0.88	4
6/17/2010	3.74	98%	3.77	bag	5.83	19	3.27	4	0.83	4
7/14/2010	1.44	98%	1.47	bag	6.12	19	3.28	4	0.97	4
8/9/2010	2.61	98%	2.66	bag	7.09	19	3.69	4	1.70	4
9/2/2010	2.71	95%	2.85	bag	-	-	3.52	4	1.52	4
10/4/2010	3.89	100%	3.89	bag	7.46	19	3.98	4	1.64	4
11/12/2010	7.47	100%	7.47	bag	-	-	-	-	-	-
11/18/2010	-	-	-	-	8.81	19	4.66	4	2.46	4
12/2/2010		97-99%	7.62	bag	-	-	-	-	-	-
12/15/2010	-	-	-	-	8.98	19	4.70	4	2.52	4
1/24/2011	-	-	-	-	8.06	19	4.66	4	2.28	4
1/25/2011	8.89	97%	9.16	bag	-	-	-	-	-	-
2/23/2011	8.80	100%	8.80	bag	9.65	19	5.00	4	2.50	4
3/17/2011	10.02	98%	10.22	bag	-	-	-	-	-	-
3/24/2011	-	-	-	-	7.87	19	4.61	4	1.93	4
4/21/2011	5.72	99%	5.78	bag	8.66	19	4.76	4	2.25	4
5/23/2011	-	-	-	-	8.77	19	4.59	4	1.89	4
5/25/2011	4.09	98%	4.17	bag	-	-	-	-	-	-

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	**GPM**	**Estimated % of flow captured***	**Estimated GPM***	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**
6/23/2011	immeasurable				6.80	19	3.46	4	1.55	4
7/25/2011	1.45	99%	1.47	bag	6.11	4	3.11	4	-	-
8/18/2011	0.89	100%	0.89	bag	5.52	19	3.42	4	1.21	4
9/23/2011	immeasurable				7.04	19	4.05	4	1.88	4
10/25/2011	not visited				7.19	19	4.35	4	1.94	4
12/12/2011					8.75	19	4.88	4	2.03	4
1/26/2012					9.06	19	4.69	4	2.69	4
2/23/2012					7.19	19	4.62	4	2.50	4
3/19/2012					8.37	19	5.06	4	2.66	4
4/10/2012					6.82	19	4.60	4	2.49	4
5/24/2012					5.23	19	3.39	4	1.58	4
6/26/2012					3.90	19	3.07	4	0.83	4
7/25/2012					6.00	19	3.56	varied	0.91	4
8/16/2012					6.40	19	3.55	4	1.30	4
10/1/2012					-	-	4.05	4	1.72	4
10/24/2012					7.11	19	3.92	4	2.16	4
11/15/2012					8.83	19	4.46	4	2.58	4
12/10/2012					7.51	19	4.76	4	2.59	4
1/23/2013					icy		icy		2.96	4
2/14/2013					9.57	19	5.19	4	2.84	4
3/12/2013					9.51	19	7.5	4	2.66	4
4/25/2013					7.92	19	4.44	4	2.34	4
5/16/2013					6.77	19	3.87	4	-	-
6/11/2013					4.54	19	2.88	4	-	-

Appendix B. Spring Discharge Measurements, December 2000–December 2014

	Courthouse Boundary				Sleepy Hollow		Sevenmile Boundary		Poison Ivy	
Date	**GPM**	**Estimated % of flow captured***	**Estimated GPM***	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**	**GPM**	**Volume of catch (L)**
7/23/2013					5.72	19	2.91	4	-	-
8/20/2013					-	-	3.00	4	1.12	4
9/27/2013					-	-	3.88	4	1.78	4
10/23/2013					8.18	19	4.51	4	2.25	4
11/18/2013					9.28	12	4.82	4	2.48	4
1/16/2014					8.41	12	-	-	2.72	4
2/14/2014					8.98	12	**7.43** [b]	4	2.85	4
3/25/2014					13.32	19	5.01	4	2.48	4
4/21/2014					12.01	12	4.43	4	2.02	4
5/28/2014					9.00	12	3.97	4	1.34	4
6/23/2014					7.51	12	3.05	4	0.87	4
7/14/2014					6.48	12	2.85	4	0.70	4
8/25/2014					8.24	12	3.68	4	1.35	4
9/25/2014					7.89	12	4.15	4	1.23	4
10/20/2014					8.14	12	4.78	4	1.92	4
11/13/2014					8.43	12	4.84	4	2.47	4
12/9/2014					8.93	12	4.78	4	2.61	4

*Percent of flow captured was estimated at all sites but is only significant for the record at Courthouse Boundary Spring.

GPM = gallons per minute; L = liters

[a] imprecise flow measurement

[b] flow potentially affected by run-off

[c] flow potentially affected by ice

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