Quantify soil-water percolation to Apache Spring, Fort Bowie National Historic Site, Cochise County, Arizona

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Final Report Brief

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Background

This project was focused on obtaining regular measurements of flow at Apache Spring (Photograph 1) and determining the contribution of soil water percolation to total discharge at Apache Spring, Fort Bowie National Historic Site (NHS), Cochise County, Arizona. Results of this study provide a baseline of hydrologic components in the Apache Spring watershed from April 2005 to June 2006.

Figure 1 illustrates key features at the park, including Apache Spring. Apache Spring occupies a central role in the history of the opening of the North American Southwest to Anglo-American settlement. The site has been a focal point of activity for many different cultures because of its physiography and a year-round presence of water (Pinto et al., 2000). A spring collector box was constructed at the primary bedrock discharge point in Apache Wash sometime in the 1930's (Ludwig, 2008). The fort was closed in 1894 and in the early 1900's some of the grassland areas were purchased by local ranchers. These private lands and the remaining public lands were used for cattle grazing until recently. The National Park Service assumed administrative responsibilities of the area with the designation of Fort Bowie NHS in 1964 (Pinto et al., 2000), but did not establish a presence there until 1972.

Average flow rates at Apache Spring have declined from rates of 7.5 to 10 gpm reported in the 1970's (Werrell, NPS Water Resource Division) to rates between 3 and 6 gpm observed since 1999. This decline concerns NPS staff because in addition to providing sustenance to wildlife, the spring is the primary reason for the presence of the fort at this location, and is thus a focal point for park interpretation and the visitor experience. A water supply well was constructed near the park administrative area in 2000. Pumping from this well averages about 1,400 gallons per day.

For the purposes of this study, soil percolation is defined as water reaching the Apache Spring waterfall following a path other than outflow from the spring collector box or direct surface flow. It is likely that a significant portion of this water emanates from rock fissures in the Apache Spring area and is thus aquifer-derived groundwater. The remaining portion consists of water from infiltrated precipitation moving downslope within the soil cover and discharging to the spring. Since it was not possible to separate the components of this soil borne water, water reaching the waterfall by pathways other than the spring box or surface flow are designated here as soil percolation.

Geologic Setting

Geologic conditions are directly responsible for the location of Fort Bowie. The dependable springs that have attracted humans to this place for thousands of years are the result of a complex history of repeated horizontal and vertical earth movement (Bezy, 2001). The strategic corridor that is Apache Pass exists because of the hardness differences and structure of the one to two kilometer wide Apache Pass fault zone

(Bezy, 2001). Springs in the area drain fractured rocks along the weakened zone, primarily the Horquilla limestone where it is intensely fractured on its bounding faults (Davidson, 1965).

Siphon Canyon is the largest drainage within the park boundary (Figure 1). The ephemeral Apache Wash is a tributary of Siphon Canyon. Apache Wash drains the watershed that encompasses Apache Spring and most of the ruins of the second fort. Water reaching Apache Spring is derived primarily from storage in the fractures of the fault zone. There are episodic contributions from rainwater that infiltrates the thin soil veneer and migrates downslope along the bedrock surface, and from ephemeral surface runoff, but the base flow to the spring that sustains it throughout the year is from the aquifer. Groundwater stored in fractures originates as precipitation arriving either as direct infiltration or as runoff from higher ground that eventually infiltrates through soils and deeper into rock fissures. Most recharge to the fractured aquifer is believed to occur rapidly, as the thin soils that cover most of the park have little capability to store water for delayed release. The exceptions to this are thicker soils in the drainage bottoms, but these are undergoing rapid erosion and are in an advanced state of degradation. Discharge to the springs occurs as gradually released "overflow" from the fractured aquifer at the low points, where erosion has intercepted the water table at the surface (Martin, 2007).

Soils

Soils in the drainage contributing to Apache Spring are derived from the granitic, limestone and siltstone bedrock types occurring in the area. Except for soils in and immediately adjacent to the drainage bottoms, soil cover at the site is for the most part less than 20 inches in depth, and bedrock outcrops occur frequently. All of the soils within park boundaries are listed as land capability classification VIs (Denny and Peacock, 1999), indicating that these are thin soils with severe limitations, often due to steep slopes and erosion hazard, that require relatively greater management input to prevent soil deterioration by erosion or other means (Hausenbiller, 1972). All of the upland soils are characterized by the soil survey as well drained, with very low available water capacity and high runoff potential.

The implication of these soil properties to groundwater at Fort Bowie NHS is that soils at the park possess a limited ability for infiltration, very low potential for water retention, and a high susceptibility to soil loss. Precipitation that does not infiltrate will not recharge the fractured aquifer that supplies Apache Spring, but will rapidly move downstream out of the drainage as surface flow and be lost to the spring system. Precipitation events that lead to runoff in Apache Wash are infrequent, but the combination of steep slopes and shallow soils with minimal water capacity results in surface flows with sufficient velocity and turbulence to produce significant soil losses with runoff events of even relatively small magnitude. The process creates positive feedback, as each unit of soil loss results in less ability to capture and retain precipitation, causing an even greater volume of runoff which becomes more powerful and erosive with increasing channelization. Formerly deep soils in the Apache Wash drainage that were capable of storing water and releasing it slowly are now deeply gullied. In addition to the direct loss of storage capacity due to lost soil volume, gully entrenchment creates a lowered seepage boundary for the surrounding soils, reducing the ability of remaining soils to store infiltrated water. The Apache Spring watershed is a textbook example of accelerated erosion directly attributable to a history of human disturbance in the area of the second fort.

Methods

Measurements at the spring waterfall were made approximately monthly over the study period. Flow from the spring box was measured using an in-line flow meter and by the timed catch method. Total flow at the spring was measured by a timed catch method and with a portable flume, and soil percolation was determined by subtracting the spring box contribution from the total discharge. Concurrently, water level, temperature and electrical conductivity in the spring box were monitored as well as water levels in the park water supply well.

Results

Measured total and spring box discharge and calculated soil percolation discharge are listed in Table 1 and plotted in Figure 2 with daily precipitation. Maximum total flow during the study was 4.8 gpm, and minimum total flow was 3 gpm. These figures show that maximum flow rates occurred in March and April following the winter season, and minimum flow rates occurred in late June to early July, prior to the onset of the summer monsoon season. Spring box discharge shows a decreasing trend over the study period, from a high of 2.5 gpm at the start to a low of 1.3 gpm at the end of the measurement period. These results are in part a function of the timing of these first and last data points (April and June respectively), and are also related to changes in water level within the spring box over that period. During plant growth periods, daily fluctuations in surface water levels inside the spring box are caused by an increasing number of roots that have penetrated into the spring box. The daily water level fluctuations have a negligible effect on day-to-day flow rates from the spring box. Seasonally, transpiration reduces storage inside the spring box by more than a foot of depth, reducing outflow from the box somewhat. Physical situation of the discharge pipeline, buried beneath the sediments, also affects discharge rate from the spring box.

Calculated soil percolation discharge to the spring system varied from a low of 1.2 gpm to a high of 2.6 gpm during the study (Table 1). As the figures illustrate, variability in soil percolation accounts for almost all of the annual variability in total flow to the waterfall. Both spring box and soil percolation components responded to larger precipitation events during the study period, but the coarse sampling schedule provides little information on this aspect of the system. Changes in contributions of both flow components were affected by evapotranspiration and precipitation, but these were significantly dampened for the spring box discharges due to the regulating effect of the flow meters and the storage in the spring box. Table 1 shows that fractional contributions of discharge to the spring for both components varied throughout the year, ranging from a high of 62% of total flow to a low of 38% of total flow. The maximum fraction of flow originated from the spring box in early July 2005 and the maximum fraction from soil percolation occurred in late December 2005.

Discussion

Inflow (gain) from precipitation and outflow (loss) by evaporation drive the hydrologic system at Fort Bowie NHS. Seasonal meteorological cycles result in predictable flow rate cycles at the Apache Spring waterfall throughout the year. Potential explanations for the decrease in flow were considered, including 1) pumping from the park's water supply well; 2) increased loss of water through transpiration ; 3) increased runoff/decreased recharge associated with soil losses; and 4) decreased recharge due to drought.

The possibility that a significant portion of the observed decrease of flow at Apache Spring is due to pumping at the park water supply well is ruled out for two reasons. First, reductions in spring flow were observed before the new water supply well was constructed (Martin, 1999, 2000). Second, the decline in flow rate at the spring is four times as great as the amount that would result if 100% of the water pumped from the well came from the spring. On average, the water supply well pumps one gallon per minute.

Flow rate decline at the springs since the 1970's is on the order of four gallons per minute. For this reason, water consumption at Fort Bowie NHS is not considered to be a primary factor in explaining the flow decrease at the springs. However, pumping at the well is believed to be a contributing factor. Unfortunately, water levels in the fort area were not known until the new supply well was constructed in 2000, so it is not known whether or not groundwater levels were substantially higher in previous decades. This information would be extremely valuable to the current analysis were it available.

There is a likelihood that flows at Apache Spring are decreased due to increased transpiration losses in the watershed over the years since NPS established a presence in 1972. Prior to that time, while the upper Apache Wash drainage was not formally part of a grazing allotment, the area was not fenced and some grazing occurred there. Grazing was likely more concentrated in the riparian area due to a higher density of palatable vegetation. Since then, an increase in vegetative cover would have the effect of increasing water losses by transpiration and reducing aquifer recharge, especially during the summer rainy season. It is believed that the number of annuals and woody plants in the Apache drainage has increased in density and extent since the early 1970's, but this is a topic that would benefit from additional research, possibly by comparison of historic photographs. Increased transpiration losses most likely account for some portion of the flow decreases seen at the spring. Similar phenomena have been documented at protected springs in Austrailia (Kodric-Brown et al., 2006) and in semiarid watersheds experiencing woody plant encroachment (Huxman et al., 2005). Selective removal of woody species in the watershed by NPS is ongoing and may show a positive impact to spring flows at some time in the future, although this is likely to be a gradual and subtle effect and would be difficult to identify within the framework of natural variability and other processes active within the watershed.

Decreased spring flow is also attributed to the ongoing loss of soils within the upper watershed. Erosion accelerated by human disturbance has been documented to cause soil loss from 10 to 1,000 times more rapidly than would occur by natural geologic processes (Brady and Weil, 2002). Soil losses in the upper watershed have been observed to be significant in the last few years. As discussed above, the effects of soil loss compound from year to year. Soil loss has a direct effect in the reduction of infiltration needed to recharge the fractured aquifer and the corresponding increase in runoff, which removes water from the system. Gullying also lowers local water tables and reduces soil water storage.

Based on the Palmer Hydrological Drought Index (PHDI) for Arizona Division 7, drought is another certain long-term contributor to the decrease in flow at Apache Spring. The PHDI is calculated by the National Climatic Data Center (NCDC) monthly to quantify drought and wet conditions as these relate to hydrologic conditions (http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html). Since 1995, negative PHDI (water deficit relative to average) months have exceeded positive PHDI (water surplus relative to average) months by a 3 to 1 ratio. Since January of 1995, there have been 43 months of positive PHDI and 125 months of negative PHDI. These data may explain the four-foot decline in groundwater levels since 2000, and are certainly responsible for some of the discharge decrease at Apache Spring.

The data show a time lag in changes in discharge at the springs relative to changes in precipitation inputs. Spring discharges in March 2006, following a very dry winter, are only slightly less than they were in March 2005 following a winter of above average precipitation. Even if recharge occurs rapidly, percolation to the springs is a relatively slow process by comparison. Storage within the aquifer dampens the discharge response to changes in surface conditions. Drought effects are not dramatic in the short term, but they undoubtedly have a link to gradual long-term declines in discharge at Apache Spring.

Conclusions

Water flow rate measurements and environmental observations were made on an approximately monthly schedule at Apache Spring over the period from April 2005 to June 2006. As may be expected, the data show a strong seasonal signal of summer evapotranspiration (ET) water losses from the system, followed by recovery to a higher flow rate in the winter months when ET losses are at a minimum. Flow from the spring collector box provides a stable source of water to the waterfall compared to that from soil percolation due to the ability of the collector box to store water and release it at a uniform rate through the flow meter. When the meter is not present, this storage does not occur and periods of no or minimal water at the waterfall may be expected to occur in the summer months as they have in the past prior to installation of the meter. When flow is regulated, the collector box acts as a reservoir to provide water to the spring through the dry months.

This study highlights the importance of aquifer storage to spring discharges at Fort Bowie NHS and identifies aquifer depletion as the most probable factor causing reduced flows at the spring. Several processes that effectively reduce recharge to the aquifer were identified as probable causes. Observed decreases in flow are attributed to the cumulative effect of these processes that result in either reduced input to the system, increased losses from the system, or both. The most important of these include:

- Drought
- Soil losses causing increased runoff and reduced infiltration
- Increased transpiration losses

Interrelationships between these processes exist and solutions may be identified that address more than one of these at a time. However, these processes do not lend themselves to simple management solutions. In addition, projected climate changes further threaten flows at Apache Spring. Partly as a result of this study, a modest NPS project has been funded to assist in identifying and implementing methods to reduce the rate of soil loss in the watershed beginning in fiscal year 2010. Soil losses that have already occurred cannot be reversed. A need for a recording rain gauge has been identified and will likely be addressed in the current or the next fiscal year.

Acknowledgements

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A more in-depth report describing this project is available by emailing colleen_filippone@nps.gov. This report may be published as an NPS technical report at a future date.

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Table 1. Apache Spring measured and calculated discharge with fractions of total flow from the spring box and soil percolation.

	Apache Spring spring box discharge (gpm)	Apache Spring soil percolation discharge (gpm)	Apache Spring total discharge (gpm)	Apache Spring spring box discharge fraction of total flow	Apache Spring soil percolation discharge fraction of total flow
Maximum	**2.50**	**2.65**	**4.80**	**0.62**	**0.62**
Minimum	**1.34**	**1.19**	**2.97**	**0.38**	**0.38**
Date					
4/18/2005	2.50	2.29	4.80	0.52	0.48
5/19/2005	2.33	2.31	4.64	0.50	0.50
6/17/2005	2.07	1.30	3.37	0.61	0.39
7/6/2005	1.94	1.19	3.13	0.62	0.38
8/5/2005	2.05	1.75	3.80	0.54	0.46
9/14/2005	1.92	1.64	3.55	0.54	0.46
9/21/2005	2.14	1.86	4.00	0.53	0.47
10/25/2005	1.88	2.09	3.97	0.47	0.53
12/22/2005	1.58	2.57	4.15	0.38	0.62
1/5/2006	1.66	2.12	3.78	0.44	0.56
2/16/2006	1.70	2.53	4.23	0.40	0.60
3/28/2006	1.87	2.65	4.52	0.41	0.59
4/28/2006	1.73	2.52	4.25	0.41	0.59
6/15/2006	1.34	1.60	2.97	0.45	0.55

Photograph 1. View of Apache Spring waterfall on December 8, 2004, showing rock wall, collection pool and Apache Wash upstream of the waterfall. The area was heavily scoured during flooding of late July 2006.

Figure 1. Map of Fort Bowie National Historic Site including key features.

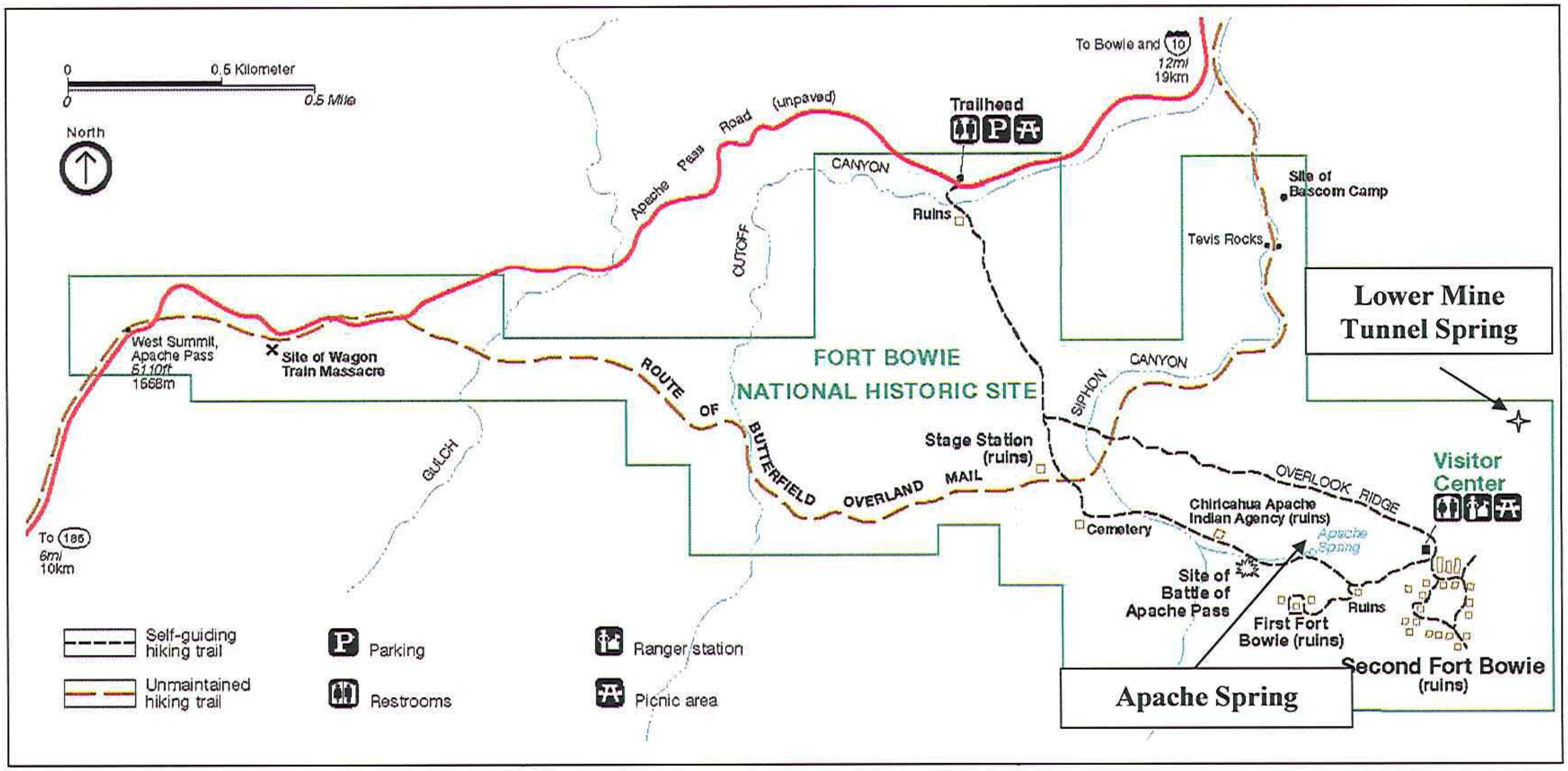

Figure 2. Discharge to Apache Spring from the spring box, soil percolation, and total flow at Apache Spring with daily precipitation.