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Hydrology of a Southern Appalachian Hypocrene Spring-Fed Fen

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ABSTRACT

Garland Seep is a Southern Appalachian fen that supports a population of federally endangered green pitcher plants (*Sarracenia oreophila*). The wetland is underlain by clayey stream deposits above fractured bedrock, is located at the base of a mountain slope, and is fed by groundwater that originates as recharge on the adjacent hillslope. Groundwater wells were installed following a hydrologic restoration in the mid-1990s and have been monitored at varying frequencies since that time. The 20+ year record provides evidence that Garland Seep can be classified as a "hypocrene fen," in which spring flow rarely reaches the ground surface because of low discharge rates and high evapotranspiration (ET). In general, water-level fluctuations followed seasonal ET patterns, with higher water levels in the winter and early spring (when ET is low) and lower levels in the summer and fall. During wetter years, the water table remained near the ground surface for much of the year, with the clay layer underlying the site retaining moisture even after water levels had dropped. The "clay wetting" period was shorter during dryer years and corresponded with a reduction in the number of pitcher plant clumps observed at the site. In addition to the geologic and climatic controls on hydrology, previous landowners used fire to maintain open space for grazing, and The Nature Conservancy has continued the practice to combat woody vegetation and to open the canopy. Prescribed burns reduce ET (at least initially), cause a rise in water levels, and have helped maintain a thriving *Sarracenia* population.

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INTRODUCTION

Garland Seep is a Southern Appalachian mountain wetland in western North Carolina (United States) that supports a vibrant population of federally endangered green pitcher plants (*Sarracenia oreophila*) (Figure 1). *Sarracenia* seedlings require high soil moisture and light intensity, and as a result, land-use conversion, hydrologic alterations, and absence of fire have likely contributed toward relegating this carnivorous plant to Garland and a few dozen other known locations in northern Georgia and Alabama (United States) (USFWS, 2011). The presence of *Sarracenia* at Garland Seep is curious because it grows in clumps in an atypical "wetland" where the ground surface is mostly solid and dry (Figure 2). The goal of this study was to identify and describe the hydrologic conditions supporting the wetland and its rare flora. Garland Seep is presented in this special issue as a classic example of a "hypocrene spring," a classification that helps explain the recent success of wetland management to preserve—and expand—the *Sarracenia* population.

SITE DESCRIPTION

Garland Seep is a 5-acre (2.02-ha) Southern Appalachian wetland that has been owned and managed by The Nature Conservancy (TNC) since 1988. It is also designated as a Conservation Partnership Area for the Mountain Bogs National Wildlife Refuge, which was officially established in April 2015 (USFWS, 2019). The seep supports a variety of grasses, sedges, and moisture-tolerant forbs in addition to the federally endangered green pitcher plants (*Sarracenia oreophila*). Rapidly growing trees and shrubs within and surrounding the herbaceous wetland core include tulip poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), red chokeberry (*Aronia arbutifolia*), swamp rose (*Rosa palustris*), and sweet white azalea

Figure 1. Federally endangered green pitcher plants (*Sarracenia oreophila*). Photos by Karen Vaughn.

(*Rhododendron arborescens*) (Schwartzman, 2016; Weakley and Schafale, 1994).

The wetland is located about 2,000 ft (610 m) above sea level, between the western base of a mountain slope and the eastern shore of an artificial valley reservoir (Figure 3). The site is underlain by Hemphill loam and Nikwasi fine sandy loam (Warwick, 2019): gray, clay-rich soils with rounded but irregularly shaped pebbles and cobbles (Richardson and Huang, 1996; Braun, 1997). Well-construction reports for nearby domestic wells indicate the unconsolidated clay unit is 10–12 ft (3.0 to 3.7 m) thick and rests directly above fractured bedrock (Wilcox, 2012). Prior to TNC's acquisition of the property in 1988, several 6-in. (15-cm) drainage tiles had been installed within the clay layer to drain the site. The outlets of these drainage tiles were plugged in the early 1990s (TNC, 2010), but the gravel beds surrounding the drainage tiles continued to provide preferential flow zones beneath the wetland (Braun, 1994). In 1995, TNC excavated the drain tiles at 50-ft (15-m) intervals and permanently blocked them in an effort to restore the natural hydrology of the site.

Garland Seep has been subject to controlled burns since the early 1900s, and wildfires before then likely played a role in preventing rapid forest succession (Warwick, 2019). Historical records indicate that a single landowner burned the site every winter from 1908 to maintain open land for grazing cattle. Following a 20-year absence of fire, TNC resumed the practice in

Figure 2. *Sarracenia oreophila* grow in clumps at Garland Seep, where the ground surface is typically dry enough to wear normal shoes and even kneel in jeans. Photos by Jeff Wilcox (left) and Karen Vaughn (right).

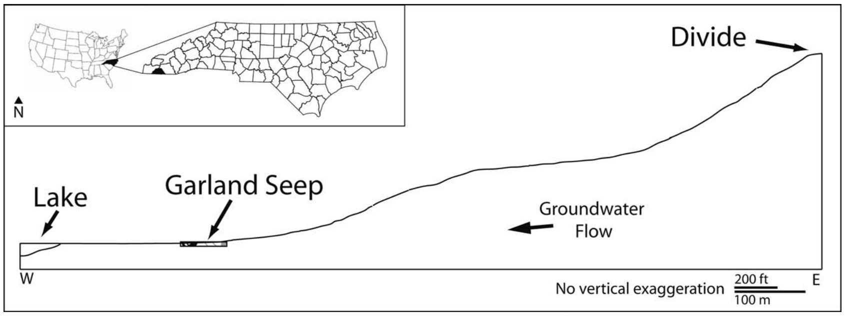

Figure 3. Site location and cross section, Garland Seep, Clay County, NC (Unied States).

April 1992 and conducted their ninth prescribed burn in March 2019.

TNC has monitored the *Sarracenia oreophila* population since 1990, counting flowers, leaves (pitchers), and clumps of pitchers along eight transects. As the *Sarracenia* population grew—purportedly in response to the aforementioned management activities—it became infeasible to count flowers and pitchers along all eight transects or to differentiate between neighboring clumps that had grown together. Nevertheless, TNC continued counting pitchers and flowers along three of the original transects, and it became clear that the *Sarracenia* were thriving. Whereas 157 pitchers and seven flowers were counted along the three transects in 1990, there were 5,614 pitchers and 390 flowers in the 2018 survey (Figure 4). Only 43 flowers were counted across the entire site during the first survey in 1990, while over 2,000 were counted in 2018 (Warwick, 2019).

METHODS

Hydrologic Monitoring

A network of 16 groundwater monitoring wells was installed in the mid-1990s following hydrologic restoration (drain tile blockage and removal) to provide a baseline prior to residential development on the hillslope above Garland Seep (Richardson and Huang, 1996). The wells were constructed with 1.25-in. (3.2-cm) diameter steel or 2-in. (5.1-cm) polyvinyl chloride (PVC) pipe with 5-ft (30.5-cm) or 10-ft (61-cm) screens. Well depths ranged from 2.0 to 13.0 ft (1.6 to 4.0 m) below ground surface and included three sets of well nests to evaluate the vertical component of groundwater flow. Richardson and Huang (1996) also conducted slug tests and collected water samples for water-quality analyses. Measured hydraulic conductivities ranged from 1.3E-4 to 0.49 ft/d (4.0E-5 to 0.15 m/d). Following the conclusion of this initial study, a resident living near Garland Seep continued to measure water levels on a weekly basis from 1996 to 2013 (unless he was on vacation), after which we deployed pressure transducers (Onset HOBO U-20, Onset Corporation, Bourne, MA) in six of the wells to record water levels at hourly intervals.

Reliable weather data were not available dating back to 1996 in the vicinity of Garland Seep or even the nearest towns in Clay County. We installed a tipping-bucket rain gauge onsite in 2013, and records from the closest weather station at Andrews-Murphy

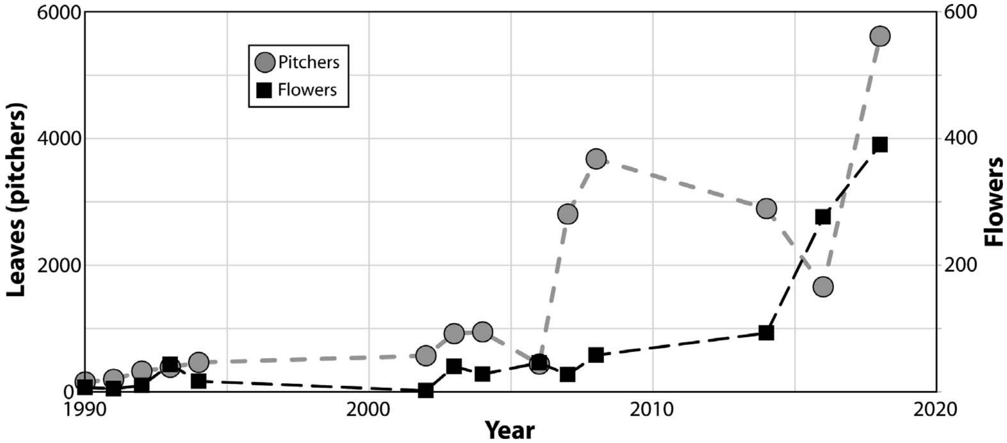

Figure 4. The Nature Conservancy has documented an increase in the number of *Sarracenia oreophila* leaves (pitchers) and flowers along three survey transects (TNC, 2010).

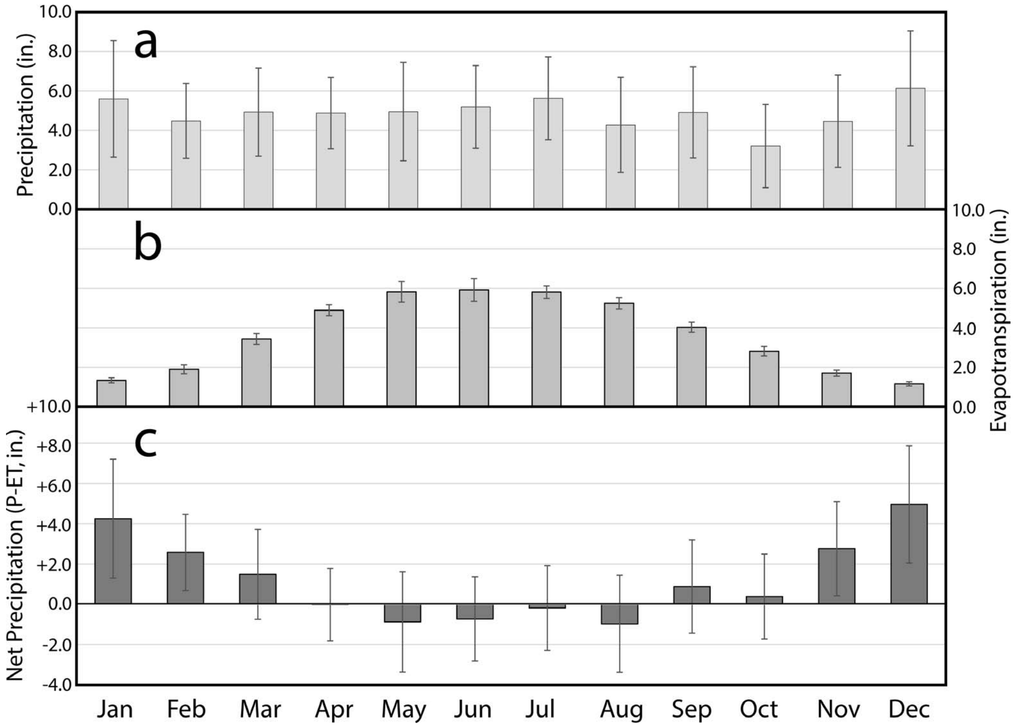

Figure 5. Mean monthly precipitation (a), evapotranspiration (b), and net precipitation (c), 1996–2018.

airport about 15 miles (24 km) away only go back to June 2001. The closest weather stations with complete precipitation records (1996–2018) were located over 16 miles (26 km) away, to the west in Murphy, NC, and to the east at Coweeta Hydrologic Laboratory in Otto, NC. Given precipitation variability from individual storms in a mountainous region, we downloaded only monthly precipitation totals from the State Climate Office of North Carolina (SCONC, 2019). SCONC also provided monthly evapotranspiration (ET) estimates using the FAO Penman-Monteith method (Allen et al., 1998) and net radiation, ground heat flux, temperature, humidity, and wind speed data from the Andrews-Murphy airport.

RESULTS

Precipitation and Evapotranspiration

Precipitation measurements collected onsite at Garland Seep from 2013 to 2018 were generally consistent with those collected in Murphy, NC (west of Garland), but about 20 percent lower than those collected at the Coweeta Hydrologic Laboratory (east of Garland Seep). For this reason, we relied on the historical precipitation record from Murphy, NC, from 1996 through 2018; mean precipitation was 58.3 ± 11.7 in. (148 ± 30 cm), with a maximum of 77.7 in. (197 cm) in 2013 and a minimum of 33.9 in. (86 cm) in 2016. Mean monthly precipitation ranged from 3.20 ± 2.21 in. (8.1 ± 5.6 cm) in October to 6.13 ± 3.05 in. (15.6 ± 7.7 cm) in December (Figure 5a). Mean annual reference ET at the Andrews Airport was 43.4 ± 2.3 in. (110 ± 6 cm), with monthly ET ranging from 1.17 ± 0.11 in. (3.0 ± 0.3 cm) in December to 5.92 ± 0.57 in. (15.0 ± 1.5 cm) in June (Figure 5b). Mean annual net precipitation (P-ET) was +20.8 ± 12.5 in. (+53 ± 32 cm) and ranged from +42.5 in. (108 cm) in 2018 to −0.6 in. (−2 cm) in 2016. Monthly net precipitation ranged from +4.96 ± 2.92 in. (12.6 ± 7.4 cm) in December to −0.97 ± 2.41 in. (−2.5 ± 6.1 cm) in August (Figure 5c).

Water Levels and Groundwater Flow

Groundwater flows from east to west beneath Garland Seep, with a horizontal gradient of approximately 0.05 (Figure 6). The vertical gradient ranges from −0.36 to +0.24, with both extremes recorded at the well nest located near the upper edge of the wetland boundary and *Sarracenia* habitat (wells 1 and 14 in Figure 6). The vertical component of groundwater flow at this well nest is generally upward in the late winter and spring months and downward in the late summer and fall months (Figure 7). During dryer years (2000, 2001, 2007, 2008, 2016) there is a longer period of downward flow (“draining” conditions), while

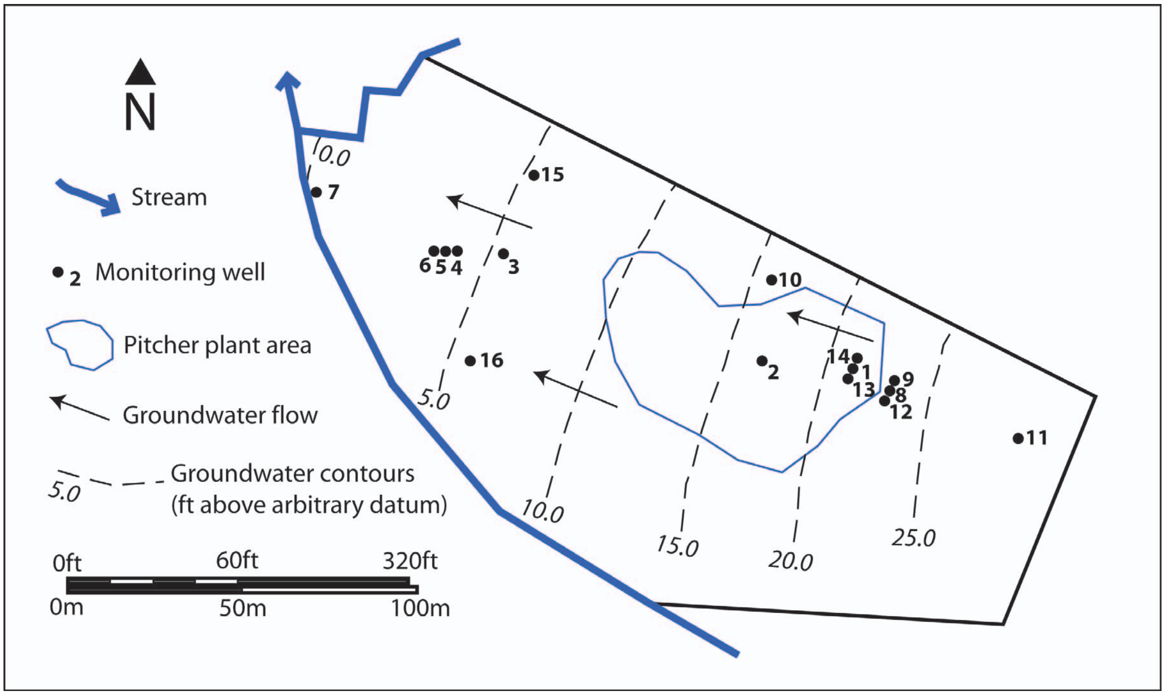

Figure 6. Garland Seep water-table map.

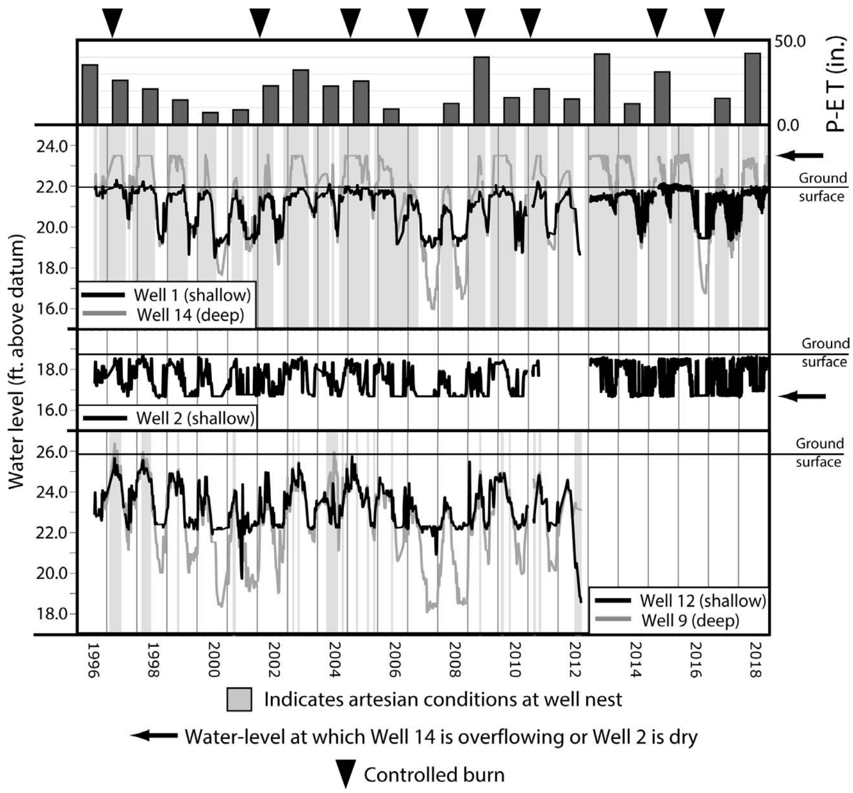

Figure 7. Net precipitation (top) and water levels measured at Garland Seep (1996–2018). The dates of prescribed fire are indicated with triangles above the figure.

in wetter years, upward flow dominates. Artesian conditions are often so great that the deeper well 14 is free-flowing. During these wetter periods—and years—with extended artesian conditions, water levels approach the ground surface and occasionally exceed it (see hydrographs for water-table wells 1 and 2 in Figure 7). We estimated a maximum upward seepage velocity of 0.8 to 3.0 in./mo (2.0 to 7.6 cm/mo) based on a vertical gradient of +0.24 and hydraulic conductivity values measured by Richardson and Huang (1996). The well nest located just upgradient of the core wetland complex (wells 9 and 12, Figure 6) showed a similar seasonal pattern, with higher water levels in winter and spring than in summer and fall, but artesian conditions were rare, and the potentiometric surface only occasionally approached the ground surface (Figure 7, bottom).

DISCUSSION

A Hypocrene Spring

Water levels measured within the pitcher plant habitat at Garland Seep frequently rose within inches (centimeters) of the ground surface over the 20-year record, particularly during wetter seasons and years. When this happened, the clay layer immediately underlying the site retained moisture even after water levels had dropped. The repeated wetting of this shallow clay layer from below (as indicated by artesian conditions in wells 9 and 14, Figure 7) is probably the most important hydrologic factor supporting the *Sarracenia*. For example, the numbers of pitcher plant clumps were lower in 2002 (compared to previous monitoring, 1990–1994), then increased for 5 years until dropping again in 2007–2008 (Roe and Croll, 2009). This pattern corresponds with precipitation and water-level data also collected at the site—the water table remained near the ground surface for much of the year during wetter years (e.g., 2003–2006), while the "clay wetting period" was shorter during dryer years (2000–2001, 2007–2008). Groundwater discharge through the clay layer was mostly offset by evapotranspiration, even in wetter seasons and years, allowing wetland flora to flourish in a wetland that is not wet. This conceptual model is consistent with a "hypocrene spring," which Springer and Stevens (2009) define as follows:

> …springs in which groundwater levels come near, but do not reach the surface … discharge from the springs is low enough that evaporation or transpiration consumes all discharge and there is no surface expression of the water.

Wetland Management

TNC has actively managed Garland Seep since the early 1990s and has documented a dramatic increase in *Sarracenia* clumps, pitchers, and flowers (Figure 4). While there may be several contributing factors to the success of TNC management, the recognition of Garland Seep as a hypocrene spring provides a hydrologic mechanism with which to explain the thriving *Sarracenia* population. First, TNC recognized that drain tiles running below the site were likely drying the wetland. The manner in which the drain tiles functioned, though, turned out to be unusual: rather than draining excess water downward from the soil surface, as in a typical wetland, the tiles instead intercepted artesian flow before it could reach the shallow soil or ground surface above. Plugging the drain tile outlets and excavating the gravel beds around the tiles had the effect of allowing more water to reach the root zone.

TNC also recognized the historic importance of fire at Garland Seep and has burned the site every 2 to 5 years since re-introducing controlled fire in 1992 (see markers at the top of Figure 7). The greatest observed hydrologic impact of these fires followed a prescribed burn on 29 March 2015. When we returned to the site on 1 May 2015, we observed standing water at the ground surface and thousands of new pitcher leaves (Figure 8). Precipitation had been below average every month so far that year, and the rise in water levels following the burn was unmistakable (see wells 1 and 14 in Figure 7). The obvious explanation is that the burn reduced ET (at least initially) and allowed upwelling groundwater to reach the surface. The reasons for which the 2015 prescribed fire had such clear effects on ET and water levels compared to those conducted previously are not as obvious. Looking at the historical record, standing water would have also been observed in the vicinity of well 1 following burns in 1997, 2005, 2009, and 2011. These burns coincided with relatively wet years—years in which P-ET exceeded 20 in. (50 cm)—but none resulted in such a significant or long-lasting rise in water levels as observed in 2015. TNC had recently hired a new stewardship manager prior to the 2015 burn, and the firing techniques may have been different than when TNC relied on partners to lead burns. The new manager also emphasized aggressive removal of competing hardwoods, which would have reduced overall ET and possibly intensified the impact of prescribed fire on the undergrowth. Perhaps the weather conditions simply allowed for a particularly effective burn. In any case, periodic prescribed fires at Garland Seep may help preserve the *Sarracenia* population by both keeping an open canopy and reducing ET to keep water levels near the surface.

Figure 8. New *Sarracenia oreophila* leaves on May 1 (left) and May 22 (right) following 29 March 2015 prescribed fire.

CONCLUSIONS

Garland Seep is a classic example of a hypocrene spring. Discharge through the clay layer was low and was typically exceeded by ET. The water table rarely reached the ground surface, but the clay layer was able to retain moisture and support federally endangered *Sarracenia oreophila* and other wetland flora. Wetland management by TNC has included prescribed fire and woody vegetation removal. These activities were not only used to combat succession and open the canopy but they have preserved—and even enhanced—site hydrology by reducing ET above the seep. The result has been a wetland with frequent standing water and a thriving *Sarracenia* population.

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