SEASONAL PATTERNS OF SPRING DISCHARGE AT SILVER FALLS, CROSBY COUNTY, TEXAS

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Abstract.–Beneath the high plains of the Llano Estacado lies the southern extension of the Ogallala aquifer, which provides a key source of groundwater for the region. Along the eastern fringes of the Llano Estacado one can find numerous natural springs that discharge from the Ogallala formation and provide a valuable source of freshwater. Large-scale irrigation has altered hydrological conditions, which has influenced the flow of springs along the eastern escarpment. In late 2012, the author began a study of one such spring located at Silver Falls in Blanco Canyon, east of Crosbyton, Texas. The goal was to monitor the discharge of this naturally flowing spring over a period of many years to establish temporal patterns. Measurements of spring flow rates over a seven-year period did not show an appreciable reduction associated with the depletion of the Ogallala aquifer; however, discharge was found to follow a seasonal pattern of declining flow during the summer followed by a recovery starting in late fall and reaching maximum discharge during winter and early spring. Whereas seasonal variations of spring discharge can be measured precisely, the cause of these seasonal patterns is less certain. It is likely that the combined effects of seasonal groundwater extraction for irrigation and the growth and transpiration of natural vegetation contribute to the observed seasonal patterns of groundwater discharge at Silver Falls.

Keywords: *groundwater, seasonal patterns, spring flow, Ogallala Aquifer, Blanco Canyon, irrigation, Llano Estacado*

In the late 19th century, many large ranches were established in West Texas along the breaks at the eastern edge of the Llano Estacado (Holden 1972). Historic ranches such as the Matador, Spur, Pitchfork and the Four Sixes were located near spring-fed streams that provided a reliable supply of water in a region with otherwise limited water resources (Williams 1954). The rolling grasslands east of the Caprock escarpment provided vast pastures and a measure of protection from the weather but more importantly this region provided a source of

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freshwater, a critical resource for both man and livestock (Gould 1906; Hatcher 1944).

During this early period of cattle industry expansion, well drilling equipment and windmills were not readily available in the West Texas frontier and, therefore, spring-fed ponds and streams were critical for livestock production (Holden 1975). Numerous springs discharging from the Ogallala aquifer provided natural watering places within the deeply dissected canyons etched into the eastern edge of the Llano Estacado (Gould 1906; Holden 1970). There was little surface water available on the high plains of the Llano Estacado to the west and most streams become highly saline farther to the east. Thus, early ranch pioneers took advantage of the well-watered belt just below the Caprock where grass was abundant and springs naturally fed streams of “live water” (Holden 1932).

Historical accounts suggest that spring discharge was considerably more significant before irrigated agriculture was introduced to the high plains of the Llano Estacado (Cummins 1890; Holden 1975). Cropland irrigation began around 1910 and increased dramatically after World War II (Nativ & Smith 1987). Water volumes withdrawn from the aquifer far exceed recharge; thus, the volume of stored water in the Ogallala aquifer has declined over the past century. Based upon a simple mass balance argument, the Texas Board of Water Engineers concluded that “any artificial discharge, such as pumping from an irrigation well, must decrease the natural discharge” of springs (Barnes et al. 1949). However, in 1949, the board claimed that the decline of the water table had not been widespread enough to “materially decrease” natural spring flows. In the latter half of the 20th Century, however, the depletion of the Ogallala aquifer accelerated and significant reductions of spring flows have been observed (Brune 1981). Today, many of the once gushing springs have either dried completely or have been reduced to dripping springs or seeps (Fenton 1991; Reeves & Reeves 1996).

In addition to an overall reduction of spring discharge, it has been suggested that seasonal extractions of groundwater can induce seasonal variations of spring flow (Theis 1941; Brune 1981). In his seminal book on Texas springs, Brune (1981) stated that many springs “show a seasonal variation in flow” with discharge rates “three times as high in winter as in summer”. Brune (1981) offered no quantitative evidence nor did he cite any scientific studies to support this claim. Most likely, Brune’s (1981) conclusions were based on his numerous site visits and discussions with local residents, ranch hands, and land owners who had first-hand knowledge of the springs located on their property.

In October of 2012, the author began an investigation of a spring located in Blanco Canyon, about 65 km to the east of Lubbock, Texas. The chosen spring, located at Silver Falls in Crosby County, is familiar to most residents of the South Plains. The primary goal was to monitor the discharge rate of groundwater naturally flowing from this spring.

Materials & Methods

Study Site.–Silver Falls is a roadside park located within Blanco Canyon along US Highway 82 in Crosby County, Texas (Figure 1) (33.6658° N, 101.1589° W). This scenic rest area is maintained by the Texas Department of Transportation and contains facilities and short hiking trails for travelers as well as local residents. The central focal point is a waterfall where the White River cascades across sandstone ledges. The White River, a tributary of the Salt Fork Brazos River, is actually an ephemeral creek that is partially fed by spring discharge and occasionally receives significant runoff when strong storms pass across the watershed (Irelan & Mendieta 1964).

Below the falls, the White River has carved deeply into the sandstone substrate and today cliffs rise as high as 10 m above the streambed. At various points along the canyon walls one can find

Figure 1. Map of the Llano Estacado showing the location of Silver Falls (33.6658° N, 101.1589° W) in relation to the White River in Blanco Canyon and the small town of Crosbyton, Texas.

numerous springs seeping out of cracks and crevices. Most of the springs appear at or near the contact between the water-bearing sands and gravels of the Ogallala formation and the underlying Dockum sandstone (White et al. 1940; Smith 1973).

Another key point of interest within the park is a "public fountain" that provides access to a flowing spring (Figure 2). Here a scenic alcove with benches was constructed at the site of an existing spring. At the center of the structure is a large rock wall constructed from cut stone. A steel pipe passes through the wall and extends into the Ogallala formation. The rock wall acts as a dam that partially blocks spring discharge thereby channeling the flow to the pipe, which provides a path of least resistance (Figure 3). The flow rate of groundwater issuing from the pipe can be accurately measured with a stopwatch and graduated cylinder.

Figure 2. A scenic alcove and "public fountain" that provides access to a naturally flowing spring at Silver Falls.

Measurement of spring discharge.–No attempt was made to measure the flow of all springs and seeps within the canyon walls at Silver Falls. The focus here was on the flow of spring water issuing from the pipe extending from the rock wall. The flow rate of water passing through the pipe represents only a small fraction of the total spring discharge within the basin but I have assumed that the flow from the pipe generally reflects the total flow of all springs within the basin. In other words, when the collective flow of all springs within the basin is high then the flow from the pipe will also be high and when the flow of all springs within the basin is low then the flow from the pipe will be low. Thus, temporal variations of flow from the pipe will track the total spring discharge within the basin.

It was not possible to attach a flowmeter to the pipe at Silver Falls so the flow rate was measured only during site visits. The goal was to measure flow rates twice a month if possible; however, it was difficult to maintain a strict schedule due to the distance and time required to visit the site. As a result, samples were taken at slightly irregular

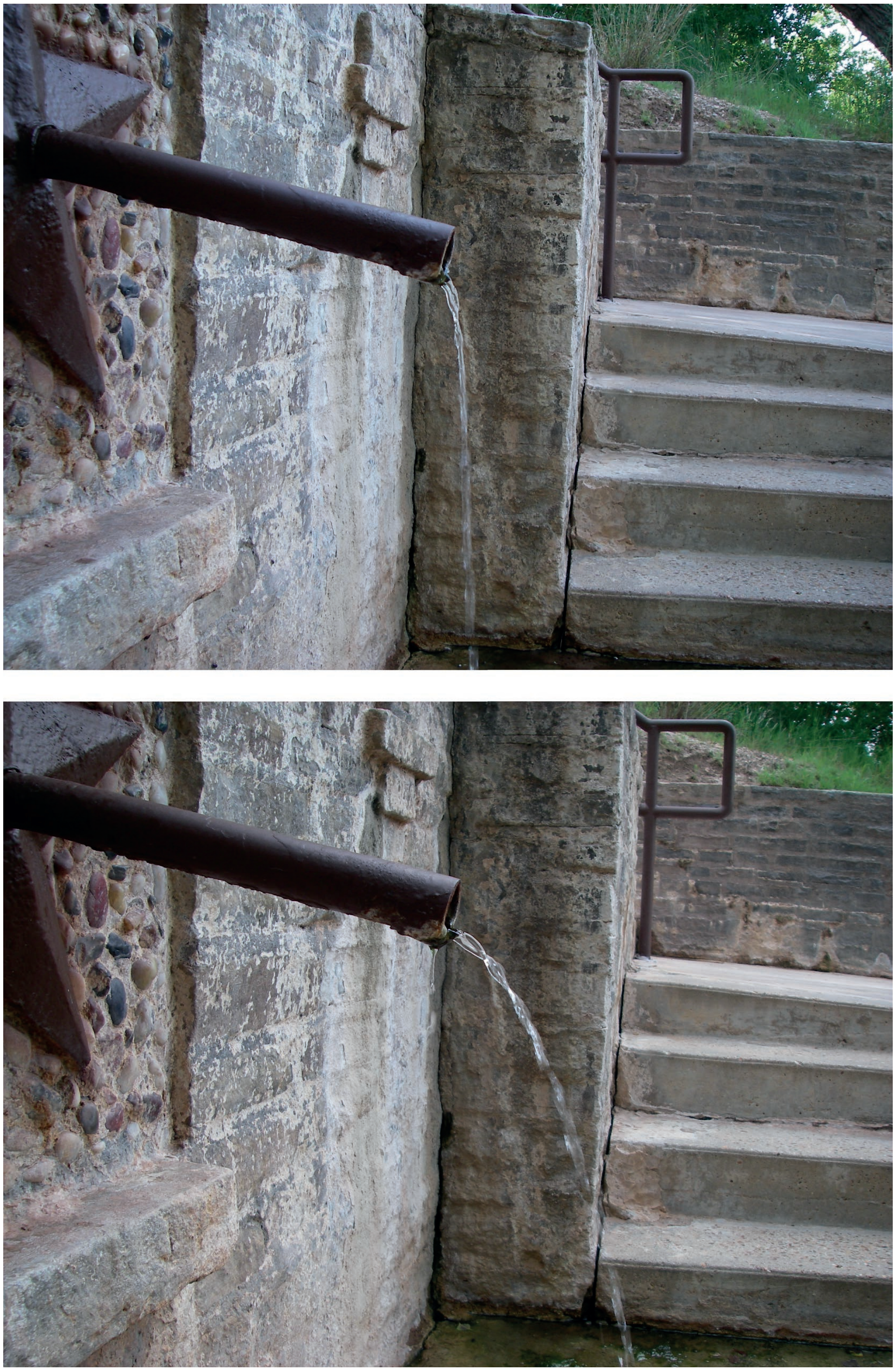

Figure 3. Spring discharge from a pipe that extends through a rock wall into the Ogallala formation at Silver Falls. The upper photo shows a flow of 0.5 L/min on 13 June 2017 and the lower photo shows a flow of 0.8 L/min on 7 March 2016.

intervals with an average of around 16 days between samples. It would have been preferable to sample more frequently to determine if there are detectable flow variations at shorter time scales; however, it was assumed that sampling twice a month was sufficient to establish seasonal and long-term patterns.

Results & Discussion

The full record of measurements obtained at Silver Falls, plotted in Figure 4, stretches from 10 October 2012 to 27 March 2020, a period of more than seven years. Here, flow rates are expressed in units of liters per minute (L/min) and the vertical grid lines mark the start and end of each year of the study.

At first glance, the time series appears fairly chaotic with flow rates varying dramatically over time. Flow rates varied from a low of 0.05 L/min on 18 September 2018 to a high of 0.89 L/min on 21 March 2016 with an overall average (mean) flow of 0.5 ± 0.2 L/min (SD). One possible explanation for the large and seemingly chaotic variations of flow may be that water extractions from the Ogallala aquifer vary from one year to the next in a complex manner as irrigation demands vary with climatic conditions. However, it is difficult to say with any confidence why measured flow rates rise or fall during any given period.

Measured flow rates do not show any obvious long-term reductions associated with the depletion of the Ogallala aquifer, as one might expect. In fact, there is an overall increase in spring discharge from 2013 through 2016 followed by a slight decrease from 2016 to 2019. Perhaps a seven-year sampling period is insufficient to establish long-term trends, which may be more clearly defined over periods of many decades.

A careful inspection of the measured time series, plotted in Figure 4, reveals a discernible seasonal variation of flow for most years, with the exception of 2015. Typically, there are high flow rates during the

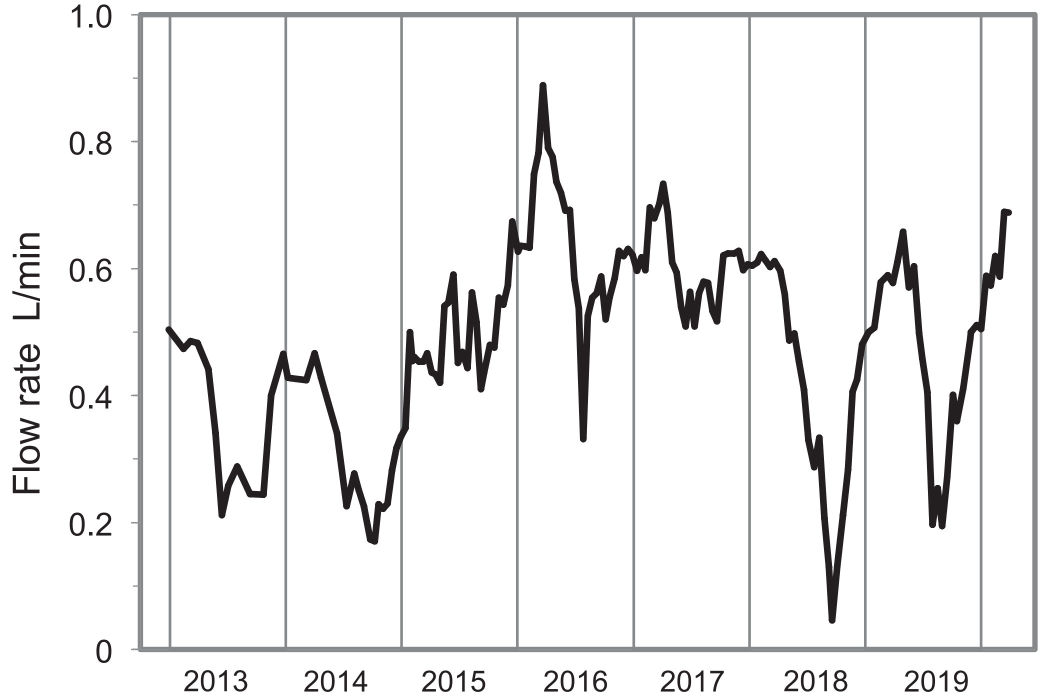

Figure 4. Plot of spring flow rates measured twice a month at Silver Falls.

early portion of each year and a reduction of flow during the latter half of the year. However, seasonal patterns are not clearly defined by plotting the raw data. Consequently, an attempt was made to more precisely quantify seasonal patterns by computing seasonal values of spring discharge through a multi-step process. First, each measured value was assigned to one of four seasons based on the date of collection and the timing of the seasons as defined by the United States Naval Observatory. The full dataset was then sorted by season, forming seasonal subgroups that could be analyzed separately. Season-specific flow rates were then computed by conditionally averaging values for each specific season. The results, presented in Figure 5, suggest that flow is relatively high during winter and spring and relatively low during the summer and fall.

It is possible to define seasonal patterns more precisely by using similar techniques to compute conditionally averaged monthly flow rates. In this case, each measured value is assigned to a monthly subgroup based on the date of collection. The full dataset is then

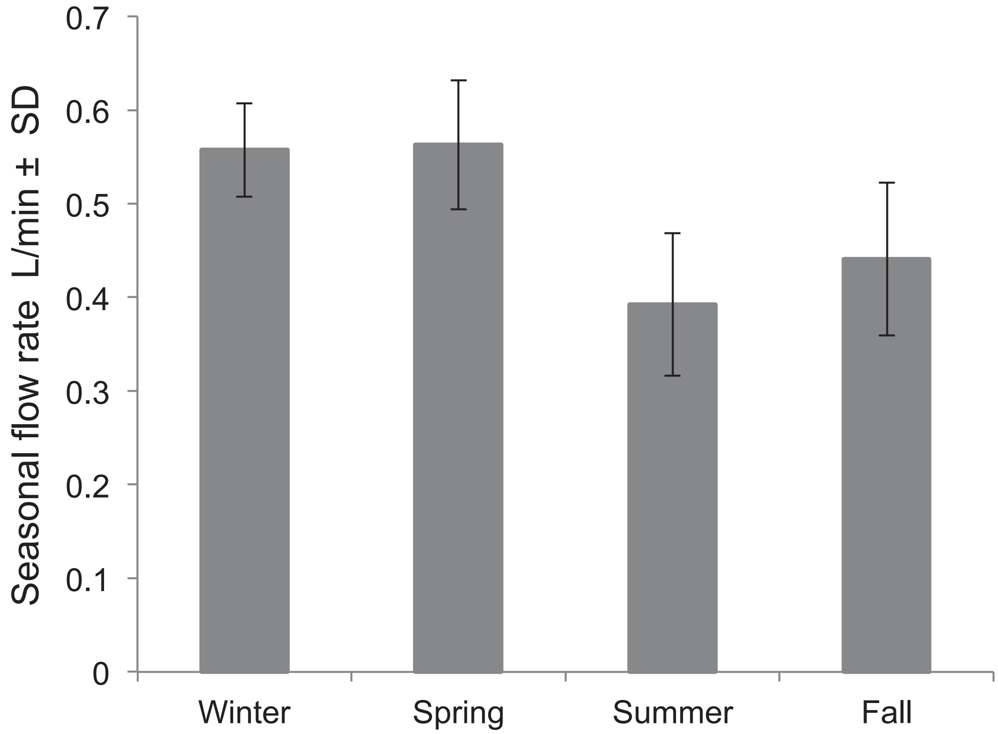

Figure 5. Seasonal average spring flow rates at Silver Falls between 10 October 2012 - 27 March 2020. Each measured value was assigned to one of the four seasons based on the collection date and timing of the seasons as defined by the United States Naval Observatory.

sorted by month and month-specific flow rates are computed by averaging all values within a monthly subgroup. The results of this analysis are presented in Figure 6.

Overall, Figure 6 follows the same general pattern as Figure 5, with more temporal resolution. Results suggest that the distribution tends to peak during the spring months of March and April whereas the lowest flow rates are associated with the summer and fall months of July through October.

It is interesting to note that the distribution of monthly flowrates varies smoothly from one month to the next with the exception of August, which exhibits a slight increase compared to its neighboring months of July and September. The monthly average flow rate for

August is the fourth lowest value but it is slightly higher than one might expect.

Photographic evidence of seasonal patterns.–During each site visit, the author would hike upstream of the park and photograph the streambed of the White River. As mentioned previously, the White River is partially fed by spring discharge and occasionally receives runoff when rain falls within the watershed. Photographs (Figure 7) provided evidence of either a relatively clear spring-fed base flow, a highly turbid stream due to rainfall runoff, or a dry streambed.

A single photograph was selected for each site visit and photographs were sorted into monthly subgroups based on date. The fraction of photos with a spring-fed baseflow were then computed for each monthly subgroup by counting the number of photographs with evidence of spring flow and dividing by the total number of photographs within the monthly subgroup. For the lack of a better

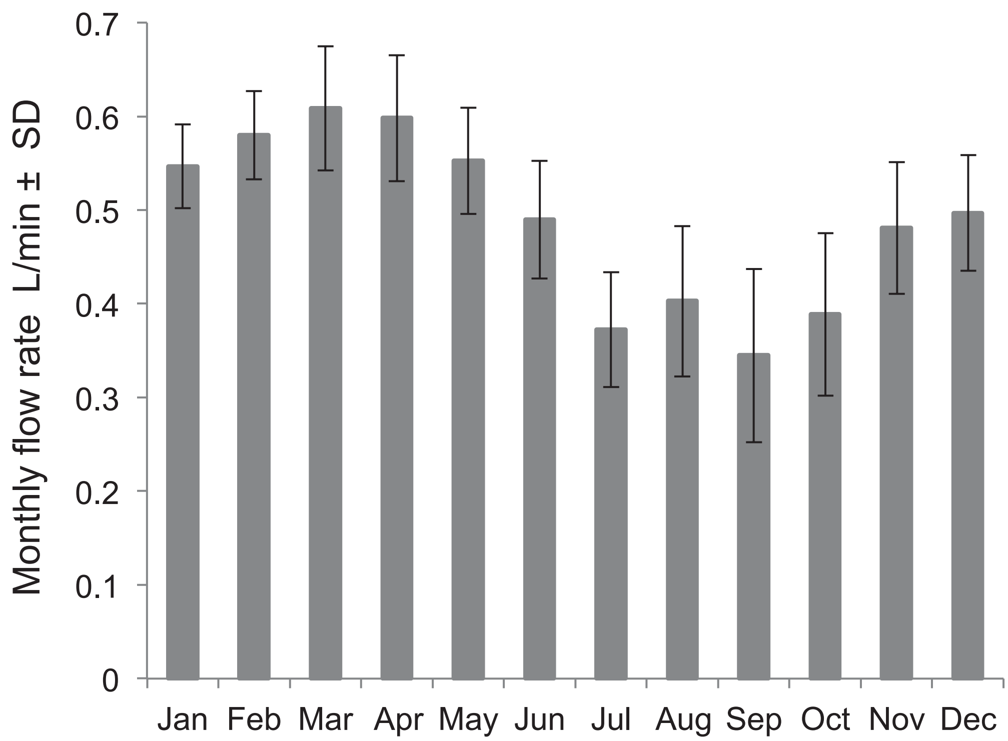

Figure 6. Monthly average spring flow rates at Silver Falls between 10 October 2012 - 27 March 2020.

Figure 7. Photos of the White River streambed upstream of Silver Falls showing a clear spring-fed stream in April 2018 (top) and a dry channel in June 2018 (bottom).

name, this fractional value was called “spring activity”. Thus, a spring activity of 1.0 indicates that all of the photos within the monthly subgroup showed a spring-fed baseflow whereas a spring activity of 0.5 indicates that half of the photos within the monthly subgroup showed a spring-fed baseflow.

The results of this analysis, plotted in Figure 8, suggest that all of the photos taken in February, March, and April showed clear evidence of a spring-fed baseflow whereas none of the photos taken in August and September show any evidence of a spring-fed baseflow. Other monthly subgroups had spring activity values less than 1.0, indicating there was evidence of a spring-fed baseflow in a fraction of the photos. Despite the subjective nature of this photographic method, the overall seasonal pattern depicted in Figure 8 is somewhat similar to that depicted in Figure 6.

Rainfall and spring discharge.–On the high plains of the Llano Estacado, recharge is negligible (Theis 1937; Gurdak & Roe 2010). Thus, rainfall does not appreciably increase the saturated thickness of the Ogallala aquifer nor does it appreciably increase the groundwater discharge of springs flowing out of the aquifer. However, rainfall can have an indirect effect on spring discharge.

Abundant rainfall can reduce irrigation needs (Stout 2018). During periods of plentiful moisture, farmers may decide to turn irrigation pumps off to conserve water and reduce operating expenses. If a sufficient number of farmers stop irrigating and collectively switch to rain-fed crop production then spring discharge may remain at high levels throughout the year. This may explain why there was little if any reduction of spring discharge during the exceptionally wet year of 2015 (Figure 4), when annual precipitation was 60% above normal.

However, it is difficult to draw specific connections between rainfall, irrigation, and spring discharge due to a lack of information regarding irrigation schedules and agricultural pumping rates. Such information, if it exists, is considered proprietary information and is not made available to the public. Nevertheless, it is possible to

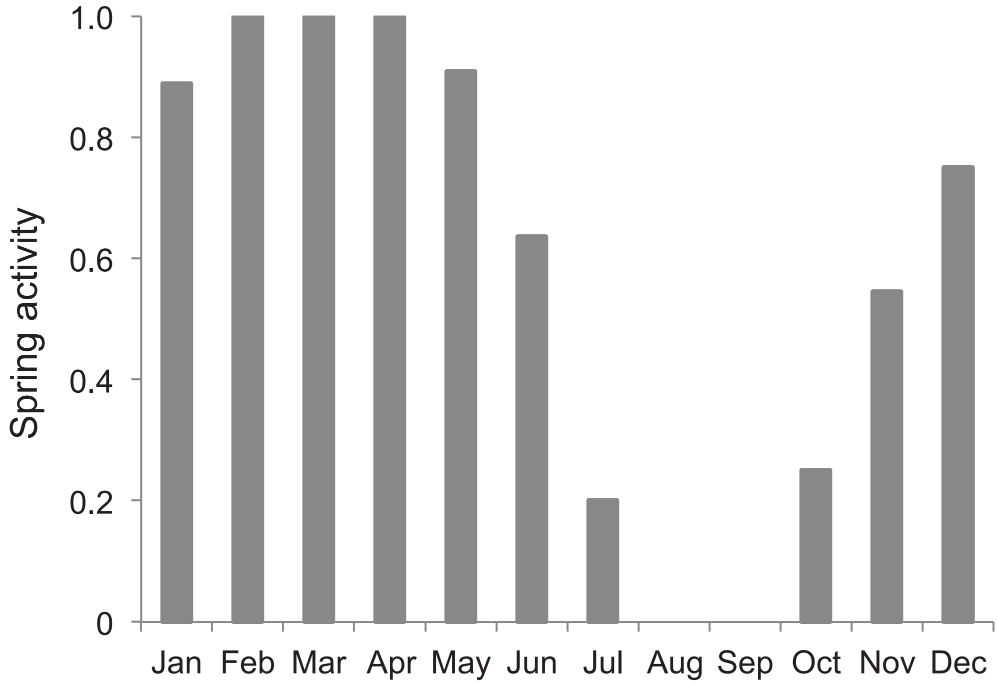

Figure 8. Spring activity based on the fraction of photographs of the White River streambed that provide evidence of a spring-fed baseflow.

quantify seasonal rainfall patterns using data collected in the nearby town of Crosbyton. Daily rainfall observations have been collected in Crosbyton since 1893 as part of the National Weather Service Cooperative Observer Program. As shown in Figure 1, Crosbyton lies near the western edge of Blanco Canyon, which defines the western edge of the White River watershed.

To compute monthly rainfall patterns, daily rainfall observations were sorted into twelve monthly subgroups and rainfall was summed for each monthly subgroup. Then each monthly total was divided by the total amount of rain that fell over the entire sampling period. Thus, each monthly value represents the fraction of rain associated with each of the twelve-monthly subgroups. The results of this analysis, shown in the upper plot of Figure 9, depicts the normal monthly distribution of rainfall in this region. It is interesting to note that the overall seasonal rainfall pattern for Crosbyton is similar to other

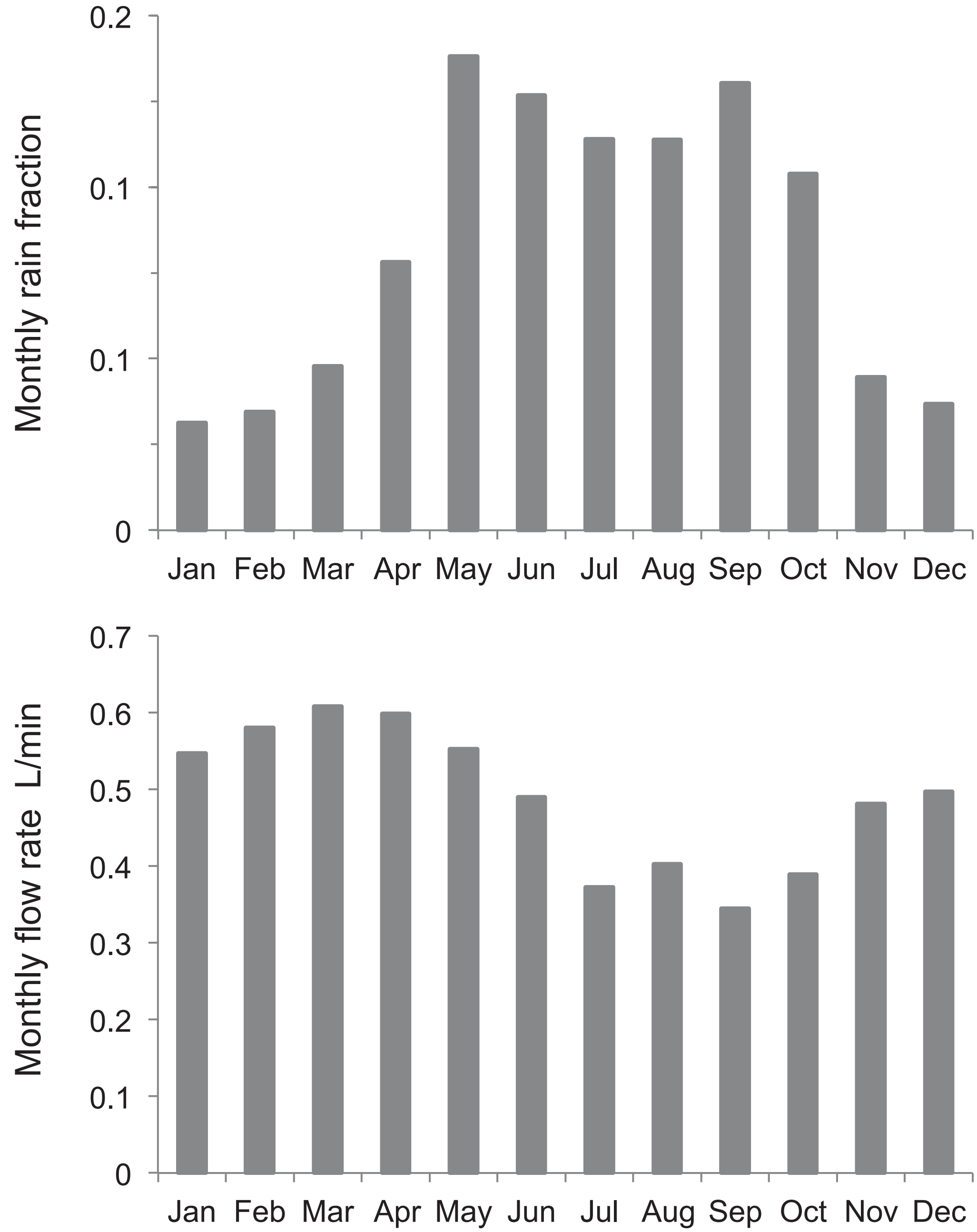

Figure 9. Comparison of monthly rainfall and monthly flow rates at Silver Falls.

locations across the Llano Estacado (Bomar 1983), with peaks occurring in late spring and early summer and a secondary peak occurring in the late summer and early fall. The majority (62%) of annual rainfall is recorded during the five months of May, June, July, August and September, which roughly corresponds to the growing season.

A comparison of the computed monthly rainfall pattern and the distribution of monthly spring flow rates shows that the two distributions appear to be out of sync (Figure 9). When monthly rainfall is increasing to a maximum from April to May, spring discharge is decreasing. During the summer months of June, July and August, rainfall is still above average whereas monthly flow rates are very low and during the month of September, rainfall reaches a secondary peak whereas the monthly flow rate for September reaches a minimum. Thus, a comparison of the annual distribution of rainfall and the annual distribution of spring flow rates appears to confirm that there is a general lack of correlation between spring flows and rainfall.

CONCLUSIONS

Measurements of spring discharge at Silver Falls, taken over a period of more than seven years, do not show an appreciable reduction of flow associated with the depletion of the Ogallala aquifer; however, flow rates were found to follow a seasonal pattern of low flow during summer and early fall followed by a recovery starting in late fall and reaching maximum discharge during winter and early spring.

The interpretation of seasonal discharge curves requires some speculation. Whereas monthly and seasonal spring-discharge curves can be computed precisely from data collected at the site, the cause of these seasonal variations of flow is less certain. Seasonal patterns likely result from multiple causes involving both natural and anthropogenic activity.

With regard to anthropogenic activity, cropland irrigation is probably a key factor. The overall seasonal pattern of discharge at Silver Falls closely corresponds to the "growing season," which typically extends from late spring to early fall. It is during the growing season that crops on the high plains are irrigated. Each year farmers assess soil moisture and climatic conditions and make decisions regarding irrigation scheduling. Farmers make independent decisions; however, they are guided by weather conditions and the need to raise a crop during a specific growing season. Thus, the collective actions of numerous farmers can lead to the extraction of a considerable volume of water from the underlying Ogallala aquifer, which reduces the remaining volume of stored water within the aquifer. It is likely that these seasonal water-table perturbations drive seasonal variations of spring discharge.

With regard to natural causes, it is possible to rule out rainfall as an important factor. Unlike the Edwards aquifer in central Texas, rainfall does not appreciably increase the saturated thickness of the Ogallala aquifer and since springs along the eastern escarpment of the Llano Estacado flow from the saturated portion of the Ogallala formation, it is unlikely that rainfall has a direct influence on groundwater discharge. A general lack of correlation between the annual distribution of rainfall and the annual distribution of spring flow rates appears to support this conclusion. However, it is possible that abundant rainfall can have an indirect effect on spring flows since farmers on the high plains may choose to shutoff irrigation systems when irrigation is not necessary.

Brune (1981) proposed that vigorous plant growth and associated transpiration during the spring and summer months could also lead to seasonal variations of spring discharge. As is typical of the deep canyons etched into the eastern escarpment, the roadside park at Silver Falls contains abundant plant life including large trees as well as many other plant types. These trees and plants can extend their roots directly into the saturated zone of the aquifer and thereby influence groundwater discharge (White et al. 1946). Plant growth and transpiration tend to peak during the summer months, which corresponds to the period when spring flows are weakest.

Thus, it is likely that the combined effects of groundwater extraction for irrigation and the growth and transpiration of local vegetation combine to influence groundwater discharge at Silver Falls. Both irrigation and transpiration tend to peak during the summer months, which directly corresponds to the period when spring discharge at Silver Falls is at a minimum.

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