MULTI-DECADAL FOREST STREAMFLOW BEHAVIOR IN FALLING CREEK, GEORGIA

Todd C Rasmussen and Scott Raulerson

AFFILIATION: UGA Warnell School of Forestry & Natural Resources, Athens GA 30602-2152

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Abstract. We present long-term streamflow datasets (1964 - 2018) for four Georgia Piedmont watersheds. While most watersheds contain a mix of developed, agricultural, and forest uses, over 95% of the Falling Creek watershed contains forests managed by the US Fish and Wildlife Service and the US Forest Service. Peak discharges (normalized by watershed area) are consistent between watersheds, but Falling Creek skews toward lower flows, possibly due to increased evapotranspiration, low-permeability subsoils, numerous gullies and deeply incised channels from legacy cotton farming, or the absence of ponds. Identifying the cause of the poor hydrologic behavior of this forested watershed is needed to guide restoration efforts.

INTRODUCTION

Until its collapse in the 1920s, the Georgia Piedmont was dominated by row-crop agriculture, primarily cotton, which left badly eroded landscapes, depleted topsoil, and deeply incised stream channels (Trimble, 1974). After cotton's demise, these lands were either abandoned to forests or converted to pasture, with only modest efforts to mitigate widespread erosion. The multi-generational effects of soil erosion on a watershed in the Georgia Piedmont are documented in Jackson et al. (2005).

Some of these abandoned lands were acquired by the Federal government, which established national forests and national wildlife refuges including the Oconee National Forest (est. 1959, currently 181 mi^2) and the Piedmont National Wildlife Refuge (est. 1939, currently 54 mi^2) in the Georgia Piedmont that are managed for ecosystem services, including water, wildlife, fisheries, recreation, and wood products.

Use of private lands evolved over time, with numerous small headwater ponds being constructed between the 1950s and 1980s to mitigate erosion and to support livestock and fishing. More recently, urban development has led to increased demands for water supply and wastewater assimilation along with a change in land use from agricultural to development.

As watersheds are reforested, overland flows diminish, thus reducing the amount of sheet and rill erosion. Yet residual gullies and deeply incised channels remain, with continual bank and bed erosion during storm events (Mukundan et al., 2010; 2012). This ongoing erosion is a major source of sediment loads that impair aquatic habitats (Holmbeck-Pelham and Rasmussen, 1997).

In addition, lakes and ponds reduce peak flow and sequester sediments and nutrients (Parker and Rasmussen, 2001; Parker et al., 2003; Zeng and Rasmussen, 2001; Ignatius and Rasmussen, 2015; 2016).

While peak flows from forested landscapes are also expected to be attenuated due to improved soil quality, watershed studies display high runoff curve numbers, likely due to the lasting effects of soil disturbance (Tedela et al., 2012a; 2012b)

The details of these landscape changes are poorly understood due to the lack of reference watersheds (Ssegane et al, 2012a; 2012b). Thus, reference forested watersheds provide the opportunity for evaluating landscape changes over time.

METHODS

Four watersheds were selected from the Georgia Piedmont (Table 1, Figure 1). At least 54 years of daily streamflow data available for each site from the US Geological Survey data portal. All sites are currently in operation. The earliest records began in 1911 on the Flint River, one in 1937, and two in 1964.

Falling Creek near Juliette, GA, is located on a managed forest watershed that lies within the Piedmont National Wildlife Refuge and the Oconee National Forest. Line Creek near Senoia, GA, is a nearby watershed that is similar in size to Falling Creek but has a land use and land cover that is more typical for the region.

The Flint River near Griffin, GA, is another nearby watershed that is about twice the area of Line Creek, and three times the size of Falling Creek. The Flint River near Carsonville, GA, is a larger watershed that has similar land use and cover to both the Flint River near Griffin and Line Creek (Table 1)

Table 1. Georgia Piedmont watersheds examined in this study.

USGS Station Name	USGS ID	Area (km^2)	Lat (ºN)	Long (ºW)	Elev (m)	Start date
Falling Creek nr Juliette GA	2212600	262	33.100	83.724	112	7-Jul-64
Line Creek nr Senoia GA	2344700	347	33.319	84.572	222	1-Sep-64
Flint River nr Griffin GA	2344500	800	33.244	84.429	217	1-Mar-37
Flint River nr Carsonville GA	2347500	5015	32.721	84.233	102	1-Jul-11

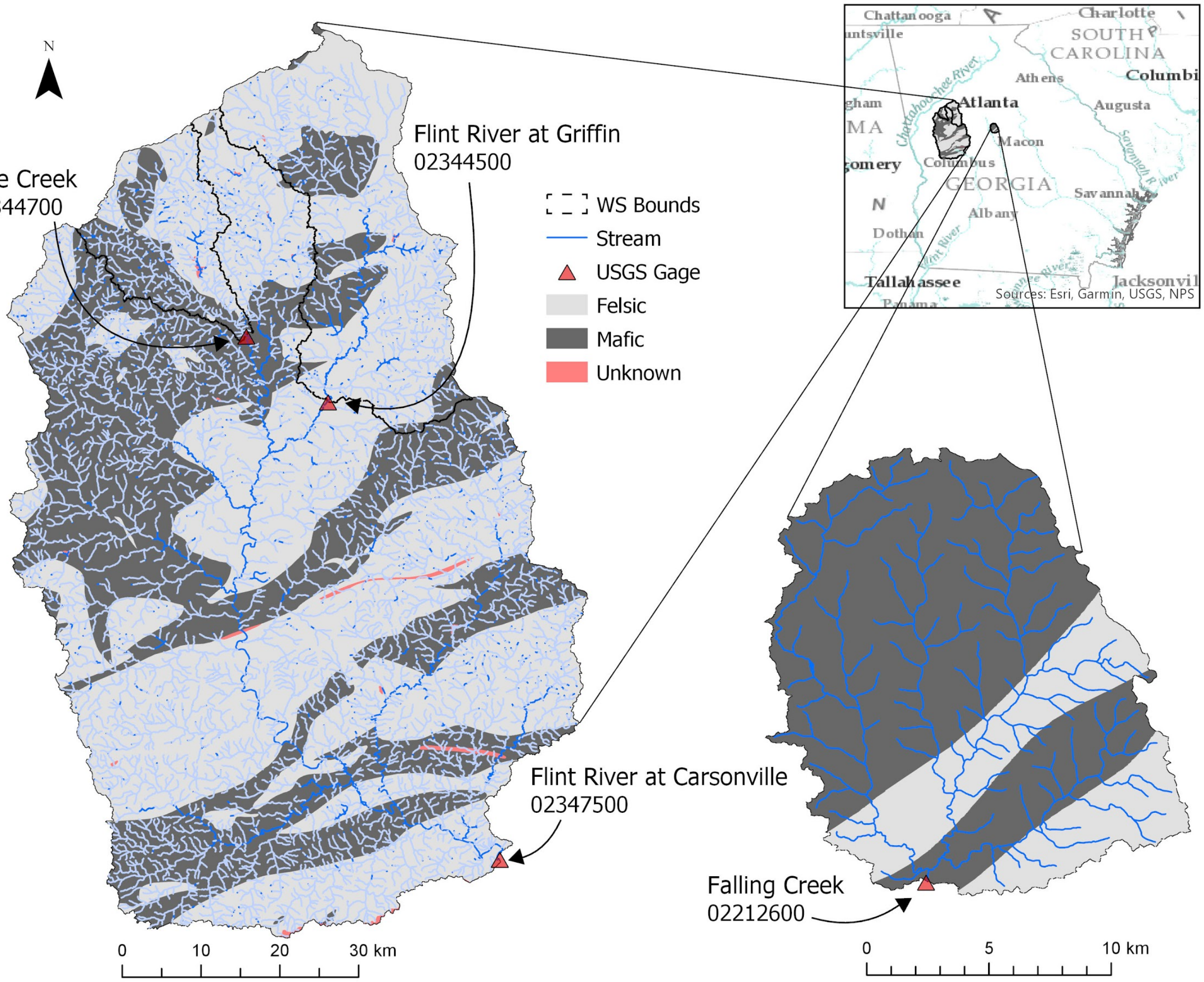

Figure 1. Location map of four Georgia Piedmont watersheds examined in this study. Figure also shows bedrock geologic type, where Felsic rocks tend to weather to acid soils with 1:1 (non-swelling) clays, and Mafic rock tend to weather to basic soils with 2:1 (swelling) clays.

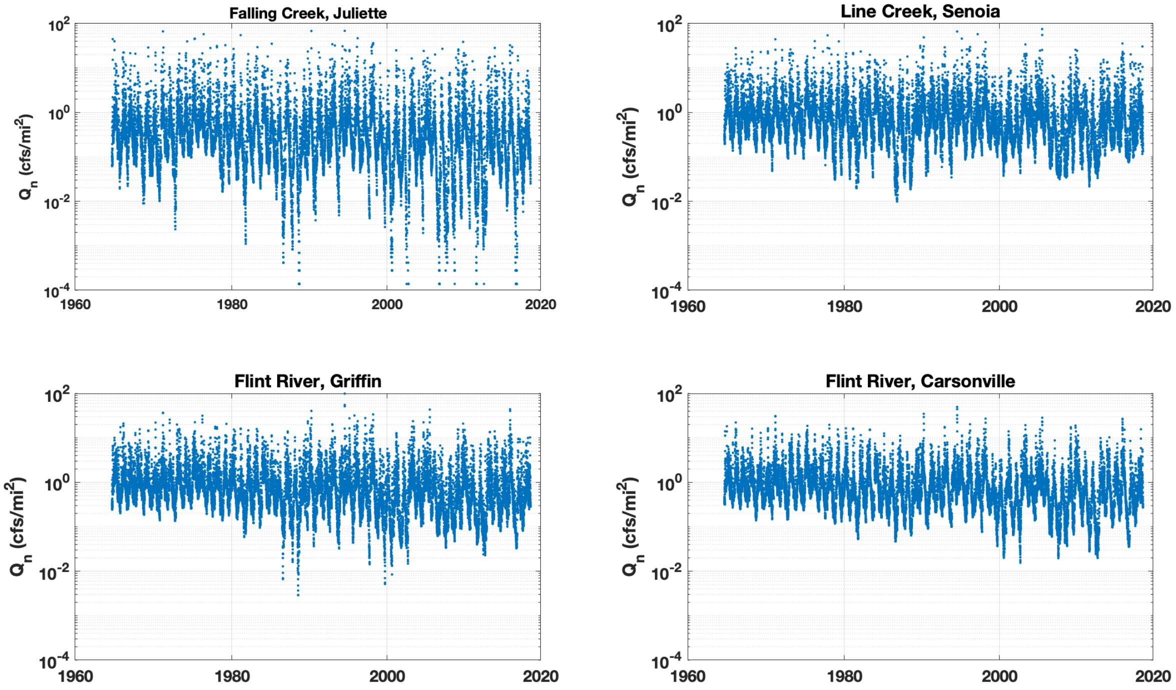

Figure 2. Area-normalized daily mean discharge, Q_n (cfs/mi^2), for four Georgia Piedmont watersheds, 1 Sep 1964 - 31 Aug 2018.

Table 2. Attributes of Georgia Piedmont watersheds examined in this study.

USGS Station Name	**Land Use (%)**			**Bedrock Type**		**# Dam**		**Dam Area**	
	Forest	**Dev**	**Ag**	**Felsic**	**Mafic**	**(#)**	**(#/km^2)**	**(km^2)**	**(%)**
Falling Creek nr Juliette GA	83.8	4.2	1.8	17.6%	72.7%	55	0.21	2.2	0.8%
Line Creek nr Senoia GA	43.6	40.2	11.5	76.2%	23.7%	341	0.98	15.5	4.5%
Flint River nr Griffin GA	35.6	42.2	12.3	56.3%	43.1%	852	1.06	24.0	3.0%
Flint River nr Carsonville GA	55.1	15.9	19.9	59.2%	40.4%	4,418	0.88	108.3	2.2%

RESULTS AND DISCUSSION

Figure 2 presents a 54-yr time series (1 Sep 1964 to 31 Aug 2018, n = 19,723) of area-normalized mean daily discharge for the four Piedmont streams examined in this study. Discharge is plotted on a logarithmic scale so that low flows are more readily observed. Days with zero discharge do not plot on a logarithmic scale, so these values are replaced with 0.005 cfs, which is one-half of the smallest finite observation of 0.01 cfs.

Table 2 summarizes landscape features for the four Georgia Piedmont watersheds examined in this study. Note that while the land-use within the Falling Creek watershed is primarily forested, it has fewer ponds and more mafic soils than the other three watersheds.

Figure 3 and Table 2 summarize the statistical distribution of logarithmic daily discharges for the four Georgia Piedmont stations used in this study. Mean daily normalized discharges are presented as histograms in Figure 4 for these watersheds.

Note that:

- Watersheds have similar peak normalized daily discharges.
- Low-flows tend to occur more frequently during the latter period of record for the Falling Creek Watershed.
- Falling Creek has larger standard errors, skewness, and range of values compared to the other watersheds.
- Normalized flows are more similar between Line Creek and the Flint River than with Falling Creek.

- Line Creek and the Flint River have similar flow distributions even though Line Creek is an order-of-magnitude smaller in area than the Flint River.
- Falling Creek displays a different flow behavior, with greater tailing to the left (i.e., more below-average discharges).

The provocative hydrologic behavior displayed by Falling Creek could have multiple causes. Streamflow is influenced by landscape characteristics, such as climate, topography, geology, soils, vegetation, and land use; with extremal behavior (low, high flows) being especially sensitive to channel and terrestrial components of watershed attributes.

Also, ponds alter hydrologic responses by attenuating peak flow. Another mechanism for altering hydrologic response are soil properties, where clay subsoils can alter drainage and runoff. Non-swelling (1:1) clays tend to maintain their macropores during wet periods, as opposed to swelling (2:1) clays that expand and seal when wetted.

Large peak stormflow from this forested watershed may be due to:

1. Limited infiltration and recharge due to low permeability units within the soil profile along with numerous gullies. Brender (1952) notes that 39% of the soils on the Hitchiti Experimental Forest (which lies within the Falling Creek Watershed) belong to the Vance, Wilkes, and Louisburg soil series, which are either shallow or have compacted subsoils that retard water movement. These conditions limit soil moisture storage, which results in increased overland and shallow subsurface stormflow compared to other soil types.
2. Channel structure, such as incisement and the lack of water storage within stream channels. The hydraulic time of concentration may result, not from overland flow and water delivery to channels, but rather due to high channel velocities.

Possible reasons for the observed baseflow reduction include:

1. Increased evapotranspiration from this mature-forest watershed, which depletes soil water during the prolonged growing season of this warm-temperate climate.
2. Lack of recharge due to poor soil-moisture storage. Groundwater recharge that might normally occur during precipitation events is limited by shallow soils or low subsoil permeabilities.
3. Deeply incised channels that drain groundwater that would normally support baseflow. Lack of groundwater storage due to rapid drainage following storm events may adversely affect water supplies during droughts.

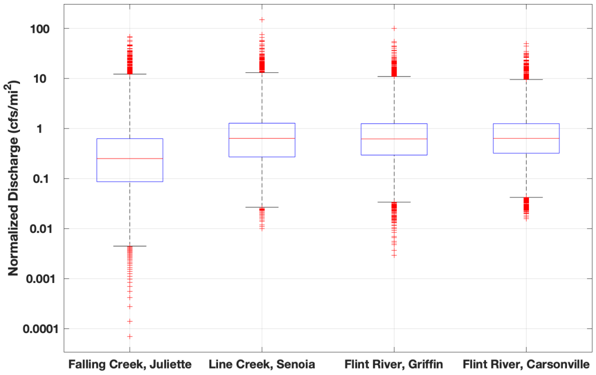

Figure 3. Box plots showing geometric means, standard errors, and extreme values for four Georgia Piedmont watersheds.

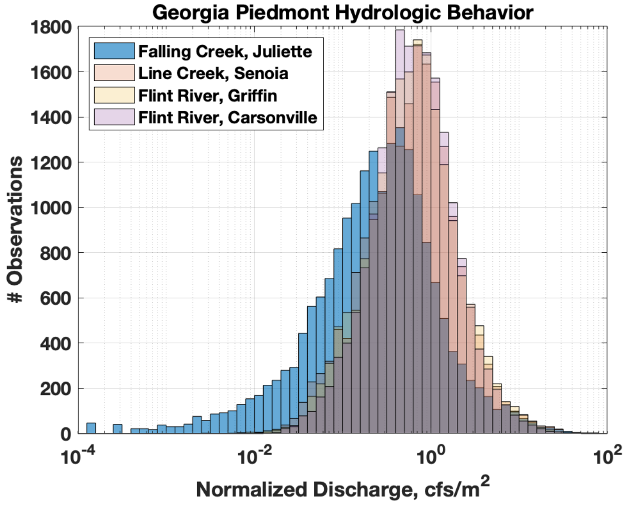

Figure 4. Comparison of flow frequencies between Georgia Piedmont watersheds.

Table 3. Summary statistics of Georgia Piedmont watersheds examined in this study. AVG is geometric mean of daily values, SE is standard error of geometric mean, Skew is skewness of $\log_{10}$-discharges, Range is log-ratio of largest to smallest values.

Watershed	**Discharge (cfs)**			
	AVG	**SE**	**Skew**	**Range**
Falling Creek, Juliette	14.69	0.20	-1.12	6.00
Line Creek, Senoia	59.73	0.51	-0.03	4.18
Flint River, Griffin	164.3	1.36	-0.04	4.53
Flint River, Carsonville	1,161	8.83	-0.02	3.51

CONCLUSIONS

A widely accepted paradigm states that forests moderate peak flows and augment water supplies during droughts. Yet over fifty years of hydrologic data show that a well-managed forest in the Georgia Piedmont has similar unit-peak discharges (discharge divided by watershed area) and has lower baseflow than other, nearby watersheds with greater development and agriculture.

Possible reasons for this behavior include increased evapotranspiration (which does not explain large peak flows), poor drainage due to low permeability subsoils (which increases stormflow and reduces baseflow), deeply incised channels within the Falling Creek watershed (which reduces the time of concentration and lower water tables), and the paucity of lakes and ponds (which intercept stormflow and sustain baseflow during droughts).

Restoring eroded channels and providing additional channel storage would likely decrease peak flows and increase baseflow. Remediating channel structure may reduce peak flows with concomitant channel erosion and sediment transport. While structural remedies may be used to improve channel structure (ponds, check dams), non-structural remedies (e.g., providing beaver habitat) are likely to be more practical and cost-effective. Fostering colonization by beaver and associated vegetation may assist in restoration, and lead to enhanced ecosystem services.

Recommendations for further study include:

- Identifying and characterizing the hydrologic behavior of nearby Georgia Piedmont watersheds with varying soil types, land cover and uses;
- Characterizing Falling Creek channels with respect to their dimensions, woody debris, and fish and wildlife abundance;
- Identifying vegetation that supports beaver habitat; and
- Tracking channel changes as well as beaver and aquatic species diversity and abundance over time.

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