WHERE HAS ALL THE WATER GONE? EXAMINING HYDROLOGIC CHANGE AND HUMAN RESPONSE IN THE UPPER FLINT RIVER, GA

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Abstract. Recent droughts have elevated concerns about water security in Georgia and the southeastern US. Given uncertainty, there is a need for systematic assessment of hydrologic change and recognition of biological responses. We used long term climate and stream flow data to assess hydrologic change in the upper Flint mainstem based on a period of 1940 to 2016. Annual rainfall averaged 55-56 inches per year and did not show a consistent trend during the record. Metrics of minimum flows (1-day, 7-day, and 30-day) did show significant declines since the mid-1970's. Median monthly flows were also reduced throughout the year since the 1970's. The specter of increasing water scarcity in the upper Flint presents a difficult challenge. The approach taken in the upper Flint has been largely voluntary, facilitated by regional and national conservation advocacy organizations working with water utilities and stakeholders within the Upper Flint River Working Group (UFRWG). The responses to water scarcity are utility-specific but fall into several general categories including improving water efficiency and conservation, increasing return flows of treated wastewater, and improving storm water management through development of urban green infrastructure.

INTRODUCTION

Humans, through both direct (extraction, storage, release) and indirect (land-use and conversion, climate change) actions, are probably the greatest cause of stream flow alteration globally (Poff and Zimmerman 2010). Stream flow is acknowledged as a "master" variable that controls the ecological structure and function of streams and rivers (Poff and Zimmerman 2010). Researchers generally think of stream flow as a pattern, using multiple variables to quantify the magnitude, duration, frequency, timing, and rate of change in both common and uncommon events (i.e., low flows, base flows, and flood pulses) (Poff et al. 2010). This complicates evaluations of human water extraction on rivers, as it is generally desirable to base assessments on a limited number of variables with known ecological effects. Also, water management strategies based on a few easily measured response variables are more likely to be successfully implemented.

While researchers are concerned about patterns of stream flow, water managers tend to be concerned with water volumes and yields, often expressed at a monthly or annual scale. Unfortunately, managing streams and rivers for water yield does not assure adequate flow patterns to support biotic diversity or stream ecosystem function. Conversely, the use of multiple variables quantifying flow regime does not lend itself well to the needs of water managers who are more concerned with issues of predictable supply. This disconnect between the way researchers and managers view streams has been an impediment to developing sustainable water management.

Recent droughts have elevated concerns about water security, i.e., the ability to provide for public supply and support in-stream requirements for healthy biota and associated ecosystem services. These concerns are amplified in Georgia and the southeastern US by projections of increasing population, increasing temperatures, and variable precipitation. Given uncertainty, there is a need for systematic assessment of hydrologic change and recognition of biological responses.

The occurrence of four substantial climatic and hydrologic droughts since 1998 has raised acute concerns in the upper Flint River Basin where low flows of unusual duration and magnitude have been observed since the late 1990's. The main stem of the Flint River is undammed from its source southward throughout the Piedmont and well into the Coastal Plain, making it one of only 42 river segments in the lower 48 states running for more than 125 miles (200 km) without obstruction by a dam (Benke 1990). The absence of mainstem reservoirs stands in contrast to the numerous impoundments throughout the system's tributary network. In addition to being an important water supply, the Flint River is noted for its biological and habitat diversity (Upper Flint River Working Group 2019).

In response to droughts and stakeholder concerns about low river flows, the Upper Flint River Working Group (UFRWG) was convened in 2013. Representatives included conservation/advocacy organizations, water utilities, and stakeholders in the upper Flint. The group's purpose is "… to keep the upper Flint River and its tributary streams flowing to protect the social, ecological, recreational, and economic values the river system provides" (UFRWG 2019). Participation in the UFRWG is voluntary, choosing to build resilience through cooperation rather than assign blame and foster competition for water resources (UFRWG 2019). Researchers from within and outside the basin have been engaged by the group at various stages to provide technical information relevant to group concerns. This paper describes the climatological and hydrologic status of the upper Flint Basin, provided to the group for context in discussing water management challenges. It also provides a brief overview of how the UFRWG used this information as a catalyst for response.

SITE DESCRIPTION

The Flint River originates in metro Atlanta and flows southward 350 miles to its confluence with the Chattahoochee River, in southwestern Georgia. The upper Flint Basin is an 1850 mi^2 area originating in southwestern Metropolitan Atlanta and extending to the Fall Line separating the Piedmont from the Coastal Plain between Macon and Columbus. The northern part of the basin is urban and rapidly developing suburban. The lower portions are largely rural, with forest and pastureland, row cropping, and quarrying. Rainfall averages just over 55 inches across the upper Flint, being slightly greater in the northern most areas compared to the southern portion (Emanuel and Rogers 2013, Figure 1). The upper Flint River is an important water source for the region through both direct withdrawals and reservoir storage. Monthly maximum average permitted withdrawals are 140.3 MGD or 217 CFS (Emanuel and Rogers 2012).

METHODS

We obtained rainfall and temperature data from the NOAA National Centers for Environmental Information (NCEI) online climate archive (ncdc.noaa.gov/cag). Data are available for a variety of geographic regions. No single geographic division corresponds with the upper Flint River Basin. Therefore, we chose to present data from North Central Georgia (region 2) as representative of the region. To conform to streamflow analysis, we chose 1940-2017 as our period of record.

For hydrologic analyses we used long term daily flow records from the Carsonville USGS streamflow station (02347500, usgs.gov/centers/sa-water) to examine potential changes in hydrologic characteristics. Hydrologic analyses were conducted using Indicators of Hydrologic Alteration Software (IHA, conserveonline.org/workspaces/iha). Software settings were non-parametric analyses, water-year data, and two periods of interest (1940-1974, 1975-2011).

For statistical analyses we compared annual and 1-day minimum flow for the period of 1940-1974 to 1975-2017. The later period represented rapid water resource development and population growth in throughout the basin. Comparisons were made using Rank Sum Tests (Sigmaplot 13.0) since data seldom met the assumptions of a normal distribution. Rainfall and temperature data are provided without statistical inference although locally-weighted scatterplot smoothing (lowess) was used as a visualization technique.

RESULTS

Rainfall in the upper Flint Basin averaged 55.5 inches per year (Figure 1). There was no obvious trend in annual rainfall totals over the period of record (1940-2017). There was an extended period of above normal rainfall (1960-1980). From 2000 to 2017 most years were below the long-term average and the period included three severe droughts (1999-2001, 2006-2008, 2010-2012, and 2016). Average annual temperature was 58.6ºF over the period of record. From 1960 to 1980 temperatures tended to be below the long-term average. Since 1980 there has been a trend towards increasing average annual temperature and increasing inter-annual variation in annual temperature. Since 2000, only 2 of 17 years have been below the long-term average, with eight years being 1-2ºF above.

Average annual discharge in the Flint River at Carsonville ranged from ~660 to 3800 CFS. All annual averages below 1000 CFS occurred after 1975. The median annual average discharge declined ~20% during 1975-2017 (1924 CFS) compared to the earlier period (1940-1974; 2392 CFS) ($p=0.04$). The 1975-2017 period was also characterized by a greater range of average annual discharge. One-day minimum flows showed substantial declines from 1940-1974 to 1975-2017. Prior to 1975, only 2 years had one day minimum flows < 100 CFS (1942, 1955; 98 and 97 CFS). Post 1975, 13 years had 1-day minimum flows < 100 CFS, with the least occurring in 2002 with a 1-day minimum flow of 29 CFS. Median 1-day minimum flow declined significantly 320 to 179 CFS ($p < 0.001$).

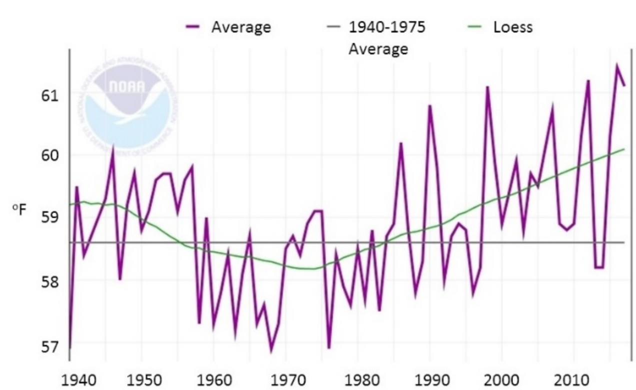

Figure 1. Average annual rainfall in North Central Georgia, 1940-2017. Data from NOAA, Climate at a Glance.

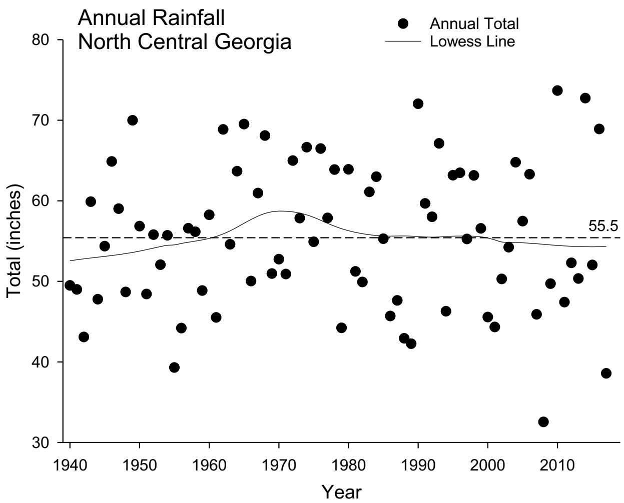

Figure 2. Average annual temperature in North Central Georgia, 1940-1974. Data from NOAA, Climate at a Glance.

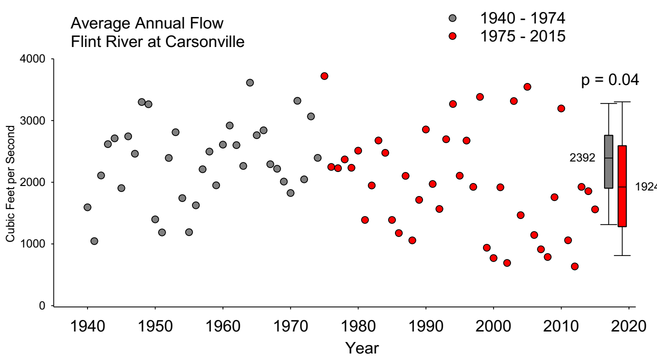

Figure 3. Average annual discharge in the Flint River at Carsonville GA, 1940-2017. Data from US Geological Survey.

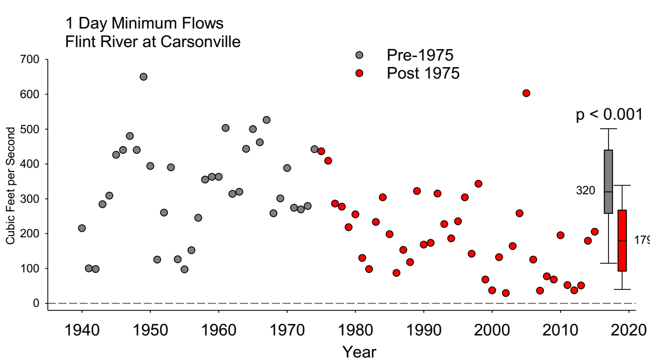

Figure 4. One day minimum flow in the Flint River at Carsonville GA, 1940-2017. Data from US Geological Survey.

DISCUSSION

Our analysis indicates that substantial hydrologic alteration has occurred in the upper Flint River and is reflected in lower flows. One-day minimum flows have been substantially affected but declines are also apparent in annual flow. Seasonal minimum flows typically occur during the growing season (Emanuel and Rogers 2013) making recent declining flows stressful to aquatic life, particularly during recent droughts. Under generally accepted climate change scenarios, warmer temperatures along with possible decreasing or increasingly variable rainfall will result in a continuing trend of hydrologic alteration (Sun et al. 2013). Projections of increasing human populations, along with greater evapotranspiration rates under warming scenarios (e.g., Hwang et al. 2018), suggest ongoing stress on water resources in the upper Flint Basin and regionally. Therefore, it is reasonable to expect a trend towards increasing water scarcity and low stream flows during dry and drought periods.

Reduced summer stream flow and increased stream temperature have implications for ecological communities in the river. Freshwater mussels, a group of concern in the Flint River, have experienced declines in abundance associated with dry and drought flows (Golladay et al. 2004, Emanuel and Rogers 2013). Ongoing declines in sensitive mussel species would be expected to continue. Similar changes have been observed in mid-western streams during shifts in climatic conditions (Allen et al. 2013). Shifts in fish assemblages would also be expected and flow sensitive species would likely show the greatest declines in response to unusual low flows (Freeman et al. 2012). Shoal bass (*Micropterus cataractae*) populations, an iconic endemic and important game species, could be particularly susceptible to low flows and increased stream water temperatures (UFRWG 2019). In addition to direct ecological effects, low flows would reduce the seasonal volume of water available to receive permitted discharges. Increased discharge concentration, along with ecological changes may alter river assimilative capacity and increase water treatment costs for downstream users. And, the resiliency of water suppliers" ability to meet customer needs may be challenged.

The likelihood of increasing water scarcity in the upper Flint presents a difficult challenge. Water managers are being asked to provide more water (meet projected growth in water demand), while maintaining or improving stream health (reducing low flows), under projections of uncertain water availability (rainfall variability, increasing ET, changing drought frequency or severity). As managers realize the difficulty of confronting challenges from within a single organization, a coordinated approach to problem solving becomes more appealing (Schultz et al. 2015). This makes the UFRWG's stated mission of critical importance to all concerns in the upper Flint Basin. The strategy of restoring resiliency is much more robust than simple implementation of water conservation measures within a water utility. In its theoretical development, the concept of resilience recognizes that "human" and "natural" systems are actually integrated Social-Ecological Systems (SES) with inherent variability (e.g. Chaffin et al. 2014). This notion shifts responsibilities for management/governance from one of limiting change to one of building mechanisms to cope with, adapt to, and allow for change to occur (Chaffin et al. 2014). Problems like "water scarcity" can be viewed at a bioregional or "problemshed" scale that crosses administrative or political boundaries. Promoting resilience is also more likely to encourage cooperation rather than competition and the UFRWG is an excellent emerging example of this approach.

A number of approaches have been suggested or are in the process of being implemented to promote resilience in the upper Flint River (e.g., UFRWG 2019). Among these are better early recognition of drought conditions and faster responses in reducing water use when faced with potential scarcity. The Flint River is already part of a NOAA-NIDIS Drought Early Warning System (www.drought.gov/drought/regions/dews) indicating that a great deal of climate and stream-flow monitoring capability is already in place. This information can allow water managers to more aggressively initiate water conservation measures before water availability reaches critical thresholds. Earlier or coordinated conservation actions might have reduced drought effects observed on stream flows during recent dry and drought periods (e.g., Emanuel and Rogers 2013).

Another important axis of building resilience is to reverse known practices that have been and remain contributors to altered flows. Water utilities participating in the UFRWG have different characteristics and are thus pursuing opportunities that make sense relative to their respective water, waste water, and storm-water systems. Within the context of the UFRWG they fall into several general categories including improving water efficiency and conservation, increasing return flows of treated wastewater, improving storm water management through development of urban green infrastructure (UFRWG 2019). As conservation volumes and "return" volumes build, other opportunities are created; additional consideration is being given to alterations in reservoir management, land protection, and implementation of greenways at a landscape scale. Details of these actions are provided by UFRWG (2019).

A large shift in water management philosophy has been in the handling of treated waste water. Until recently, there was a preference for land application or non-potable water reuse, or directing waste flows to larger receiving waters in adjacent basins. Participants in the UFRWG have become aware of the greater value of returning highly treated waste water to support river base flows and are planning accordingly (UFRWG 2019). Also emerging from conversations within the UFRWG have been recognition of information needs and research priorities. The UFRWG is an unusual collaboration between the management and research communities. Among the needs identified include better indicators of river function and restoration, model development to evaluate water conservation and management strategies, and field scale evaluation of green infrastructure to assess hydrologic outcomes (UFRWG 2019). The cooperative nature of the UFRWG facilitates research support and information dissemination.

For the upper Flint and other southeastern rivers, potential problems associated with climate change and increasing water demands have become critical societal concerns. The approach taken in the upper Flint has been largely voluntary, facilitated by regional and national conservation advocacy organizations, and has proceeded productively to date in the absence of direct participation by state government or regional environmental management agencies.

State government has not been involved in the UFRWG, and the success thus far of this "bottom-up" approach reflects, in large part, the ongoing lack of any meaningful or effective instream flow policy-making on the part of state government.

Inherent in this "bottom-up" approach is the direct engagement of river basin stakeholders and water managers on the ground within the basin over a period of many years. The ability to recognize and pursue mutual interest is undoubtedly not unique to the upper Flint Basin (see Schultz et al. 2015). Perhaps it is a model that other river basins should consider in addressing water scarcity.

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