Using the Sustainable Boundary Approach (SBA) to assess and develop flow guidelines: the Flint River, Georgia

Stephen W. Golladay[1] and David W. Hicks[2]

Affiliation: [1]Associate Scientist, [2]Scientist, Joseph W. Jones Ecological Research Center, 3988 Jones Center Drive, Newton, Georgia, 39870, 229-734-4706.

Reference: McDowell RJ, CA Pruitt, RA Bahn (eds.), *Proceedings of the 2015 Georgia Water Resources Conference*, April 28-29, 2015, University of Georgia, Athens.

Abstract. Recent droughts over the past 15 years 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, increasing agricultural production, and uncertain precipitation. We used the Sustainable Boundary Approach (SBA) to assess and develop flow guidelines using data from two long-term USGS gauging stations on the Flint River. The analysis showed substantial declines in daily flows during April through October in the past 30+ years. The Flint River appears at risk for moderate to severe ecological degradation due to flow alteration. Biota and ecological processes depending upon historic summer flows appear to be at greatest risk. Sufficient technical information exists to guide initial management responses and a stream-flow monitoring network is in place to provide feedback. The challenge lies with engaging diverse social and economic interests in a formal process leading to provision of stream flows that sustain ecological structure and function.

INTRODUCTION

Stream flow is considered a 'master' variable that controls the ecological structure and function of streams and rivers (Poff and Zimmerman 2010). There is no single measurement that can characterize stream flow. Instead, it is generally described 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) (Olden and Poff 2003, Poff et al. 2010). The underlying assumption of this approach, termed 'environmental flows', is that the maintenance of hydrologic diversity sustains the structure and function of streams and rivers even with water extraction (Poff et al. 2010). This, in turn, is assumed to promote ecosystem services (e.g., assimilative capacity, recreation, fisheries) beyond simple water supply. In essence, this views rivers as legitimate water-users or 'stakeholders' in management strategies (Gao et al. 2009). Assessment of hydrologic change requires long-term, continuous, stream-flow records spanning climate variability and preceding extensive resource development, often 15-20 years. Metrics chosen for analysis must have known ecological relevance to the biota of particular streams (Olden and Poff 2003, Poff et al. 2010). Ideally, an ongoing commitment to hydrologic monitoring is essential in evaluating strategies for water withdrawal. These requirements are seldom met.

The methodologies for characterizing riverine hydrologic regimes are well developed (e.g., Olden and Poff 2003, Gao et al. 2009). However, information concerning biotic responses to altered stream flows is site specific and often lacking. Olden and Poff (2010) reviewed recent studies of biological responses to flow alteration. They noted that alterations of flow frequency, magnitude, and duration generally had negative effects on macroinvertebrates and fishes but varied across taxonomic groups. Thresholds for biotic responses were difficult to identify due to scarcity of data across a range of flow magnitudes (Olden and Poff 2003). Studies of functional responses (i.e., changes in production, nutrient cycling) to flow alteration were almost entirely lacking. Another limitation of environmental flows methodology is the complexity of metrics used to evaluate flow alteration. Complex metrics can be challenging to incorporate into guidelines for timing and magnitude of water withdrawals or releases. Together, poor understanding of biological responses and complexity of hydrologic metrics have hampered the adoption of environmental flows methodologies in river management guidelines (Richter et al. 2011).

An alternative to full implementation of environmental flows methodology has been proposed in areas where biological response information is lacking and immediate action is warranted. The Sustainable Boundary Approach (SBA) uses allowable percentages to determine the extent of hydrologic alteration specified on a daily or seasonal basis (Richter 2009). Using a combination of stakeholder consensus and expert-opinion/evidence, allowable upper and lower boundaries are established based on acceptable deviations from average daily flow (Richter 2009). The SBA approach has been further developed with the introduction of a 'presumptive standard' for environmental flow protection (Richter et al. 2011). The authors argue that sufficient technical information is available to set presumptive flow guidelines, generally modifications of $< 20\%$ of daily flow, to ensure 'high' to 'moderate' levels of ecological protection. Richter et al. (2011) suggest that the adoption of presumptive standards provides better guidelines for management than ignoring environmental flows or waiting for sufficient technical information to become available.

In the Flint River Basin, water is withdrawn for municipal supply, irrigation, industry, and power generation. In the upper Flint (Piedmont region), most water is derived from surface sources (mainstem, tributary reservoirs, or tributary withdrawals). A combination of surface and groundwater sources supply water in the lower Flint (Couch et al. 1996). Water use throughout the basin began expanding rapidly in the 1970s. In the upper basin, increases were due largely to expanded public supply in metro-Atlanta and surrounding suburban areas. In the lower basin, demand increased rapidly with the adoption and expansion of center-pivot irrigation during the same period (Couch et al. 1996). Water resource development occurred without systematic efforts at assessing potential hydrologic alterations in the Flint mainstem or its major tributaries. In the Flint River, like many river systems, the development of water management guidelines is hindered by the lack of systematic assessment of hydrologic change and lack of information concerning biological responses. In the lower Flint, stream flows are declining during the peak growing season, particularly during seasonal or climatological dry and drought periods (Rugel et al. 2012, Emanuel and Rogers 2012). Throughout the Flint Basin, recent stream flow declines during dry periods greatly exceed those during similar periods in the historic record. We use the Flint River as an example of how the SBA and Presumptive Standard approach might be useful in assessing hydrologic alteration and initiating water planning in the absence of detailed studies of hydrologic alteration and ecological response.

Study Site. The Flint River originates in southwestern Atlanta GA and flows southward 350 miles to its confluence with the Chattahoochee River near the state line. In total, the Flint River drains approximately 8,460 mi2. The basin is largely rural with about 44% forest, 39% agriculture, and 7% urban (LaFontaine et al. 2013). Annual rainfall averages 50 inches basin wide, being slightly greater in southernmost and northernmost areas compared to the east central region (range 45-55 inches) (Couch et al 1996).

Land-use and water-use vary across the basin. In the lower Flint, row crop agriculture is the predominant land and water user. Between 1970 and 1980, the lower Flint saw a rapid increase in agricultural water use. Irrigated acres increased from 130,000 in 1976, to 261,000 in 1977 (Pollard et. al 1978). By 1980, irrigated farmland had increased to more than 452,000 acres and presently is reported to exceed 650,000 acres (Georgia EPD, 2009 Wetted Acreage Database). Moving northward in the basin, agriculture remains an important land use. However, since the early 1980s urban areas have expanded from 1.4 to 5.1 % of land area with concomitant increases in human population of 1.0 to 1.3 % per year (Georgia EPD-DNR 1997). Population increases of 63% are projected for the upper basin between 2010 and 2050 (Emanuel and Rogers 2013). Total water use in the Flint River Basin is projected to increase from 1,133 million gallons per day (MGD) in 2010 to 1,305 MGD in 2050 (Lower Flint Ochlockonee Watershed Council 2011, Upper Flint Watershed Council 2011). The mainstem of the Flint River has a number of long-term USGS gauging stations along its length. The period of record for most of these stations begins in the 1940s to 1950s and is generally continuous to present. The Flint River is largely unregulated with two run-of-the-river reservoirs along its length.

METHODS

We used daily flow data from USGS gauging stations as a basis for the SBA and Presumptive Standard analysis (Richter et al. 2011). The Carsonville Station (USGS 02347500) is located southwest of Macon, GA and is considered in the physiographic transition between the upper Flint (largely Piedmont) and lower Flint (Coastal Plain). The Newton Station (USGS 02353000) is located in Newton, GA on the central Dougherty Plain. For calculations, average daily flow data were obtained from the station website (accessible at ga.water.usgs.gov). We calculated median average daily flow for each day of the year for various periods (below) in SBA calculations. Median values are less likely to be strongly biased by high or low flows that have a recurrence interval greatly exceeding the interval of analysis. Upper and lower boundaries for SBA were calculated as the median daily flow ± 20% (i.e., presumptive standard, e.g. Richter et al. 2011). Data from WY 1940-1974 were used to estimate 'pre-alteration' conditions; WY 1975-2012 represented 'altered' flows.

RESULTS

Seasonality of stream discharge is apparent in both the upper and lower Flint River (Figure 1). December through April is a period of rising and generally greater daily flow while June through November flow tends to be lower. Winter discharge also shows a greater range of variation, reflecting the combination of frontal induced periods of rainfall and low evapotranspiration rates.

Median daily flow for the altered flow period shows substantial departure from the pre-alteration period at both gauging stations. From April through mid October for WY 1974-2012, median daily flows are often at or below the lower SBA boundary. Even during winter, when the WY 1974-2012 flow generally resided within the SBA band, median daily flow seldom equals or exceeds the pre-alteration median value. This analysis suggests that hydrologic alteration has occurred throughout the Flint River and is reflected in lower flows, particularly during late spring and summer.

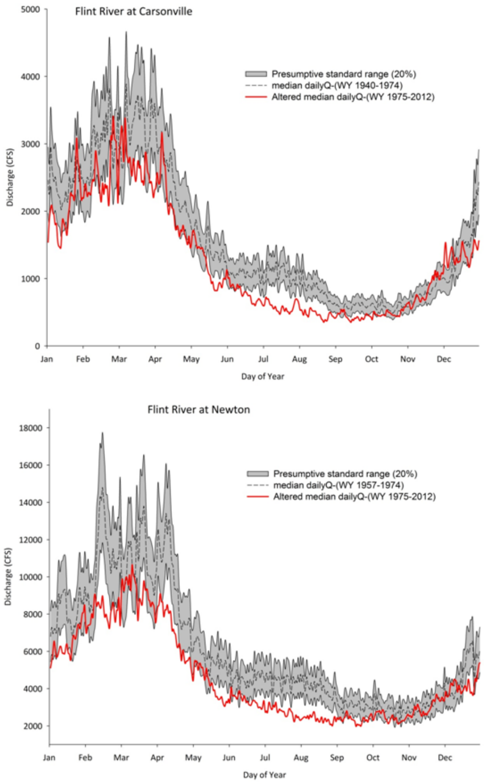

Figure 1: Examples using the Sustainable Boundary Approach to determine a presumptive standard for USGS gauging stations on the Flint River, GA.

DISCUSSION

This analysis suggests that substantial hydrologic alteration has occurred in the Flint River and is reflected in lower flows, particularly during late spring and summer. 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). Based on climate projections, it is reasonable to expect lower growing season flows and lower stream flows during dry and drought periods. If current rates of water use persist (*per capita use*) then increasing human population predicted for the region would create additional stress on water resources, exacerbating climate effects.

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 2012). 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). In the lower Flint, elevated stream temperatures are associated with the displacement of native crayfish by an invasive species (Sargent et al. 2011). 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 endemic but important game species, would be particularly susceptible to low flows and increased stream water temperatures (Emanuel and Rogers 2012). Also, in the lower Flint, the Gulf Strain of Striped Bass (*Morone saxatilis*) depends on groundwater springs and seepage areas as thermal refugia (van den Avyle and Evans 1990). Reduced summer stream flows and corresponding reduction in groundwater flows could reduce access to and availability of critical cool-water refuges. In addition to direct ecological effects, low flows would reduce the seasonal volume of water available to receive permitted discharges, these along with ecological changes may alter river assimilative capacity and increase water treatment costs for downstream users.

If one accepts the underlying assumptions of the SBA concept and Presumptive Standard Approach, then the Flint River appears to be at risk for moderate to severe ecological degradation due to flow alteration. Biota and ecological processes depending upon historic summer flows appear to be at greatest risk. Several actions could be considered immediately to address risks associated with extended periods of low flows. Since increasing the availability of storage reservoirs is expensive and may be geologically challenging (Sun et al. 2013), efforts at reducing demand or, perhaps, loses from interbasin transfers might be emphasized over the short term.

A number of approaches have been suggested for the Flint River (e.g., Emanuel and Rogers 2012). Among these would include better early recognition of drought conditions and faster responses in reducing *per capita* water use in response to anticipated shortages. The Flint River is already part of a NOAA test program for regional drought early warning efforts (http://www.drought.gov/drought/content/regional-programs) indicating that a great deal of climate and stream-flow monitoring capability is already in place. Water managers could use NOAA seasonal outlooks to more aggressively initiate water conservation measures before water storage 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 2012). Urban irrigation demand approximately doubles during the growing season, largely due to landscape watering (Emanuel and Rogers 2012). Changing landscape practices (xeric landscapes) and improving the efficiency of lawn irrigation systems can also reduce water demand during seasonal dry periods.

Another approach is improving water distribution and use efficiency. This can be accomplished through aggressive repair of leaks in distribution systems and incentives for improving end-user efficiencies. Several municipalities in the upper Flint have initiated programs to improve efficiency of distribution and household water use (e.g., Emanuel and Rogers 2012). In the lower Flint, improvements in agricultural irrigation efficiency are being adopted to reduce seasonal demand (Perry and Yager 2011). There are significant opportunities to not only increase water-use efficiency, incrementally, but to also produce a meaningful result in terms of improvement of stream flow.

Many of the changes described herein do not require substantial investment in infrastructure. Instead, they are largely a distributed education and communication challenge directed at stakeholders. For the Flint and other southeastern rivers, potential problems associated with climate change and increasing water demands have risen to the level of societal concern. The next step in southeastern river conservation is to rapidly evaluate alterations to river flow regimes and prioritize actions based on evaluations of risk and availability of resources for problem solving. The model we present could be used as a conceptual starting point for this process.

REFERENCES

Allen, D.C., H.S. Galbraith, C.C. Vaughn and D.E. Spooner. 2013. A tale of two rivers: implications of water management practices for mussel biodiversity outcomes during droughts. Ambio 42:881-891.

Couch, C.A., E.H. Hopkins, and P.S. Hardy. 1996. Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chattahoochee-Flint River basin. USGS Water-Resources Investigations Report 95-4278.

Emanuel, B. and G. Rogers. 2012. Running dry: Challenges and opportunities in restoring healthy flows in Georgias upper Flint River Basin. American Rivers. (www.AmericanRivers.org/RunningDry).

Freeman, M.C., G.R. Buell., L.E. Hay, W.B. Hughes, R.B. Jacobson, J.W. Jones, S.A. Jones, J.H. LaFontaine, K.R. Odum. J.T. Peterson, J.W. Riley, J.S. Schlinder, C. Shea, and J.D. Weaver.2012. Linking river management to species conservation using dynamic landscape-scale models. River Research and Applications DOI: 10.1002/rra.2575.

Gao, X., R.M. Vogel, C.N. Kroll, N.L. Poff, J.D. Olden. 2009. Development of representative indicators of hydrologic alteration. Journal of Hydrology 374: 136-147.

Georgia EPD, 2009. Wetted Acreage Database.

Georgia EPD-DNR. 1997. Flint River Basin Management Plan 1997. Georgia EPD, Atlanta.

Golladay, S. W., P. Gagnon, M. Kearns, J. M. Battle, and D. W. Hicks. 2004. Response of freshwater mussel assemblages (Bivalvia: Unionidae) to a record drought in the Gulf Coastal Plain ofsouthwestern Georgia. Journal of the NorthAmerican Benthological Society 23:494-506.

LaFontaine, J.H., L.E. Hay, R.J. Viger, S.L. Marstrom,R.S. Regan, C.M. Elliot, and J.W. Jones. 2013. Application of the precipitation-runoff modeling system (PRSM) in the Apalachicola-Chattahoochee-Flint River Basin in thesoutheastern United States. U.S. GeologicalSurvey Scientific Investigations Report 2013-5162.

Lower Flint Ochlockonee Watershed Council. 2011. Regional Water Plan. http://www.flintochlockonee.org/pages/our_plan/index.php .

Olden, J.D., and N.L. Poff. 2003. Redundancy and thechoice of hydrologic indices for characterizing streamflow regimes. River Research andApplications 19: 101-121.

Perry, C., and R. Yager. 2011. Irrigation waterconservation efforts at the UGA C.M. StriplingIrrigation Research Park. Proceedings of the2011 Georgia Water Resources Conference.Athens.

Poff, N.L., B.D. Richter, A.H. Arthington, S.E. Bunn,R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M.C. Freeman, J. Henriksen, R.B. Jacobson, J.G. Kennen, D.M. Merritt, J.H. OKeefe, J.D. Olden, K. Rogers, R.E. Tharme,and A. Warner. 2010. The ecological limits of hydrologic alteration (ELOHA): A newframework for developing regional environmental flow standards. Freshwater-Biology 55: 147-170.

Poff, N.L., and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literaturereview to inform the science and management of environmental flows. Freshwater Biology 55: 194-205.

Pollard, L.D., R.G. Grantham, and H.E. Blanchard, Jr.1978. A preliminary appraisal of the impact of agriculture on groundwater availability in southwest Georgia. U.S. Geological Survey Water-Resources Investigations Report 79-7.

Richter, B.D. 2009. Re-thinking environmental flows: From allocations and reserves to sustainability boundaries. River Research and Applications DOI: 10.1002/rra.1320

Richter, B.D., M.M. Davis, C. Apse, and C. Konrad. 2011. A presumptive standard for environmental flow protection. River Research and Applications DOI: 10.1002/rra.1511

Rugel, K., C. R. Jackson, J. J. Romeis, S. W. Golladay,D. W. Hicks, and J. F. Dowd. 2012. Effects of irrigation withdrawals on streamflows in a karst environment: lower Flint River Basin, Georgia, USA. Hydrological Processes 26:523-534.

Sargent, L. W., S. W. Golladay, A. P. Covich, and S. P. Opsahl. 2011. Physicochemical habitat association of a native and non-native crayfish in the lower Flint river, Georgia: implications for invasion success. Biological Invasions 13:499-511.

Sun, G., P.V. Caldwell, S.G. McNulty, A.P. Georgakakos, S. Arumugam, J. Cruise, R.T. McNider, A. Terando, P.A. Conrads, J. Feldt, V. Misra, L. Romolo, T.C. Rasmussen, D.A. Marion. 2013. Impacts of Climate Change and Variability on Water Resources in the Southeast USA. NCA Southeast Technical Report 204-234.

Upper Flint Watershed Council. 2011. Regional WaterPlan. http://www.upperflint.org/pages/our_plan/index.php

van den Avyle, M.J., and J.W. Evans. 1990. Temperature selection by Striped Bass in a Gulf of Mexico coastal river system. North American Journal of Fisheries Management 10: 58-66.