EFFECTS OF THE UPPER FLORIDAN AQUIFER ON WATER CHEMISTRY AND OXYGEN METABOLISM IN THE LOWER FLINT RIVER DURING DROUGHT

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Abstract. The lower Flint River in southwestern Georgia flows through the limestone formation of the Upper Floridan aquifer, and large exchanges of water occur through natural spring conduits between the river and the aquifer. Our studies center on how exchanges of river and aquifer water affect these aquatic ecosystems, particularly during periods of drought when both the aquifer and river are heavily stressed due to the combined effects of climatic conditions and human use. Large increases in nitrate and calcium concentrations in the lower Flint River between Albany and Bainbridge are attributed to an increase in the proportion of aquifer water that comes in from springs. Conversely, decreases in phosphate and ammonium result from dilution by groundwater. Measurements of microbial metabolism based on oxygen consumption indicate very low rates of bacterial activity and a strong dependency on bioavailable dissolved organic carbon during drought conditions. Groundwater inputs from the Upper Floridan aquifer play a critical role in maintaining the health of the river and should be sustained to ensure the ecological integrity of the lower Flint River ecosystem.

INTRODUCTION

The Flint River is about 560 km in length and drains an area of approximately 21,900 km^2 (Couch et al., 1996). As the lower Flint River flows through the Dougherty Plain, the river channel cuts into the Ocala limestone to reach the water table of the Upper Floridan aquifer. Numerous springs and large seeps along the lower Flint River serve as conduits that permit rapid exchanges of water between the lower Flint River and the Upper Floridan aquifer. During drought conditions, groundwater discharges from the Upper Floridan aquifer can contribute as much as 40% of the base flow in the lower Flint River (Hicks et al, 1987).

The Flint River flows through a region of exceptionally high biological diversity. Numerous rare plants, fish, and aquatic invertebrates reside in the lower Flint River and its tributaries, and some of these undoubtedly thrive due to the positive impact that natural springs have on biological communities. For example, many of the larger springs along the lower Flint River provide a thermal refuge for the striped bass during the warm summer months, which allows them to sustain a breeding population. The aquifer springs also represent a source of high quality water which helps to mitigate the negative effects of wastewater discharge directly into the river and its tributaries.

There are growing concerns that the ecological integrity of the Flint River system may be in jeopardy. These concerns stem from the growing demand on the surface water and groundwater resources within the Flint River basin. Uncertainties remain regarding the effects that direct withdrawals from the Flint and its tributaries, and pumping from the aquifer adjacent to the river, have on in-stream flows. There are also concerns that the quality of groundwater is steadily deteriorating as a function of various land use practices, and the positive impact that groundwater has on the Flint River may be compromised. Furthermore, the negative effects are undoubtedly exacerbated during drought conditions. The purpose of this study is to examine how groundwater from the Upper Floridan aquifer is affecting the chemistry and biology of the lower Flint River, during a period of excessive drought. Through these initial efforts, we hope to identify future information needs, and better understand how to maintain the health of the lower Flint River.

STUDY AREA

The study area included the lower Flint River between Albany and Bainbridge (Fig. 1). Six stations were chosen along the main stem of the Flint River beginning just below Lake Chehaw dam and ending just above Bainbridge city limits. Two springs that flow into the Flint River were also sampled on three occasions during the study period. Radium Springs was chosen because it occurs within the Albany city limits and may be impacted by urban development. Bovine

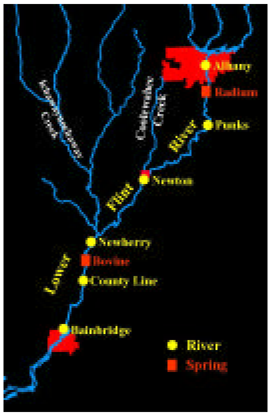

Figure 1. Map of sampling locations.

Springs is adjacent to agricultural and livestock land and thus may be impacted by farming activities.

Flow data from the USGS gauge at Newton for July through December is shown in Figure 2. Following a large rain event in June, river flows were always below the long term average for this station. The river sustained near record low flows during October and November 2001.

METHODS

During July through December of 2001, water was collected from sampling sites along the main stem of the lower Flint River and two springs between Albany and Bainbridge (Fig. 1). Triplicate grab samples were collected in acid-washed 1-liter polycarbonate bottles from each location and the samples were immediately placed on ice. In the laboratory, the samples were filtered using Whatman 142 mm GF75 filters and a stainless steel filter tower. From the filtered samples, subsamples were collected and analyzed for nitrate, ammonium, and phosphate using a Latchet QuikChem 8000. Calcium was measured using a Perkin Elmer 5100 PC atomic absorption spectrophotometer. Dissolved oxygen was measured on triplicate samples collected in BOD bottles using the Winkler titration method as described in Oudot et al. (1988). A Mettler-Toledo Graphix 50 DL autotitrator was used to titrate the samples.

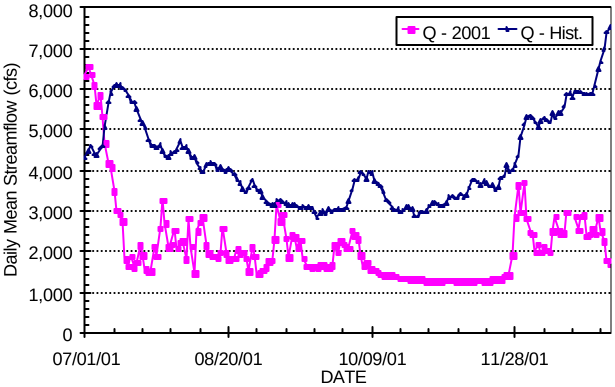

Figure 2. Mean daily discharge for July through December 2001 compared to the long-term average.

During an extreme drought condition (November 2001) and a winter flood (January 2002), microbial respiration rates and growth-limiting substrates were measured at 4 of the river sites. An acid-washed 10-L Nalgene carboy was filled at each station, and water from these carboys was used to fill up a series of 60-mL glass BOD bottles at each site. Four bottles from each site were fixed in the field using $MnSO_4$ and NaI/NaOH to scavenge the available O_2 and served as T_0 samples. Four nutrient solutions (NH_4Cl, $NaNO_3$, Na_2HPO_4, and Glucose) were used to test for growth limiting substrates. Bottles were amended with one of the four solutions in the field. The bottles were incubated in the dark at a constant temperature. After 4 to 10 hours, a second set of four bottles was fixed to serve as the T_1 samples. The reagents were added to bottles used for nutrient additions approximately 24 hours after the T_0 samples had been fixed. Winkler titrations were performed on all of the samples as described above.

RESULTS

Spring water chemistry was typical of most groundwater in the Upper Floridan aquifer (Table 1). Nitrate and phosphate concentrations were significantly higher in Bovine Springs, while calcium concentrations were lower. Ammonium was measurable during one of the three sampling periods at Radium Springs, and not detected at Bovine Springs.

Dissolved oxygen was found to be near saturation levels throughout the entire length of the lower Flint River (Fig. 3). This is attributed to the geomorphology of the lower Flint River which is shallow with abundant

Table 1. Comparison of water chemistry at two reference springs (n=3)

	Radium (n=3) conc. (std. dev.)	Bovine (n=3) conc. (std. dev.)
NO_3^- (ppm)	1.5 (.1)	2.1 (0.5)
Ca^{2+}(ppm)	55.2 (0.5)	48.7 (1.7)
PO_4^-(ppb)	2.9 (0.8)	3.6 (0.1)
NH_4^+(ppb)	2.1 (3.6)	0.0 (0)

ppm, parts per million; ppb, parts per billion.

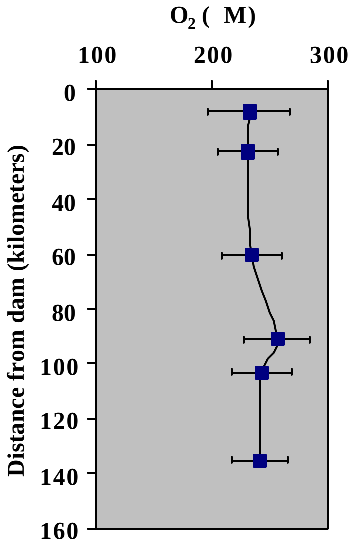

Figure 3. Dissolved oxygen concentrations in the lower Flint River.

shoals that allow efficient exchange of oxygen with the atmosphere.

Nitrate and calcium concentrations progressively increased over the length of the lower Flint River (Fig. 4a, b). These increases are attributed to contributions by groundwater from the Upper Floridan aquifer which has high concentrations of both nitrate and calcium (Table 1). The tight coupling between nitrate and calcium suggests that the majority of nitrate acts conservatively over the course of the river. The slight decreases in both between 105 and 135 km may result from backwater effects caused by the Jim Woodruff dam below Bainbridge.

Phosphate and ammonium showed different distributional patterns (Fig. 5a,b). Both phosphate and ammonium increased significantly between the first two stations. These increases are attributed to the discharge of wastewater effluent by the city of Albany, which is estimated to be about 10 million gallons per day. However, both phosphate and ammonium concentrations decreased considerably by the time the water reached Newton (60 km). Phosphate and ammonium serve as nutrients for aquatic plants and microorganisms, and are probably removed from the river by biological processes and dilution by groundwater.

Mean microbial respiration rates were lower during the drought than during the winter flood (Table 2). However, all respiration rates are low relative to those reported for other south Georgia rivers (Moran et al., 1999). In all respiration experiments, only the addition of organic carbon (glucose) stimulated microbial activity. The addition of inorganic nutrients (nitrate, ammonium, or phosphate) did not stimulate bacterial growth above background levels. This suggests that during drought conditions, microbial activity in the lower Flint River is limited by the presence of bioavailable dissolved organic carbon (DOC) rather than inorganic nutrients.

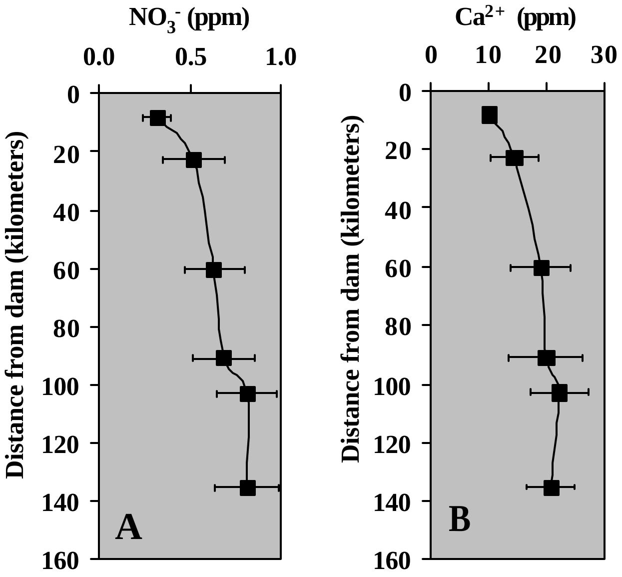

Figure 4. Nitrate and calcium concentrations in the lower Flint River.

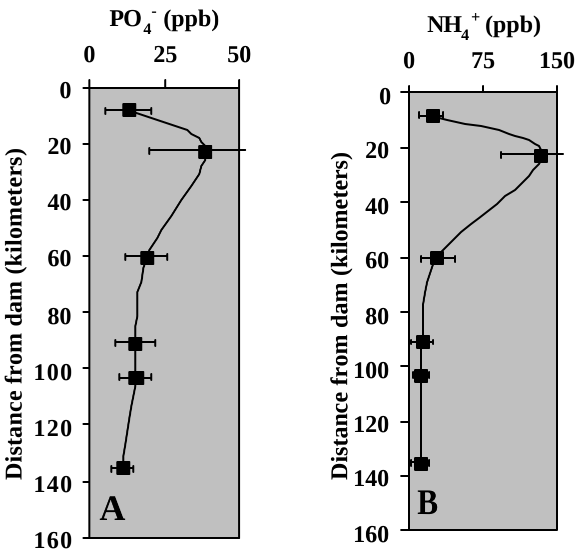

Figure 5. Phosphate and ammonium concentrations in the lower Flint River.

Table 2. A comparison of Flint River dark respiration rates ($\mu M\ O_2\ l^{-1}\ hr^{-1}$) during drought and flood conditions

	Drought (November 2001)	Flood (January 2002)
Albany	0.38	1.60
Punks	0.24	0.83
Newton	0.64	0.63
Bainbridge	0.22	ND
mean ± SD	0.37 ± 0.19	1.02 ± 0.51

CONCLUSIONS

The lower Flint River is unique among rivers in Georgia because water chemistry is substantially altered by groundwater contributions from the Upper Floridan aquifer. Nearly identical patterns of increase in both nitrate and calcium were observed (Fig. 4), although the ultimate source of these constituents differ. Calcium is derived from dissolution of the Ocala Limestone. Nitrate is derived from nitrogen that was deposited on the land's surface and then migrated into the aquifer. Nitrate measurements from both springs indicate that concentrations are above historic background levels (<0.5 ppm). Thus, nitrate contamination of groundwater in the Upper Floridan aquifer from human activities on land, is now affecting nitrogen concentrations in the lower Flint River.

The wastewater effluent that is discharged from Albany caused 5-10 fold increases in the concentrations phosphorous and ammonium (Fig. 5). By the time the water reached Newton, phosphorous and ammonium concentrations were reduced to concentrations near those measured above the wastewater discharge point. The reduction in these nutrients was probably caused by a combination of dilution from groundwater and biological uptake. However, any biological activity that was stimulated by this nutrient pulse was not large enough to deplete oxygen in the river (Fig. 3).

Measurements of dark respiration indicated very low rates of microbial activity in river water during drought conditions. Respiration rates were somewhat higher during a winter flood event. In all respiration experiments, metabolism was stimulated by the addition of glucose but not inorganic nutrients. This was surprising given that DOC concentrations in the lower Flint River range from 2 to 9 mg/l (Opsahl, unpublished). Thus, the activity of natural microbial populations is not dependent on the presence of DOC, but on the bioavailability of DOC that is present. Higher respiration rates observed during the winter flood were probably supported by more labile DOC that was present in surface water runoff. These results suggest that during drought conditions, when the bioavailability of DOC is low, there will be reductions in nutrient processing by microorganisms, and reduced contributions by microbes into riverine food webs.

MANAGEMENT IMPLICATIONS

The broader implications of these studies should be considered in terms of water resource management strategies. Specifically, what happens if groundwater flow from the Upper Floridan aquifer to the lower Flint River is reduced? From a quantitative standpoint, groundwater reductions carry a number of consequences. These include: 1) reducing the unique thermal habitat that supports the striped bass and perhaps other species, 2) substantially reducing the total surface flow in the Flint River which is of concern to downstream interests, and 3) allowing aquifer flow reversal to occur for more extended periods of time which could negatively impact aquifer water quality. From a qualitative standpoint, groundwater flow reductions would reduce the dilution effect on wastewater effluent which may lead to more serious water quality problems including stagnation, algal blooms, and oxygen depletion. Additional monitoring is a partial solution, but more studies of biological processes and nutrient cycles are needed to understand how human activities are changing the Flint River.

ACKNOWLEDGEMENTS

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