EFFECTS OF LAND-USE ON GROUNDWATER QUALITY IN SPRINGS OF THE UPPER FLORIDAN AQUIFER

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Abstract. We examined groundwater chemistry over a seven year period beginning in June 2001 to September 2008 in Radium, Riverview, Bovine, and Hog Parlor springs that discharge into the lower Flint River between Albany and Bainbridge, Georgia. The Radium Spring springshed includes substantial urbanized land cover; whereas, the other three springs are recharged in areas dominated by agriculture. Significantly lower nitrate (NO_3^-) concentrations in Radium spring were attributed to differences in land use and lower rates of fertilizer application ($p<0.05$). Long-term trends demonstrated a statistically significant increase ($p<0.05$) in groundwater NO_3^- concentrations for all four springs with net increases ranging from 0.6 to 2.0 mg/L. Based on isotope analysis for $\delta^{15}N$-NO_3^- of 10 springs from the Upper Floridan aquifer, multiple sources of NO_3^- contamination were evident and may differ depending on landuse. This study demonstrates the importance of long-term datasets for evaluating the effects of anthropogenic activities on regional groundwater quality.

INTRODUCTION

Groundwater contamination, particularly from nitrate (NO_3^-), is an emerging global problem with consequences for both human and ecosystem health (McLay et al. 2001; Almasri and Kaluarachchi 2004; Choi et al. 2007). Agricultural activities are considered the primary anthropogenic source of nitrogen contamination in aquatic ecosystems (Nolan 2001; Howarth 2004). Elevated NO_3^- levels in streams, wetlands, lakes, and coastal waters pose ecological problems such as loss of biodiversity, increased growth of aquatic vegetation, and eutrophication which decrease aquatic ecosystem health and degrade suitable habitat for fishes and aquatic invertebrates (Vitousek et al. 1997; Rabalais et al. 2002; Howarth 2004). Elevated NO_3^- (above 10 mg l^{-1}) levels in drinking water can increase an infant's susceptibility to methemoglobinemia which decreases blood oxygen levels that can result in infant death (Spalding and Exner 1993).

In Southwest Georgia, groundwater in the Upper Floridan aquifer is susceptible to chemical alteration, the extent of which may vary depending on land use within recharge areas. Springs along the lower Flint River discharge large quantities of water from the aquifer directly into the river providing baseflow for most of the year. and potentially elevating NO_3^- concentrations in these downstream systems. Thus, groundwater discharge is often the source of NO_3^- enrichment in rivers and streams (Katz et al. 1997; Opsahl 2003).

Potential sources of NO_3^- can be identified through the use of stable nitrogen isotopes due to distinct isotopic signatures among NO_3^- sources (Kendall 1998). In agricultural dominated areas, sources for NO_3^- enrichment include inorganic fertilizer and livestock manure (Widory et al. 2004). Synthetic fertilizers exhibit $\delta^{15}N$-NO_3^- values between -3‰ and +4‰; whereas, $\delta^{15}N$-NO_3^- values between +8‰ and +22‰ indicate human waste or organic manure (Heaton 1986; Hübner 1986, Iqbal et al. 1997; Katz et al. 1999; Choi et al. 2007). Isotopic signatures for $\delta^{15}N$-NO_3^- ranging between +3‰ and +10‰ may indicate a mixed source of both inorganic fertilizers and animal/human waste or natural soil organic nitrogen (Iqbal et al. 1997; Katz et al. 1999; Oren et al. 2004; Choi et al. 2007).

METHODS

Site Description

A total of 10 springs were sampled throughout the study area in Dougherty, Decatur, Mitchell, and Baker counties of southwestern Georgia (Figure 1). The springs discharge groundwater from the Upper Floridan aquifer directly into the lower Flint River. The Upper Floridan aquifer provides water for agricultural, domestic, municipal, and industrial uses. Agriculture is the dominant land-use in this region which is mainly corn, cotton, and peanuts, and cattle and poultry livestock operations. Decatur and Mitchell counties are among the top ten producers in Georgia of corn, cotton, and peanuts (Boatright and McKissick 2008).

Sampling & Analysis

NO_3^- concentrations were assessed over a 7-year period from May 2001 to September 2008 in Radium, Bovine, and Hog Parlor springs. Beginning in April 2006, the springs have been sampled on a monthly basis. The sampling periodicity varied depending on accessibility of springs; however, sampling was not conducted during 2005. Riverview, Bovine, and Hog Parlor springs were sampled by boat; whereas, Radium spring was accessed by land.

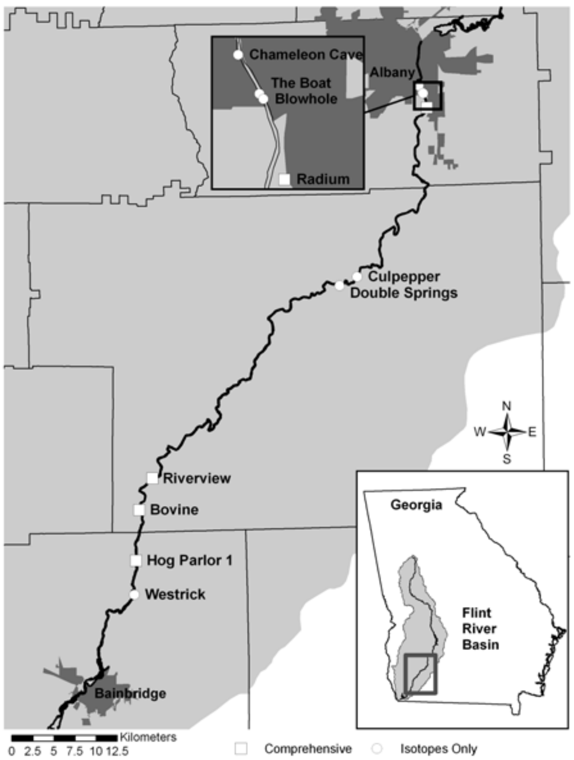

Figure 1. Study sites along the lower Flint River between Albany and Bainbridge, Georgia

Triplicate groundwater samples were collected in acid-washed 1-liter polycarbonate bottles and stored on ice for transport to the laboratory. Samples were filtered within 24 hours using pre-ashed 47 mm glass fiber filters with 0.7 µm nominal pore size. A subsample of the filtrate was analyzed for NO_3^- on a Lachet QuikChem 8000. Statistical analyses of NO_3^- concentrations were conducted using rank transformed analysis of variance and regression analyses in SAS® (SAS Institute, Cary, NC). Statistical tests were analyzed at the $\alpha = 0.05$ significance level.

In addition to Radium, Riverview, Bovine, and Hog Parlor springs, on October 1, 2005, Chameleon Cave, The Boat, Blowhole, Culpepper, Double, and Westrick springs were sampled using scuba for $\delta^{15}N\text{-}NO_3^-$ and NO_3^- analysis. Samples were collected at the head of the spring in acid-washed 60-ml bottles and stored on ice until filtered as described above. $\delta^{15}N\text{-}NO_3^-$ analysis was conducted at the Stable Isotope Facility at the University of Arkansas using the denitrifier method (Sigman et al. 2001).

RESULTS AND DISCUSSION

NO_3^- concentrations averaged over the entire study period were 1.7, 3.0, 2.9, and 3.3 mg/l for Radium, Riverview, Bovine, and Hog Parlor springs, respectively. Radium spring exhibited significantly lower NO_3^- concentrations than Riverview, Bovine and Hog Parlor springs ($p<0.05$) (Figure 2). Significantly higher NO_3^- concentrations found in Riverview, Bovine, and Hog Parlor springs indicate a potential agricultural source as these springsheds are represented by extensive agricultural land cover (Figure 2). Several studies have demonstrated a correlation between NO_3^- concentrations and agricultural land uses (Katz et al. 1999; McLay et al. 2001; Choi et al. 2007). NO_3^- concentrations within all four springs demonstrate anthropogenic alteration of groundwater as the concentrations are above background levels of 0.1 mg/l reported for the Upper Floridan aquifer (Figure 2) (Katz 1992).

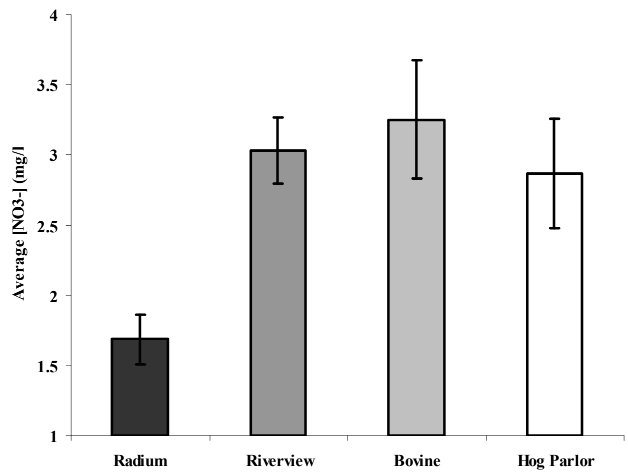

Figure 2. Average NO_3^- concentrations over the entire study period for Radium, Riverview, Bovine, and Hog Parlor springs

The long-term trends demonstrated a statistically significant increase in groundwater NO_3^- for Radium ($r^2 = 0.29$; $p= 0.005$), Riverview ($r^2 = 0.91$; $p < 0.0001$); Bovine ($r^2 = 0.45$; $p < 0.0051$), and Hog Parlor ($r^2 = 0.88$; $p < 0.0001$) springs (Figure 3). Over the seven year period, the net change in NO_3^- concentrations for each spring were 0.6, 0.9, 1.8, and 2.0 mg/L for Radium, Riverview, Hog Parlor and Bovine springs, respectively. Increasing NO_3^- concentrations within these springsheds may pose threats to both ecosystem and human health if the trend continues.

$\delta^{15}N\text{-}NO_3^-$ ranged from +4.4‰ to +14.4‰ (Table 1). $\delta^{15}NO_3^-$ values ranged from +6.89‰ (Radium) to +14.35‰ (Chameleon Cave) in the urban springs and from +4.4‰ (Hog Parlor) to +8.4‰ (Culpepper) in the rural springs (Table 1). The NO_3^- isotope data for the urban springs Chameleon, Boat, and Blowhole springs exhibit isotopic $\delta^{15}NO_3^-$ signatures consistent with animal/human waste which could originate from leaky septic tanks or wastewater effluent (Heaton 1986; Hübner 1986, Kendall 1998).

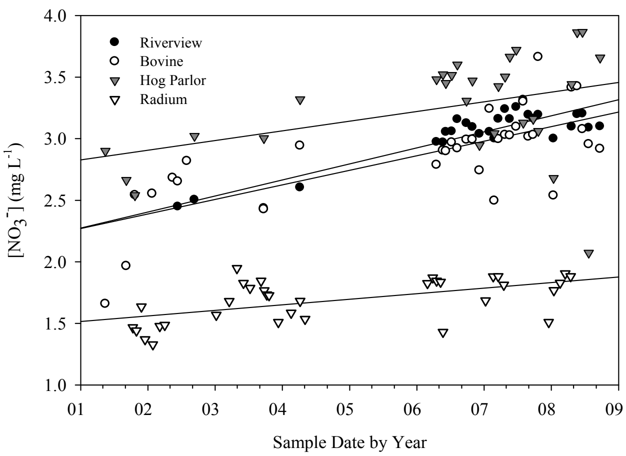

Figure 3. Changes in NO_3^- concentrations in Radium, Riverview, Bovine, and Hog Parlor springs

Although Radium spring is within the city limits of Albany, the $\delta^{15}N$ signal was not elevated at this urban spring. $\delta^{15}N$-NO_3^- values for the rural springs and Radium spring, an urban spring, had $\delta^{15}NO_3^-$ values between +6‰ and +9‰ which indicates that the source of NO_3^- may be a mixture of both inorganic fertilizers and animal/human waste (Iqbal et al. 1997; Katz et al. 1999; Oren et al. 2004; Choi et al. 2007) (Table 1). Agricultural activities surrounding these springs include both vegetative crops and livestock operations which explains the evidence for both fertilizer and animal waste NO_3^- sources. Other studies have reported difficulties in determining a predominant source of NO_3^- enrichment in regions with mixed agricultural activities (Iqbal et al. 1997; Choi et al. 2007).

CONCLUSION

NO_3^- enrichment was evident at Radium, Riverview, Bovine, and Hog Parlor springs and differences in NO_3^- concentrations are attributed to differences in land-use. Significantly higher NO_3^- concentrations found in the Riverview, Bovine, and Hog Parlor springs indicate a potential agricultural source as these springs are recharged in areas with extensive agricultural land cover. The increases in NO_3^- concentrations is an artifact of the changes in landuse related to agricultural production in the Dougherty Plain district of southwest Georgia. Multiple sources of NO_3^- enrichment were evident and $\delta^{15}NO_3^-$ signatures suggest a difference between land-use. The results indicate distinct $\delta^{15}NO_3^-$ signatures between the urban and rural springs.

NO_3^- contamination has not been seen as a threat in the Southeast even though certain regions are characterized by extensive agricultural activities (Spalding and Exner 1993; Stuart et al. 1995; Nolan 1999). Although NO_3^- concentrations from the sampled springs did not exceed the EPA drinking water standard of 10 mg l^{-1} (Spalding and Exner 1993), NO_3^- concentrations exceed background concentrations in the study area which poses both environmental and health concerns if the trend continues. Evidence suggests that NO_3^- concentrations as low as 1 mg l^{-1} may threaten spring ecosystems (Florida Springs Task Force 2000). However, the potential effects of elevated NO_3^- concentrations on the lower Flint River and downstream aquatic ecosystems are currently unknown.

Table 1. δ^{15}N-NO_3^- and NO_3^- data for lower Flint River springs between Albany and Bainbridge, Georgia (urban springs highlighted in gray – refer to Figure 1). Replicates are designated by A and B.

Sample Site	*Mean δ15N*	*NO3- (mg/L)*
Chameleon Cave A	14.4	1.95
Chameleon Cave B	12.4	1.96
The Boat	11.7	2.08
Blowhole	10.3	2.00
Radium A	8.5	1.88
Radium B	6.9	1.87
Culpepper	8.4	2.32
Double Springs A	7.9	1.39
Double Springs B	8.0	1.58
Riverview	6.6	2.72
Bovine A	6.0	2.75
Bovine B	6.2	2.72
Hog Parlor 1 A	4.4	3.22
Hog Parlor 1 B	5.1	3.20
Westrick	8.1	3.26

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