HYDROLOGIC CONTROLS ON WATER CHEMISTRY AND MICROBIAL ACTIVITY IN A SMALL COASTAL PLAIN STREAM

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Abstract. Relationships between water chemistry, microbial activity, and hydrology were examined in Chickasawhatchee Creek, a small coastal plain stream in southwestern Georgia. Microbial activity in the creek was determined by measurement of water-column respiration rates and growth-limiting substrates through oxygen consumption experiments. Water chemistry parameters (nitrate-N, soluble reactive phosphate, dissolved organic and inorganic carbon, major cation species) were measured in order to evaluate introduction and removal of various compounds and to identify ground water contributions. Results indicated substantial differences in water chemistry between the upstream and downstream reaches that were related to streamflow variation. During low flow periods, the upper reach of the creek was regulated by surface runoff while groundwater inflow played a more important role in the lower reach. Conversely, during periods of high flow, surface water runoff dictated streamflow for the entire system. There is strong evidence that dissolved organic carbon (DOC) always served as the growth-limiting substrate, and that DOC concentrations varied based on dilution by low-DOC groundwater. However, there was no correlation between measurements of water-column respiration and dissolved organic carbon.

INTRODUCTION

Information that distinguishes the effects of groundwater inputs and overland runoff on stream water chemistry and biological activity is especially lacking in the lower Flint River Basin, where extensive agricultural development over the past thirty years has been associated with an impairment of water chemistry, particularly when accompanied by loss of riparian corridors (Lowrance et al., 1983, 1984). Recent drought periods have heightened concerns about further degradation of surface- and ground-water chemistry, and clarified the need for research efforts designed to investigate the impacts of land use on regional water resources.

One of the lower Flint River Basin's most unique features is the Chickasawhatchee Swamp, which is the second largest wetland complex in the state of Georgia (Georgia News, 2000). Since access to the swamp was limited until recently, little is known about the role it plays in the regional hydrology, or to what extent it influences surface- and ground-water quality in southwestern Georgia. Previous studies (Golladay and Battle, 2001, 2002) have identified the Chickasawhatchee Swamp as a water quality buffer and a provider of important ecosystem services in the region.

Three sites along the Chickasawhatchee Creek, which flows south through the swamp, were monitored monthly for surface-water chemistry and microbial activity from the end of 2000 through the end of 2001. The goal of this effort was to examine changes in surface-water chemistry and microbial response resulting from a wide variety of flow conditions.

STUDY SITE

The Chickasawhatchee Creek watershed has a catchment area of 86,800 ha (Golladay and Battle, 2002). Row-crop agriculture and managed forestlands constitute the primary land uses, although the Chickasawhatchee Creek watershed contains slightly less (10-13%) agricultural area and slightly more (7%) wetland area than adjacent watersheds (Golladay and Battle, 2002). The Chickasawhatchee Swamp accounts for most of the wetland area within the watershed.

Low topographic relief in combination with porous surface geology results in low stream drainage density and a dominance of subsurface water flow in regional hydrology (Hicks et al., 1987). Winter is the primary season when most groundwater recharge occurs in the region. During typical winters both the regional water-table and streamflow increase in response to extended rainfall and inundation of riparian areas. During the summer months, most precipitation is lost through evapotranspiration, groundwater recharge is minimal, and base flows in regional streams are largely supported by discharges from the aquifer (Hicks et al., 1987).

METHODS

Monthly monitoring at three stations along Chickasawhatchee Creek was initiated in December 2000 (Figure 1). Stations were located so that the impact of passage through the Chickasawhatchee Swamp could be determined. There was a station upstream of the swamp complex (CR234), a middle station at the northern swamp boundary (CR62), and a lower station downstream of the swamp (CR37).

At each station, a grab sample was collected just below the water surface in well-mixed areas with measurable flow. This single sample was collected in an acid-washed polypropylene bottle, stored on ice, and transported back to the lab for further processing. Samples were filtered (ashed Whatman 4.25 cm GF/F) and filtrate subsamples were collected to allow for subsequent analysis of various chemical constituents. Dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) were measured using a Shimadzu TOC-5050 analyzer. Nitrate-N (NO_3-N) and soluble reactive phosphate (SRP) samples were analyzed using a Lachat QuikChem 8000. Concentrations of major cation species, including calcium (Ca), were obtained using a Perkin-Elmer 5100PC atomic absorption spectrophotometer.

During each monthly sampling event, water-column microbial respiration rates and growth-limiting substrates were measured at each of the creek sites. Although primary production was not measured directly, the contribution of photosynthetic respiration was probably minimal in this system. Sampling

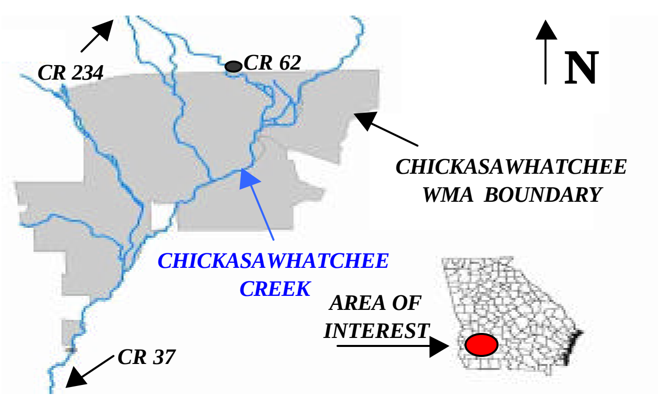

Figure 1. Study site location in southwest Georgia.

locations were low-order, shaded, turbid, surrounded by intact riparian vegetation, and had high dissolved organic carbon concentrations (range of 1.87 to 19.4 with a mean of 8.5 mg/L). All of these conditions have been shown to favor heterotrophic, rather than autotrophic, processing (Minshall et al., 1983, Webster et al., 1995). 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 as the limiting substrates. Bottles were amended with one of the four solutions in the field. After field processing was complete, the headspace in each bottle was filled with water, covered to minimize the introduction of atmospheric oxygen to the samples, and incubated at room temperature (~20°C). The bottles were also kept in the dark to eliminate the possibility of photosynthetic oxygen production. After a period between 4 and 10 hours had elapsed, a second set of four bottles was fixed to serve as the T_1 samples. 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 using a Mettler-Toledo DL50 Graphix.

RESULTS AND DISCUSSION

There were substantial differences in surface-water chemistry between the upstream and downstream reaches of Chickasawhatchee Creek, and these differences were related to variable hydrologic conditions. Streamflow was highest during late March and early April following spring rains (Figure 2). Summer rains were much less frequent than normal, and as a result, there was low (<20 cfs) streamflow for much of the time between mid-July and late November.

There was strong evidence of groundwater inputs in the downstream reach of the creek, particularly during low-flow conditions. Calcium and DIC are both known to be high in groundwater from the Upper Floridan aquifer (Hicks et al., 1987) relative to surface runoff, and downstream levels of both parameters exceeded levels reported upstream (Table 1). Measurements of NO_3-N provided additional evidence of groundwater inflow because groundwater is known to have higher NO_3-N concentrations (1,000-3,000 µg/L) than creeks and wetlands (1000 µg/L) (Hicks et al., 1987). During periods of reduced streamflow, NO_3-N

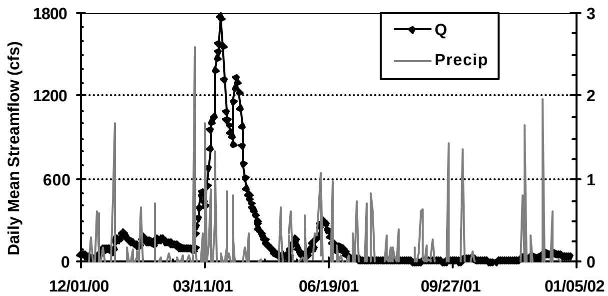

Figure 2. Daily mean streamflow values for Chickasawhatchee Creek, along with daily precipitation measurements. Streamflow data are from U.S. Geological Survey (USGS) Gage 02354500 on Chickasawhatchee Creek. Rainfall data are from the Georgia Automated Environmental Monitoring Network weather station in Dawson, GA.

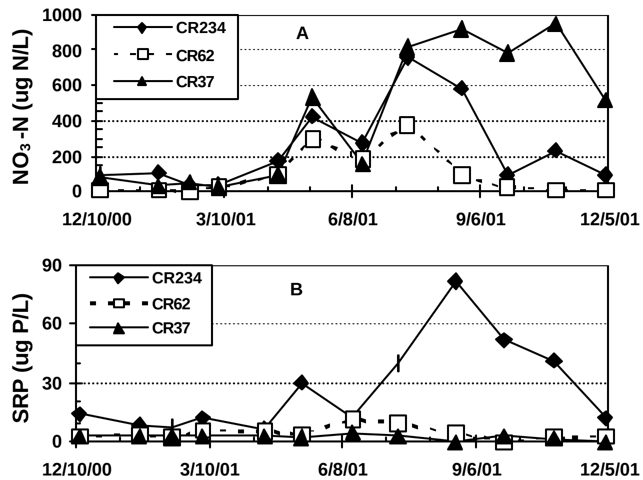

Figure 3. Measured concentrations of nitrate-N (NO_3-N) (3A) and soluble reactive phosphorus (SRP) (3B) in Chickasawhatchee Creek.

concentrations were higher at the downstream station than at either of the upstream stations (Figure 3A).

Nutrient dynamics were different in the two reaches of Chickasawhatchee Creek and varied with streamflow. Looking over the entire creek stretch covered in this study, concentrations of SRP were reduced as the creek flows south (Figure 3B). In most instances, the majority of the removal occurred in the upstream reach of the creek between CR234 and CR62. Elevated levels of SRP in the creek were probably due to the presence of an upstream wastewater treatment plant. The upstream reach also appeared to have NO_3-N removal capacity as concentrations were always lower at CR62 than at CR234 (Figure 3A). However, NO_3-N concentrations at CR37 were higher than those from upstream stations during more than half of the sampling events. The results suggested that baseflow through the swamp was more reliant on groundwater inflows than other runoff, particularly during low-flow conditions. It was only during the highest flow periods that NO_3-N concentrations decreased over the entire creek reach. Removal of both SRP and NO_3-N was lowest during high-flow periods.

Table 1. Calcium and dissolved inorganic carbon (DIC) measurements in Chickasawhatchee Creek

Reported concentrations represent the mean of all sampling events. Standard deviations are given in parentheses.

	CR234	CR62	CR37
[DIC] (mg/L)	16.30 (3.68)	18.01 (3.95)	30.59 (4.92)
[Ca] (mg/L)	17.22 (2.16)	20.08 (3.00)	44.43 (6.07)

Nutrient removal in streams is typically accomplished by a combination of processes including biological uptake, sedimentation, and adsorption. One possible explanation for the decrease in nutrient concentrations in the upstream reach of the creek would be dilution by groundwater from the Upper Floridan aquifer. However, if there were substantial ground-water inputs in this reach of the creek, NO_3-N and calcium concentrations would be significantly higher at CR62 than at CR234 (Figure 3A; Table 1). Therefore, groundwater dilution appeared to play a minimal role in reducing nutrient concentrations between CR234 and CR62. In contrast, observed increases in NO_3-N and calcium levels between CR62 and CR37 indicate that there are significant groundwater inputs to the downstream reach, and that during dry periods these inputs make up a greater relative percentage of streamflow. Therefore, as the creek flowed through the swamp between CR62 and CR37, nutrient reduction was at least in part due to dilution. However, it is likely that other mechanisms including biological uptake and abiotic removal were also actively involved in nutrient cycling.

Swamp hydrology likely played a role in governing water-column microbial activity in Chickasawhatchee Creek. During wet, high-flow periods, overland runoff dominated streamflow for the entire system. DOC concentrations increased as water moved through the complex and the swamp effectively exported organic carbon downstream (Figure 4A). As it became drier over the summer months and streamflow decreased, groundwater inputs became increasingly influential in the southern reach of the creek, while the northern

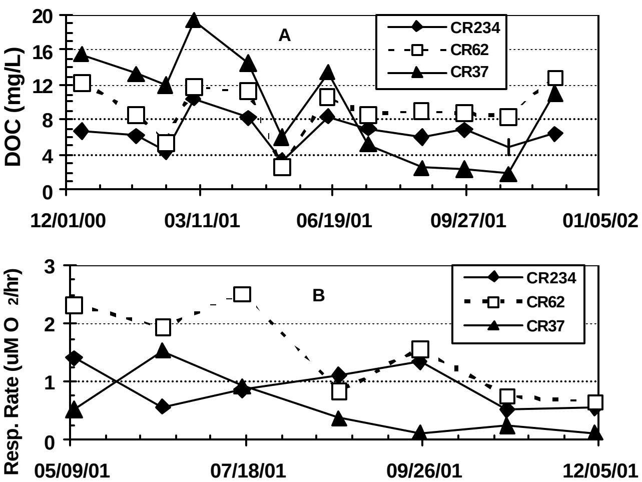

Figure 4. Measured concentrations of dissolved organic carbon (DOC) (4A) and water-column respiration rates (4B) in Chickasawhatchee Creek.

reach was still regulated by surface runoff. Regardless of streamflow conditions, organic carbon was always found to be the growth-limiting substrate in the creek. However, our measurements of water-column respiration (Figure 4B) did not correlate well with DOC concentrations (r^2=0.0363, $p<0.05$). This indicates that microbial respiration is not dependent on the concentration of DOC, but rather its bioavailability. It should be noted that in this study, we did not assess benthic respiration, which has been shown to be a significant portion of overall microbial respiration in streams (Edwards et al., 1990, Webster et al., 1995). It is possible that benthic communities respond more strongly than those in the water column to large inputs of organic matter.

CONCLUSIONS

The role that the Chickasawhatchee Swamp plays in regional hydrology is only beginning to be understood. Areas just upstream of the swamp complex have the capability to reduce nutrient levels, which could help to minimize downstream enrichment problems. Passage through the swamp does not have much of an impact on SRP concentrations, but can serve to increase NO_3-N concentrations, especially during dry, low-flow conditions, through groundwater inputs. Swamp-derived organic carbon export during elevated streamflow conditions is more biologically available and likely contributes to downstream aquatic productivity. Further studies addressing the role of benthic metabolism in overall ecosystem production would provide more complete insight to carbon and nitrogen cycling in the swamp. Overall, an understanding of the surface water/groundwater interactions and associated water quality improvements is necessary to ensure appropriate wetland protection measures are taken, and so that comprehensive regional water resource plans can be developed.

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