CONCENTRATIONS AND ESTIMATED LOADS OF NITROGEN CONTRIBUTED BY TWO ADJACENT WETLAND STREAMS WITH DIFFERENT FLOW-SOURCE TERMS IN WATKINSVILLE, GA

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Abstract. Inorganic, fixed nitrogen from agricultural settings often is introduced to first-order streams via surface runoff and shallow ground-water flow. Best management practices for limiting the flux of fixed N to surface waters often include buffers such as wetlands. However, the efficacy of wetlands to immobilize or reduce nitrate depends on several interacting local conditions that are not well understood.

Two adjacent streams (14 m apart at source) draining a wetland depression have partly different flow-source terms. One has a flowing spring at its head-cut, and is protected by surface runoff by a man-made berm. The other accepts run-off from the upland pasture and does not have a conspicuous spring. The lower discharge and higher organic substrate, residence times and water/sediment contact all apparently contribute to the lower nitrate loads from the runoff stream

INTRODUCTION

The increase in littoral, estuarine and lacustrine "dead zones" and human health issues such as blue baby syndrome have increased concerns about sources of fixed N, in particular from agricultural practices. The amount of fixed nitrogen and other chemical constituents from low order streams to receiving waters depends largely on the interaction between transport and reaction processes (Ocampo et al., 2006). Research has recently focused on new conceptual models such as nutrient "spiraling" – the interaction between N cycling and advective transport – and renewed efforts to establish Total Maximum Daily Loads (TMDLs) and effective agricultural Best Management Practices (BMPs). However, specific conditions conducive to sequestering and/or removing N from agricultural runoff are still poorly understood.

The load of a chemical species, expressed as mass per unit time, is the product of its concentration (C) and stream discharge (Q). The ability to identify localized conditions that may affect C, Q or both can improve our understanding, and hence ability to predict, where the larger loadings of N are occurring and what conditions are conducive to reducing the loads. This will help both with predictive (modeling) and management efforts, which are among several "major needs" for improving the TMDL program (USEPA, 2002).

MATERIALS AND METHODS

Study Area Description

At the USDA-ARS, J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville, Georgia, two adjacent streams (14m apart at head-cut) in a wetland depression provide drainage for an upland pasture for beef cattle. One of the streams is protected from surface run-off by a man-made berm and has a flowing spring at its head-cut (Figure 1). During the two-year project period, discharge from the spring varied from about 7 to 31 L/min, with an average of 23 L/min. The other stream is not protected from runoff and does not have a conspicuous spring. Both streams receive base flow from ground water. Chemical-species distribution is very different in the two adjacent stream channels due to the partly different flow-source terms. For example, over a two-year, approximately monthly, dry weather sampling program, average in-stream concentrations of relatively oxidized species such as NO_3^-, Fe^{3+} and dissolved CO_2 and O_2 are consistently higher in the protected, spring-fed channel than in the runoff channel. However, concentrations of some chemically reduced species such as dissolved organic C, CH_4, NO_2^-, NH_4^+ and Fe^{2+} are often two- to five-times higher in the runoff channel, depending on location along the flow path (non-N data not shown).

An experiment in which the chemical tracers nitrate and bromide (Cooper, 1994) were injected simultaneously to both streams showed that mean residence time is about 3-4 hours, and is somewhat longer in the runoff stream. Three more tracer experiments in only the pro-

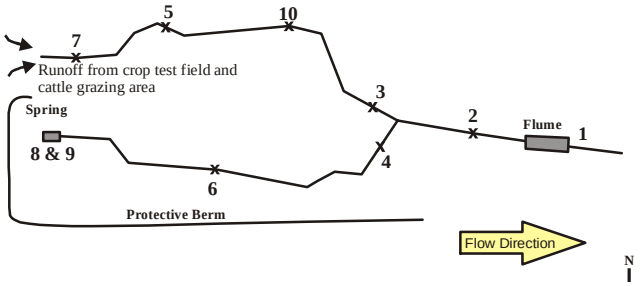

Figure 1: Map of field area.

tected stream showed similar residence times. Nitrate recoveries were calculated based on $[NO_3^-]/[Br^-]$ ratios.

Study Design

Surface-water samples were collected approximately monthly at stations in each of the two adjacent streams. Chemical species were quantified using the following methods: 1) NO_3^- and Cl^- using a Metrohm Peak Ion Chromatograph/conductivity detector; 2) NO_2^- using Diazotization/Hach 2010 spectrometer; N_2O using an Agilent 6890N gas chromatograph with electron capture detector, and NH_4^+ using the phenate wet-chemistry method (Washington et al., 2004 after Clesceri et al., 1998).

Discharge Calculations

Discharge is measured directly using a bucket and stopwatch at flumes at stations 8 (spring) and 1 (first-order stream). However, the wetland streams are both too slow and shallow to accurately measure velocity during each sampling round. Thus, discharges at Stations 3 and 4 were calculated using the steady-state conservation-of-mass equations for fluid and a conservative solute. The continuity equation for conservation of mass of an incompressible fluid is given by:

$$Q_3 + Q_4 = Q_1 \qquad (1)$$

where Q_n (n = 1, 3, 4) is the discharge at Station n. The steady-state conservation-of-mass equation for a non-reacting solute is given by:

$$Q_3C_3 + Q_4C_4 = Q_1C_1 \qquad (2)$$

where C_n (n = 1, 3, 4) is the concentration at Station n. Combining equations (1) and (2) and solving for Q_3 results in the following equation:

$$Q_3 = Q_1 \frac{C_1 - C_4}{C_3 - C_4} \qquad (3)$$

Chloride concentrations are conservative along the flow paths and are consistently two times higher in the runoff (Station 3) than the spring-fed stream (Station 4). For each sampling date, equation (3) was solved using the measured discharge at Station 1 and the measured chloride concentration data at Stations 1, 3, and 4. The discharge at Station 4 was then calculated using equation (1).

RESULTS

Nitrate concentrations at the downstream locations of both streams exhibit a strong seasonal trend, with nitrate concentrations less than 1 mg N/L in the summer and early Fall of 2003 and 2004, and increasing to 4.5 mgN/L during winters (Figure 2). There is also a decrease in nitrate concentrations along the flow path of both streams, with a larger decrease along the unprotected stream. Nitrite (NO_2^-), dissolved nitrous oxide (N_2O), and ammonium (NH_4^+) are higher in the runoff stream, especially at upstream sampling locations, where nitrate concentrations are also higher.

For most sampling dates, nitrate loads in the protected stream are somewhat lower at the downstream location (Station 4) than at the spring (Station 8) (Figure 3). At the two downstream locations of each stream, calculated loads in the protected stream (Station 4) are 3 to 18 times higher than in the runoff stream (Station 3).

DISCUSSION AND CONCLUSIONS

The runoff stream delivers smaller loads of nitrate than the protected stream due largely to the smaller discharge in the runoff stream. Direct comparison of geochemical distribution and nitrate loads in the two streams is complicated by the presence of non-wetland water introduced at the headcut of the protected stream, whereas water in the runoff stream on sampling dates – which are all at least 48 hours after rainfall – is due to flux through the stream bed. However, water from the headcut spring flows through the wetland, and analysis of the geochemical distributions in the two streams offers insight into which stream supports greater potential for denitrification. Evidence for enhanced denitrification potential in the unprotected stream includes 1) a higher concentration of reduced N species than in the protected, spring-fed stream (Figure 3); 2) dissolved organic carbon values of two- to five-times higher in the unprotected stream (not shown); 3) lower discharge with longer residence times and greater potential for water/organic sediment

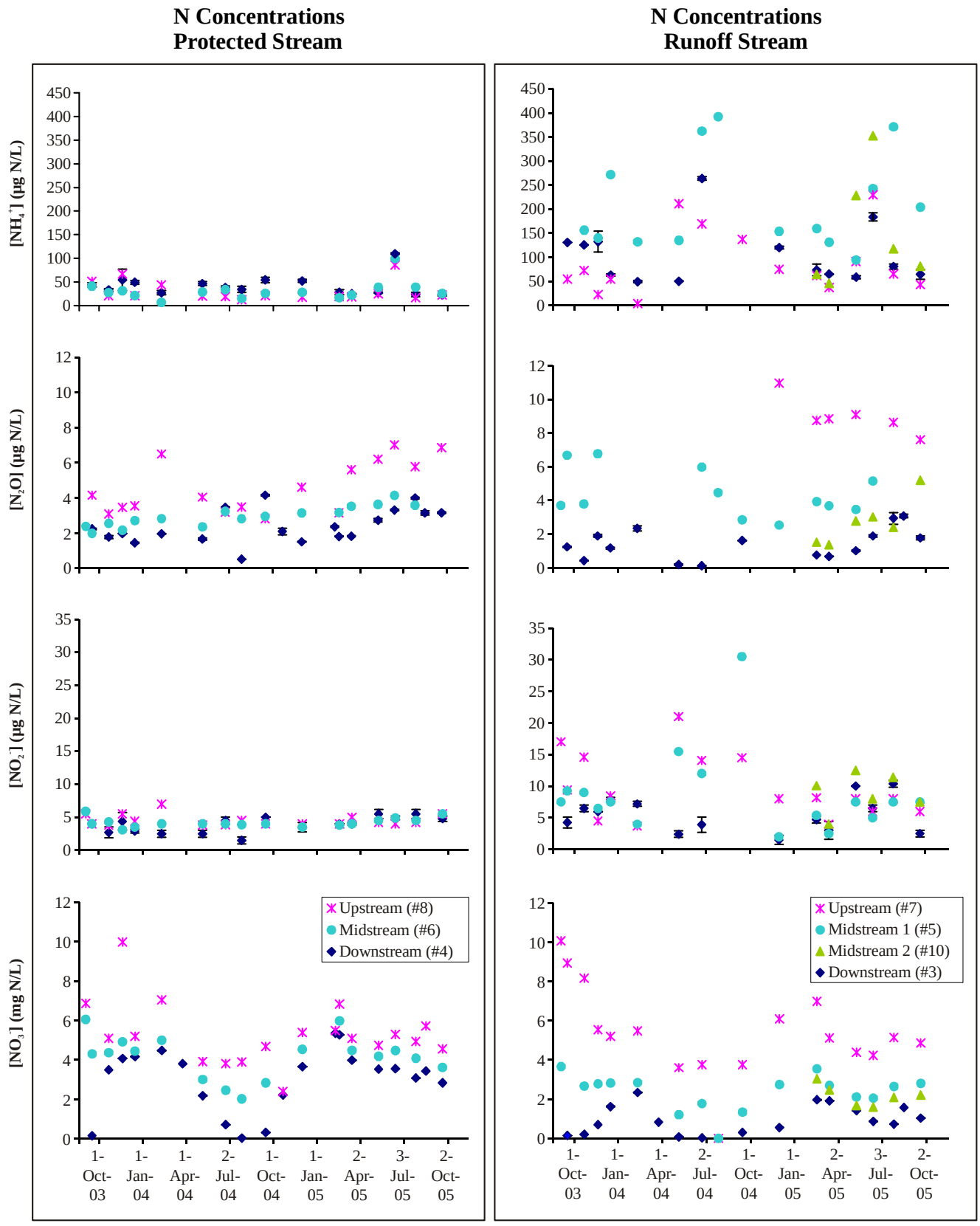

Figure 2: Nitrogen species distributions in the two streams. Refer to map (Figure 1) for sampling stations.

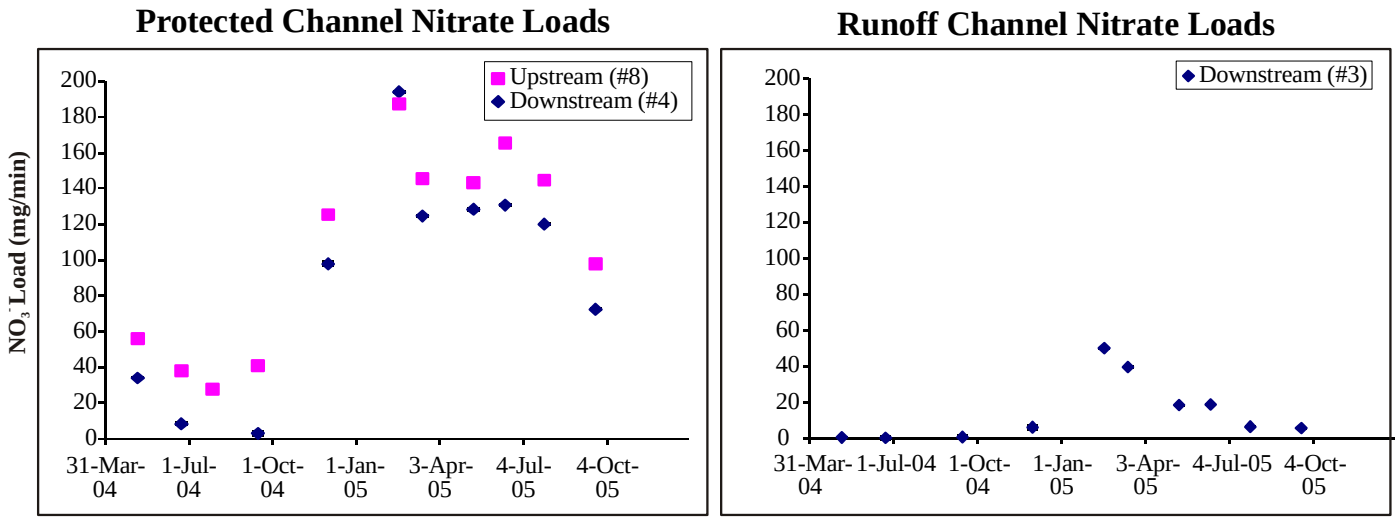

Figure 3: Nitrate loads using measured (Station 8) and calculated (Stations 4 and 3) discharges.

contact; and 4) increasingly lower nitrate recoveries and higher nitrous oxide concentrations and subsequent recovery to background corresponding to the nitrate breakthrough curve during the summer tracer injection experiment (trend not seen in the protected stream). These results have implications for managing wetlands to reduce nitrate from agricultural runoff.

DISCLAIMER

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's and U.S. Department of Agriculture's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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