Report as of FY2009 for 2007IN227G: "Nutrient and carbon delivery to streams in artificially drained landscapes of the Midwest: matrix flow, overland flow or macropore flow?"

Publications

- Articles in Refereed Scientific Journals:
    - Vidon, P. and P.E. Cuadra*, 2010. Impact of precipitation characteristics on soil hydrology in tile-drained landscapes. Hydrological Processes, DOI: 10.1002/hyp.7627 (Online – Early View).
    - Cuadra*, P.E., and P. Vidon. Storm nitrogen dynamics in tile-drain flow in the US Midwest. Biogeochemistry (in review).
    - Vidon, P., and Cuadra*, P.E. Phosphorus dynamics in tile-drain flow during storms in the US Midwest. Agricultural Water Management (in review).
- Conference Proceedings:
    - Cuadra, P.E., P. Vidon, 2009. Natural Variability in Dissolved Organic Carbon and Dissolved Organic Nitrogen Transport in Artificially Drained Landscapes of the U.S. Midwest. Abstract#B34A-04. American Geophysical Union Joint Assembly, Toronto, ON, Canada, May 2009

Report Follows

Progress Report for Award # 08HQGR0052 - Nutrient and carbon delivery to streams in artificially drained landscapes of the Midwest: matrix flow, overland flow or macropore flow? – **YEAR 2**

04/08-04/11, (PI) P. Vidon, (Co-PIs) J.W. Frey, N.T. Baker. USGS-NIWR National Competitive Grant Program (Award # 08HQGR0052). Title: Nutrient and carbon delivery to streams in artificially drained landscapes of the Midwest: matrix flow, overland flow or macropore flow? $129,042

Abstract / Summary

Understanding the processes controlling the delivery of nitrogen, phosphorus and carbon to streams in artificially drained landscapes of the Midwest is of critical importance to developing comprehensive nutrient management strategies at the watershed scale. Most nutrient and carbon losses in artificially drained landscapes of the Midwest occur during precipitation events through tile drain flow and overland flow. In addition, recent research has identified preferential flow through soil macropores as an important export mechanism contributing to tile drain flow. There is nevertheless a lack of empirical data documenting the relative importance of overland flow (OLF), matrix flow (MF) and preferential flow through soil macropores (PF) on nitrogen, phosphorus and dissolved organic carbon (DOC) losses to streams. For this project, a team of USGS scientists has teamed up with the PI (Vidon) to measure the relative importance of OLF, MF and PF during 6-8 storms over a two-year period in an artificially drained Midwestern watershed, and to identify the changes in the nature of in-stream nitrogen (nitrate, ammonium, total Kjeldahl nitrogen (TKN)), phosphorus (soluble reactive phosphorus (SRP), total phosphorus (TP)), and DOC (aromaticity) during storms.

Fieldwork is taking place in a small first order watershed, which is continuously monitored by the U.S. Geological Survey as part of the National Water Quality Assessment Program (NAWQA) for the White River, Great, and Little Miami River Basins. Water quality data have been collected in precipitation and at 2-4 hour intervals during 7 storms in overland flow, tile flow and the stream. Data analysis is underway and the PIs will used a two phase (tile + stream) multi-tracer (chloride, cation, oxygen-18) approach to independently estimate the relative importance of tile drain flow, overland flow, precipitation and seepage in the stream, and the relative importance of matrix flow and preferential flow through soil macropores in tile flow. The potential of DOC and DOC specific UV absorbance (SUVA) as potential hydrologic tracers to identify water sources in a watershed context will also be evaluated.

By providing a direct quantification of the relative importance of each water delivery pathway to NPC transport to streams for a variety of storms and crop development conditions, data collected as part of this project provide an increased understanding of the processes controlling NPC delivery to streams, and provide tools to better target best management practices (BMP) to minimize the impact of agriculture on raw rural water quality in the Midwest.

Problem

Phosphorus, nitrogen and carbon losses to streams affect aquatic productivity, food web structure, and water quality (Martin et al., 1999; Dalzell et al., 2005). Understanding the processes controlling the delivery of these solutes to streams is therefore of paramount importance in order to develop comprehensive watershed nutrient management strategies.

It is well established that most nutrient exports occur during episodic high flow periods (Royer et al., 2006) and that nutrient concentration in streams, hydrological processes and flowpaths often change rapidly during precipitation events in response to variations in precipitation intensity/duration and pre-event moisture conditions (Creed and Band, 1998; Sidle et al., 2000; Hangen et al. 2001; Wigington et al. 2003; Inamdar et al., 2004). The nature of dissolved organic carbon (DOC) (aromaticity, relative abundance of humic/non-humic substances) in streams also often varies during storms, indicating a change in the sources of DOC as a function of discharge (Katsuyama and Ohte, 2002; Hood et al 2006).

High nutrient losses and quick changes in nutrient and carbon concentration/nature during storms stress the importance of conducting research aimed at thoroughly understanding nutrient dynamics and flowpaths during storms. This will increase our ability to predict nutrient and carbon losses at the watershed scale with more precision in the years to come. It is especially important to address this issue in artificially drained landscapes of the Midwest, as agricultural states like Indiana, Ohio and Illinois have been identified as major contributors to excess nutrients in the Mississippi River (Goolsby et al., 2000; Royer et al. 2006).

Recent research has identified preferential flow through soil macropores as an important transport mechanism for solute transport during precipitation events in artificially drained landscapes of the Midwest (Kung et al., 2000a; Stone and Wilson, 2006). Nutrient losses via overland flow in artificially drained landscapes have also been shown to influence the dynamics of NPC losses to streams (Kurz et al., 2005; Royer et al., 2006). Nevertheless, there is a dearth of empirical data documenting the relative importance of overland flow (OLF), matrix flow (MF), and preferential flow through soil macropores (PF) during storms and/or the relative importance of each of these processes on the delivery of nutrients and carbon to streams in artificially drained landscapes of the Midwest.

Research Objectives

<u>Primary objective 1:</u> Identify the relative importance of overland flow, stream bank seepage, matrix flow and preferential flow through soil macropores to streamflow during storms in artificially drained landscapes of the Midwest.

<u>Primary objective 2:</u> Identify the relative importance of each of these water delivery pathways on nitrogen, phosphorus and carbon delivery to streams during storms. Particular attention will be given to characterizing the changes in the nature of N (nitrate, ammonium, total Kjeldahl nitrogen (TKN)), P (soluble reactive phosphorus (SRP), total phosphorus (TP)), and dissolved organic carbon (DOC) (aromaticity) losses to the stream during the storms studied.

Achieving these objectives will help manage raw rural water quality and quantity by allowing landscape managers to better target BMPs, as BMPs often influence soil moisture and water infiltration in soil, and therefore the relative importance of overland flow, matrix flow, and preferential flow through soil macropores. This broad objective is identified as an area of high priority in the RFP FY2007 of the Water Resources Research National Competitive Grant Program, section 104G (page 4).

Two corollary objectives will also be addressed as part of this project:

Corollary objective 1: By monitoring tile drain flow in two tile drains draining two fields under till and no-till, respectively, we will assess the impact of this best management practice (BMP) on raw rural water quality in the watershed.
Corollary objective 2: Assess the potential of using DOC and DOC Specific UV Absorbance (SUVA) to identify the relative contribution of various sources of water to the stream during storms. This objective will contribute to the development of better techniques to assess various components of the water cycle, which is a priority area for the 104G program in 2007 (RFP FY 2007, page 4).

Methodology

The project is field based in nature and is taking take place in the headwaters of Sugar Creek Watershed, in a small watershed (7.2 km^2), locally known as Leary Weber Ditch (LWD). Soils in LWD are suited for row crop agriculture such as corn and soybeans but require artificial drainage to lower the water table, removing ponded water, adding nutrients and ensuring good soil tilth. LWD is representative of many watersheds in the Midwest where poorly drained soils dominate and where artificial drainage is commonly used to lower the water table.

For this project, we quantified water and nutrient fluxes and delivery pathways in LWD for a total of 7 storms in years 1 and 2. These storms varied in duration and intensity and 3 of them generated significant amounts of overland flow. For each storm, a stream water mass balance will be performed (in progress). This approach will allow the team of PIs to identify the relative contribution to discharge of overland flow, tile flow, stream bank seepage, and direct interception of precipitation by the stream. Hydrological tracers (cation, oxygen-18, chloride) will be used to differentiate the relative contribution of new water (event water) and old water (pre-event water) to the stream during each storm, and to differentiate the relative importance of new water and old water in tile drain flow. In tile drains, old water will be considered equivalent to matrix flow (MF) and new water equivalent to preferential flow through soil macropores (PF) (Stone and Wison, 2006). Nitrogen (nitrate, ammonium, total Kjeldahl nitrogen (TKN)), phosphorus (soluble reactive phosphorus (SRP), total phosphorus (TP)) and dissolved organic carbon (DOC) will be measured in overland flow, tile drain flow, streamflow and precipitation to identify the relative importance of each water delivery pathway to nutrient and carbon losses to the stream. The change in the nature of DOC during each storm will be monitored spectrometrically to determine the usability of DOC as a tracer and characterize changes in the sources of DOC to the stream during storms.

Results

Analysis of data for the whole watershed is currently underway. However, three manuscripts looking at water, N and P dynamics in tile drains only (for now) are in various stages of publication (See list below). A summary of the findings presented in these manuscripts is shown here.

In spring, although variations in antecedent water table depth imparted some variation in tile flow response to precipitation, bulk precipitation was the best predictor of mean tile flow, maximum tile flow, time to peak and runoff ratio. The contribution of macropore flow to total flow significantly increased with precipitation amount, and macropore flow represented between 11% and 50% of total drain flow, with peak contributions between 15% and 74% of flow. For large storms (>6 cm bulk precipitation), cations data indicated a dilution of groundwater with new water as discharge peaked. Although no clear dilution or concentration patterns for Mg^{2+} or K^+ were observed for smaller tile flow generating events (<3 cm bulk precipitation), macropore flow still contributed between 11% and 17% of total flow for these moderate size storms.

Bulk precipitation amount had little impact on solute median concentrations in tile-drains during storms, but clearly impacted NO_3^- concentration patterns. For large storms (> 6 cm of bulk precipitation), large amounts of macropore flow (43-50% of total tile-drain flow) diluted NO_3^- rich groundwater as discharge peaked. This pattern was not observed for NH_4^+ and DON or for smaller tile-flow generating events (< 3cm) during which macropore flow contributions were limited (11-17% of total tile-drain flow). Precipitation amount was positively ($P<0.01$) correlated to NO_3^- and NH_4^+ export rates, but not to DON export rates. Limited variations in antecedent water table depth in spring had little influence on N dynamics for the storms studied. Although significant differences in flow characteristics were observed between tile-drains, solute concentration dynamics and macropore flow contributions to total tile-drain flow were similar for adjacent tile-drains. Generally, NO_3^- represented >80% of N load during storms, while DON and NH_4^+ represented only 2-14% and 1-7% of N load, respectively.

Depending on the storm, median concentrations varied between 0.006-0.025 mg/L for SRP and 0.057-0.176 mg/L for TP. For large storms (> 6 cm bulk precipitation), for which macropore flow represented between 43-50% of total tile-drain flow, SRP transport to tile-drains was primarily regulated by macropore flow. For smaller tile-flow generating events (<3 cm bulk precipitation), for which macropore flow only accounted for 11-17% of total tile-drain flow, SRP transport was primarily regulated by matrix flow. Total P transport to tile-drains was primarily regulated by macropore flow regardless of the storm. Soluble reactive P (0.01-1.83 mg/m^2/storm) and TP (0.10-8.64 mg/m^2/storm) export rates were extremely variable and positively significantly correlated to both mean discharge and bulk precipitation. Soluble reactive P accounted for 9.9-15.5% of TP fluxes for small tile-flow generating events (<3 cm bulk precipitation) and for 16.2-22.0% of TP fluxes for large precipitation events (>6 cm bulk precipitation). Although significant variations in tile-flow response to precipitation were observed, no significant differences in SRP and TP concentrations were observed between adjacent tile-drains.

Major Conclusions and Significance

Results presented above significantly increase our understanding of the hydrological functioning of tile-drained fields in spring, when most N losses to streams occur in the US Midwest. In particular, results stress the non-linear behavior of N export to tile drains during spring storms in artificially drained landscapes of the US Midwest, at a critical time of the year for N management in the MRB. For P, results stress the dominance of particulate P and the importance of macropore flow in P transport to tile-drains in the US Midwest. This brings critical insight into P dynamics in tile-drains at a critical time of year for water quality management.

Publications (* = graduate students)

Vidon, P. and P.E. Cuadra*, 2010. Impact of precipitation characteristics on soil hydrology in tile-drained landscapes. *Hydrological Processes*, DOI: 10.1002/hyp.7627 (Online – Early View).

Cuadra*, P.E., and P. Vidon. Storm nitrogen dynamics in tile-drain flow in the US Midwest. *Biogeochemistry* (in review).

Vidon, P., and Cuadra*, P.E. Phosphorus dynamics in tile-drain flow during storms in the US Midwest. *Agricultural Water Management* (in review).

Presentations

Vidon, P, P.E. Cuadra*, 2010. Phosphorus dynamics in tile-drain flow during storms in the US Midwest. Annual meeting of the American Water Resources Association, Philadelphia, PA, November 2010 (Forthcoming)

Hennessy*, M, P. Vidon, 2009. Constraining nitrogen, phosphorus and carbon exports in a Midwestern Agricultural Watershed. American Geophysical Union Joint Assembly, Abstract#H71B-07. page 5, Toronto, ON, Canada, May 2009.

Cuadra*, P.E., P. Vidon, 2009. Natural Variability in Dissolved Organic Carbon and Dissolved Organic Nitrogen Transport in Artificially Drained Landscapes of the U.S. Midwest. Abstract#B34A-04. Page 103, American Geophysical Union Joint Assembly, Toronto, ON, Canada, May 2009.

Grant Submissions n/a

Students

Graduate students: 3
Undergraduate Researchers: 4