Coupling in-ditch studies and modelling to understand the landscape - wide nitrogen transport and denitrification (N$_2$, N$_2$O) potential of roadside ditch networks across catchments

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Abstract
In this project, we evaluated the potential for roadside ditches to transport and transform nitrogen (N) across mixed use, agricultural landscapes by coupling site-specific field measurements and a GIS-based modeling tool. We compared dissolved (NO$_3$+NO$_2$) and gaseous N (N$_2$O) fluxes among three rural roadside ditches – 2 associated with active agricultural fields and one ditch draining a woodlot. Both ditches adjacent to ag fields were major conduits of dissolved nitrogen (with concentrations ranging from 10-40 mg/L and high flow rates), whereas the woodlot ditch was frequently dry and had nitrate concentrations of less than 0.1 mg/L. Nitrous oxide fluxes from the soils were present on all 7 sampling dates (May – late Sept), with the highest levels in the two ag ditch sites; however, flux rates varied substantially through time and among sites. Currently, no simple and cost-effective tools exist to estimate the impacts of roadside ditches on the entire interconnected network of streams and ditches in a watershed. In order to begin scaling up our site-specific field data to whole watersheds, and to aid in identifying “hot spots” for greenhouse gas production and N transport or removal, we developed a GIS-based toolset (Ditch Tools) that incorporates the specific effects of a watershed roadside ditch network into the hydrologic landscape using publicly available GIS data sets.

Three Summary Points of Interest

- Roadside ditches are significant conduits of dissolved nitrogen moving from agricultural fields to adjacent streams. Nitrous oxide flux from ditch substrates is pervasive during the spring through fall, but the potential for significant filtering and nitrogen removal via denitrification processes either intermediately as N$_2$O (a greenhouse gas) or fully to N$_2$ (inert gas) is dependent on multiple localized and landscape factors.
- Based on our model, roadside ditches can significantly reduce water flow distance and travel time in mixed use, predominantly agricultural landscapes. Under heavy precipitation conditions, flow distance from the land to open channels was reduced by 50%, and runoff travel time was decreased throughout the test-modeled watershed, with the fastest transport in areas with the highest road (and so roadside ditch network) density.
- Ditch Tools can be expanded to incorporate spatially explicit landscape parameters and further developed as a useful, cost effective tool for guiding larger-scale field studies of roadside ditch networks, towards identifying best ditch management practices to protect water and environmental quality.

Keywords: roadside ditches, nitrogen, greenhouse gas (GHG), denitrification, agriculture, manure, GIS, model
Introduction

Roadside ditches have the potential to alter hydrologic flow paths significantly, with consequences for water movement, biogeochemical processes, and water quality. In this project, we focused on the potential role of roadside ditches as transporters and filters of nitrogen moving from farm fields. We conducted field-based monitoring to quantify site specific processes and, to investigate the critically important but still poorly characterized role of these ditch networks at the watershed scale, we developed a GIS-based toolset estimating some indices of ditch functionality (“Ditch Tools”). The tools facilitate calculation of several water flow network metrics with and without the impact of road ditches, including length of travel, average travel time, area and proportions of landscape drainage directly to road ditches and to natural streams. Building on the basic characteristics of the landscape as inputs (elevation, slope, road network, land type), we can create a series of maps of more complex functions of the drainage network, which help identify “hotspots” of ditch alteration on natural stream flow. The long-range goal of this exploratory modeling is to develop a cost-effective tool to allow estimation of potential importance of an entire roadside ditch network in transporting and transforming N, and to guide field studies toward identifying best ditch management practices to minimize N pollution and protect water and environmental quality throughout NYS.

Results & Discussion

Field Monitoring: Both ditches adjacent to agricultural fields (AG-1,-2) were major conduits of dissolved inorganic nitrogen moving directly from the field to an adjacent stream. AG-1 had average nitrate+nitrite concentrations of 33.2 ± 6.41 mg N/L and frequently had outflowing loads of 10 kg N/day or more. AG-2 had slightly lower and more variable concentrations (21.5 ± 10.9 mg N/L). In contrast the site adjacent to woodland (WOOD-3) was frequently dry and had extremely low nitrate concentrations when water was present (0.047 ± 0.05 mg N/L). Nitrous oxide fluxes were present on all 7 sampling dates (May through late September), with the highest fluxes in the two AG ditches, and considerable variation through time and among sampling sites (Figure A). In order to understand the management potential for reducing nitrogen pollution in streams and minimizing the flux of greenhouse gases (GHG’s), it will be important to scale up and evaluate the cumulative transfer of nitrogen from agricultural fields to streams across entire watersheds, given the extensive roadside ditch networks.

Ditch Tools: We applied the model to first evaluate the change in hydrologic parameters such as flow distance from the landscape to open channels (ditch and / or stream) and water runoff travel time through the watershed under natural, stream-only conditions, and then with the interconnected network of roadside ditches and streams. When the tool was run without road network, the runoff travel time ranged from 0.0015 to 44.2 hours, with an average of 2.83 hours (Figure B). With the road network, there was little change in the range of travel time (0.0015 to 44.6 hours), but the average travel time decreased substantially (1.81 hours, Figure C). Flow distance to open channels without road network ranged from 0 to 1982 m, with an average distance of 504.6 m. With the road network, there was a 50% reduction in flow distance from the land to open channels (243.8 m). Similar patterns were found by Buchanan et al. (2013a). Both of these flow metrics can have a large effect on flooding potential, as well as nitrogen transport downstream or the transformation to either an inert (N2), or a damaging greenhouse gas (N2O), as we are investigating in the smaller-scale, field component of our study.

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Policy Implications

The results of this work clearly show that roadside ditches are significant conduits of dissolved nitrogen from ag activities to nearby streams, and that within-ditch removal through microbial denitrification processes may help offset some of this loading, but may also contribute to GHG production. Improving roadside ditch management is a critical first step to reduce this mechanism of pollutant transfer. Our goal with modeling is to develop a simple and cost effective set of tools to explore functional relationships between ditch characteristics, hydrology, sources and transport or transformation of N and other pollutants along the watershed - estuary continuum. With further modifications to allow more fine-scale prediction of landscape response to precipitation and the addition of explicit land use in each cell, Ditch Tools can be a cost effective way to identify priority areas in the landscape for study and implementation of best management practices, and to do scenario testing of major parameters affected by ditch maintenance and management strategies (width, vegetation type, slope), as they affect flow rate, water travel time, and N processing, to best protect environmental quality. This tool would be of interest and use to municipalities, NGO’s, and managers both for targeting actions and for education.

Methods

Field Monitoring: We compared the transport of dissolved NO$_3$+NO$_2$ and the production of N$_2$O across three roadside ditches: 2 associated with active farm fields and one ditch draining a woodlot, all located within a 15 km$^2$, agriculture-dominated catchment in central NYS. A total of 171 water samples were collected on 18 dates in AG-1, on 13 dates in AG-2, and 7 dates in WOOD-3 over a 6-month period, from immediately post snowmelt in early April, through late September, as water was available in the ditches for collection. Flow velocities and discharge were measured using a Marsh-McBirney flow meter at the inflow and outflow points on each ditch to determine loads. Fluxes of N$_2$O, CO$_2$, and CH$_4$ were measured on 7 dates in four static chambers, distributed over 30 m in each of the three ditches.

Ditch Tools: Input data maps for outlet location, land type (identifies stream and road cells), and slope were generated from USGS elevation data (http://nationalmap.gov/elevation.html), NHD Plus flowlines to define stream cells (http://www.horizonsystems.com/nhdplus/), and the TIGER (Topologically Integrated Geographic Encoding and Referencing) website (https://www.census.gov/geo/maps-data/data/tiger.html) to define road cells; roadside ditches were assumed to be associated with all roads. Agricultural ditches are not identified in this analysis. Flow direction and accumulation maps for the natural (stream only) and roadside ditch network conditions were created using Arc Hydro Tools (http://downloads.esri.com/archydro/archydro/). A series of Python codes were used to compute water
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travel path length and travel time, based on the procedure used by Buchanan et al. (2013a, 2013b). These codes are implemented as a custom ArcToolbox running in ArcGIS, referred to as “Ditch Tools”. The test study area was a 50 km² sub-watershed of the Wappinger Creek Watershed, within the Hudson River basin. We chose this because of the availability of hydrology and nutrient flux data (a stream gauge and water monitoring station at the downstream outlet is maintained by the Cary Institute of Ecosystem Studies), as well as previous modeling studies performed in this area (Hong et al. 2012). Runs reported on here were done using a 100-yr precipitation event intensity, to allow for comparison with results from Buchanan et al. (2013a).

Outreach Comments
The findings from this project have been incorporated into the Report to the Chesapeake Bay Program for improving roadside ditch management across the Chesapeake Bay Watershed.

Student Training
One undergraduate student assistant (Vassar College) was trained in basic field water and gas sampling methodologies.

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References
