Agricultural Water Management 152 (2015) 31–40

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Sediment-assisted nutrient transfer from a small, no-till, tile drained watershed in Southwestern Ontario, Canada

Bryce Molder[1], Jaclyn Cockburn*, Aaron Berg, John Lindsay, Kathryn Woodrow

Department of Geography, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1, Canada

ARTICLE INFO

Article history:
Received 27 August 2014
Accepted 20 December 2014
Available online 7 January 2015

Keywords:
Suspended sediment transport
Nutrient transfer
Hysteresis
Extreme events
Particle size
Lake Erie

ABSTRACT

Sediment and nutrient exports were evaluated in a small agriculture-dominated watershed that drains into Rondeau Bay, on the northern shore of Lake Erie in Southwestern Ontario, Canada. The following hypothesis was tested: the quantity and quality of suspended sediment yields in agricultural settings controls nutrient transfer from surface runoff. Stream discharge and water quality were monitored at three locations along a tributary reach within the Rondeau Bay basin during the 2013 growing-harvest season (May–October). Water samples were analyzed in the laboratory for suspended sediment concentration, particle size, and sediment-assisted nitrogen and phosphorus content. Estimated total sediment yield over the 6-month monitoring period was ∼50 t (0.13 t ha^{-1}). A mid-season change in contributing sediment sources was inferred based on the observations of suspended sediment transfer and particle size following a ∼92 mm rainfall event. This extreme runoff event marked a change in the discharge-suspended sediment response seen in the catchment, which included a July–September abrupt decrease in suspended sediment concentration and a coincident increase in fine-grained particle abundance. Clockwise event hysteresis suggested adjacent and/or likely channel derived sediment sources. Finally, there was a positive relationship between suspended sediment concentration and phosphorus ($R^2 = 0.86$, $n = 63$) and orthophosphate ($R^2 = 0.75$, $n = 63$). Estimated nutrient concentrations exceeded provincial load guidelines, which suggests that present land management efforts to minimize nutrient loading via surface runoff require further evaluation. This research concludes that agricultural-based nutrient loading into Lake Erie is sediment-assisted and that this sediment potentially derives from in-channel and tile drain sources. The findings have important implications for future soil loss and thus nutrient loading from agricultural settings, especially during extreme events.

1. Introduction

North American agricultural watersheds having a significant agricultural land-use component are commonly characterized by above-average suspended sediment concentrations (SSCs) and nutrients. This is due to increased erosion rates associated with various agricultural land management practices (Tiessen et al., 2010; Verhulst et al., 2010; Schilling et al., 2011; Heathcote et al., 2013). Suspended sediment transfer from agricultural landscapes degrades downstream water quality because as a physical presence, high SSCs reduces water transparency, disrupts watercourse drainages, and covers aquatic habitats (Carpenter et al., 1998, 2011; Collins and Walling, 2007; Tiessen et al., 2010; Mukundan et al., 2013). In addition, fine-grained sediments adsorb and thus transport nutrient pollutants within surface runoff to nearby stream networks and water bodies (Ballantine et al., 2009; Belmont et al., 2011). Pollution caused by agricultural-based sediment and nutrient transfer is suggested to be the most common cause of water impairment in the Great Lakes region (Environmental Protection Agency [EPA], 2012).

Water quality in Lake Erie was identified as a serious issue due to agricultural activities in the 1970s (EPA, 1978). In response, nutrient loading reduction strategies were adopted throughout Canada and the United States to reduce eutrophication (EPA, 1978). Nonetheless, Lake Erie has experienced episodic algal bloom re-emergences since the 1970s, and as recently as summer 2011, the largest bloom to date occurred (Michalak et al., 2013). It is possible that Lake Erie's current eutrophic state is due to increased nutrient loading stemming from recent changes in land use. For instance,

* Corresponding author. Tel.: +1 519 824 4120x53498.
E-mail addresses: bmolder@uoguelph.ca (B. Molder), jaclyn.cockburn@uoguelph.ca (J. Cockburn), aberg@uoguelph.ca (A. Berg), jlindsay@uoguelph.ca (J. Lindsay), kwoodrow@uoguelph.ca (K. Woodrow).
[1] Tel.: +1 416 418 2881.

http://dx.doi.org/10.1016/j.agwat.2014.12.010
0378-3774/

Ontario reports increases in no-till operations, tile drainage operations, and decreased fertilizer use over the last decade (StatsCanada, 2007; van Bochove et al., 2009; Michalak et al., 2013). Research suggests that no-till prevents fertilizer-based nutrients from being mixed into soils, allowing for rapid nutrient transport in surface runoff, with tile drains linking the nutrient-laden runoff directly to draining streams (Simard et al., 2000; Macrae et al., 2007b; Tiessen et al., 2010; López-Vicente et al., 2013; Heathcote et al., 2013; Schottler et al., 2014). Other factors, such as increases in rainfall intensity and occurrence throughout Southern Ontario, also promote nutrient loss by increasing local erosion (Adamowski et al., 2003; Bruce and Lean, 2006; Michalak et al., 2013; Stone et al., 2000). Therefore, extreme rainfall events that often lead to increased sediment yield from agricultural watersheds (e.g., Rudra et al., 1989; Steegen et al., 2000) have important implications for water pollution in the Great Lakes.

In light of the trends in poor water quality, land use changes, and rainfall increases in Southern Ontario (e.g., Stone et al., 2000; Macrae et al., 2007a; Bosch et al., 2014), it is necessary to evaluate agricultural sediment transfer and identify contributing sources in order to mitigate the detriments associated with sediment and nutrient pollution. Insight can be gained by investigating variations in the stream discharge–SSC relationship. For example, chronological clockwise hysteresis patterns occur when transported sediment derives from near or in-channel sources (e.g., Klein, 1984; Williams, 1989; Rodríguez-Blanco et al., 2010). Furthermore, nutrient transport pathways can be inferred through the relationship between suspended sediment flux and nutrient loading (e.g., Singh et al., 2007). Current research suggests a connection between surface water nutrient loading and fine-grained soil fractions (Quinton et al., 2001; Collins and Walling, 2007). More specifically, clay-sized particles are often positively correlated with nutrient loading due to their large surface area, high exchange capacity, and charged surfaces (Stone and English, 1993). This is important because clay-sized particles are preferentially eroded from source areas and potentially mobilized through frequent, low magnitude runoff events (Quinton et al., 2001; Belmont et al., 2011).

This study proposes that the quantity and quality of suspended sediment yields in agricultural settings contributes to nutrient transfer from surface runoff, and that agricultural practices such as no-till and tile drains have an impact on the hydrological, and the sediment and nutrient loading responses to rainfall inputs. Two primary objectives were considered in order to test this hypothesis: (1) identify sediment mobilization mechanisms and transport processes as they relate to rainfall events and (2) establish a relationship between transported sediment character (e.g., concentration and grain size) and nutrient loading.

2. Methods

2.1. Study site

Water quantity and quality were monitored in a small portion of a tributary draining into Rondeau Bay, Lake Erie, during the period of May–October, 2013. The monitored reach is ~2.5 km in length, and drains a sub-watershed approximately 3.8 km^2 in area (Fig. 1). Within the study area, the stream channel ranges from 1 to 2 m in width and 5–25 cm in depth during low-flow conditions, though some deeper pools over 50 cm deep exist. The channel is deeply incised with little presence of a floodplain. Bank incisions extend up to 2 m in height. The streambed generally consists of 5–25 cm of fine-grained material. The tributary extends southward toward Lake Erie from the elevated Blenheim moraine (Gilbert et al., 2007). Streamflow is generated by rain and snow; the near-by Chatham, ON Environment Canada Weather Station reports 803 mm of rainfall and the 79 cm of snowfall as the 1981–2010 climate normals (Government of Canada, 2014). The soils underlying the tributary are classified as a silty clay loam, derived from Quaternary Period glaciolacustrine deposits (Gilbert et al., 2007). The soil is characterized as poorly drained due, in part, to the fine-textured nature of the regions surficial deposits (Gaynor and Findlay, 1995). The region is dominated by agricultural activities (e.g., related to crop growth and pastures), and has been degraded by intensive land management practices dating back to the 1960s (Gilbert et al., 2007). Many farmers have adopted no-till operations over the last several decades, as a way to address and mitigate land degradation issues (Gilbert et al., 2007). Fields adjacent to the monitored tributary were cropped with soybean, corn, and hay during this study. Seeding occurred early May and crops were harvested throughout October. Agriculture field tile drainage networks are in place with outlets linking field runoff directly to the stream channel throughout the study area. A dense riparian buffer along parts of the stream was present that promoted localized woody debris buildup in the stream course and dense aquatic vegetation growth. As a result, portions of the stream were waterlogged and stagnant during low-flow conditions between rainfall events throughout the monitoring period.

Recent ecological assessments report high nutrient loadings into Rondeau Bay, as evidenced by seasonal, typically late summer, algal blooms and aquatic vegetation growth (Gilbert et al., 2007). Total SSC, phosphorus, nitrogen, and *E. coli* exceeded proposed provincial levels and dissolved oxygen were blow provincial levels for the majority of tributaries draining into Rondeau Bay (Gilbert et al., 2007). Despite poor water quality conditions at present, continuous tributary monitoring for discharge, SSC, and nutrient content is not in place (Gilbert et al., 2007). Furthermore, special concerns have been raised in regard to a number of species at risk (SAR), which seek refuge within Rondeau Bay. Numerous retention ponds, buffer strips, and treatment wetlands were established in the area (e.g., 2007–2010) through provincial government funding in response to environmental concerns, though none were located in the studied sub-watershed.

2.2. Data collection

Precipitation from rainfall was the primary weather factor that controlled runoff generation in this field site during the study period. Rainfall and temperature were recorded with a Davis Instruments, Vantage Pro2 Plus weather station and tipping bucket located nearby (~10 km) west of the study area in the hamlet of Cedar Springs. Each bucket tip is equivalent to 0.3 mm moisture accumulations. Temperature was monitored at 15-min intervals. Weather Innovations Consulting Incorporated maintains the weather station.

Monitoring stations were established ~10–15 m upflow at each of the three roads; Talbot, Eds, and Front that intersect the monitored reach from which the stream was accessed for gauging and sample collection (Fig. 1). Stream level was monitored with pressure transducers (HOBO U20 Water Level Data Logger, model #U20-001-01) and flow was estimated with a power rating curved established at each site.

Gauging at each station, water sample collection, and regular maintenance of each site was completed generally once a week between May and October 2013. Water samples were kept cool and analyzed for suspended sediment and particle size, as well as, total phosphorus (P), orthophosphate (PO_4^{3-}), and total nitrogen (N). SSC was determined by filtering the sample through a pre-weighed polycarbonate 0.4 μm membrane filter. Filter-recovered sediment was rinsed into a SEQUOIA portable LISST (Laser In Situ Scattering and Transmissometry) for particle size determination. Fluvial