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Quantifying nutrient and suspended solids fluxes in a constructed tidal marsh following rainfall: The value of capturing the rapid changes in flow and concentrations

J. Randall Etheridge, François Birgand*, Michael R. Burchell II

North Carolina State University, Biological and Agricultural Engineering, Campus Box 7625, Raleigh, NC 27695, USA

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ABSTRACT

Coastal tidal wetlands are perceived to provide nutrient dissipation services and serve as the final buffer between excess nutrient loads coming from nearby upland watersheds and sensitive estuarine waters. The construction and restoration of tidal marshes has the potential to benefit coastal waters. However, the water quality services of tidal wetlands have yet to be established with any certainty. This is in part due to the difficulty of monitoring these systems where flow and concentrations vary widely with tidal ebb and flood along with rainfall events mobilizing nutrients in pulses from upstream watersheds. In this article, we show over a period of 10 days following a rainfall event, the value of high temporal resolution data to characterize the complex nutrient and flow dynamics and to reliably calculate material balances in a created coastal marsh in North Carolina. Ultraviolet–visible spectrometers were used to obtain 15-min concentration data for nitrate, total Kjeldahl nitrogen, dissolved organic carbon, total suspended solids, phosphate, and total phosphorus. Our results show that a pulse of nitrate moved through the marsh from upstream agricultural production following the rainfall event and 25% (13 kg of 53 kg) of the nitrate was retained in the marsh over a period of 10 days. No other material showed a clear pulse from the upstream agricultural production. The marsh acted as a sink for total suspended solids (40 kg) and had near neutral mass balances for dissolved organic carbon, total Kjeldahl nitrogen, total phosphorus, and phosphate. Subsequent simulations indicated that different and erroneous results would have been obtained from 2-, 6- or 12-h sampling intervals. These results demonstrate, even on a short term basis, why high-frequency data acquisition is necessary in these tidal marsh systems to truly quantify their impact on water quality ecosystem services.

1. Introduction

Quantifying and understanding the role that tidal marshes play in coastal energy and nutrient dynamics has been a focus of research since the introduction of the marsh outwelling theory (Teal, 1962; Odum, 1968). Gaining a clearer understanding of the ecosystem services provided by coastal marshes, both natural and constructed, has increased in importance due to continued marsh loss from sea level rise and coastal development. Many different approaches have been taken to quantify the ecosystem services of nutrient and suspended solids retention including monitoring the fluxes at the inlet/outlet of marshes (e.g. Dame et al., 1991; Jordan and Correll, 1991; Gardner and Kjerfve, 2006) and modeling the biogeochemical processes (Aziz and Nedwell, 1986; Anderson et al., 1997). The highly dynamic nature of systems with tidal flow makes it difficult to capture the variations in nutrient concentrations and process rates over multiple tidal cycles.

Improvements in technology and new methods give present day researchers many advantages over previous attempts to quantify the nutrient and suspended solids fluxes in tidal systems. Equipment that can be installed on-site for automated monitoring makes possible the collection of water quality parameters at a frequency unimaginable in the past due to the cost of sample collection and analysis. Monitoring of water quality at a high temporal resolution in upland watersheds has been used to gain information on residence times and diurnal variations in chemical concentrations (Kirchner et al., 2000; Pellerin et al., 2012). Recently developed portable ultraviolet–visible (UV–vis) spectrometers have made possible the collection of water quality parameters including, but

* Corresponding author. Tel.: +1 919 513 2499; fax: +1 919 515 7760.
E-mail addresses: jretheri@gmail.com (J.R. Etheridge), francois_birgand@ncsu.edu (F. Birgand), mike_burchell@ncsu.edu (M.R. Burchell II).

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not limited to, nitrate (NO_3—N), total Kjeldahl nitrogen (TKN), dissolved organic carbon (DOC), phosphate (PO_4—P), total phosphorus (TP), and total suspended solids (TSS) at a high temporal resolution in brackish tidal waters (Etheridge et al., 2014).

A common theme throughout the literature examining sediment fluxes in coastal marshes is the influence of storm conditions on sediment delivery to marshes (Jordan et al., 1986; Cahoon, 2006; Turner et al., 2006). Many of these published accounts referred to extreme tropical weather systems with storm surges and increased wave action, but the importance of rainfall events in shaping marshes and driving biogeochemical processes should not be overlooked (Day et al., 2002). For instance, Whiting et al. (1989) noted an increase in the export of all forms of nitrogen when their sample collection occurred following rainfall events. The increase in NO_3—N and ammonium (NH_4—N) concentrations was attributed to high concentrations of these solutes in the rain. Particulate nitrogen, mobilized when rain impacted the marsh surface, showed the largest increase in concentration following storm events. Pulses of DOC and particulate organic carbon were observed by Chalmers et al. (1985) following rainfall events, and the particulate fraction showed the greatest increase in concentrations. These studies show the importance of capturing storm events when trying to understand coastal marsh nutrient dynamics in marshes that have few inputs from upstream sources.

The flux of nutrients derived from within coastal wetlands is small compared to the nutrient input from urban or agricultural sources when these sources are present. Whiting et al. (1989) noted an increase in NO_3—N concentrations of less than 0.4 mg L^{-1} due to rainfall, whereas Poe et al. (2003) found that NO_3—N concentrations in a coastal wetland receiving agricultural drainage increased by a minimum of 2.8 mg L^{-1} during each monitored rainfall event. A portion of the nutrients applied to agricultural fields as fertilizer are mobilized by both surface and subsurface flow, discharging to surface waters that flow toward coastal wetlands. Agricultural drainage systems, which are required to maximize yields on poorly drained coastal soils, increase the rate at which nutrients leave these facilities. The combination of elevated nutrient concentrations and increased flows following rainfall events can cause substantial fluxes of these nutrients to downstream aquatic systems (including coastal wetlands) in short periods of time (e.g. Birgand et al., 2011). Therefore, a high proportion of the annual nutrient delivery to wetlands may result from just a few rainfall events (Raisin et al., 1997; Jordan et al., 2003).

The goal of this work was to examine water quality data collected at a high temporal resolution in a created brackish marsh in the 10 days following an April 2012 rainfall event, to demonstrate how nutrient and suspended solids dynamics could be described in detail. The nutrient and suspended solids retention or release was quantified using a mass balance approach to determine whether the marsh was a source or sink for nutrients and suspended solids during the short term event. Simulations of 2-h, 6-h, and 12-h sampling intervals were run to additionally demonstrate the potential error induced by less frequent sample collection and the value of near continuous concentration data.

2. Methods

2.1. Site description

The study site was a constructed marsh in Carteret County, North Carolina (34.82°N 76.61°W). The marsh and tidal stream system was located between a row crop agricultural production facility to the north and the upper reaches of the North River to the south. The agricultural operation grew crops such as corn, soybeans, and wheat and was drained using 1 m deep parallel ditches placed 80 m apart. The area was a natural wetland until it was drained and converted to agricultural production in the late 1970's as North River Farms. During the fall of 2005 and the spring of 2006, 6.9 ha of brackish marsh and 1000 m of tidal stream were constructed on a portion of the land (Fig. 1). The goal of the marsh construction was to create habitat equivalent to that available in natural marshes, while improving the quality of water reaching the North River estuary. The stream and marsh were designed using reference-based design principles. To achieve target elevations, significant grading was required. Topsoil was stockpiled during excavation and replaced during final grading to provide suitable conditions for plant establishment. The constructed marsh was planted with *Spartina alterniflora*, *Spartina patens*, and *Juncus roemerianus* at appropriate elevation ranges based on observations from local reference marshes.

Drainage from the agricultural land was directed into the constructed marsh with the idea that biogeochemical processes occurring in the constructed system would remove a portion of the nutrients before the water reached the sensitive estuarine ecosystem. A portion of the agricultural drainage flowing in a large canal just west of the site was diverted into one of the constructed streams, Broome's Branch, by a low level rock weir. This constructed tidal stream discharged to the estuary, but was linked to the same drainage canal at the southern end of the project, creating a hydraulic loop. Drainage from the agricultural production also entered the constructed system through Evans' Creek which transitioned from a freshwater stream at its northernmost point to a brackish stream a few hundred meters northeast of its confluence with Broome's Branch.

The constructed system was monitored to quantify the nutrient retention capacity of the created marsh/tidal stream system and gain insight into the nutrient dynamics in the marsh. The focus of this research was on 5.6 ha of tidal marsh adjacent to 660 m of Broome's Branch (Fig. 1). An upstream/downstream monitoring design was used to calculate a mass balance for the portion of the constructed system located between the two monitoring stations. This reach of tidal stream was chosen as there were no major inputs of surface water to the marsh other than through the two monitoring stations. Measurements of flow and nutrient concentrations at the upstream station (closest to the drainage canal diversion) and the downstream station (closest to the estuary) were required to calculate the mass balance for the marsh.

2.2. Flow and rainfall monitoring

Measuring flow (Q) in tidal systems creates challenges not faced in upland systems with unidirectional flow. Bi-directional flow due to tides prevents the use of stage-discharge curves. The flow through each monitoring station was calculated using the continuity equation ($Q = VA$) from 15-min data.

Five-meter long trapezoidal flumes fitted with ramps were installed at each monitoring station to funnel bidirectional flow over a section of known and constant geometry to lower uncertainties in velocity (V) and wetted cross sectional area (A) measurements. These flumes should not be confused with the flumes used in conducting studies on the marsh platform (e.g. Wolaver et al., 1983; Whiting et al., 1989). The cross section (A) was calculated from water levels measured above the flume bottom using pressure transducers (ISCO 750 and ISCO 6712, Lincoln, NE, USA; Infinities USA, Port Orange, FL, USA) and digital imagery (GaugeCam, Raleigh, NC, USA). The flume bottom elevation at the upstream station was 0.02 m (NAD83) and the flume bottom elevation at the downstream station was −0.49 m (NAD83).

Measured bidirectional velocities at the center of the flume (ISCO 750 and ISCO 6712, Lincoln, NE, USA) were taken as index