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Water quality dynamics of ephemeral wetlands in the Piedmont ecoregion, South Carolina, USA

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ABSTRACT

Small ephemeral wetlands are commonly found in the Piedmont ecoregion of the southeastern USA. Ephemeral wetlands have important ecological functions but information about their water quality over its flooding periods is relatively limited. In this study, the water chemistry and physical parameters of three ephemeral wetlands and their nearby water bodies, including first order and second order streams and groundwater in the Piedmont ecoregion of South Carolina, were closely monitored during their flooding periods from January to June 2012. Nutrient and water quality analyses demonstrated the chemistries of wetlands, stream, and groundwater were different from each other in spite of their proximity. Greater concentrations of dissolved organic carbon (DOC) and dissolved organic nitrogen with a major portion in humic-acid-like and fulvic-acid-like fractions were generally found in wetland waters. In contrast, significantly lower DOC concentrations with a greater portion of inorganic nitrogen were observed in stream and groundwater. Electrical conductivity at 25 °C (EC_{25}) and temperature measurements showed a greater fluctuation in wetlands, indicating their poor buffering capacity against environmental changes. Results of this field study suggested that these small ephemeral wetlands in the Piedmont Ecoregion have relatively unique biogeochemistry in comparing their adjacent water bodies.

1. Introduction

Ephemeral wetlands (i.e., isolated, seasonal, temporary, dry end, or headwater wetlands; vernal pools) provide numerous watershed-level functions including critical wildlife habitat, floodwater storage, groundwater recharge, and water filtration. Global declines in ephemeral wetlands have been linked to amphibian declines, loss of habitat for reptiles and invertebrates, and alterations to hydrological regimes (Gibbons et al., 2000; Jenkins et al., 2003; Zedler and Kercher 2005). Smaller wetlands are less able to recover functions after human disturbance (Moreno-Mateos et al., 2012), yet because of their dispersion in the landscape provide value disproportionate to their size (Gibbs, 1993; Leibowitz 2003). Despite the importance of these wetlands, they are poorly protected in much of the United States and have, at best, ambiguous levels of regulatory oversight under the CWA (Zedler, 2003). U.S. Supreme Court decisions (e.g., Rapanos et ux et al. v. United States, 547 U.S. 715, 2006) suggested that water bodies other than traditional navigable waters (TNWs) and the adjacent wetlands and relative permanent tributaries of TNWs and the abutting wetlands could be jurisdictional waters if a significant nexus based on hydrological or ecological connectivity existed with a TNW (Grumbles et al., 2008). A recent U.S. rule expands the definition of waters of the United States and establishes a pressing need for better scientific information to define connectivity among water bodies (Federal Register, 2014). The Piedmont ecoregion of the southeastern United States is a useful instance of loss of wetlands to historical agriculture that had intensive impacts on geomorphology of aquatic systems; such have been compounded by recent urbanization and land-use changes (Campbell et al., 2008; Napton et al., 2010). The extent of wetland loss is largely unknown and, until recently, few small, ephemeral, 'isolated' wetlands in the Piedmont ecoregion had been mapped, let alone studied (Pitt et al., 2012). Population growth, land use trends, and the resultant pressure on wetlands and other aquatic resources has created a need to better understand small, ephemeral, 'isolated' wetlands.

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Different methods and characteristics have been used to examine the connectivity of wetlands and their nearby water bodies, including physical measurements i.e., water level and temperature, (Cabezas et al., 2011; Glinska-Lewczuk, 2009), chemical parameters such as nitrogen and phosphorus (Wolf et al., 2013; Glinska-Lewczuk, 2009), biological indicators such as macrozoobenthos patterns (Obolewski, 2011), as well as mathematical modeling (Golden et al., 2014). These methods, generally used in floodplain or riparian wetlands, may not be directly applicable to more geographically isolated, ephemeral wetlands in the Piedmont ecoregion because of the wetlands' unique physical characteristics including small size, shallow depth, and relatively short hydroperiod.

In order to understand the connectivity and ecological function of Piedmont ephemeral wetlands, we first need to understand their water quality dynamics through the entire hydroperiod. In this study, we examined the water chemistry and physical parameters of three ephemeral wetlands and the nearby water bodies between 26 January and 5 June 2012, a time period that encompassed the typical flooded period of ephemeral wetlands in Piedmont ecoregion of the southeastern United States. In addition to general water quality and nutrient analyses, we introduce the use of optical properties of dissolved organic matter (DOM) to examine ephemeral wetland biogeochemistry compared to nearby water bodies. DOM produced from different sources has a unique optical signature in ultraviolet and visible light absorption and fluorescence spectra and has been used in source-water tracking (Osburn et al., 2012; Chow et al., 2008). We hypothesized that small, ephemeral, 'isolated' wetlands have unique biogeochemical characteristics in comparing with nearby permanent water bodies which had different hydrology. We designed our study to contribute to the growing understanding of how to evaluate chemical relationships among water bodies in the context of "Significant Nexus".

2. Materials and methods

2.1. Study sites

We selected two index landscapes within the Piedmont ecoregion of South Carolina, USA (Fig. 1a and b). The first index landscape contained a first order stream, two ephemeral wetlands with varying degrees of geographic isolation, and a cypress swamp with surficial hydrological connections with the stream and a lake. Site A within the first index landscape (Fig. 1c) had the smallest ephemeral wetland with a maximum surface area of 6.75 m^2 and it was approximately 10.7 m from the perennial stream. The ephemeral wetland in site B (Fig. 1c) of the first index landscape had a maximum surface area of 37.74 m^2 and was adjacent to a formerly ephemeral wetland that became permanent and surficially hydrologically connected with the stream due to beaver damming activity. Site B also contained the cypress swamp with surficial hydrological connections to the stream and lake (Fig. 1c). The second index landscape contained site C (Fig. 1d) which included a second order stream, an ephemeral floodplain wetland, and a marsh with surficial hydrological connections with a lake. The wetland in site C had a maximum surface area of 2444.0 m^2, excluding the areas that became flooded for a short duration ($\leq$1 week) during flooding events of the adjacent stream.

2.2. Piezometer construction and water level measurement

Piezometers were installed on 8–10 January 2012 in order to sample groundwater. The locations of the piezometers were selected based on their relative positions between the ephemeral wetlands and nearby streams (Figs. SI-1–SI-3, as available in Supplementary information [SI]). For constructing a piezometer, a 15 cm-diameter x 50 cm-depth borehole was drilled. A 1 m-long x 5 cm-diameter PVC pipe was placed in the borehole. The bottom of the PVC pipe was capped with a slotted screen 30 cm from the bottom. Gravel was placed around the slotted interval and bentonite was added on top to prevent water infiltrating from the soil surface. Levels of groundwater (denoted as G) were manually measured using a portable water level meter. Depths of wetlands (denoted as W) and streams (denoted as S) at selected locations were determined manually using meter sticks. Rain gauges (denoted as R) were placed in each site for precipitation determination. There are a total 9 sampling points in Site A (i.e., 5 groundwater denoted as A-G1 to A-G5; 2 wetland waters denoted as A-W1 and A-W2; 2 stream waters denoted as A-S1 and A-S2), 13 sampling points in Site B (i.e., 5 groundwater denoted as B-G1 to B-G5; 5 wetland waters denoted as B-W1 to B-W5; 3 stream waters denoted as B-S1 to B-S3), 16 sampling points in site C (i.e., 10 groundwater denoted as C-G1 to C-G10; 3 wetland waters denoted as C-W1 to C-W3; 3 stream waters denoted as C-S1 to C-S3). Measurements were conducted at least three times per week during the study period. Rates of change in water level or water depth ($\Delta h/\Delta t$) at each point were calculated by dividing the difference between two measurements by the time interval.

2.3. Water quality determination

General water quality of stream and wetland waters was determined using YSI 556 Multiprobe System equipped with dissolved oxygen (DO), pH, electrical conductivity corrected to 25 °C (EC_{25}), turbidity, oxidation-reduction potential (ORP), and temperature sensors (YSI, Inc., Yellow Springs, OH, USA). The probe was gently placed 5–10 cm below the water surface to minimize any disturbance of wetland sediments. Measurements were generally taken between 0900 and 1500 h and these field surveys were conducted at least three times per week. Grab samples were collected once a month for nutrient analysis and dissolved organic matter (DOM) characterization (Section 2.4). Surface water, approximately 5 cm below the water's surface, was collected in 125 mL pre-acid washed polyethylene bottles. Soil pore water was manually pumped from the pre-installed piezometers (Section 2.2). At least one liter of water was pumped and discarded from the piezometer before collecting into a 125 mL bottle. Each sample type (i.e., wetland, stream, and groundwater) had at least two sampling spots and 3 sampling months, and the sample size was always $\geq$6. All samples were immediately stored in an ice cooler and transported to the laboratory. Waters were then filtered through 0.45 μm membrane filters (Millipore Express PLUS Membrane, polyethersulfone, hydrophilic, 47 mm). Filtrates were then stored at 4 °C until further analysis. All measurements and samples were collected between 26 January and 15 June 2012. Water quality measurements ended when the ephemeral wetlands were dry. Only one wetland in site B was fully examined for six months. The wetlands in sites A and C (Fig. 1c and d) were completely dry in April.

2.4. Chemical analyses

Each filtered sample was analyzed for dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) using a Shimadzu TOC/TN analyzer. Inorganic N, including NH_4-N and ($NO_2 + NO_3$)-N were determined using a Systea® Easychem™ discrete analyzer (EPA Methods 350.1 and 325.2, respectively; Eaton and Franson, 2005). DOC was further characterized by Shimadzu UV-1800 visible and ultraviolet spectrophotometer scanning from 200 to 700 nm. Specific ultraviolet absorbance (SUVA) was calculated by normalizing ultraviolet absorbance at 254 nm to DOC concentration, recorded as L mg-C^{-1} m^{-1}. SUVA has been widely used as a surrogate for aro-