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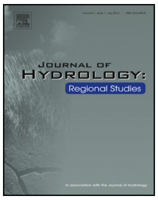

Groundwater influence on water budget of a small constructed floodplain wetland in the Ridge and Valley of Virginia, USA☆

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ABSTRACT

Study region: A floodplain in the headwaters of a tributary to the Chesapeake Bay, Ridge and Valley of the Eastern United States.
Study focus: This study investigated the influence of groundwater exchange in the annual wetland hydrologic budget and identified spatial and temporal variability in groundwater hydraulic gradients using an array of nested piezometers.
New hydrological insights for the region: Data showed that the created wetland met hydrologic success criteria, and that the wetland storage was fully connected with the groundwater table. Water-surface storage fluctuation was not fully explained by precipitation and evapotranspiration, suggesting that storage was highly influenced by groundwater inputs. The potentiometric surface showed that hillslope seep recharge was the dominant groundwater vector. However, during the summer and fall months, the adjacent stream channel was a losing system, and storm-driven rise in stream stage affected wetland storage. The complex hydrology of this relatively small wetland indicates that predicting the fluctuations of storage for design of unconfined floodplain wetlands is challenging, and that if the influence of groundwater seepage is negated, then fluctuations may be underestimated to the point of harming vegetation.

1. Introduction

Constructed wetlands (CWs) provide ecological services that improve water quality and are often used as engineered best management practices (BMPs) for controlling and treating stormwater runoff from land disturbance (Guardo et al., 1995; Kadlec, 2009; Mitsch et al., 2005). CWs have the potential to act as nutrient sinks, which are essential tools for nutrient management in ecologically sensitive areas, such as the Chesapeake Bay Watershed (Boesch et al., 2001) and in the face of changing climates (Seavy et al., 2009). The capacity of a CW to remove pollutants from stormwater is a function of site-specific physical and chemical characteristics of wetland substrates and vegetation (Carleton et al., 2000; Kincanon and McAnally, 2004; Reddy et al., 1999), as well as the pollutant delivery pathways and hydrology of the area (Braskerud, 2002; Kadlec,

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2009). The characteristics that affect wetland nutrient-removal capacity must be considered during design, construction, and management of these built systems (Fisher and Acreman, 2004; Kadlec and Hey, 1994).

Floodplains offer a suite of characteristics that facilitate hydraulic and nutrient retention, such as wetland vegetation, low slope gradients, and proximity to streams (Bradley, 2002). These characteristics make floodplains desirable locations for CWs by enhancing connectivity to the stream and, subsequently, the physicochemical processes performed by wetland vegetation, microbes, and soils found in riparian zones (Tockner et al., 2010). Nutrient removal by constructed floodplain wetlands has been reported often in literature (Carleton et al., 2001; Moustafa et al., 1996; Noe and Hupp, 2007), making them practical options for stormwater managers in the appropriate hydrogeomorphic setting. Hydrology is the driver for many of retentive processes that occur through the establishment and proliferation of wetlands. Groundwater and surface waters intersect at seep or slope wetlands that are commonly found in the floodplain of a stream (Mitsch, 2000). These hydrologic intersections act as hotspots along the stream network for biogeochemical processing, fueled by continual carbon and nutrient loading from contributing flows and with meso- and micro-scale energy gradients in redox potentials (Burt and Pinay, 2005; Tockner et al., 1999). The dynamic pattern of saturation and drying caused by a fluctuating water table facilitates nutrient retentive processing preformed by both anaerobic and aerobic microbes (Reddy and DeLaune 2008). Understanding this hydrologic pattern may better inform wetland creation or restoration where the goal is to re-establish the hydrology that creates optimal environments for microbial immobilization of nonpoint source (NPS) pollutants in stormwater runoff (Rucker and Schrautzer, 2010). To this end, it is beneficial for the wetland designer to quantify hydrologic inputs and losses, and evaluate water-table fluctuations to estimate the effective wetland water-quality volume for both anaerobically and aerobically facilitated nutrient transformations.

Groundwater exchange in natural and constructed wetlands has been shown to be a driving factor in biogeochemical processes (Hunt et al., 1999). However, knowledge gaps exist in the literature related to unique complexity of groundwater exchange in riparian wetland-stream systems in the Ridge and Valley and the implications of seasonal variability on floodplain wetland establishment. Recent studies on floodplain groundwater and surface-water exchange highlight a need to expand from the traditional scale of surface-water nutrient fate and transport to a focus on in-channel processes that encompasses the active floodplain (Woessner, 2000). Hydrologic interaction and flux is also important relative to dynamic water chemistry, such as pH, which field studies have shown to influence vegetation densities, particularly in sensitive bog wetlands (Mouser et al., 2005). Due to the complex nature of groundwater flux and the period of time needed to fully characterize water-table fluctuations, few wetland water budgets completely characterize the hydrologic budget to include groundwater exchange, despite the complex interactions of adjacent topography and how they influence riparian hydrology (Claxton et al., 2003; Winter, 1999) and potential role in nutrient fate and transport (Bradley and Gilvear, 2000; Raisin et al., 1999). A study of wetland water budgets found that the groundwater component had the highest level of uncertainty and had the largest amount of error (Favero et al., 2007).

As part of a larger study to implement and monitor innovative stormwater BMPs, a constructed floodplain wetland was built in 2007 near Winchester, VA, along Opequon Creek. The objectives of this study were to: (1) determine if the constructed system met hydrologic success criteria; (2) investigate the influence of the groundwater component in the annual wetland hydrologic budget during the time period of this study; and (3) identify spatial and temporal variability in groundwater hydraulic gradients. The data collected describe local hydrology of a built environment that may be applied in other efforts to restore retention capacity of floodplains of tributaries in sensitive watersheds. These results will inform better design of CW in floodplains in terms of hydrology and hydraulic storage in the floodplain, as well as address the knowledge gap that exists between scientific research of connectivity of floodplain groundwater and estimating wetland water budgets.

2. Materials and methods

2.1. Study area

Hedgebrook Farm CW lies along Opequon Creek, just south of the City of Winchester, VA, in the larger Potomac Watershed (Fig. 1). The CW encompasses 0.2 ha of floodplain pasture provided by the private landowner at Hedgebrook Farm. The contributing catchment basin to Opequon Creek at this location is approximately 30 km^2; predominately cattle pasture with increasing residential and commercial development. At stream baseflow, the wetland is disconnected from the stream, receiving hydrologic inputs of precipitation and groundwater only. The study period included the first establishment year after construction and the majority of the subsequent year, from February 2008 to September 2009. January 2008 was used to establish a baseline water table elevation.

Soils within the study location are mapped as predominantly Massanetta loam, alluvium derived from limestone with less than 2% slopes and clay subsoil. The geology of the area is characterized by karst features such as sinkholes, springs, poorly developed surface drainage over carbonate bedrock (Orndorff and Harlow 2002). The average annual precipitation for the area is 88 cm, but during the two years of this study, the area received 106 and 85 cm (January 2008–October 2009), respectively (NOAA, 2010). A 9-year period of record for discharge of Opequon Creek was available at gage station 1.683.450, located 2.4 km downstream from the CW. Peak discharge was 1.78 cm and mean annual daily discharge was 0.14 cm during the period of study (USGS, 2009). Stream gage records show seasonal responses of the creek to precipitation and a discernable