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The multiscale effects of stream restoration on water quality

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ABSTRACT

Stream restoration is often considered as an effective watershed management tool to reduce riverine loads of nitrogen, phosphorus, and suspended sediments, and meet government-mandated water quality goals. However, despite the billions of dollars which have been spent on stream restoration, questions remain about its effectiveness for improving water quality, as many studies report either mixed success or lack the adequate methodological framework to detect water quality improvements. In this study, we measured fluxes of nutrients and sediment in an eroded stream before and after restoration by filling the eroded channel with a mixture of sand, gravel, and woodchips stabilized with rock weirs at intervals along the channel. Our monitoring design used a before-after-control-impact (BACI) approach at two spatial scales, one at the reach-scale, and one farther downstream to detect whether reach-scale changes in nutrient and sediment loads propagated downstream. At the reach scale, we found that the restoration enhanced stream function, removing 44.8% of the phosphate, 45.8% of the total phosphorus, 48.3% of the ammonium, 25.7% of the nitrate, 49.7% of the total nitrogen, and 73.8% of the suspended sediment. However, due to hydrological variance, monitoring stations farther downstream suggested no detectable changes at the larger spatial scale relative to a reference stream, which highlights the challenges of detecting watershed-scale responses to small-scale stream restoration projects. This study provides a methodological framework for evaluating the effect of stream restoration on water quality at multiple scales and shows that reach-scale improvements may not be detectable at watershed-scales.

1. Introduction

Streams are unique as they are both receptors of watershed discharge, and chemically and biologically reactive conveyances that transport and transform water, nutrients, and particulate matter from terrestrial environments to larger water bodies (Cole et al., 2007, Gibson et al., 2015, Gomi et al., 2002). In the urban-suburban environment, increased development of impervious surfaces has disrupted the natural ability of streams and their floodplains to process nutrients and sequester sediment due to increased peak flows, reduced base flows, and enhanced channel erosion, which together limit water transit time and decrease habitat for organisms responsible for the biological retention of nutrients (Galster et al., 2006, Shuster et al., 2005, Walsh et al., 2005a).

Historically, urban storm water has been managed primarily via rapid transmission of storm water to streams to prevent flooding (Dunne and Leopold, 1978). The increasing recognition that urbanization and historical storm water management systems continue to cause negative impacts on the ecological health of freshwaters has led to an increased push for retrofitting urban and suburban landscapes with green infrastructure, such as storm water detention ponds, to ameliorate the negative impacts of urbanization on receiving waters (Weber et al., 2006, Walsh et al., 2005b). Some studies have reported the relative success of green infrastructure in reducing nutrient and sediment discharges to streams at the watershed scale (Pennino et al., 2016, Dietz and Clausen, 2008).

Data from a recent study encompassing the period 1945–2012 indicated that although nitrogen loading within the Chesapeake Bay is beginning to decline, the reductions still lag behind many comparable estuaries undergoing intense management (Harding et al., 2016). As part of a push to improve water quality, the Chesapeake watershed Total Maximum Daily Load (TMDLs), adopted in 2010, have dictated pollutant reduction requirements of 25% for total nitrogen (TN), 24% for total phosphorus (TP), and 20% for total suspended sediment (TSS). The U.S. Environmental Protection Agency (EPA) has set a tight timeline requiring the implementation of all necessary pollution control measures to achieve these levels by 2025 (https://www.epa.gov/chesapeake-bay-tmdl).

Within the mid-Atlantic region of the U.S., and particularly the coastal plain of the Chesapeake Bay watershed, stream restoration has become an increasingly used tool to improve water quality and meet water quality goals such as TMDLs by enhancing the natural pollutant-

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attenuating functions of streams. Meeting these goals through stream restoration has come at a large financial cost globally, with a total of over 9 billion dollars invested in stream restoration projects in the contiguous U.S. (Bernhardt et al., 2005), and costs per project averaging 3.21 million euros in Europe (Pander and Geist, 2013).

Recently, stream restoration has evolved from stream stabilization techniques to dramatic geomorphological alterations. One contemporary restoration approach backfills deeply incised channels using a mixture of sand, gravel, and woodchips, and places large rock weirs across the channel to restore pool and riffle sequences and enhance stream-floodplain connectivity (Brown et al., 2010). These newer, more invasive techniques, termed regenerative stormwater conveyance, have come under scrutiny with suggestions that philosophically, stream restoration has moved stormwater management structures into the stream, thereby shifting the onus of responsibility away from the watershed and onto the channel (Palmer et al., 2014). Recent studies have indicated the variable effect that stream restoration has on nitrogen and sediment retention and observed a limited capacity for pollutant removal during high flows (Filoso et al., 2015, Filoso and Palmer, 2011).

Despite large public and private investment, there have been relatively few published studies evaluating the effect that these newer stream restorations have on water quality and hydrology. A recent review by Newcomer Johnson et al. (2016) found 27 peer reviewed studies of nutrient retention within streams that were restored by raising the stream bed to near bank-level, as in our study. Yet 19 of these studies were assessed using short term nutrient addition experiments to determine nutrient uptake and the potential for denitrification, with a further four assessing the effect by differences in nutrient concentrations between treatment and control reaches. Only four studies out of 27 in the review by Newcomer Johnson et al. (2016) used a mass balance approach to determine the nutrient retention effect of this type of restoration, with none of the synthesized studies assessing the effect of restoration using a before-after-control-impact design.

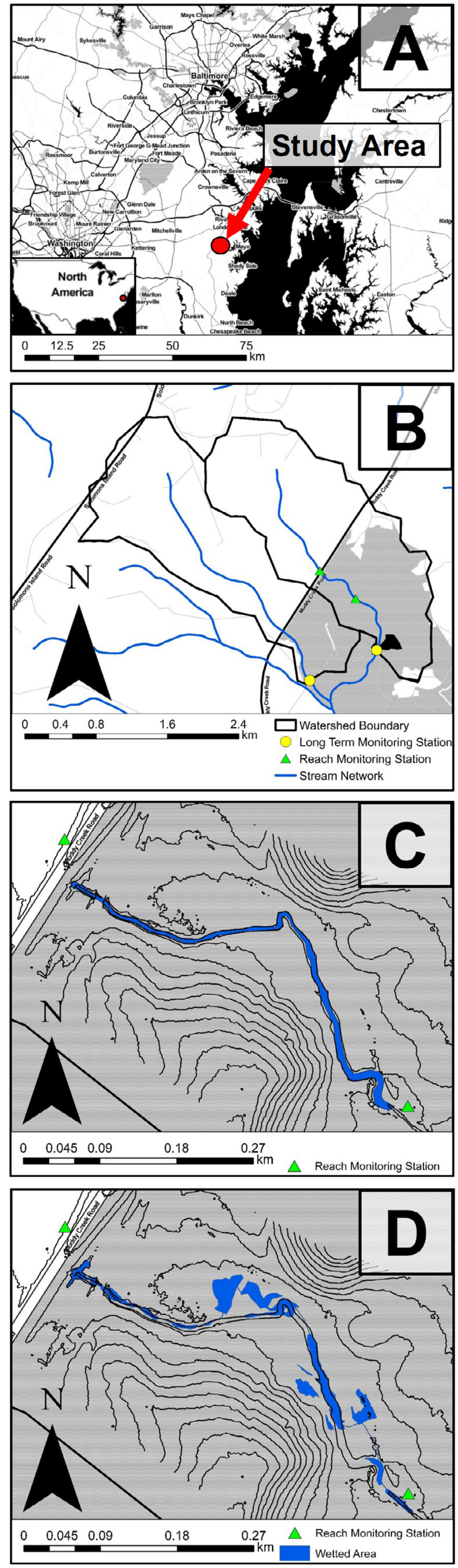
Inadequate monitoring of restoration projects is not unique to the U.S. and is an issue in Europe. Pander and Geist (2013) found that 87% of restoration projects in Bavaria, Germany from 1994 to 2011 had no monitoring data, with only 4% of restoration having any form of prerestoration characterization. Monitoring the success of restoration is critical, as it is only with adequate data that success can be judged (Pander and Geist, 2013; Geist, 2015; Geist and Hawkins, 2016).

Many existing studies have been limited to highly urban environments (Filoso et al., 2015, Filoso and Palmer, 2011, Williams et al., 2017, Cizek et al., 2017), yet stream restoration and stormwater management are not unique to urban environments. Further, while isolating the water quality benefits of stream restoration at the reach scale provides useful information on their effectiveness, there is also a need to place these reach-scale water quality changes within a larger spatial perspective to see if local water quality changes propagate farther downstream. In this study we quantified the effects of a stream restoration on hydrology and on net removal of nutrients and suspended solids within the restored reach and downstream of the reach within a larger watershed. We used a before-after-control-impact design to test our hypotheses that stream restoration reduces nutrient and sediment fluxes at both the reach and watershed scales.

2. Methods

2.1. Study system and design

We studied the restoration of a 452 meter (m) reach of the North Branch of Muddy Creek in Edgewater, Maryland, USA (Fig. 1), which was constructed between late December 2015 and February 2016. Before restoration, the reach had become deeply incised (up to 2.9 m below bankfull height) downstream of the culvert under Muddy Creek Road (MD 468). The reach was restored using a regenerative storm water conveyance design (Brown et al., 2010), which involved filling



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