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Research article

Effectiveness of a newly reconstructed floodplain oxbow to reduce NO_3-N loads from a spring flood

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ABSTRACT

Enhancing NO_3-N processing in floodplains offers opportunities to achieve water quality improvements in agricultural watersheds but few studies have quantified the effectiveness of newly reconstructed oxbows to reduce loads delivered from floods. In this study, we evaluated NO_3-N retention during a spring storm water runoff event in a newly reconstructed oxbow (<1 year old) located along Morgan Creek in eastern Iowa. A 30-h flood connected the oxbow to the creek for approximately nine hours and delivered 14.7 kg of NO_3-N into the oxbow. Using a NO_3-N sensor, oxbow NO3-N concentrations were observed to increase from 0.7 to 5.3 mg/l after the flood event, but decreased to background conditions over the next 21 days. We estimated NO_3-N retention to be 0.30 g N m^{-2} d^{-1} and the NO3-N retention efficiency to be 74.2% for the single flood event. The NO_3-N mass reduction in the oxbow intersected with predicted mass reduction from a first-order denitrification decay model after 21 days which suggests that denitrification was largely responsible for the observed NO_3-N decrease. However, the effectiveness of the oxbow for reducing watershed-scale N loads appears to be limited, since the oxbow is located in a low-nutrient floodplain and would only retain NO_3-N loads when delivered to the oxbow via flooding. Study results suggest that oxbows provides valuable ecosystem services during non-flooding periods and are activated for NO_3-N load reduction during floods.

1. Introduction

Nitrogen loss from agricultural areas in the U.S. Midwest impacts aquatic ecosystems at both local and regional scales including the Gulf of Mexico (USEPA, 2013). The U.S Environmental Protection Agency (USEPA) has called for a 45% reduction in total nitrogen and phosphorus loading in the Mississippi-Atchafalaya River Basin to reduce the size of the Gulf of Mexico hypoxia zone by 2035 (HTF, 2015). In an effort to meet this goal, states across the Midwest are working to reduce nutrient export by adopting conservation practices outlined in state nutrient reduction strategies (e.g., INRS, 2013).

Enhancing nutrient processing in floodplains offers opportunities to achieve nutrient reduction benefits in agricultural watersheds while minimizing loss of crop production areas (McLellan et al., 2015) Floodplains are considered prime conservation targets for enhancing ecosystem services in watersheds (Opperman et al., 2010), and research has shown that functional floodplains increase biodiversity (Tockner and Stanford, 2002), floodplain fisheries (Jones et al., 2015; Costanza et al., 1997), floodwater storage (Opperman et al., 2009), and recreational opportunities (Golet et al., 2006) along with providing nutrient retention benefits (Vidon and Hill, 2004; Krause et al., 2008). Fink (2007) suggested conservation practices that include the restoration of 2 million hectares (ha) of floodplain wetlands could be used to reduce the Gulf of Mexico hypoxia zone. With floodplains offering a host of ecosystem services, McLellan et al. (2015) recommended additional investigation of floodplain best management practices (BMPs) to help meet watershed-scale water quality goals.

Oxbow lakes are natural floodplain features formed when a river cuts off a meander loop as it migrates within its floodplain (Wohlman and Leopold, 1957). Although natural oxbows are among the most biologically diverse systems in the world (Bayley, 1995; Ward et al., 1999; Goetz et al., 2015), accumulation of sediment and organic material often fill the oxbow over time and the systems transition from a lentic to terrestrial habitat (Piegay et al., 2000;

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Constantine et al., 2010). Removing the oxbow fill material and restoring the lentic habitat is known as a viable strategy to improves habitat for fishes, including the federally endangered Topeka shiner (*Notropis topeka*) (Bakevich et al., 2013) and waterfowl (LaGrange and Dinsmore, 1989). The nutrient reduction benefits of oxbow restorations are being increasingly recognized (Schilling et al., 2017; Jones et al., 2015).

Research has shown that floodplain oxbows and wetlands are capable of retaining a substantial portion of inflow NO_3-N. Fink and Mitsch (2007) quantified the difference in inflow and outflow water quality associated with flood pulses through an engineered oxbow system and reported annual NO_3-N mass reductions of 48%. Mitsch et al. (2014) later reported NO_3-N retention for the same engineered oxbow diversion system to be approximately 15.5% over a long term period (32 wetland years). García-García et al. (2009) quantified NO_3-N retention of a floodplain wetland dominated by high inflow NO_3-N concentrations (above 20 mg/l) and estimated retention to be 72%. Harrison et al. (2014) monitored two relict oxbow lakes near an urban stream and reported that the oxbows retained 23–87% of NO_3-N load that entered the oxbow during four storm events. Average NO_3-N removal rates ranged from 0.8 to 1.2 g N/m^2/day for the two oxbows (Harrison et al., 2014). Jones et al. (2015) compared mean NO_3-N concentrations in three oxbows to inlet tile water and found a 45–61% reduction in concentration. Schilling et al. (2017) quantified NO_3-N retention efficiency of a reconstructed oxbow fed by tile drainage and estimated retention to range from 44% to 47% from May to September. Overall, these studies suggest that floodplain oxbows are capable of reducing inflow NO_3-N loads delivered via a number of different hydrologic pathways, including river diversions, storm pulses and tile drainage.

Although studies have been conducted to quantify NO_3-N retention in oxbows or floodplain wetlands, many have been focused on existing or "relict" conditions rather than oxbows specifically reconstructed to benefit water quality or habitat. Interest in oxbow reconstruction as an agricultural BMP is growing (Jones et al., 2015) and it is important to assess the water quality benefits of this potential practice. In this study, we evaluated NO_3-N retention in a newly reconstructed oxbow (<1 year old) along a rural stream in eastern Iowa. NO_3-N concentrations and loading patterns into the oxbow were quantified during a spring storm water runoff event using a continuously-reading NO_3-N sensor. Our study objectives were to characterize the landscape and hydrologic setting of the new oxbow and quantify the ability of the reconstructed oxbow to reduce NO_3-N loading during a spring flood event. Developing a better understanding of the NO_3-N retention capacity of reconstructed oxbows will enable landowners and conservation professionals to better incorporate these features in N load reduction strategies.

2. Methods and materials

2.1. Site description

The Morgan Creek oxbow reconstruction is located along Morgan Creek in Linn County, Iowa (Fig. 1). Morgan Creek drains a watershed area of approximately 32 km^2 above the oxbow monitoring site and it discharges into the Cedar River in Cedar Rapids. Morgan Creek is located in the Iowa Erosion Surface landform of Iowa (Prior, 1991), a region characterized by gently rolling hills of eroded pre-Illinoian glacial till and loess overlying Devonian and Silurian age carbonate bedrock. Land cover in Morgan Creek watershed above the oxbow site is dominated by row crops of corn and soybeans (~80%) and grassland (13%).

In 2016, the Linn County Conservation Board (LCCB) selected a remnant oxbow located within Morgan Creek Park as a suitable site for a reconstruction project. In August 2016, the oxbow was excavated and shaped using an excavator and bulldozer and approximately 2500 m^3 of floodplain alluvium was excavated (Fig. 2). The shape of the oxbow followed the former stream channel and the depth was based on reaching a layer of coarse-textured alluvium at an elevation similar to the streambed of the existing channel. The surface area of the oxbow covered 1760 m^2 when completely filled with water.

The center of the oxbow measured to a depth of approximately 1.6 m, whereas the two arms averaged approximately 0.75 m during wet periods. During the summer and winter months following excavation, the arms of the oxbow are allowed to go dry. The staggered arm depths were designed to promote vegetative growth while the center of the oxbow provided year round water. The banks were graded to a 4:1 slope. The oxbow was designed to connect to the stream only during out-of-bank flood periods.

2.2. Hydrogeologic investigation

A network of monitoring wells was installed in the floodplain to evaluate the groundwater flow direction and water quality (Fig. 1). In June 2016, eight monitoring wells were installed using a hand auger to a depth of approximately 2 m. The 3.2 cm diameter wells consisted of a 1.5 m factory-slotted white polyvinyl chloride (PVC) well screen, and a PVC riser that extended the well above the land surface. Silica sand was poured around the well screen to provide a filter pack in the borehole, and bentonite clay sealed the top of the borehole to prevent surface water intrusion. The wells were located using a GPS and each well casing was surveyed according to a benchmark well. Slug tests were performed to estimate the hydraulic conductivity of the aquifer and analyzed using the Bouwer and Rice (1976) method. Water table depths were measured using a Solinist water level meter. In-situ pressure transducers were installed in Well 5 and the oxbow to measure water levels at a 15-min sampling interval. Continuous water level monitoring was conducted from August 2016 to June 2017 at Well 5 and from April 2017 to June 2017 in the oxbow.

2.3. Field hydrology

A hydrologic budget was developed for the oxbow using measured precipitation and quantifying the various water inflow and outflow pathways. Precipitation was measured using tipping bucket rain gauges operated by the Iowa Flood Center (IFC) (Fig. 1). The rain gauge is located 0.30 km from the border of the watershed, and 4.5 km from the centroid of the watershed.

The rate of groundwater flow into the oxbow was estimated from Darcy's Law:

$$V = -Ki/n \qquad (1)$$

where K is the hydraulic conductivity (m/s), i is the hydraulic gradient and n is effective porosity. Mean K of the aquifer was estimated from the slug test results and an effective porosity of 0.25 was assumed for the alluvium. The rate of groundwater flow (v) was multiplied by the upgradient saturated thickness of the oxbow (107 m long and 1.2 m water depth) to estimate the daily groundwater discharge rate into the oxbow. A depth-volume relationship was developed to calculate the volume of water in the oxbow for a specified stage (Fig. 3). Cross sectional profiles were created by surveying the site for depths and measuring the widths of the oxbow.

Daily outflow seepage from the oxbow was estimated by calculating the average daily change in oxbow volume ($Vol_i - Vol_{i-}$