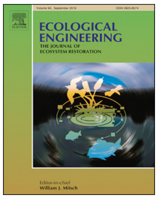
Ecological Engineering 124 (2018) 19–22

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



Short communication

Nitrate-N load reduction measured in a central Iowa restored oxbow

Keith E. Schilling[a,*], Keegan Kult[b], Anthony Seemon[b], Karen Wilke[c], Christopher S. Jones[d]

[a] Iowa Geological Survey, Trowbridge Hall, University of Iowa, Iowa City, IA, United States
[b] Iowa Soybean Association, Ankeny, IA, United States
[c] The Nature Conservancy, Des Moines, IA, United States
[d] IIHR Hydroscience and Engineering, University of Iowa, Iowa City, IA, United States

ARTICLE INFO

Keywords:
Oxbow
Nitrate-nitrogen
Floodplain
Nutrient reduction
Mass balance

ABSTRACT

This short communication presents new data collected from a tile-fed oxbow site in north-central Iowa and reports on the quantification of NO_3-N load reductions using a mass balance approach. Using improved monitoring equipment deployed at the site in 2017, including a continuously-reading nitrate sensor, a NO_3-N budget for the oxbow was developed to estimate annual and monthly load reductions occurring in the reconstructed oxbow. Daily NO_3-N input was primarily from two drainage tiles and concentrations in the oxbow ranged from < 0.2 to 3.5 mg/l. Based on daily mass balance, the oxbow retained 42.3 kg of NO_3-N, or 0.21 $g\,N\,m^{-2}\,d^{-1}$, and the NO_3-N retention efficiency was 35.4%. Removal efficiencies in early spring and late summer and fall were much higher than late spring and early summer. Based on mass load reductions, the effectiveness of oxbows for N load reductions is greatest when oxbows receive greater N loads from tile drainage compared to N loads delivered from flood pulses.

1. Introduction

Floodplain oxbows formed when stream meanders are cut off through bank erosion or artificial straightening (Ward et al., 2002) will often accumulate sediment and organic material over time and transition from lentic to terrestrial habitat (Constantine et al., 2010). Removing the oxbow fill material to restore the lentic habitat has been proven to be viable strategy to improve habitat for fishes, including the federally endangered Topeka shiner (*Notropis topeka*) (Bakevich et al., 2013) and waterfowl (LaGrange and Dinsmore, 1989). Recent work in Iowa is focusing on quantifying the nitrate-nitrogen (NO_3-N) reduction benefits of reconstructed oxbows.

Jones et al. (2015) compared mean NO_3-N concentrations in three restored oxbows to inlet tile water and found a 45–61% reduction in concentration. Kalkhoff et al. (2016) reported on a two-year study comparing a restored oxbow to an unrestored oxbow in north-central Iowa and found that the restored oxbow reduced nitrate concentrations approximately 54% compared to the incoming flows from a field tile. At a central Iowa site located in the recently glaciated Des Moines Lobe (DML) of Iowa, Schilling et al. (2017) used N:Cl ratios to quantify NO_3-N retention efficiency of a reconstructed oxbow fed by tile drainage and reported retention to range from 44% to 47% from May to September. At an eastern Iowa site located off the DML, Schilling et al. (2018) quantified NO_3-N retention during a spring storm water runoff event in a newly reconstructed oxbow (< 1 year old) in eastern Iowa. They deployed a continuously-reading N-sensor to show oxbow NO_3-N concentrations decreasing from 5.3 mg/l after the flood event to background conditions over 21 days.

NO_3-N concentration reductions in restored oxbows have been more easily documented than mass load reductions. At the eastern Iowa oxbow site, Schilling et al. (2018) used a N mass balance approach to report that the new reconstructed oxbow processed ~14.7 kg of flood-derived NO_3-N over a three-week period, equivalent to a NO_3-N retention rate of 0.30 $g\,N\,m^2\,d^{-1}$ and a retention efficiency of 74%. However, since the oxbow in this case was only connected to the stream for a short period during the flood, the oxbow did not actually intercept much of the stream N load (approximately 0.14% of the total NO_3-N load for the event) and the retention of ~15 kg of NO_3-N in the oxbow was largely negligible against the backdrop of high loading rates during the flood. In contrast to limited flood-derived N delivery, oxbows that capture tile-fed NO_3-N have the potential to intercept much greater agricultural N loads. For example, a tile-fed oxbow in central Iowa received approximately 220–450 kg of NO_3-N per year, as much as 30-times the amount of load delivered from a flood. Unfortunately, Schilling et al. (2017) were unable to close the N balance to quantify N mass reduction at the tile-fed oxbow site due to limitations in monitoring.

This short communication revisits the tile-fed oxbow site in north-

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[*] Corresponding author.
E-mail address: keith-schilling@uiowa.edu (K.E. Schilling).

https://doi.org/10.1016/j.ecoleng.2018.09.018
Received 31 July 2018; Received in revised form 10 September 2018; Accepted 14 September 2018

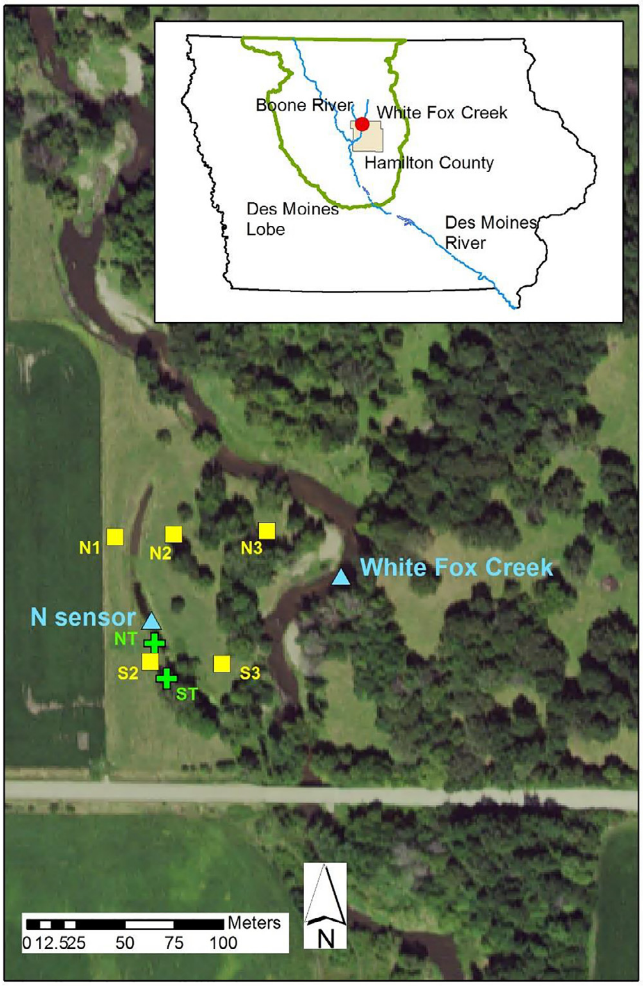

Fig. 1. Location of Frye oxbow site in north-central Iowa and oxbow sampling sites, including wells (N1, N2, N3, S2, S3) and tiles (NT and ST).

central Iowa and reports on the quantification of NO_3-N load reductions using a mass balance approach. Using new monitoring equipment deployed at the site in 2017, including a continuously-reading nitrate sensor, we were able to close the NO_3-N budget and estimate annual and monthly load reductions occurring in the reconstructed oxbow.

2. Methods and materials

Site description, oxbow construction details and field and analytical methodologies were provided in Schilling et al. (2017) and pertinent details are presented herein. The Frye oxbow was constructed in the floodplain of White Fox Creek (Fig. 1) in fall 2012 by excavating approximately 2071 m^3 of post-settlement alluvium to a depth of approximately 1.8–2.2 m. The oxbow consisted of two 0.08 ha oxbow cells connected by a 2.4 m long, 0.4 m deep connective channel and the oxbow outlet is connected to the channel of White Fox Creek during high flow events. The total surface water area of the oxbow is approximately 825 m^2. Two 15 cm diameter tile lines drain into the oxbow (north tile (NT) and south tile (ST); Fig. 1) from an adjacent agricultural field (Fig. 1). Five shallow (4.5 m deep) monitoring wells were utilized in this study (N1, N2, N3, S2, S3) (Schilling et al., 2017).

Tile discharge into the oxbow was measured by Teledyne ISCO 2150 Area Velocity (AV) Flow Modules. AV sensors were secured to expansion rings placed approximately 0.3 m into the tiles from the outlet. Discharge from the oxbow into White Fox Creek was measured by placing a 0.25 M modified HXL flume into the channel to give a defined geometry and placing an ISCO 2150 AV in the middle of the approach.

Water samples from the wells, tile lines, oxbow and White Fox Creek were collected approximately bi-monthly from March 22 to November 11, 2017 using methods described previously (Schilling et al., 2017) and analyzed for NO_3-N and Cl at the Iowa Soybean Association certified testing laboratory in Ankeny, Iowa. Samples were analyzed on the day of collection using Environmental Protection Agency method 300.0 (National Environmental Methods Index 2008a). On April 18, 2017, a Hach Nitratax SC plus, 2-mm path length (Hach Company, 2011) was installed in the oxbow to monitor NO_3-N concentrations. A CR1000 data logger continuously recorded NO_3-N concentration and water temperature at a 5-min interval (Campbell Scientific Inc.).

A daily NO_3-N mass balance for the oxbow was developed for the March to November 2017 period. Daily inflow NO_3-N was the sum of the daily tile loads from the north and south tiles and groundwater seepage and outflow was the product of the oxbow concentration and daily discharge from the oxbow into White Fox Creek:

$$NO_3\text{ - N retention (kg)} = \sum [NO_3\text{ - }N_{(kg)}]_{in} - [NO_3\text{ - }N_{(kg)}]_{out} \tag{1}$$

Previous assessment of the oxbow site indicated that NO_3-N delivered via groundwater seepage was insignificant relative to the tile flow ($< 0.1\%$). Hence for the NO_3-N mass balance we rounded up the contribution of groundwater inflow NO_3-N to 0.001 kg/day based on previous monitoring.

3. Results

Precipitation measured nearby in Webster City, Iowa, was 719 mm for the March to November monitoring period (Fig. 2a). Monthly rainfall ranged from 81 to 84 mm in March, April and June, and exceeded 120 mm in May, August and October 2017. Lowest monthly precipitation was recorded in July when only 18 mm fell on the ground.

Water samples collected from tiles, groundwater wells, oxbow and White Fox Creek showed variable nitrate and chloride concentrations in 2017 (Table 1). Highest NO_3-N concentrations were detected in White Fox Creek (up to 16 mg/l) whereas tile and upgradient groundwater concentrations were similar (2–4 mg/l) (Fig. 2b). Continuous NO_3-N concentrations measured in the oxbow using a Nitratax sensor showed considerable variability, varying from < 0.2 to 3.5 mg/l (Fig. 2a). NO_3-N concentrations in the oxbow peaked on June 29 (3.5 mg/l) following approximately 70 mm of accumulated rainfall during the previous two week period, and then rapidly declined to < 0.2 over the next 25 days. NO_3-N concentrations in the oxbow peaked again on October 9 (2.5 mg/l) following another extended period of rainfall (125 mm in 15 days) and subsequently decreased thereafter.

NO_3-N loads into the oxbow were dominated by tile discharge and daily input tile loads ranged from 0 (tiles not flowing) to 2.8 kg/day and averaged 0.49 ± 0.56 kg/day from April 2 to October 31, 2017 (Fig. 2c). Tile loads were greater than 1–2 kg/day on several occasions in the spring and early summer before the last occurrence on June 29, and then were observed to decrease to < 0.1 kg/day from mid-July to October 9. Following early October rainfall, the tiles resumed discharging approximately 0.2–0.4 kg N per day, causing the increasing spike in October NO_3-N concentrations in the oxbow. Total cumulative loads from both tiles was 119.4 kg, whereas total input load from groundwater was approximately 0.24 kg.

In contrast, daily NO_3-N discharge from the oxbow ranged from 0 (no oxbow discharge to White Fox Creek) to 6.8 kg/day and averaged 0.37 ± 0.71 kg/day (Fig. 2c). The greatest single day discharge of NO_3-N from the oxbow occurred on June 30 when approximately 4.9 kg of NO_3-N was exported from the oxbow than was input from tiles and groundwater. Overall, total cumulative NO_3-N loads discharged from the oxbow in 2017 was 77.3 kg. During the monitoring period, there were no occurrences of surface water backflow from the creek into the oxbow. Based on daily NO_3-N balance in the oxbow, (Eq. (1)), the

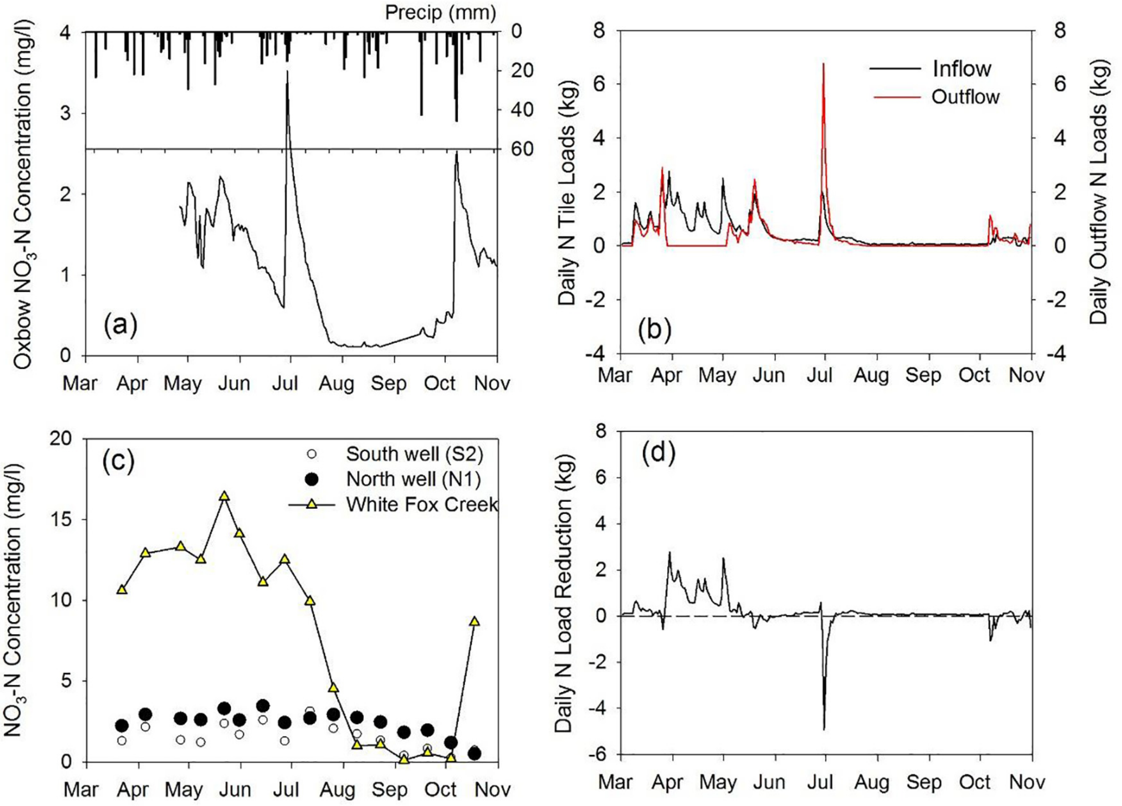

Fig. 2. Summary of 2017 monitoring at Frye oxbow sites: (a) precipitation and oxbow NO_3-N concentrations measured using Nitratax sensor; (b) daily inflow and outflow NO_3-N loads to the oxbow; (c) NO_3-N concentrations measured in upgradient groundwater monitoring wells and in White Fox Creek; (d) daily NO_3-N load reduction in oxbow.

oxbow retained approximately 42.3 kg of NO_3-N in 2017 for an overall retention efficiency of 35.4%. Daily NO_3-N retention varied from −4.93 kg (more NO_3-N exported to White Fox Creek than tile flow and groundwater inputs) to 2.77 kg and averaged 0.17 ± 0.65 kg/day (Fig. 2d). Using the total load reduction over the 244 day monitoring period (42.3 kg), the retention rate for the oxbow was estimated to be 0.21 $\mathrm{g\,NO_3\text{-}N\,m^{-2}\,d^{-1}}$.

On a monthly basis, NO_3-N retention was 42% in March, 100% in April, 23% in May and was negative in June and July (−28% and −19%, respectively). NO_3-N retention was > 99% in August and September, but was negative again in October following an intense fall rainfall period (−110%). Hence, NO_3-N retention was variable in the reconstructed oxbow in 2017 with seasonal load reduction most prominent in April, August and September.

4. Discussion

In this short communication, we report follow-up monitoring at a reconstructed oxbow site in north-central Iowa and used a mass balance approach to indicate that the oxbow reduced inflow NO_3-N loads by 35.4% in 2017. Previous monitoring used N:Cl ratios to estimate that the oxbow reduced NO_3-N approximately 44–47% in 2014 and 2015 (Schilling et al., 2017). However, tile and groundwater concentrations were much higher in 2014 and 2015 (tiles 9–17 mg/l; wells 4–8 mg/l), as were tile input loads to the oxbow (200–400 kg). Differences in NO_3-N reductions measured in the same oxbow (35–47%) are due differences in the methodology used, as well as different input concentrations and loading patterns and rates to the oxbow among years. Ongoing monitoring activities at the oxbow have indicated substantial variations in NO_3-N reduction occurring following an influx of tile-fed N loads. In the 2017 monitoring, NO_3-N load reductions were high in the spring (March, April, May) when reductions could keep pace with tile-fed inputs (average of 55% reduction), but following a period of late June rainfall and a spike of tile-fed N inputs to the oxbow, more NO_3-N was exported from the oxbow than retained (Fig. 2d). Following this pulse of NO_3-N load, NO_3-N reduction efficiencies increased through the late

Table 1

NO_3-N and Cl concentrations (in mg/l) measured at the Frye oxbow site in 2017. Number of samples collected ranged from wells (N1, N2, N3, S2, S3), oxbow and White Fox Creek (WFC; n = 18), north tile (NT; n = 9) and south tile (ST; n = 13). Sampling locations are shown in Fig. 1.

		N1	N2	N3	NT	Oxbow	S2	S3	ST	WFC
NO_3-N	Mean	1.47	0.59	0.43	3.13	1.17	2.28	0.58	2.37	7.97
	s.d.	0.76	0.34	0.28	0.64	0.93	0.78	0.32	0.69	5.49
	Min	0.23	0.05	0.07	2.17	0.05	0.49	0.05	1.33	0.10
	Max	3.13	1.32	1.14	4.21	2.97	3.45	1.37	3.76	16.40
Cl	Mean	4.80	3.20	9.56	9.89	11.56	9.90	3.33	13.21	17.68
	s.d.	1.60	0.93	1.01	3.31	2.51	1.23	1.18	3.58	3.57
	Min	1.42	1.00	7.80	6.59	7.36	7.06	1.00	8.88	7.62
	Max	7.17	4.89	11.30	18.00	17.30	11.70	5.87	19.60	21.70

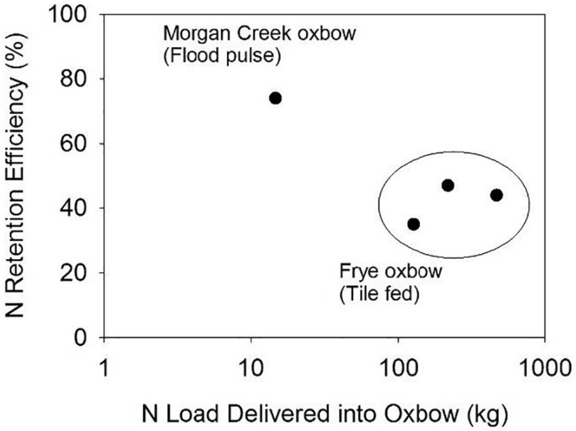

Fig. 3. Relation of N retention efficiency (in %) to mass of N load delivered to oxbow. Morgan Creek data from Schilling et al. (2018).

summer and early fall when NO_3-N retention efficiency was near 100%. Hence, the 35% reduction of NO_3-N loads provided by the oxbow represents a weighted average of the daily load reductions, with daily N loads reduced for long periods of time punctuated by events when the processing capacity of the oxbow is exceeded by input loading rates.

We estimated annual NO_3-N retention to be $0.21\ g\,N\,m^{-2}\,d^{-1}$ which is comparable to other oxbow studies fed mainly through storm events. In Iowa, Schilling et al. (2018) estimated NO_3-N retention to be $0.30\ g\,N\,m^{-2}\,d^{-1}$ for the single flood event delivered to a newly reconstructed oxbow in eastern Iowa. Likewise, Harrison et al. (2014) developed a mass balance for two relict oxbows in Maryland and reported NO_3-N retention rates ranging from 0.2 to $2.7\ g\,N\,m^{-2}\,d^{-1}$. Kadlec (2010) estimated overall NO_3-N retention rates ranging from 0.01 to $0.55\ g\,N\,m^{-2}\,d^{-1}$ (mean $0.19\ g\,N\,m^{-2}\,d^{-1}$) for diversion wetlands in the Illinois Des Plains floodplain, whereas Fink and Mitsch (2007) estimated NO_3-N retention rates of $0.71\ g\,N\,m^{-2}$ per flood pulse for their engineered diversion channel wetland.

Comparing two reconstructed oxbow sites in Iowa where N load reductions have been quantified, we observe differences in NO_3-N reduction efficiencies for oxbows fed by tiles or by flood pulses (Fig. 3). At the Morgan Creek oxbow site in eastern Iowa, the oxbow received 14.7 kg of N from the flood pulse and was found to reduce the input load by 74%. At the Frye oxbow site where the oxbow was fed primarily by tile drainage, input N loads were significantly higher (~100–400 kg) but N reduction efficiencies were less (35–47%). The relation between N retention efficiency of the oxbow to input loading is similar with the concept of hydraulic loading rates (HLRs) developed to describe N removal efficiencies in wetlands (Crumpton et al., 2008; Drake et al., 2018). HLRs are used to quantify the volume of water a wetland receives based on discharge it receives relative to its pool area. Annual and monthly N removal efficiency in wetlands typically decreases as the HLR increases, because water residence times decrease with more water flux into the wetland. For the Iowa reconstructed oxbows, less N retention efficiency was provided when input loads were higher, as input loading rates occasionally exceed the processing capacity of the oxbow. With a retention rate of approximately $0.2–0.3\ g\,N\,m^{-2}\,d^{-1}$, a reconstructed oxbow is able to process a greater fraction of the input load when it sees less N following a flood pulse compared to the N it receives from constant tile drainage. However, a reconstructed oxbow is able to process a greater mass of N load from tile drainage because of much greater input N delivered. Based on mass reduction potential, use of reconstructed oxbows as a strategy for N load reduction would appear to be best suited for high N loading conditions, such as those reconstructed to receive concentrated N loads from subsurface drainage tiles (Schilling et al., 2017).

5. Conclusions

In this study, we quantified the NO_3-N load reduction provided by a reconstructed oxbow fed by tile drainage. For the March to November period of 2017, daily NO_3-N input was primarily from two drainage tiles and a nitrate sensor deployed in the oxbow showed NO_3-N concentrations ranging from < 0.2 to 3.5 mg/l. Based on daily mass balance, the oxbow was found to retain approximately 42.3 kg of NO_3-N, or $0.21\ g\,N\,m^{-2}\,d^{-1}$, and the NO_3-N retention efficiency was 35.4%. Removal efficiency varied throughout the year as steady daily N load reductions were occasionally punctuated by events when the processing capacity of the oxbow was exceeded by high input loading rates. Removal efficiencies in early spring and late summer and fall were much higher than late spring and early summer. Overall, study results provide new quantification of N load reductions at the reconstructed oxbow site that complements previous study at the same oxbow site (Schilling et al., 2017). We confirm that the effectiveness of oxbows for N load reductions is best utilized when oxbow receive greater N loads from tile drainage compared to N loads delivered from flood pulses.

Acknowledgements

This material is based upon work supported by the Natural Resources Conservation Service, U.S. Department of Agriculture, under number 69-6114-14-008.

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