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Contribution of wetlands to nitrate removal at the watershed scale

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Supplementary Information for

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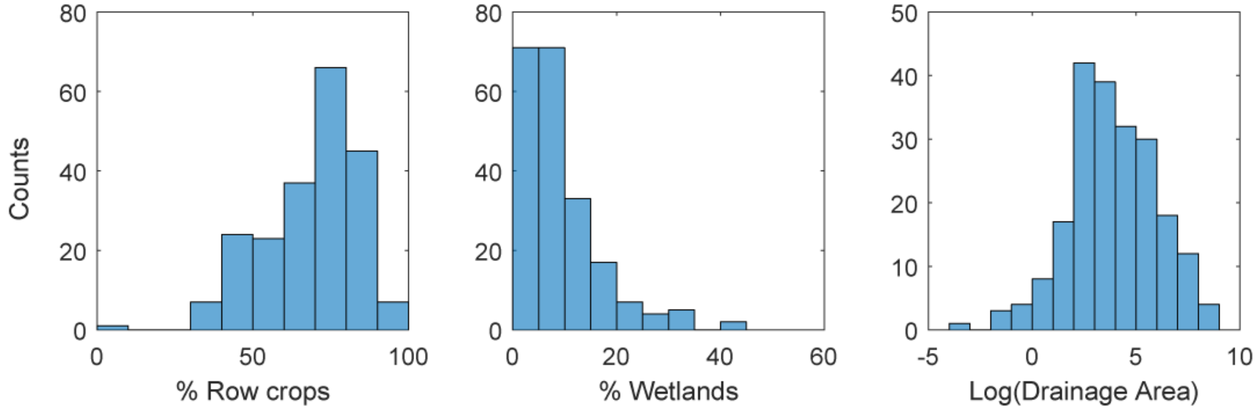

Figure S1

Figure S1. Distribution of land use and log of contributing drainage area (km^2) for all sample sites (n = 206).

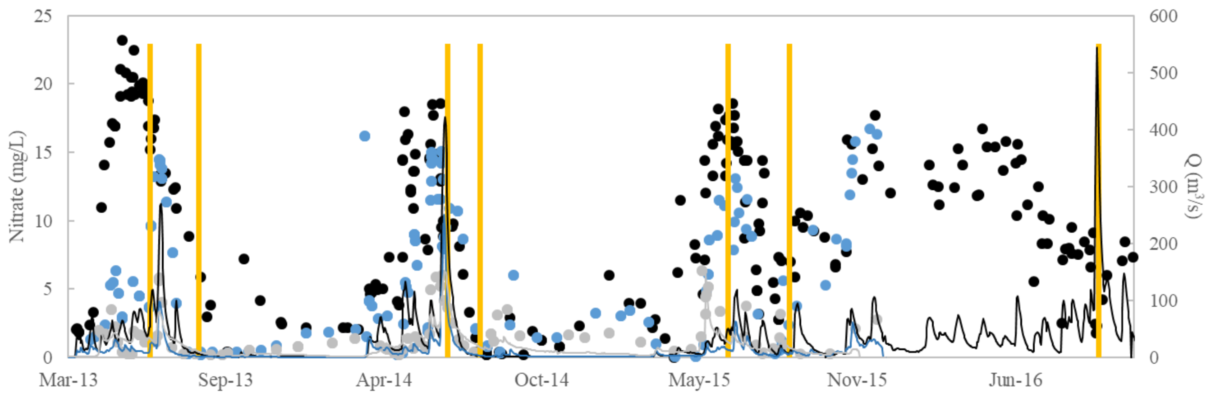

Figure S2.

Figure S2. Time series of nitrate and streamflow. Gaging data for streamflow (lines) and nitrate (markers) from outlets of three sub-basins (Le Sueur black, Cottonwood blue and Chippewa grey) demonstrated that nitrate is very weakly dependent on the higher frequency variability of streamflow. Yellow vertical lines are sampling events.

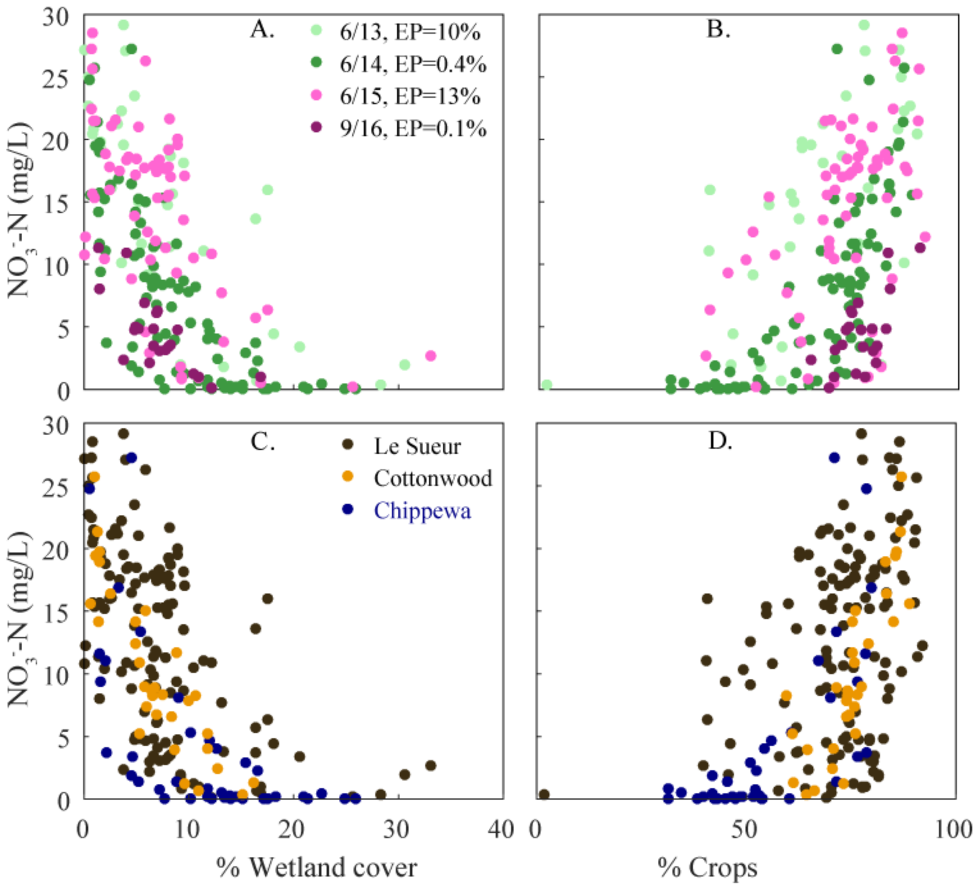

Figure S3

Figure S3. Nitrate observations vs. wetland cover and vs. crop cover for all moderate to high streamflow conditions (quantified as exceedance probability (EP) at Le Sueur River basin outlet) by sampling event (panels A and B) and by basin (panels C and D). There was no detectable difference between nitrate response to land cover across years although on average sampled nitrate was lower in 2014 than 2013 and 2015. Similarly, there was no detectable difference in nitrate response to land cover by basin although on average Chippewa nitrate was lower than the other basins.

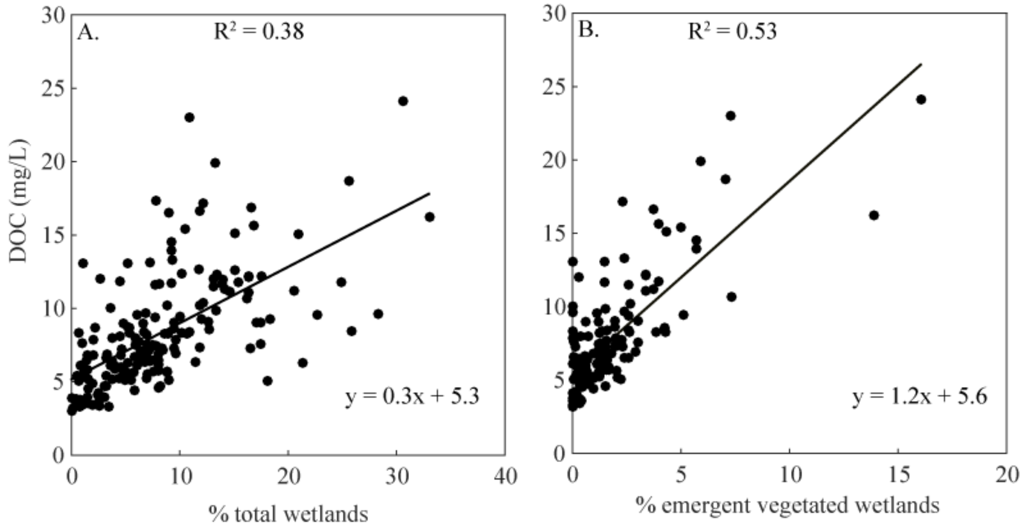

Figure S4

Figure S4. Relationship between dissolved organic carbon (DOC) and wetland cover. DOC is significantly linearly related to total % wetland cover (panel B, n = 205) and is best predicted by emergent vegetated wetland cover (panel A, n = 163). DOC is not significantly related to crop cover or drainage area.

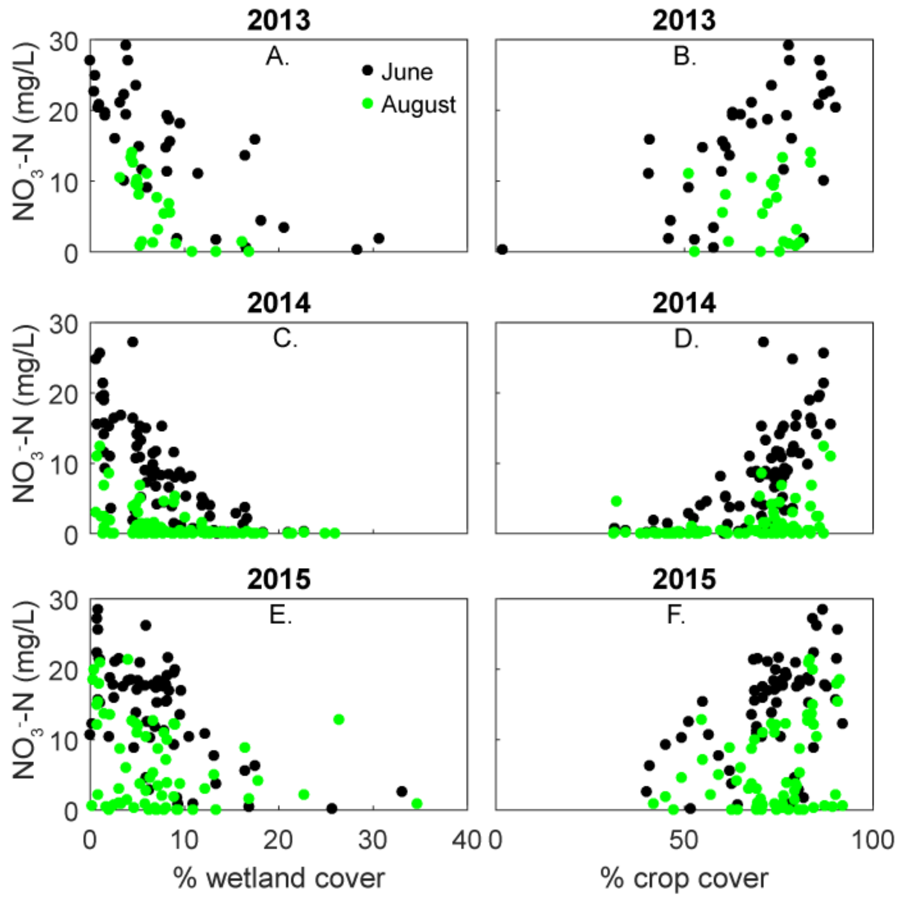

Figure S5

Figure S5. Nitrate response to % wetland cover (panels A, C, and E) and % crop cover (panels B, D, and F) by year and sample event. Nitrate decreased with % wetland cover and increased with % crop cover during June sample events for all years. In general, nitrate followed the same trends with land cover in late summer, although many sites with low wetland cover also had low nitrate. Higher channel residence times may have promoted nitrate removal within the channels, which would mask the effect of wetlands on observed nitrate.

Table S1. Summary of streamflow and nitrate at sub-basin outlets for the sampled events.

Sample event dates		Basin name	# sites sampled	NO_3^- (mg/L)	Streamflow daily average (m^3/s)	Streamflow exceedance probability (%)	Streamflow condition
6/11/2013	6/12/2013	Le Sueur	28	15.2	54	10.5	Moderate
8/13/2013	8/15/2013	Le Sueur	20	5.9	7	50.6	Low
6/23/2014	6/26/2014	Le Sueur	15	9.5	266	0.4	High
6/23/2014	6/26/2014	Chippewa	40	3.7	123	0.7	High
6/23/2014	6/26/2014	Cottonwood	32	10.9	90	3.0	High
8/3/2014	8/7/2014	Le Sueur	16	0.2	3	68.4	Low
8/3/2014	8/7/2014	Chippewa	39	1.7	18	27.1	Low
8/3/2014	8/7/2014	Cottonwood	32	0.8	3	61.2	Low
6/15/2015	6/18/2015	Le Sueur	62	17.7	45	13.6	Moderate
9/1/2015	9/3/2015	Le Sueur	62	5.9	11	40.5	Low
9/27/2016	9/27/2016	Le Sueur	23	2.4	377	0.1	High

Table S2. Land use and wetland classifications for the sample sites.

	mean	median	minimum	maximum	Sub-basin Chippewa[1]	Cottonwood	Le Sueur
Drainage area (km^2)	261.7	40.9	0.0	5239.3	5239.3	3393.6	2873.3
MLCC land use categories[2] (%)							
Row crops	68.8	73.4	1.7	91.9	55.9	75.7	72.1
Perennial grasses	13.2	10.8	0.1	43.6	20.2	9.8	10.0
Lakes and wetlands	6.1	5.7	2.6	63.6	12.0	5.3	8.3
Impervious surfaces	3.2	2.4	0.0	29.2	5.9	6.2	6.2
Deciduous forest	8.7	7.0	0.0	42.0	5.9	3.0	3.3
NWI wetland classifications (%)							
Deep lakes	0.4	0.0	0.0	10.7	n/a	0.1	0.5
Shallow lakes	1.6	0.0	0.0	29.5	n/a	0.5	1.4
Permanent marshes	2.0	1.3	0.0	16.1	n/a	1.2	1.5
Ephemeral marshes	2.7	2.3	0.0	10.0	n/a	2.0	2.5
Other lentic	1.0	0.8	0.0	7.7	n/a	1.2	2.0

[1]NWI data layer did not extend to the Chippewa River basin.

[2]MLCC land use categories not shown: extraction (maximum cover 0.05%), conifer forest (0.24%), mixed forest (0.17%)

Table S3. Statistical summary of regression analysis of nitrate and DOC vs. land use categories broken into season or streamflow condition where streamflow is quantified by exceedance probability (EP) at the Le Sueur basin outlet. Regressions are either exponential (exp) in the form $y = ae^{bx}$ or linear in the form $y = ax + b$ where x is the land cover category and y is the independent variable (nitrate or DOC).

	dataset	type	a	b	R^2	p-value*	n
All events where streamflow was moderate to high (EP < 15%, 4 events)							
Nitrate vs % wetland	EP < 15%	exp	21.66	-0.11	0.46	<0.0001	201
Nitrate vs % crop land	EP < 15%	exp	0.79	0.04	0.31	<0.0001	201
Nitrate vs % grassland	EP < 15%	exp	16.7	-0.05	0.11	<0.0001	201
Nitrate vs % impervious surface	EP < 15%	exp		n/s		0.12	201
All events where streamflow was low (EP > 15%, 3 events)							
Nitrate vs % wetland	EP > 15%	exp	9.4	-0.15	0.18	<0.0001	166
Nitrate vs % crop land	EP > 15%	exp	0.06	0.06	0.16	<0.0001	166
Nitrate vs % grassland	EP > 15%	exp	7.7	-0.08	0.07	0.0002	166
Nitrate vs % impervious surface	EP > 15%	exp		n/s		0.6	166
All late - spring sampling events (3 events)							
Nitrate vs % wetland	Spring	exp	22.31	-0.1	0.50	<0.0001	178
Nitrate vs % crop land	Spring	exp	0.89	0.04	0.40	<0.0001	178
Nitrate vs % grassland	Spring	exp	19.3	-0.05	0.18	<0.0001	178
Nitrate vs % impervious surface	Spring	exp		n/s		0.12	178
All late summer-fall sampling events (4 events)							
Nitrate vs % wetland	Fall	exp	9.54	-0.15	0.20	<0.0001	189
Nitrate vs % crop land	Fall	exp	0.05	0.06	0.17	<0.0001	189
Nitrate vs % grassland	Fall	exp	7.6	-0.08	0.07	<0.0001	189
Nitrate vs % impervious surface	Fall	exp		n/s		0.72	189
Statistics for individual sampling events							
Nitrate vs % ephemeral wetlands	Jun-13	linear		n/s		0.15	27
Nitrate vs % ephemeral wetlands	Jun-14	linear	-3.70	18.47	0.48	<0.0001	47
Nitrate vs % ephemeral wetlands	Jun-15	linear	-1.36	17.81	0.09	0.01	62
Nitrate vs % ephemeral wetlands	Aug-13	linear		n/s		0.12	19
Nitrate vs % ephemeral wetlands	Aug-14	linear	-0.95	4.06	0.10	0.02	47
Nitrate vs % ephemeral wetlands	Aug-15	linear		n/s		0.14	62
Nitrate vs % ephemeral wetlands	Sep-16	linear	-1.07	7.15	0.28	.006	22
Nitrate vs % ephemeral wetlands	Sep-16**	linear	-3.05	11.84	0.66	<0.0001	20
Dissolved organic carbon							
DOC vs % total wetlands	EP < 15%	linear	0.34	5.27	0.38	<0.0001	205
DOC vs % permanent wetlands with emergent vegetation	EP < 15%	linear	1.22	5.56	0.53	<0.0001	163

*P-value for exponential fits was determined with natural log transformed nitrate data.

**Two outlier data points excluded from regression, as described in Methods.

Table S4. Summary of statistical significance of linear regressions (y = ax + b) from conditional analysis of all spring data (Fig. 2). Regressions are in the form of y = ax+b where y is nitrate and x is the predictive land use.

		NO3 vs % crop				NO3 vs %wetlands			
crop range	**n**			**R^2**	**p**	**a**	**b**	**R^2**	**p**
0-30	0	*no observations in this range*							
30-35	3				0.91				0.55
35-40	3				0.62				0.47
40-45	9				0.38				0.43
45-50	10				0.35				0.24
50-55	13				0.45	-0.56	11.32	0.20	0.07
55-60	6				0.87	-0.43	11.19	0.59	0.04
60-65	15				0.77	-1.03	19.14	0.51	0.00
65-70	16				0.62	-1.01	20.15	0.25	0.03
70-75	32				0.62	-1.12	20.12	0.22	0.00
75-80	32				0.60				0.18
80-85	19				0.03	-1.55	22.27	0.32	0.01
85-90	15				0.69	-2.35	24.06	0.26	0.03
90-95	5				0.31				0.16
95-100		*no observations in this range*							
wetland range	**n**	**a**	**b**	**R^2**	**p**	**a**	**b**	**R^2**	**p**
0 - 5	58	0.18	3.54	0.06	0.04	-1.14	20.57	0.06	0.03
5 - 10	69	0.17	0.06	0.05	0.04	-0.55	15.54	0.00	0.34
10 - 15	25	0.11	-2.75	0.12	0.05	-1.09	16.78	0.10	0.07
15 - 20	16				0.36				0.51
20 - 25	5	0.19	-8.15	0.75	0.04				0.40
25 - 30	3				0.41				0.30
30 - 35	2	*not enough data to fit model*							
> 35	0	*no observations in this range*							