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Water Quality in Drainage Ditches Influenced by Agricultural Subsurface Drainage

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Introduction

In much of northwestern Ohio and many other areas of the Midwest, subsurface drainage is needed to allow fields to be planted in a timely fashion, enhancing crop yields (Zucker and Brown, 1998). Subsurface drains typically deliver excess water, and materials dissolved in this water, to drainage ditches, which form the smallest streams in many agricultural areas. These ditches join to form larger streams and eventually rivers, which make their way to the Great Lakes or the Mississippi River.

For many years, agricultural management practices for improved water quality focused on preventing erosion, thereby reducing losses of sediment and phosphorus. Conservation tillage and other practices enhanced infiltration and drainage via the subsurface. While sediment and phosphorus were saved, losses of soluble materials, especially nitrate, were increased. Recently, nitrate has been implicated as a major cause of impairment of the Gulf of Mexico (Rabalais and Turner, 2001) and other marine environments, leading to increased interest in understanding the transport of nitrate through the environment and in finding ways to reduce its loss from agricultural lands.

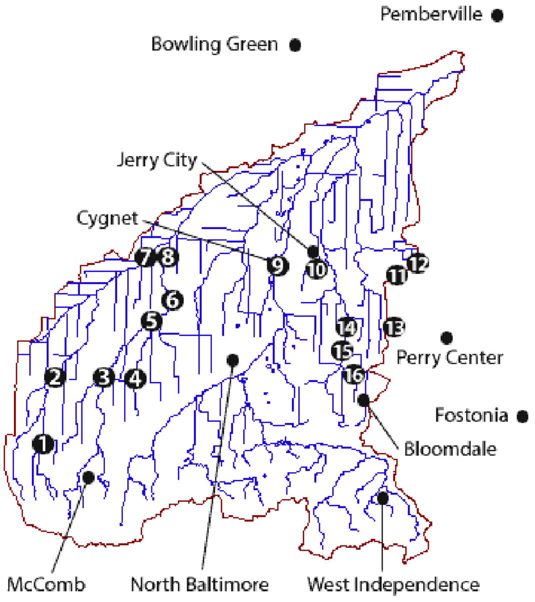
In forested ecosystems, nutrients that enter small streams are often taken up by algae and bacteria that live in these streams, and are prevented from moving downstream. Peterson et al. (2001) showed that nitrogen uptake in these streams is particularly effective. Whether the same processes operate in drainage ditches, or can be encouraged to do so, is a research question that motivates the work reported here.

The primary goal of this part of the research was to characterize water quality in typical agricultural drainage ditches, with particular emphasis on times when flow in the ditches is dominated by inputs from subsurface drainage. These times are characterized by intermediate levels of flow, neither the highest, which are associated with storm runoff, nor the lowest, which typically occur during extended dry periods in the late summer and early fall when the only sources of water, if any, are groundwater recharge and possible effluent from septic systems and other point sources.

Methods

Water samples were taken approximately once per month at sixteen sites, two or three on each of six drainage ditches within the upper Portage River watershed in northwest Ohio (see figures 1 and 2). All stations were sampled as close to the same time as possible; a typical sampling run took about two hours. Samples were delivered to the Heidelberg College Water Quality Laboratory, where they were analyzed for suspended sediment, total phosphorus, soluble reactive phosphorus, nitrate, nitrite, ammonia, total Kjeldahl nitrogen, dissolved reactive silica, specific conductance, chloride, sulfate, and fluoride.

Figure 1. Site map.



Sample Sites in the Portage River Basin

1. Needles Creek at Co. Rd 203
2. Needles Creek at Co. Line Rd
3. Rader Creek at Co. Line Rd
4. Little Rader Creek at Co. Line Rd
5. Little Rader Creek at Needles Rd
6. Rader Creek at Oil Center Rd
7. Needles Creek at Cygnet Rd
8. Rader Creek at Cygnet Rd
9. B & O Creek at Cygnet Rd
10. Bull Creek at Cygnet Rd
11. Cygnet Ditch at Cygnet Rd
12. S. Branch of Portage River at Cygnet
13. Cygnet Ditch at Oil Center Rd
14. Bull Creek at Kunkler & Huffman
15. Bull Creek at Eagleville Rd
16. Bull Creek Tributary at Fast Rd

Results

Analyses were obtained for 240 samples, collected between May 2001 and November 2002. These results include two sets of samples from high flow conditions (October and December 2001), four sets of samples taken under conditions of low to no flow (July, August, and September 2001; July 2002), and nine sets of samples from conditions of moderate flow dominated by discharge from agricultural subsurface drainage systems. These results are summarized in table 1. They are compared with results from the Maumee River for the same period of time in table 2.

Findings

1. Concentrations observed in these samples were broadly comparable to those observed in larger rivers in northwest Ohio such as the Maumee River. Concentrations of suspended solids were lower than typically found in the Maumee, whereas concentrations of the other parameters tended to be higher. These observations are consistent with reported effects of watershed size on concentration patterns (Baker and Richards, 2000). More information on concentration patterns in selected rivers and streams in northwest Ohio can be found in Baker (1993).

Figure 2. Collecting a water sample.

2. When flows are dominated by subsurface discharge, concentrations are similar from station to station, and greater differences are seen from month to month than from station to station (figure 3). All stations tend to change in the same way from month to month. In other words, the stations tend to show homogeneous behavior. Under low flow and storm runoff conditions, there are greater station to station differences. Local point sources are the major determinants of concentrations under low flow conditions.
3. Perhaps the most important finding is that, when flows are dominated by subsurface discharge, total nitrogen/total phosphorus ratios (figure 4) are much higher than would be ideal for efficient biological assimilation of these nutrients.

   While a ratio between 4.5 and 7.2 would be desirable (Kalff, 2002), these ratios are more typically in the range of 50 to nearly 800. This indicates that nutrient uptake will be phosphorus-limited, and much of the nitrogen will not be taken up by the aquatic ecosystem. Unless denitrification is an active process at these times, substantial nitrogen export is to be expected.

Table 1. Results by parameter, showing minimum, median, and maximum concentration for each flow regime. Data from all stations are combined for this analysis. All results are concentrations in mg/L, except for specific conductance, which is reported in μmhos/cm.

Parameter	**Low flow**			**Intermediate flow**			**High flow**		
	Minimum	**Median**	**Maximum**	**Minimum**	**Median**	**Maximum**	**Minimum**	**Median**	**Maximum**
Suspended solids	3.4	18.2	133.3	1.4	13.8	47	10.1	33.5	67.1
Total phosphorus	0.023	0.146	1411*	0.009	0.079	0.905	0.074	0.202	1.601
Soluble reactive phosphorus	0.001	0.024	1.92	0.002	0.041	0.482	0.022	0.108	1.354
Total Nitrogen as N**	0.41	2.40	4218*	1.81	9.05	32.45	6.64	10.39	19.37
Nitrate as N	0.00	0.75	18.50	1.42	8.30	31.01	5.72	8.76	17.46
Nitrite as N	0.00	0.00	0.24	0.00	0.04	0.26	0.00	0.02	0.07
Ammonia as N	0.01	0.04	2.55	0.01	0.06	0.75	0.05	0.08	0.72
Total Kjeldahl Nitrogen as N	0.34	1.16	4218*	0.12	0.65	1.90	0.29	1.21	1.93
Organic Nitrogen as N***	0.33	1.05	4218*	0.06	0.58	1.50	0.21	1.10	1.85
Total N / Total P ratio	2.0	13.8	155.7	8.5	124.3	735.0	6.5	49.6	165.2
Dissolved Reactive Silica	0.27	6.78	33.16	1.26	7.51	15.73	8.16	9.44	12.20
Specific Conductance	497	795	6140*	75	694	1173	443	632	737
Chloride	27	70	1442*	21	40	161	24	40	74
Sulfate	45	98	598*	44	72	214	32	56	96

* Sample impacted by a point source

** Calculated as sum of nitrate, nitrite, and total Kjeldahl nitrogen

*** Calculated as difference between total Kjeldahl nitrogen and ammonia

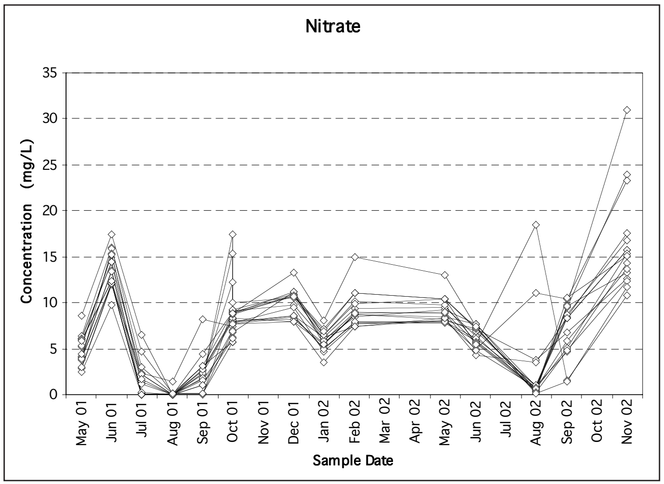


Figure 3. Nitrate concentrations for all samples during the sampling period.

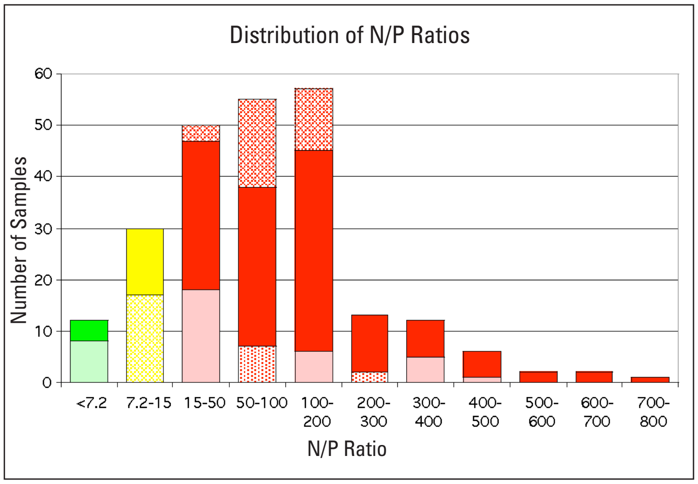


Figure 4. Note that in this figure, the bottom part of each bar represents low-flow sample, the middle part intermediate-flow samples dominated by tile drainage, and the upper part, if any, high flow samples.

Table 2. Results by parameter, comparing minimum, median, and maximum for drainage ditches with the same values for the Maumee River, May 2001 through November 2002. All drainage ditch data are combined for this analysis, but data impacted by point source influences are omitted. All results are concentrations in mg/L, except for specific conductance (μmhos/cm).

Parameter	Drainage Ditches			Maumee River		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Suspended solids	1.4	16	131.1	3.16	39.9	426
Total phosphorus	0.009	0.105	1.98	0.004	0.016	0.069
Soluble reactive phosphorus	0.001	0.041	1.92	0.000	0.003	0.022
Total Nitrogen as N*	0.41	8.16	32.4	0.87	4.52	17.3
Nitrate as N	0.00	7.48	31.01	0.00	3.56	14.5
Nitrite as N	0.00	0.02	0.26	0.00	0.00	0.04
Ammonia as N	0.01	0.06	2.55	0.00	0.01	0.10
Total Kjeldahl Nitrogen as N	0.123	0.76	5.39	0.008	1.23	4.99
Organic Nitrogen as N**	0.06	0.70	3.42	0.00	1.17	4.90
Total N / Total P ratio	2.0	70.9	735	1.5	22.8	239
Dissolved Reactive Silica	0.27	7.84	33.16	0.61	5.06	11.2
Specific Conductance	75	701	1756	358	607	962
Chloride	20.7	44.2	294.8	14	42	112
Sulfate	32.1	73.1	480.9	26	66	185

* Calculated as sum of nitrate, nitrite, and total Kjeldahl nitrogen

** Calculated as difference between total Kjeldahl nitrogen and ammonia

4. If biological processes are removing nutrients from drainage ditches, nutrient concentrations would be expected to decrease downstream, and nitrogen/phosphorus ratios would be expected to increase. In fact, the opposite is observed. This suggests that biological processing is not very effective in these drainage ditches, or at least that it is not efficient enough to keep up with new inputs along the length of the ditch.

Management Implications

This work indicates that biological uptake of nutrients in drainage ditches is not very efficient, because the balance between nitrogen and phosphorus is far from that required for plant growth. Minimizing pollutant export can be approached from two different directions. On the one hand, strategies can be developed to reduce losses from the fields, just as was done for sediment and phosphorus in the past. Approaches currently being explored include ***controlled drainage*** and ***on-farm retention of drainage water*** for re-use. These approaches recognize that the nutrients are valuable resources, and seek to prevent their loss from the agricultural operation. Information about these approaches can be found at http://ohioline.osu.edu/aex-fact/0321.html.

Modifications to the design of drainage ditches may lead to enhanced biological uptake by improving the health of biological communities in the ditches, increasing contact time between the water and the biological communities, and encouraging denitrification. Practices currently being researched include the use of two-stage ditches (see http://www.ag.ohio-state.edu/~ncd/geo/2index.html) and possible use of detention structures in ditches to slow the passage of the water when this is consistent with drainage needs.

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