Report for 2005MN129B: Water Quality Monitoring Strategy Based on Agroecoregion Boundaries in the Minnesota River Basin

Publications

- There are no reported publications resulting from this project.

Report Follows

Water Quality Monitoring Strategy Based on Agroecoregion Boundaries in the Minnesota River Basin

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Introduction

To better direct the funding of water quality monitoring and watershed remedial programs a better understanding of the relative importance of the factors associated with an elevated risk of water quality impairment in agricultural watersheds is needed. These factors include topographic slope steepness, the density and size of animal feedlots, stream channel gradient, watershed storage, stream channel density, and precipitation intensity. A land classification system developed in Minnesota by Hatch et al. (2001) incorporates many of these factors into areas termed agroecoregions. These agroecoregions are delineated based on data related to soil internal drainage, surficial geology, climatic patterns, topographic slope steepness, and land use. They represent relatively homogeneous areas and each have distinctly differing potentials for producing non-point source pollution from agricultural landscapes. Birr and Mulla (2002) found that this Minnesota agroecoregion framework was effective at characterizing regional lake water phosphorus concentration trends. The objective of this study is to combine the agroecoregion land classification system with information about animal feedlot density to assess whether agroecoregions provide a valid means to direct future monitoring efforts and remedial practices on a minor watershed scale.

Study Area

Four agricultural watersheds were monitored in south-central Minnesota (Table 1). They are located within the Steeper Till agroecoregion. Topography within the Steeper Till agroecoregion is generally steep in slope and prone to surface runoff (Table 2). In the Steeper Till agroecoregion, the soils are mixed between poorly and more moderately drained soils and surface water ponding is limited to poorly drained soils. The soil associations found within the Steeper Till agroecoregion watersheds are predominantly Webster, Clarion, and Nicollet.

Table 1. Site descriptions of the four watersheds monitored in south-central Minnesota (MN)

Site Name	Area (ha)	Mean Slope	Ag Land (%)	Outlet Description

		(%)		
NEofNwUlm	2971	4.7	94	County Ditch #38
NWofTrvse	1839	2.7	96	Rogers Creek & County Ditch #78
Hueskmp1	1160	2.9	>90	Huelskamp Creek & County Ditch #85
Hueskmp2	1131	3.2	>90	Huelskamp Creek & County Ditch #80

The predominant animal type within each of the four watersheds monitored is swine, ranging between 67 and 81% of the total animal units (AUs) permitted. Dairy animals are the second most prominent animal type within four of the four watersheds monitored, ranging from 9 to 23% of the total AUs permitted. The AU density of permitted animals observed ranges from 0.74 to 5.87 AU ha^{-1} across all four monitored watersheds (Table 2).

Table 2. Livestock population within the five watersheds monitored in south-central MN

Site Name	Permitted Animal Units (AUs)	AU Density (AU/ha)	Swine (AUs)	Beef (AUs)	Dairy (AUs)	Chicken (AUs)
NEofNwUlm	6683	4.13	5058	103	1522	0
NWofTrvse	8825	5.87	6687	423	755	960
Hueskmp1	2122	1.83	1420	327	375	0
Hueskmp2	834	0.74	674	17	143	0

Methods

Water Quality Data

Each of the four watersheds were equipped with monitoring equipment at the watershed outlet throughout the 2004 and 2005 summers. ISCO 6700 autosamplers were installed along with ISCO 730 bubbler modules and ISCO 750 area velocity probes to monitor the stage of the stream at the sampling location. At two of the sites, Campbell Scientific Inc. DB1 nitrogen gas liquid level sensors were used to monitor the stream stage. The autosamplers were programmed to initiate sampling during rainfall events when a significant increase in stream stage occurred (>3cm). Samples were collected at 15-30 minute intervals throughout the rising limb of the hydrograph and 1-2 hours intervals throughout the falling limb. Base flow grab samples were also taken at approximately two week intervals. The monitoring was conducted during ice-free periods extending from mid-May through the end of October.

The samples were typically collected within 24 hours of each storm event and refrigerated at 4ºC until analysis. Samples were analyzed for total suspended solids (TSS), dissolved phosphorus (DP), total phosphorus (TP), and nitrate nitrogen (NO_3-N) using standard methods.

A rating curve was built for each site in accordance with U.S. Geological Survey (USGS) procedures (1984). Stage data were collected at 5 minute intervals with

Campbell Scientific Inc. DB1 nitrogen gas liquid level sensors and ISCO 730 bubbler modules. Velocity readings were taken with ISCO 750 area-velocity probes and wading measurements were taken with a standard AA current meter. All of these data were utilized in the construction of rating curves for the various sites.

The loads for each watershed were determined by integrating the product of each analyte (TSS, DP, TP and NO_3-N) concentration and the five minute flow volume. Concentrations were assigned to each five minute interval by using the concentration from one sample to the next. Annual loads were calculated for each year by summing the total calculated load discharge from each watershed between May 21st and October 31st.

To compare the analyte loads discharged from each watershed the annual loads are normalized by the watershed area and cm of runoff per watershed hectare. To do this the following equation was used:

$$N_y = T_y / (T_r / W_a)$$

N_y = Normalized yield (kg/ha/cm runoff)
T_y = Total analyte yield (kg)
T_r = Total runoff (cm)
W_a = Watershed area (ha)

Results

Pollutant Loads

The mass of each analyte load measured annually and the discharge of water from each watershed throughout the monitoring period are shown in Table 3.

Table 3. The average analyte load and volume of water discharged from each watershed between May 21st and October 31st of each monitoring year

Site Name	Discharge (m^3/s)	TSS (kg)	Total P (kg)	Dissolved P (kg)	Nitrate N (kg)
2004-2005 Average					
NEofNwUlm	0.146	116,575	733	432	54,618
NWofTrvse	0.142	60,465	863	521	105,267
Hueskmp1	0.085	158,379	1188	565	65,077
Hueskmp2	0.138	252,059	602	212	35,238

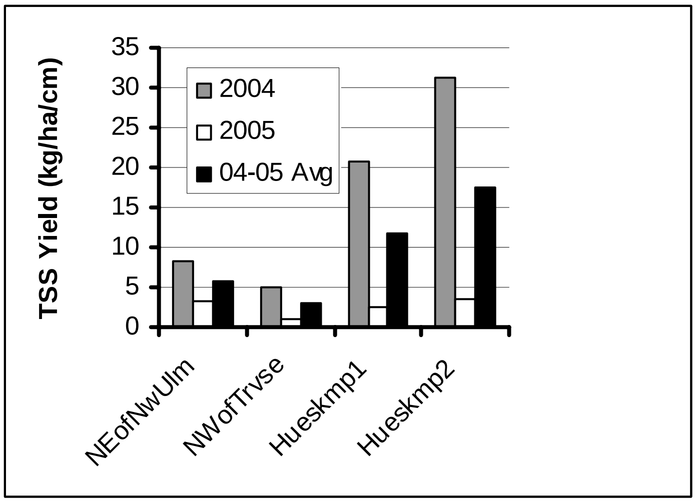
The rainfall measured at the mouth of each watershed during the 2004 monitoring period ranged from 50.44 cm (19.86 in) to 63.60 cm (25.04 in). During the 2005 monitoring season all four sites experienced a smaller total amount of rainfall ranging from 40.64 cm (16.00 in) to 61.62 cm (24.26 in). Averaging these rainfall totals over both years of the study, the range between the highest and lowest recorded rainfall equals 15.29 cm (6.02 in).

Total Suspended Solids (TSS) Yields

The normalized TSS yields measured from each watershed were higher in 2004 than in 2005, at least partly due to the higher amounts of rainfall experienced in the earlier year (Fig. 2). At 'Huelskmp1', and 'Huelskmp2' the differences between the two years appear large, while the remaining two sites, 'NEofNwUlm' and 'NWofTrvse', do not look quite as variable. Looking at the average normalized TSS over both years of monitoring both 'Huelskmp1' and 'Huelskmp2' exported the most sediment. The mean topographic slopes observed within each watershed do not correlate closely with the TSS yields measured from each watershed. The steepest watershed, 'NEofNwUlm' exported the second lowest average TSS yield.

The average discharges measured annually (Table 3), as well as over both years, also do not closely relate to the TSS yields observed. The lowest TSS yields were observed at the 'NEofNwUlm' and 'NWofTrvse' sites, which had the highest average discharges. The lowest average discharge observed each year occurred at the 'Huelskmp1' site. However this site yielded the second largest TSS yield in 2004 and the third largest TSS yield in 2005.

Figure 2. Normalized TSS yield measured at the mouth of each watershed throughout the 2004 and 2005 monitoring periods.



Discharge per unit area is more closely correlated with TSS yields than average discharge. The largest discharge per unit area (12 x 10^{-4} m^3/s/ha) occurs in the 'Hueskmp2' watershed, which has the highest TSS yield. The lowest discharge per unit area (0.5 x 10^{-4} m^3/s/ha) occurs in the 'NEofNwUlm' watershed, which has the second lowest TSS yield. Discharges per unit area in the other two watersheds are roughly 0.75 x 10^{-4} m^3/s/ha, but the TSS yield for 'NWofTrvse' is much smaller than the yield for 'Hueskmp1'.

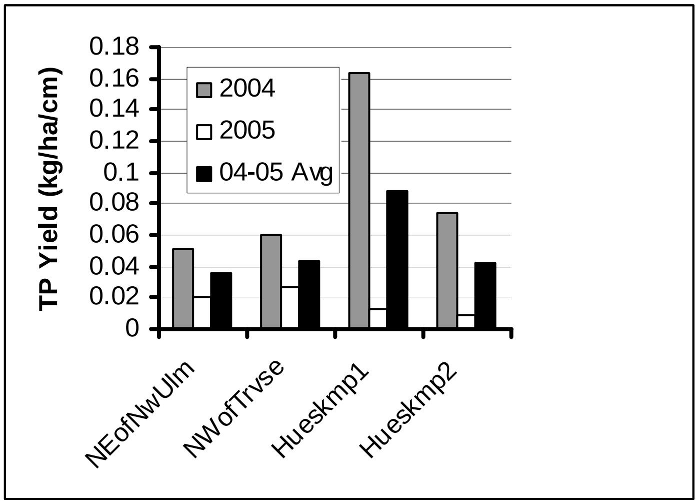
The influence of animal agriculture on the TSS load measured from the monitored watersheds may offer the best explanation for differences in observed TSS loads across watersheds. Repeated applications of manure to cropland soils build up the organic content of the soils. In addition, manure improves soil structure and soil aggregates become more stable and can better resist erosive processes (Gilley and Risse, 2000). The higher density of animal units observed in the 'NEofNwUlm' and 'NWofTrvse' watersheds and the lower TSS loads observed at these two sites compared to the 'Hueskmp1' and Hueskmp2' sites suggests that the applications of manure occurring within the former watersheds may be partially responsible for reductions in TSS loads.

Phosphorus Yields

The Total Phosphorus (TP) yields measured at each site were reasonably consistent across both years at the 'NEofNwUlm' and 'NWofTrvse' sites. However the

‘Huelskmp1’ and ‘Huelskmp2’ TP yields varied significantly over the two years that monitoring data was collected. The trend in total rainfall observed at each site closely matches the trends in TP yields across years.

Figure 3. Normalized Total Phosphorus (TP) yield measured at the mouth of each watershed throughout the 2004 and 2005 monitoring periods.



The average TP yields observed in each watershed are again apparently unrelated to differences in average topographic slope. For example, the steepest slopes occur in the ‘NEofNwUlm’ watershed, and this watershed has the lowest average TP yield. The ‘Hueskmp1’ watershed has the highest average TP yields and the second flattest watershed slopes.

As with TSS yields, there appears to be an inverse relationship between animal unit (AU) densities observed within each watershed and the normalized TP yields measured. For example, the highest animal densities occur in the ‘NWofTrvse’ and ‘NEofNwUlm’ watersheds, which also have the lowest average TP yields. The second lowest animal densities occur in the ‘Hueskmp1’ watershed, which also has the highest TP yields. Since TP yield is dominated by particulate phosphorus which is transported on eroded sediment, the similarities in relationships between animal density and either TSS or TP yields are reasonable.

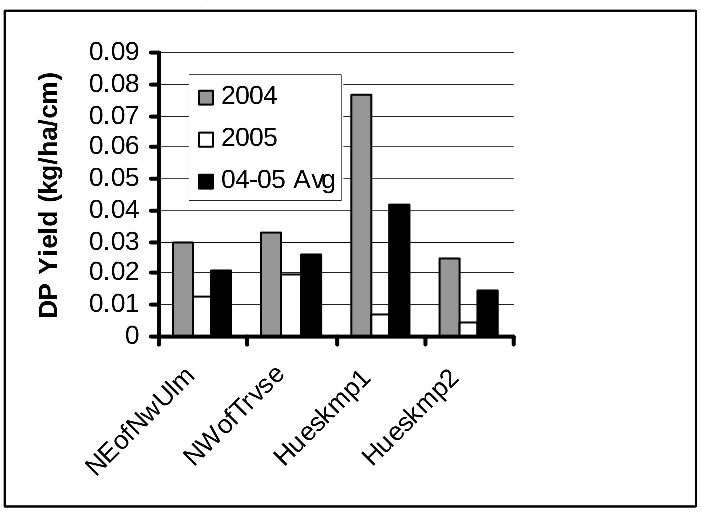
In view of the relationships between TSS and TP, it is instructive to compare the ratio of TP to TSS observed at each site relative to the animal density within the watershed (Table 4). The larger this ratio is the more TP is being measured relative to the amount of TSS discharged from each watershed. The average ratio of TP:TSS (0.012) observed at the sites with higher animal densities appears larger than the average ratio (0.004) at the sites with lower animal densities. Repeated manure applications may have built up the phosphorus content of the soil within these watersheds with higher animal densities, resulting in higher concentrations of P in runoff and eroded sediment relative to the sediment transported to the stream in watersheds with low animal densities.

Table 4. Total P to TSS normalized annual load ratios measured from each watershed over both years of monitoring.

Site Name	TP: TSS (kg/ha/cm runoff) 2004	2005	04-05 Average	AU Density (AU/ha)
NEofNwUlm	0.006	0.006	0.006	4.13
NWofTrvse	0.012	0.024	0.018	5.87
Hueskmp1	0.008	0.005	0.006	1.83
Hueskmp2	0.002	0.003	0.0025	0.74

Dissolved phosphorus (DP) yields across the four watersheds were not closely related to differences in animal density. For example, the 'Hueskmp1' and 'Hueskmp2' watersheds had the highest and lowest average DP yields but the lowest animal densities. In contrast, however, the ratios of DP:TP were closely related to animal density. The ratios of DP:TP were larger in the 'NEofNwUlm' (0.59) and 'NWofTrvse' (0.6) watersheds (having higher animal densities) than the corresponding ratios in the ' Hueskmp1' (0.47) and 'Hueskmp2' (0.35) watersheds. This difference indicates that the TP yields measured at the mouth of the 'Huelskmp' sites are made up of less DP than at the other two sites. The remaining P measured is assumed to be primarily particulate phosphorus (PP) bound to soil particles transported in stream flow. Again, it appears that watersheds in which large amounts of animal manure are applied to the land help reduce erosion and particulate phosphorus, while increasing the dissolved phosphorus relative to watersheds with lower animal densities.

Figure 4. Normalized Dissolved Phosphorus (DP) yield measured at the mouth of each watershed throughout the 2004 and 2005 monitoring periods.

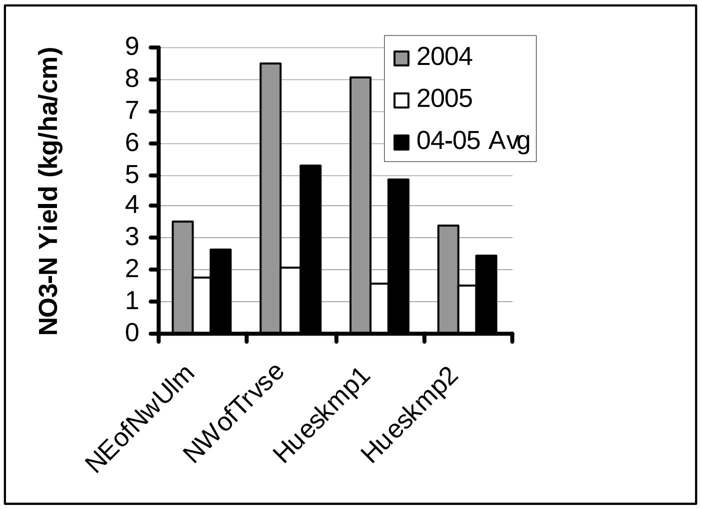


Nitrate-Nitrogen (NO_3-N) Yields

The normalized nitrate-nitrogen (NO_3-N) yields measured at each site located within the Steeper Till agroecoregion on average appear quite consistent across the four sites monitored (Figure 5). The average NO_3-N yield measured at these sites was 2.70 kg/ha/cm runoff.

The predominance of animal agriculture within the monitored watersheds correlates to some extent with the NO_3-N loads that were measured. The three sites demonstrating the highest concentrations of animal units ('NEofNwUlm', 'NWofTrvse', and 'Huelskmp1') also reflect the largest average loads of NO_3-N measured from each watershed. The 'Huelskmp2' average NO_3-N load is less than those observed in the watersheds with much larger populations of livestock. The extremely close proximity of this watershed to 'Huelskmp1', may offer some explanation for this. A portion of the manure produced within the 'Huelskmp1' watershed is very likely applied within the 'Huelskmp2' watershed.

Figure 5. Normalized nitrate-nitrogen (NO_3-N) yield measured at the mouth of each watershed throughout the 2004 and 2005 monitoring periods.



Of perhaps greater importance for NO_3-N yields than animal density, however, is watershed slope. The steepest watersheds 'NEofNwUlm' and 'Hueskmp2' had the lowest nitrate yields, while the flattest watersheds 'NWofTrvse' and 'Hueskmp1' had the highest nitrate yields. Flatter watersheds tend to have more poorly drained soils and a greater density of subsurface tile drains than steeper watersheds. Nitrate is transported to surface waters through these subsurface tiles, so it is reasonable for flatter watersheds with a greater density of subsurface tile drains to transport more nitrate-N than steeper watersheds.

Conclusions

This study focused on differences in water quality across four watersheds located within the Steeper Till agroecoregion. Watersheds differed primarily in slope steepness and animal density. In general, total suspended solid (TSS) yields were lower in watersheds with higher densities of animal livestock, presumably because of the beneficial impacts of land applied manure on soil structure and infiltration. Discharge per unit area also explained some of the differences in TSS yields across watersheds, with higher discharges being associated with higher TSS yields. Total phosphorus (TP) yields were also inversely related to animal density, with lower TP yields in watersheds with higher animal densities. This is probably due to the reduction in erosion and particulate phosphorus that occurs in areas receiving land applied manure. However, the ratio of TP:TSS was greater in watersheds with higher animal densities, indicating that sediment eroded from watersheds with higher animal densities is enriched in phosphorus relative to sediment from watersheds with lower animal densities. There were no effects of animal density on dissolved phosphorus (DP) yields. However, the ratio of DP:TP was greater in watersheds with higher animal densities than in watersheds with lower animal densities, indicating that there is a greater propensity for loss of DP than TP per unit of TP lost in watersheds with higher animal densities. Nitrate-N yields varied across watersheds in response to slope steepness, with flatter watersheds having higher nitrate yields. This is probably due to greater densities of subsurface tile drainage in flatter watersheds with more poorly drained soils. Nitrate-N yields were also somewhat related to differences in animal density, with higher yields in watersheds with a higher density of livestock.

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Hatch, L.K., A.P. Mallawatantri, D. Wheeler, A. Gleason, D.J. Mulla, J.A. Perry, K.W. Easter, P. Brezonik, R. Smith, and L. Gerlach. 2001. Land Management at the major watershed – agroecoregion intersection. J. Soil Water Conservation. 56:44-51.

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List of publications and presentations resulting from this project

None yet, results just summarized for first time a few months ago.

Description of student training provided by project:

Birr, A. 2005. Paired watershed studies for nutrient reductions in the Minnesota River Basin. Ph.D. Dissertation. Water Resources Science. College of Agricultural, Food and Environmental Sciences. Univ. Minnesota. St. Paul, MN. 169 pp.

Stuewe, L. 2006. Agricultural nitrogen and phosphorus mass-balances in south-central Minnesota. M.S. Thesis. Water Resources Science. College of Agricultural, Food and Environmental Sciences. Univ. Minnesota. St. Paul, MN. 169pp.