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Event Mean Concentration of Nitrogen and Phosphorus from a Dairy and Crop Farming Complex Watershed

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Abstract

Event mean concentration (EMC) of nitrogen (N) and phosphorus (P) is primary information for non-point source pollution assessment of a watershed. The EMCs for various types of agriculture such as dairy and crop farming under different climate and geologic conditions are not fully investigated. A diary- and crop-farming complex agricultural watershed in Piedmont region in Maryland, USA has been monitored for 10 years as a section 319 national monitoring program of US EPA. Dairy manure was the main source of fertilizer for crop farming in this watershed. Observed mean concentrations of N and P for each event were analyzed. Distribution of EMCs for N and P showed a wide range of variations. Representative EMCs of T-N and NO_3-N tended to be higher than those reported for other agricultural watersheds. This study confirmed that site-specific EMC information for various agricultural practices is required for better assessment of non-point source pollution using EMC method.

Keywords : EMC, Agricultural watershed, Nitrogen, Phosphorus, Dairy, Manure, NPS, Water quality.

I. Introduction

Water quality models, as regulatory and planning purposes, used to estimate non-point water pollution into watersheds require the input of either export coefficients (typically for rural areas) or event mean concentrations (typically for urban areas). Event mean concentration (EMC), expressed as a mass of pollutant per unit volume of water (usually mg L^{-1}), represents the concentration of a specific pollutant contained in storm-water runoff coming from a particular land use type within a watershed. Export coefficients, expressed as mass of pollutant per unit area per time (e.g. kg ha^{-1} yr^{-1}), represent the averaged total amount of pollutant load entered annually into a system from a defined area. These values are usually calculated from local storm water monitoring data (Lin, 2004).

Pollutant loads from a large basin can be easily assessed by the EMC approach due to the advent

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of GIS technology. The EMC approach has been used extensively in modeling of various pollutants since the 1980's (Huber, 1993; Bhaduri, 1998; Quenzer and Maidment, 1998; Melancon, et al., 1999). Since collecting the data necessary for calculating site-specific EMCs can be cost-prohibitive, researchers or regulators often use the values that are already available in the literature. If site-specific values are not available, regional or national averages are likely to be used despite that the accuracy of values is questionable because agricultural and urban land uses can exhibit a wide range of variability in nutrient export due to the site-specific climatologic and physiographic characteristics of individual watersheds (Beaulac and Reckhow 1982).

Even though site specific EMC data are required for the EMC approach, established EMCs for agricultural watershed are not comprehensive compared to those of urban land use (Baldys et al., 1998; Guerard and Weiss, 1995). The EMCs from agricultural watershed might vary as affected by practices such as tillage, dairy operation and manure management, and BMPs even under same climatic and physiographic conditions. Therefore, various EMCs for different management practices should be developed to ensure accuracy of the EMC method. While documented water quality responses to animal waste management practices are available on small plot or field-sized plot scale, studies on large watersheds with varying topography, land use, soils, and geology are relatively rare (Inamdar et al., 2001). The objective of this study was to evaluate EMCs of nitrogen (N) and phosphorus (P) from a rural watershed with mixed landuse including dairy operation in Piedmont region of Maryland.

Ⅱ. Materials and Methods

1. Description of Study Site

The selected 346-ha Warner Creek watershed in the Piedmont physiographic region of Maryland (Latitude: 39°, 35', 3", Longitude: 77°, 14', 31.5" at the outlet of watershed) is a part of the NPS-319 project in the Monocacy River watershed. The watershed drains into Little Pipe Creek and then into the Monocacy River. These water bodies are part of the overall 64,000 squre mile (approximately 165,759 km^2) Chesapeake Bay watershed. According to USDA report, the Monocacy River has been ranked as number three regarding the potential release of P and as number 20 in terms of the potential release of N to Chesapeake Bay among 30 priority river basins (USDA-SCS, 1990).

Overall, most of the upland soils belong to the Penn silt loam series with an average slope of 3% to 8%, indicating moderate to high runoff characteristics. Approximately 65% of the land surface is classified as moderately erodible, while 12% has been classified as severely erodible (USDA-SCS, 1960). Land use in the watershed includes a mixture of dairy and beef farming, pasture, and cropland. There are three major dairy operations, totaling to about 620 heads of milking cows. Crop management, farm fertilization habits, and manure applications were recorded by the Monocacy Watershed Project Office (Burdette, 1996). A series of monitoring stations were established along Warner Creek to collect hydrologic parameters and water quality samples (Fig. 1).

2. Monitoring Method and EMC Analysis

Station 2A (Fig. 1) was gauged and equipped with a continuous recording automatic ISCO flow meter and sampler. Rainfall data were measured using a continuous recording rain gauge near station 2A and the missing data were supplemented by daily readings of a manual rain gauge at the same station. The sampling scheme applied to all stations (1A, 1B, 1C, and 2A) involved grab sampling on weekly intervals from February through June and biweekly for the rest of the year. The automated system measured and sampled the storm events that occurred between the regular grab sampling times at the outlet of the watershed (station 2A). This selected frequency provided a reasonable trend in hydrologic and water quality response of the watershed and satisfied the EPA's National Monitoring Guidelines (USEPA, 1991). Several samples proportional to flow volume were collected for each storm, but those samples were mixed and made it a composite sample. Water samples were analyzed for NO_3^-, total Kjeldahl-N (T-N), total-P (T-P), and ortho-P. An automated ion analyzer (Lachat model 1000-1) was used for the analyses. The Quickchem® methods (reaction modules) used with the automated ion analyzer for the constituents of interest are EPA approved.

Analyzed concentration of the composite samples was considered as EMCs of the pollutants of the corresponding storm runoff. Total 238 storm event data were used for this study. Even though monitoring was conducted until 2003, the

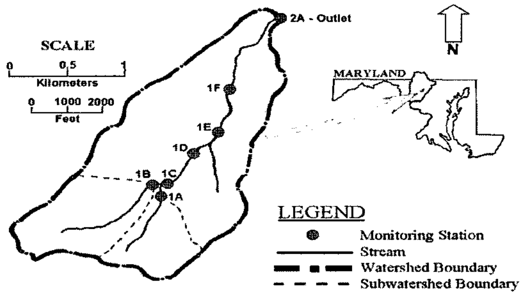

Fig. 1 Location and monitoring set up at Warner Creek watershed, Frederick County, Maryland.

data of 2003 were excluded in this study since unexplainably high concentration of N and P were observed. Basic statistical analysis such as mean and standard deviation of EMCs were conducted for each year and for the entire study period. Weibull formula was used to define probability distribution of EMCs for N and P constituents and probability exceedance plots were also developed.

Ⅲ. Results and Discussions

1. Precipitation and Runoff

The average annual precipitation amounts for the study watershed was1,081 mm with range between 688 in 2001 and 1,809 mm in 1996 (Fig. 1). Average annual stream flow depths (stream flow volume divided by watershed area) during storm period at station 2A was 162 mm with the ragne 29 mm in 1996 to 545 mm in 2001, which was 3 to 30% of annual precipitation.

Shirmohammadi et al. (1997) found that base flow was dominant compared to surface runoff in the studied watershed due to geologic formation.

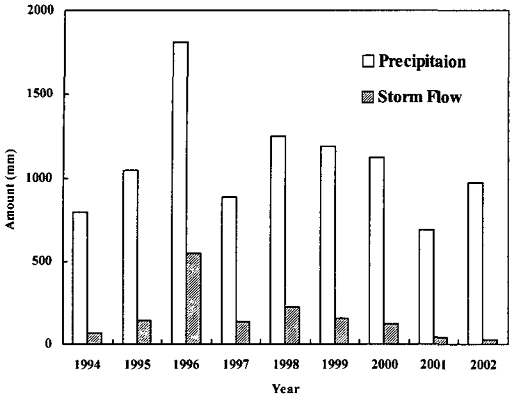

Fig. 2 Annual precipitation and storm flow amount during the study period.

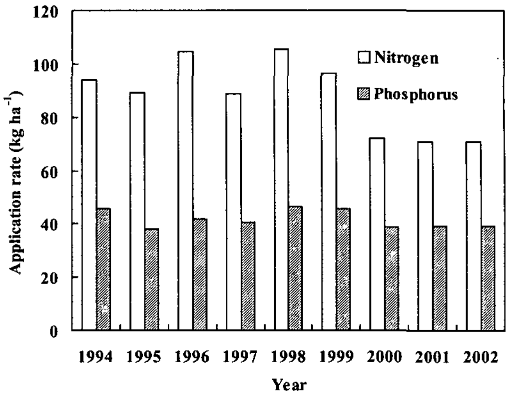

Fig. 3 Average annual N and P fertilizer application rate in the studied watershed.

2. Dairy Manure and Fertilizer Application

Row crop agriculture with corn, soybeans, and small grains (wheat and barley) being the major crops is the primary activity in the watershed. Mainly dairy manure was used for fertilization with supplementary addition of chemical N-fertilizer. Dairy manure usually applied on late April for corn and October when winter crop was planted. Annual application rates of N and P (total applied amount divided by watershed area) in the watershed ranged from 71 to 106 kg N $ha^{-1} \cdot yr^{-1}$ (average 88 kg N ha^{-1}) and from 38 to 46 P kg^{-1} ha^{-1} yr^{-1} (average 42 kg P ha^{-1}), respectively.

3. EMCs Distribution

Annual mean EMCs of N and P varied each year, showing inconsistent trends with precipitation and fertilization pattern (Fig. 4). In each year, manure application rate and timing were different due to different crop rotation, and precipitation amount and distribution were also different year by year. Furthermore, some farmers who didn't have enough livestock manure storage conducted land-application of livestock manure on pasture whenever manure was available. Thereby, a large annual variation of EMCs seemed to be expected. The mean concentration of NO_3-N was the highest in 2001when N application rate was lowest (71 kg ha^{-1}). It could be speculated that as year 2001 was the driest year (precipitation was 688 mm, Fig. 2), nitrification which is an aerobic N transformation process in the soil might be more active than other years, resulting in a high concentration of NO_3-N into intermediate runoff in turn (Choi et al., 2003).

The EMCs of NO_3^--N, T-N, ortho-P, and T-P for the entire study period are shown as probability exceedance plots in Fig. 5. Statistical summary of the observed EMCs is presented in Table 1. The EMCs in events included in this study ranged over several orders of magnitude, with the ranges 0.10-13.8 mg L^{-1} (average: 4.0 mg L^{-1}) for NO_3^--N, 1.2 - 54.4 mg L^{-1} (10.7 mg L^{-1}) for T-N, 0.1 - 9.7 mg L^{-1} (1.1 mg L^{-1}) for ortho-P, and 0.01-10.5 mg L^{-1} (1.8 mg L^{-1})

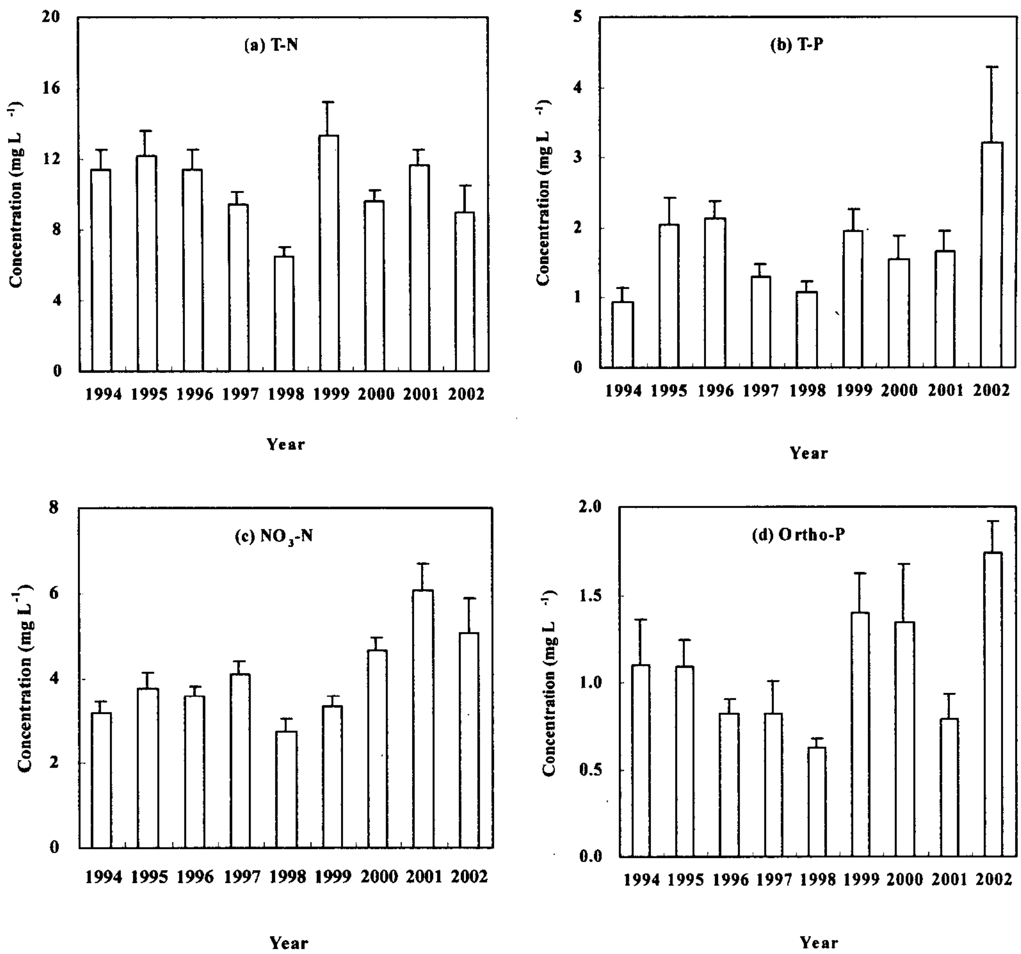

Fig. 4 Event mean concentrations of (a) T-N, (b) T-P, (c) NO_3-N, and (d) Ortho-P.

for T−P. The EMCs of probability at 50% from exceedance plots of NO_3^-−N, T−N, ortho−P, and T−P were 3.7, 9.1, 0.7, and 1.2 mg L^{-1}, respectively. Overall, the values of arithmetic mean were higher than those determine from probability at 50% from exceedance plots.

Table 2 shows comparison among published EMCs for other agricultural land uses and those of this study. The EMC value determined from 50% exceedance probability was considered representative EMC of the study watershed. Since the EMCs reviewed here do not cover all

Table 1 Statistical summary of observed EMCs.

Parameters	NO_3-N	T-N	Ortho-P	T-P
The number of samples	238	238	238	238
EMC (mg L^{-1})	4.0	10.7	1.1	1.8
Stdard deviation	2.1	6.4	1.5	1.7
Minimum concentration (mg L^{-1})	0.10	1.17	0.09	0.01
Maximum concentration (mg L^{-1})	13.8	54.4	9.7	10.5
EMCs of probability at 50%	3.7	9.1	0.7	1.2

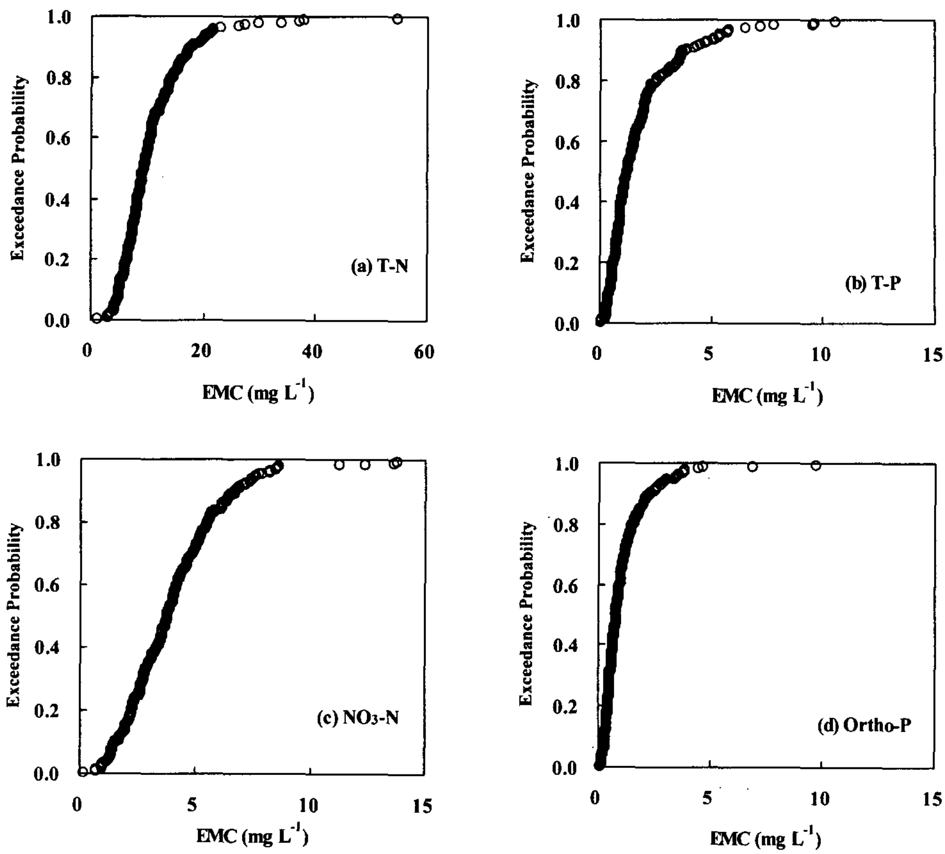

Fig. 5 Exceedance probability of EMC of (a) T-N, (b) T-P, (c) NO_3-N, and (d) Ortho-P.

areas of local, regional, and national EMCs published in journal articles and government reports, it is not straightforward to draw decisive conclusions. However, some conspicuous features could be found from this comparison. The EMC of NO_3-N in this study showed the highest value, while the EMC of T-N of this watershed was similar to those of pre-BMP conditions for dairy watershed in Piedmont region of Virginia (Brannan et al, 2000). This implies that EMC of N from dairy watershed could be higher than general agricultural watershed.

Table 2. Comparison of EMCs (mg L^{-1}) for agricultural land uses reported by researchers.

	NO_3-N	T-N	Ortho -P	T-P	Site
Harper (1988)	NA	2.32	NA	0.34	NA
Baird and Jennings (1996)	1.60	4.40	NA	1.30	Corpus Christi, TX
Inamdar et al. (2001)	0.81	5.20	0.02	0.71	Coastal Plain, VA Crop farming
Brannan et al. (2000)	2.81	8.83	0.42	2.70	Piedmont, VA Dairy watershed
This Study	3.72	9.13	0.74	1.15	Piedmont, MD Dairy watershed

NA, not available.

Ⅳ. Conclusion

The EMCs in this study was quite variable over the years and within a year, suggesting that long-term monitoring information is crucial to develop statistically viable EMCs. This study also revealed that EMCs from dairy watershed could be different from other agricultural land uses. Therefore, studies of EMCs for various agricultural management scenarios such as dairy, row crop farming under different climate and geologic conditions are recommended to improve EMC method.

Acknowledgements

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