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Winter application of manure on an agricultural watershed and its impact on downstream nutrient fluxes

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ABSTRACT

Whole Farm Planning was instituted and monitored over a 5-year period within the Graywood Gully sub-watershed of Conesus Lake, NY (USA). An array of agricultural Best Management Practices (BMPs) (strip cropping, fertilizer reduction, tiling, manure disposal practices, etc.) were simultaneously introduced to determine the impact of a concentrated management effort on nutrient and soil loss from one watershed within the Conesus Lake catchment. During the study period, significant decreases in winter concentrations of dissolved and particulate fractions, including total phosphorus (TP), soluble reactive phosphorus (SRP), total Kjeldahl nitrogen (TKN), and nitrate (NO_3) but not total suspended solids (TSS), were observed. These decreases may or may not be attributed to cessation of manuring practices. Three years into the study, an opportunity existed to test the responsiveness of the watershed to the curtailment of a single BMP — winter manure application to fields. We field-tested the hypothesis that a change in winter manure applications would impact dissolved and particulate fractions in stream water draining this watershed. We found that the water quality of Graywood Gully is very responsive to winter manure application on environmentally sensitive portions of the sub-watershed. With the short-term resumption of manure application, TP, SRP, TKN, and NO_3 concentrations rose dramatically in stream water; elevated phosphorus concentrations persisted over a 5-week period. Total suspended solids, however, were not elevated after short-term manure application. Factors that affected these results were slope of the land, application of manure over snow and during a snowfall, warm air and soil temperatures, and possibly tile drainage of snowmelt water. Managers of agricultural systems must recognize that phosphorus losses from the watershed during the nongrowing season may detrimentally affect nuisance population of algae in lakes during the summer.

Introduction

Whole Farm Planning is a process that enables a farm to balance farm profitability, community stability, and environmental vitality. It is a decision-making and evaluation model that helps farmers integrate the dynamic relationships of the economic, social, and ecological consequences of management decisions in relation to their contribution to an individual farmer's goals. The management of manure application to agricultural fields is a common practice in North America, Europe, and developing countries and is often an important consideration in any whole farm planning scenario in the United States. Manure is an agricultural by-product that can be environmentally and cost effectively returned to the land to enhance soil productivity, increase soil organic matter, and increase infiltration rates; applied manure can sometimes form a protective layer on the soil surface to reduce runoff (McDowell et al. 2004, Gilley and Risse 2000, Smith et al. 2007). There are also negative aspects to manure application. For example, manure applied in excess can pollute adjacent waterways and infiltrate into groundwater (Zebarth et al. 1996). As a result, agricultural specialists have established recommendations on the timing and field application for manure that often target environmentally sensitive areas and application during the winter season. For example, manure should not be spread on steep slopes nor in areas near water bodies during the fall and winter; manure can be applied in the winter only if adequate storage is not available on the farm; manure application on snow or frozen ground should be avoided; and winter application of manure is the least desirable from both a nutrient utilization and pollution standpoint (Beegle et al. 2000, Maryland Department of Agriculture 2004, Frankenberger et al. 2003).

The Conesus Lake Watershed Study (Makarewicz 2009), a long-term project using the small watershed approach, evaluated the impact of agricultural Best Management Practices (BMPs) on maintaining nutrients and soil on the landscape and on reducing losses of soil and nutrients to downstream aquatic systems. In Graywood Gully, one of several sub-watersheds studied within the Conesus Lake catchment, Noll and Magee (2009) identified not only the importance of critical source areas in the watershed but also the effect of the built

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environment, including drain systems and road ditches, on changing critical hydrological pathways. Also, significant changes in phosphorus (P) fractionation occurred during erosion, transport, and deposition of the particulate or sediment phase (soil) from the watershed to the nearshore sediments. Aluminum and organic matter associated P, for example, dominated in field soils while calcium associated P dominated in nearshore lake sediments (Noll et al. 2009). Zollweg and Makarewicz (2009), using the Thornthwaite-Mather soil moisture status model, demonstrated a reduction in nutrients and soil loss from the watershed to downstream systems as high as 91% and as low as 55% for soluble reactive phosphorus (SRP), indicating a significant success of the BMPs in the Graywood Gully watershed. Empirically, Makarewicz et al. (2009) investigated the effectiveness of agricultural BMPs by evaluating long-term annual changes in seasonal flux (kg/ha/d) and concentration (μg/L) of nutrients and soil in stream discharge water from the managed watershed.

The work by Makarewicz et al. (2009) focused on annual changes and did not consider seasonal aspects of BMPs. Here, we field-tested at the watershed scale the hypothesis that a change in winter manure applications would impact dissolved and particulate fractions in stream water draining the Graywood Gully sub-watershed of Conesus Lake. Evaluation of long- and short-term trends was accomplished by resuming winter manure applications on environmentally sensitive areas of the sub-watershed after 2 years of cessation of fall and winter manure application to frozen, snow-covered fields. After 5 days of manure application, manure spreading on fields in environmentally sensitive areas was once again stopped.

Site description

Graywood Gully, a small New York State sub-watershed (~38 ha) in the northwest portion of the Conesus Lake watershed within the Lake Ontario catchment, drains an upland area dominated by a single 100-cow dairy-farming operation (Jacobs 2005, Fig. 1). Graywood Gully contributes a disproportionate amount of soil and nutrients to Conesus Lake when compared to the other sub-watersheds in the catchment (Makarewicz et al. 2001, 2002; also see Table 1 in Makarewicz 2009). The stream flows eastward through a deeply incised gully (8% grade), often over fractured bedrock, and is surrounded by a small wooded area before reaching the developed margin surrounding Conesus Lake. Soils in the watershed are dominated by the Conesus silt loam, a somewhat poorly drained soil developed on limestone with the water table commonly within 15 cm to 45 cm of the surface, and the Lansing silt loam, a moderately well-drained soil developed on shale with the water table within 45 cm to 60 cm of the surface (USDA NRCS 2008). Further description of Conesus Lake and its watershed, crops planted, tile drains within the watershed, and the implemented BMPs is given in Makarewicz (2009), Noll and Magee (2009), and Herendeen and Glazier (2009). Winters are best described as severe with heavy snows, frozen ground, and long periods of freezing air temperatures interspersed by unpredictable periods of warming and thawing. An overview of the soils, geology, and climate of the Conesus Lake area is given in Forest et al. (1978) and SOCL (2001).

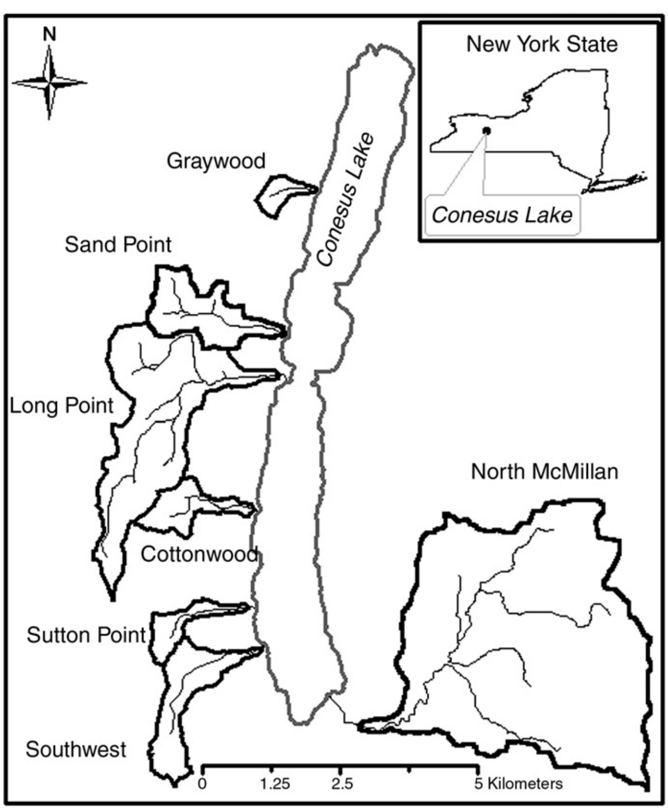

Fig. 1. Map of the sub-watershed of Conesus Lake. There are eighteen sub-watersheds to Conesus Lake. Only the seven sub-watersheds that were part of the Conesus Lake Watershed study are shown.

Table 1
Percent reduction of winter (21 December to 20 March) Graywood Gully marginal mean concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), total Kjeldahl nitrogen (TKN), nitrate, and total suspended solids (TSS) relative to winter 2002–03 under event plus nonevent (A), nonevent (B) and event (C) stream conditions.

A. Events plus nonevents

Year	2002–03	2003–04	2004–05	2005–06	2006–07
# of samples	21	14	18	15	13
TP	–	59.4[a]	37.6[a]	66.0[a]	68.7[a]
SRP	–	68.0[a]	37.9	74.9[a]	74.5[a]
TKN	–	50.0[a]	54.8[a]	57.9[a]	69.8[a]
Nitrate	–	24.1	43.7[a]	67.1[a]	69.5[a]
TSS	–	39.8	35.3	79.7[a]	64.4

B. Nonevents only

Year	2002–03	2003–04	2004–05	2005–06	2006–07
# of samples	11	13	13	13	12
TP	–	46.5[a]	26.0	53.4[a]	55.7[a]
SRP	–	58.8[a]	42.9	75.2[a]	73.9[a]
TKN	–	31.1	47.2	35.7	54.8[a]
Nitrate	–	47.5[a]	56.2[a]	78.6[a]	78.9[a]
TSS	–	−55.1	−28.0	39.6	−21.2

C. Events only

Year	2002–03	2003–04	2004–05	2005–06	2006–07
# of samples	10	1	5	2	1
TP	–	50.7	−13.7	59.7	79.7
SRP	–	98.2[a]	14.7	59.9	77.3
TKN	–	−16.1	−10.2	59.7	58.3
Nitrate	–	13.5	60.8[a]	45.2	77.3
TSS	–	−523.4	−468.0	45.5	57.8

[a] Significant difference from 2002–03. A negative sign represents a percent increase in parameter concentration.

Methods

Graywood Gully was studied for a 5-year period starting on 1 September 2002. As a result of Whole Farm Planning (Herendeen and Glazier 2009, Risse et al. 2005, Janke 2000) and soil sample nutrient analyses (Herendeen and Glazier 2009), a number of BMPs that addressed the identified water quality problems were implemented in the Graywood Gully sub-watershed of Conesus Lake, NY (Herendeen and Glazier 2009) with guidance from Cornell Cooperative Extension and the Livingston County (NY) Soil and Water Conservation District. One of the BMPs that was implemented dealt with timing of manure spreading. Spreading of manure on the surface of the land was common during the fall and winter in the Finger Lakes region, including Graywood Gully. During the winter of 2002–03, winter spreading of manure in hydrologically sensitive areas and in highly erodable land planted in corn was halted (Herendeen and Glazier 2009, Jacobs 2005). In the winter of 2005–06, traditional broadcast manure application (not a slurry) to fields in Graywood Gully was resumed from 21 to 25 January 2005. After the winter of 2005–06, winter spreading of manure was once again halted.

During the study period, Graywood Gully's stage height was monitored continuously for five annual cycles with a differential pressure transducer (ISCO 720) attached to an ISCO continuously recording flow meter (Model 6700) equipped with an automatic sampler (Makarewicz et al. 2009). Water samples were taken using two different methodologies: weekly manual grab samples and automated hydrometeorological event samples (Makarewicz et al. 2009). A hydrometeorological event was defined as a rise in the creek level of at least 2.54 cm in 30 min. Event and nonevent samples were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate + nitrite (NO_3), total Kjeldahl nitrogen (TKN), and total suspended solids (TSS) by standard methods (APHA 1999, Makarewicz et al. 2009). Replicate analysis, blind audits, and spiked additions are part of the QA/QC of our NELAC certified lab. Here we confine our analysis to concentration data from the winter seasons (21 December to 20 March) of the 5-year study period. Analysis of the entire data set may be found in Makarewicz et al. (2009). Weather data (daily temperature, precipitation) were obtained from the National Weather Service, Rochester, NY. Rochester is located 50 km north of Conesus Lake.

An Analysis of Covariance (ANCOVA) was performed on transformed (natural log) data to test for temporal trends in nutrient concentration with stream discharge as the covariate and concentration times sampling period as the interaction term. Slopes of each regression line were compared using a pairwise t-test of all possible pairs, in which the significance levels were corrected using the Bonferroni procedure. Regression line elevations were also analyzed for significant differences using a Bonferroni test of the estimated marginal means for the winter sampling period. The Bonferroni procedure offers an adjustment for multiple comparisons and is considered a conservative procedure for post-hoc analysis (Norleans 2001). The marginal means are the means for the analyte concentration after they have been adjusted for the covariate of discharge. Further information and an example of the ANCOVA may be found in Makarewicz et al. (2009).

Results

Analyses of Covariance (ANCOVA) were completed for the winter concentration of each analyte (TP, SRP, TKN, NO_3, and TSS). For example, temporal trends in winter nonevent TP concentration of Graywood Gully water were evaluated by considering the slope of the regression line of TP concentration versus stream discharge for each winter period using ANCOVA with discharge as the covariate. Pairwise t-test comparisons of the slopes of the ANCOVA regression lines for each winter period indicated that the slopes of the 2003–04, 2005–06, and 2006–07 regression lines were significantly different ($df = 1,4$; $P < 0.05$) from the regression lines of 2002–03. The slope of 2004–05 was not significantly different from the 2002–03 regression line. We also compared the difference in the elevations of each regression line by utilizing the marginal means of the discharge adjusted TP concentration from the ANCOVA analysis. The discharge adjusted nonevent mean TP concentration significantly (post-hoc Bonferroni test) decreased from 2002–03 to 2003–04, 2005–06, and 2006–07 (Fig. 2a) but not from 2002–03 to 2004–05 ($df = 1,4$; $P = 0.68$, Fig. 2a). A similar result occurred for nonevent SRP concentrations (Fig. 2b). The generally significant downward trend in nonevent winter TP and SRP marginal mean concentration was interrupted by a significant increase in 2004–05 ($df = 1,4$; $p > 0.05$, Figs. 2a, b).

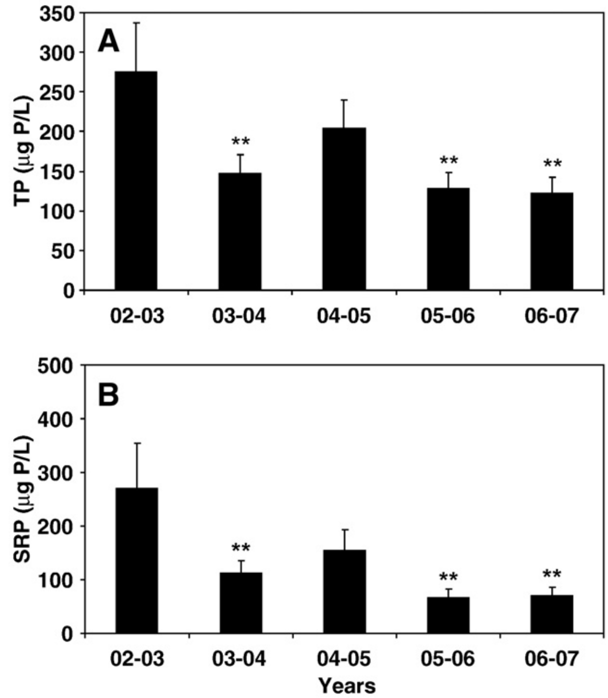

Fig. 2. Winter (21 December to 20 March) marginal mean concentration (±S.E.) of nonevent total phosphorus (TP) (A) and soluble reactive phosphorus (SRP) (B). **Significantly different from 2002–03 ($p < 0.05$, Bonferroni post-hoc test).

Considering the average of the data (nonevents plus events), SRP concentrations were not significantly different in winter 2004–05 from winter 2002–03 (Fig. 3a). This was not the case for TP (Fig. 3b). In general, considering the event/nonevent data for TKN and NO_3, the post-hoc analyses of the ANCOVA indicated that the elevation of the marginal mean winter concentration of TKN and NO_3 decreased significantly ($df = 1,4$; $p < 0.05$) from 2002–03 to 2006–07 (Figs. 3c, d). This was not true for TSS where no significant ($df = 1,4$; $p > 0.05$) decrease was observed from 2002–03 to 2006–07; however, TSS was significantly lower during 2005–06 than 2002–03 ($df = 1,4$; $p < 0.05$) (Fig. 3e).

The percent decrease in the marginal mean concentration of various analytes was surprisingly similar. We expected more variability from year to year as observed in the annual evaluations of impact of BMPs (Makarewicz et al. 2009). Where significant reductions occurred, percent reduction in marginal mean concentration (event plus nonevents) after 4 years of BMP implementation was: 68.7% for TP, 69.5% for NO_3, 69.8% for TKN, and 74.5% for SRP (Table 1a). Total suspended solids had a similar percent reduction (64.4%) as the other analytes but was not significantly different from 2002–03 to 2006–07 ($df = 1,4$; $p > 0.05$) due to the high variability within the data (Table 1a). All nonevent analytes, except TSS, had significant decreases from 2002–03 to 2006–07 (Table 1b), mimicking the results for the combined event/nonevent samples. During events, there were no significant changes ($df = 1,4$; $p > 0.05$) in TP and SRP concentrations and all other analytes in stream water (Table 1c). In general, where significant reductions of analytes occurred during the winter, they occurred during nonevent-flow regimes rather than during events.

Reductions of some analyte concentrations occurred quickly, reaching near maximum reductions within a year after the initiation of BMPs. Total phosphorus, SRP, and TKN were reduced in stream water by 50% or more by the first winter (2003–04) after BMP implementation (Table 1a, $df = 1,4$; $p < 0.05$) followed by a much slower decrease in concentrations until 2006–07. For example, there was a 50% decrease in TKN by 2003–04, 1 year after implementation of BMPs. This decrease slowly increased to a maximum of 69.8% by

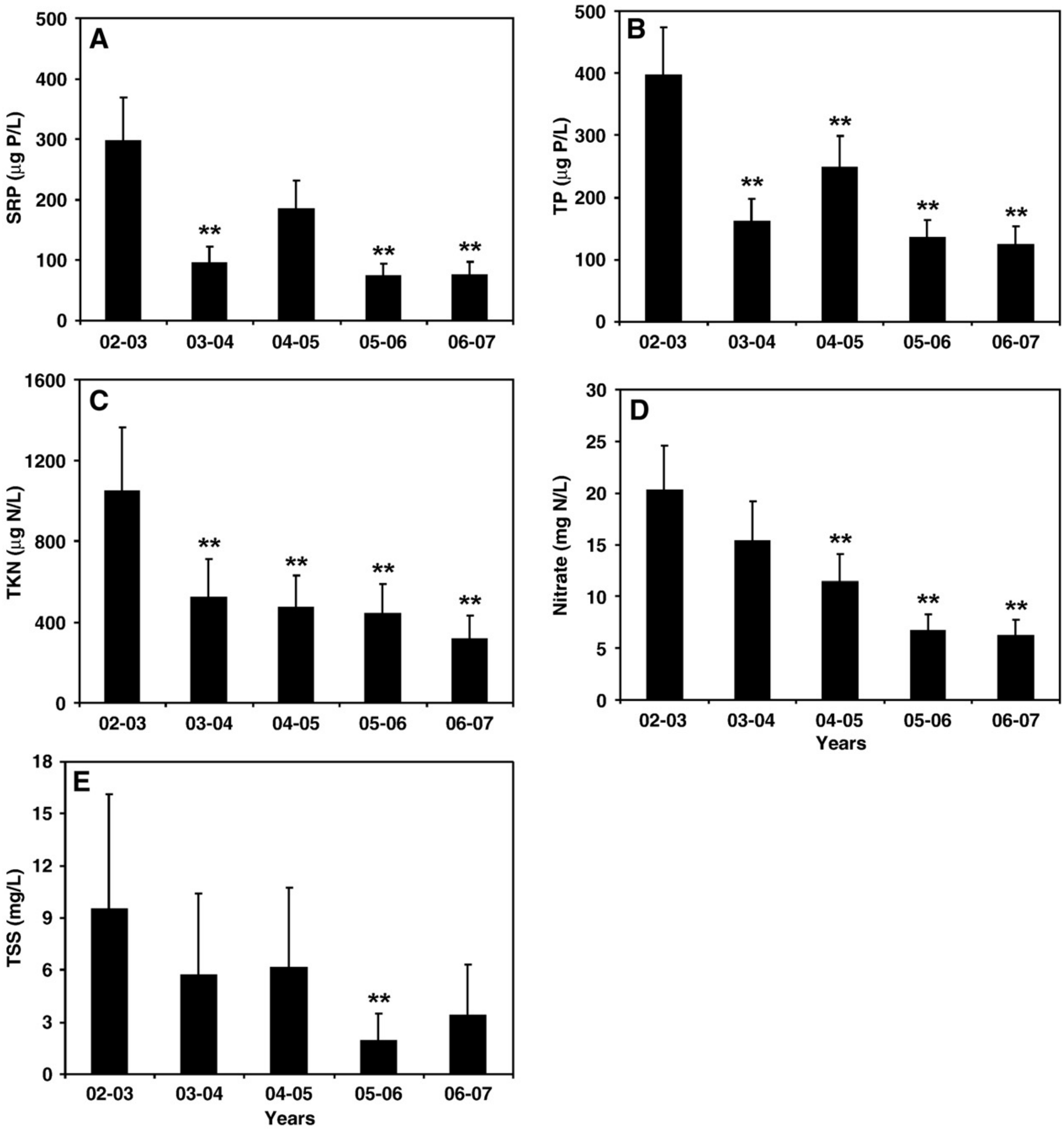

Fig. 3. Average event and nonevent winter marginal mean concentration (±S.E.) of soluble reactive phosphorus (SRP) (A), total phosphorus (TP) (B), total Kjeldahl nitrogen (TKN) (C), Nitrate (NO_3) (D), and total suspended solids (TSS) (E). **Significantly different from 2002–03 (p<0.05, Bonferroni post-hoc test).

2006–07 (Table 1a). The trends for NO_3 followed a different pattern, however. One year after the implementation, a 24.1% decrease in NO_3 was observed with an additional ~20% decrease per year to ~67% in 2005–06 with a small but insignificant decrease to 2006–07 (Table 1a). In fact, it was not until 2004–05 when NO_3 concentrations were significantly reduced (43.7% reduction, df=1,4; p<0.05) (Table 1a, Fig. 3d).

When comparing the winter yearly trends among all variables, significant decreases in TP, TKN, and NO_3 occurred with time (Figs. 3b, c, d). This was not the case for SRP. The decrease in SRP concentration was interrupted by a significant increase in the average winter SRP concentration in 2004–05 from previous years (Figs. 2b, 3a). Focusing on the winter of 2004–05, elevated levels of TKN, TSS, TP, SRP, and NO_3 were observed on 4 January 2005 prior to resumption of winter application of manure (Fig. 4). In the case of NO_3, concentrations were also high the previous week (27 December 2004) and the following week (10 January 2005). Maximum air temperatures for the 4 days preceding this peak were 13.3, 9.4, 9.8, and 2.8 °C (average above 0 °C); after this peak, maximum temperatures were generally below 0 °C with the average air temperature also below 0 °C (Fig. 5a). Through early January, creek discharge varied little (Fig. 5b).

Concentrations of TP, TKN, and NO_3 increased in the stream within 4 days of the application of manure (21 to 25 January 2005; Figs. 4a, c, d). An increase in SRP concentrations was observed but was delayed by a week (Fig. 4b). Nitrate remained elevated in the Graywood Gully stream for the rest of the winter; TKN, SRP and TP decreased for the next 7 weeks (Fig. 4). Discharge peaked for 1 day (18 January 2005), 3 days prior to the application of manure (Fig. 5b), and remained relatively similar to the end of February 2006. Average (Fig. 5a) and maximum air temperatures were below

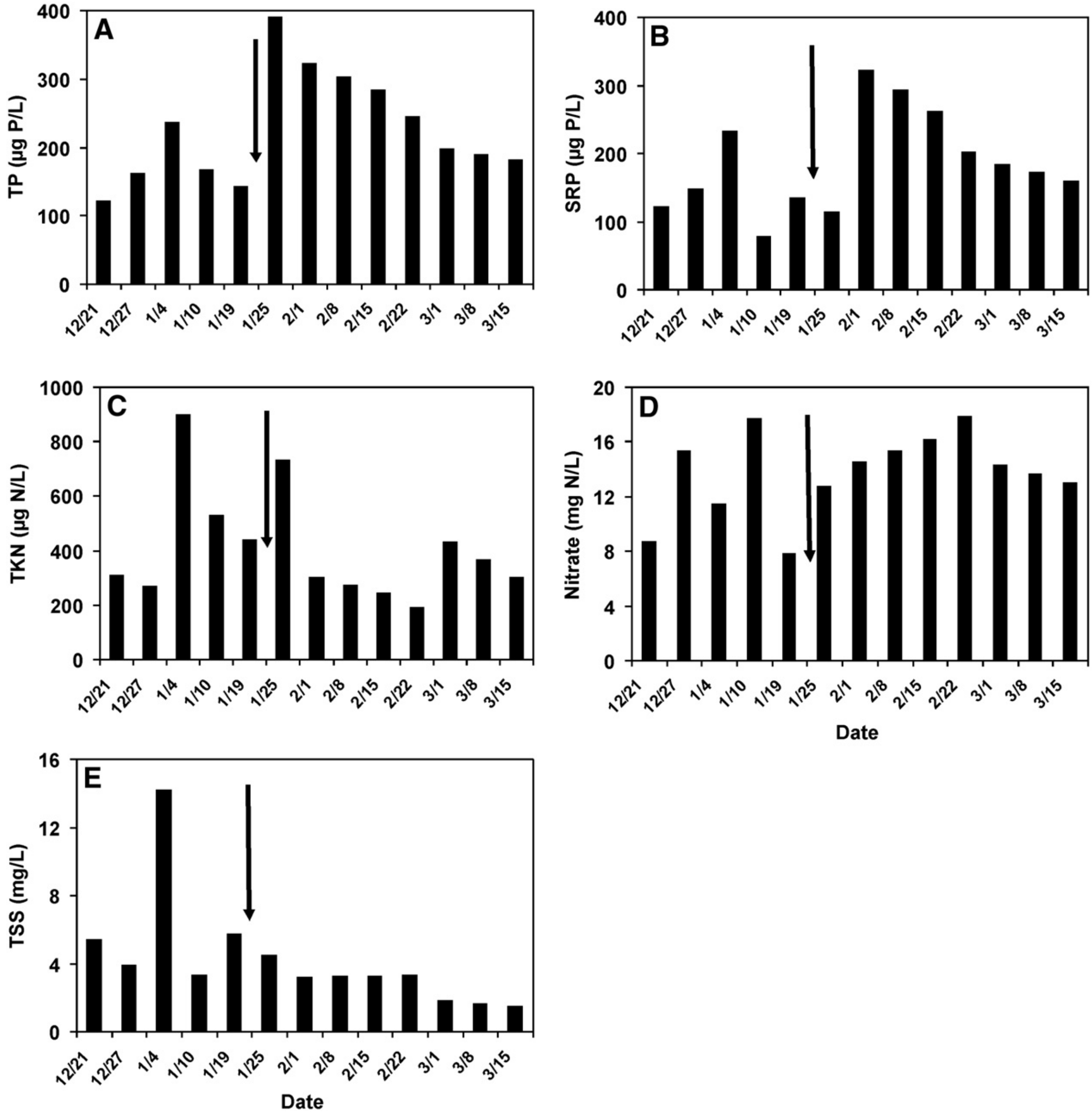

Fig. 4. Time trend of concentrations (event/nonevent) of total phosphorus (TP) (A), soluble reactive phosphorus (SRP) (B), total Kjeldahl nitrogen (TKN) (C), nitrate (NO_3) (D), and total suspended solids (TSS) (E) during the winter of 2004–05. The arrows indicate the period of manure application.

freezing for the entire period of manure application and for several weeks after application.

Discussion

Slope, application of manure over snow and during a snowfall, warm air and soil temperatures played a major role in the loss of P, nitrogen (N), and soil to downstream systems at the Graywood Gully watershed. During the winter of 2004–05 for a period of ~5 days, 2 years after the initial implementation of the BMP (curtailing winter manure applications), manure was again applied to the Graywood Gully sub-watershed. This resumption of winter manure application after a period of below freezing air temperatures (−14.4 °C) offered an opportunity to further examine the sub-watershed's response to the short-term reversal of an established management practice. Following the reintroduction of manure application, TP and SRP, albeit with a 1-week lag, increased dramatically and then slowly decreased for approximately 5 weeks back to previously observed concentrations (Figs. 4a, b). Except for the first date after application of manure, the increase in the amount of P being lost from the sub-watershed was due to the dissolved fraction of P rather than to the particulate fraction as SRP represented 91.7% of the TP concentration. Since stream discharge did not change over the 4-week period after manure application, and average and maximum air temperatures (Fig. 5) were well below freezing at least 3 weeks after the introduction of manure, the increase in concentration of nutrients was not associated with increased air temperatures nor increased flow from the watershed. However, during the manure application period, a steady snow fall occurred (over 10 cm). Also, just a few weeks before the application of manure, ground temperatures were still relatively warm due to air temperatures exceeding 10 °C. We hypothesize that the increase in SRP, TP, NO_3, and TKN, but not TSS, observed in stream water was from snow melt and perhaps from drainage tiles located in portions of this sub-watershed.

Similar to our results, Meals (1996) demonstrated that winter manure application drastically increased the export of P (SRP up to 1500%, TP 11%) from agricultural watersheds in Vermont. Repeated

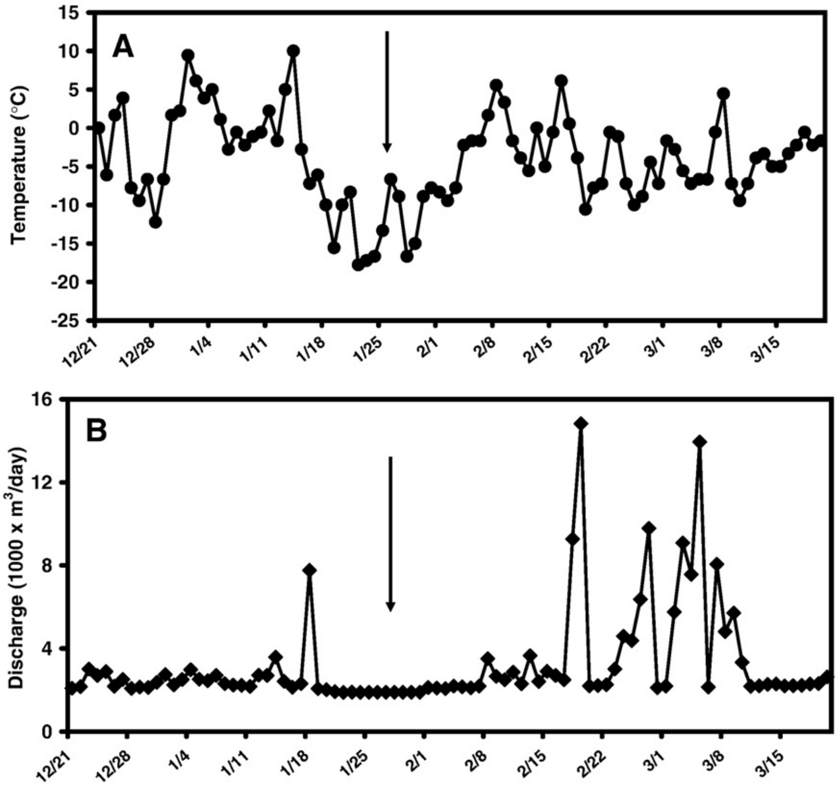

Fig. 5. Average temperatures (A) and daily discharge (B) during the winter of 2004–05 at Rochester, NY. The arrows indicate the period of manure application.

freezing and thawing significantly increased "water extractable P" from catch crop biomass and resulted in significantly elevated concentrations of dissolved P in runoff (Bechmann et al. 2005). Also, large losses of *N* in runoff occurred after the spreading of manure on frozen ground (Midgley and Dunklee 1945). Excessive nutrient losses were observed when manure spreading coincided with warming or active thawing periods (Klausner et al. 1976). Philips et al. (1981) and Lorimor and Melvin (1996) concluded that winter spreading resulted in considerably higher concentrations of N and/or P in runoff.

Others have shown differently. Hensler et al. (1970) observed that runoff losses from manure applied to frozen ground were variable. During one winter when it rained after manure application, significant losses of P and N were observed. In another year where little precipitation occurred, minimal nutrient losses were observed in runoff. In plot experiments, Converse et al. (1976) observed no significant difference in nutrient losses in various seasons of the year, including the winter. Young and Holt (1977) observed that winter-applied manure decreased runoff and soil and nutrient loss, apparently due to the mulching capabilities of solid manure. Many factors affect the quantity of nutrients that are lost from agricultural fields. These include amount and timing of precipitation and thawing (frozen ground), soil conditions, volume of runoff, slope and proximity to surface water, air temperature, snow cover, soil temperature, and soil permeability (Midgley and Dunklee 1945, Converse et al. 1976, Philips et al. 1981, Hensler et al. 1970, Steenhuis et al. 1981, Bechmann et al. 2005).

Our data also demonstrate that losses of nutrients and soil may occur during the winter even if manure is not applied. The peaks in early January of stream concentrations of TP, SRP, TSS, and possibly NO_3 were not associated with recent manure application but with air temperatures that were well above freezing for a 4-day period prior to 4 January 2005. Prior to January, manure had not been applied to the watershed since early autumn. The "January thaw" did not lead to an increase in discharge but did lead to a thawing of the soils. Application of manure to these fields in early January was not possible because of the muddy, water soaked ground.

In general, the agricultural BMP of removing winter manure spreading on environmentally sensitive areas over the 5-year study period at the Graywood Gully sub-watershed had an immediate impact on winter nutrient concentrations in the water draining off this watershed. Ultimately, a >68% decrease was observed 4 years after BMP implementation of all monitored analytes, except TSS (Table 1a). For example, there was a significant decrease in winter SRP concentrations for 2003–04, 2005–06, and 2006–07, but not 2004–05, from 2002–03. Clearly, the short-term resumption of winter manure spreading in 2004–05 lead directly to elevated analyte stream concentrations observed in the winter of 2004–05 and likely affected the interpretation of the annual SRP data by Makarewicz et al. (2009).

Unlike in Makarewicz et al. (2009), where a significant decrease in annual SRP was not observed in Graywood Gully, there was a significant decrease in winter SRP concentrations for 2003–04, 2004–05, and 2006–07 from 2002–03. Along with the decrease in SRP in drain tiles and soils (Makarewicz et al. 2009), the significant winter decrease in SRP in the stream lends support to the hypothesis that annual SRP concentrations were trending downward due to the management practices implemented. In fact, if the five sampling dates associated with the winter 2004–05 manure applications to the environmentally sensitive areas of the Graywood sub-watershed were removed from the data set, concentrations would be significantly lower (ANCOVA, $df = 1,4$; $p < 0.05$) than the initial year of 2002–03.

Decreased winter loading of nutrients to lakes is of importance. The agricultural community often assumes that winter losses of nutrients to downstream systems are not important as overabundance of algae or macrophytes is not directly observed in the lake during the winter. Thus, winter disposal of manure may occur because the environmental effects are not easily observed, often lake-cottage dwellers are not in residence, and the winter manure recommendations are not strictly followed. However, nonpoint inputs of P during the winter from manure operations can and will affect summer chlorophyll levels in a lake. Summer chlorophyll levels are a function of the lake's retention time and of P supplied from external sources seasonally. The winter concentration of TP in the water column of a lake is an excellent predictor of summer algae levels and serves as an index of the P pool available to phytoplankton during the following growing season in the Finger Lakes of New York State (Oglesby and Schaffner 1978). Managers of agricultural systems need to recognize that P losses from the watershed during the nongrowing season may detrimentally affect nuisance population of algae in lakes during the summer.

In summary, the water quality of Graywood Gully is very responsive to winter manure application on environmentally sensitive portions of the sub-watershed. Over the 5-year study period, significant decreases in winter nonevent but not event TP, SRP, TKN and NO_3 concentrations occurred within a year of the initial curtailment of manure application (BMP). A decrease in TSS concentrations was observed only in 2005–06 but not in 2006–07. The reversal of this downward trend for P was just as responsive, as the reinstatement of only a few days of winter manure application resulted in a significant increase in winter nonevent concentrations of SRP. That is, the short-term application of manure to a snow-covered landscape resulted in immediate losses of dissolved fractions including SRP and NO_3. Total Kjeldahl nitrogen, which represents ammonia and organic N, was also lost from the watershed for ~1 week after the application of manure, while the particulate fraction TSS did not increase to the downstream system. Management practices directed at improving the quality of water from agricultural watersheds that apply animal waste should consider application timing, topography, and soil and weather conditions to environmentally sensitive areas of a watershed. Deviations from the manure management plan can and do have short- and long-term effects on P concentrations in the water leaving a watershed. A comprehensive management plan should have a contingency for unforeseen circumstances, such as weather events, which may include short- to mid-term storage capabilities for manure (Edwards et al. 1997) so that the farmer can avoid any deviations from the BMP. Lastly, BMP-induced reductions of seasonal P and N losses from various Conesus Lake sub-watersheds (Makarewicz et al. 2009) have led to significant reductions in metaphyton and macrophyte populations in the nearshore zone (Bosch et al. 2009a, 2009b) and to a reduction in fecal indicators in streams coincident with the cessation of manure application (Simon and Makarewicz 2009).

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