THE EFFECT OF RETENTION PONDS AND RIPARIAN VEGETATION ON NUTRIENT CONCENTRATIONS IN A GOLF COURSE STREAM IN MILLBROOK, NEW YORK

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Abstract. Golf course fairways adjacent to waterways are a source of nutrients in streams through runoff, which often carries excess fertilizer. Vegetated buffer strips have been proven to reduce nutrient concentrations in runoff, while mixed reviews have been gathered as to how ponds affect in-stream concentrations of nutrients. This study determined if two ponds on the Millbrook Golf and Tennis Club (MGTC) have an effect on stream nutrient concentrations. It also examined how nutrient concentrations change as runoff moves through the vegetated buffer strips. During the summer of 2011, longitudinal water samples were taken throughout the reach of the stream to examine how nutrient concentrations differ upstream and downstream of several ponds. Lysimeters were placed in three buffer strips perpendicular to the stream. Runoff was collected from each lysimeter after storm events and analyzed for nitrate, phosphorus and ammonia. Finally denitrification enzyme assays (DEA) were conducted in soil and sediment samples to determine levels of potential denitrification in buffer strips and ponds. Overall data collected from the lysimeters were highly variable, with no clear trends. Changes in NO_3-N never exceeded ±0.3 mg/L. DEA`s in the buffer strips also showed low potentials for denitrification (0.52-6.11 ng N/g soil/ hour). Alternatively, longitudinal sampling showed that in-stream nitrate concentrations decreased after traveling through the ponds (average decrease of 0.43 mg/L), with similar but smaller decreases in phosphorus. DEAs in pond sediments were significantly higher than buffer strips (60.48-220.35 ng N/g soil/ hour). The results suggest that denitrification and potentially assimilatory uptake by plants is occurring in the pond while the buffer strips seem to be inefficient nutrient reducers. Therefore, focus could be placed on pond management compared to the management of buffer strips.

INTRODUCTION

Eutrophication of lakes, streams and marine coastlines has been of increasing environmental concern. In the United States alone, 7028 fresh water bodies are listed by the Environmental Protection Agency (USEPA) 303(d) as impaired due to an excess of nutrients. Of these waterways, 491 contain some degree of eutrophication, with potentially many more (USEPA: Watershed Assessment, Tracking and Environmental Results 2011). Eutrophication can be loosely defined as the proliferation of photosynthetic organisms in a waterway (Rabalais et al. 2002). This buildup is usually caused by an excess concentration of nutrients from a multitude of potential sources. Despite the natural occurrence of eutrophication in freshwater as well as in deeper marine environments, basins and fjords (Rabalais et al. 2002), it is believed that hypoxic or anoxic conditions in shallow waters are often caused by anthropogenic actions (Kemp et al. 2005, Dodds et al. 2008). Anthropogenic eutrophication is caused by a long list of activities including the increased use of fertilizers on croplands, the increased production of manure from livestock, urban runoff and atmospheric deposition of nitrogen from the burning of fossil fuels (ESA 1998).

The increased amount of nutrients being released into freshwater systems has led to the eutrophication of marine coastlines and indirectly to the formation of dead zones. Dead zones in coastal oceans have spread exponentially since the 1960s, presumably due to anthropogenic sources of nutrients (Diaz et al. 2008). Dead zones form when the buildup of organic matter from eutrophication causes an increase in microbial respiration and therefore a decrease in dissolved oxygen (DO), which may lead to hypoxic or anoxic conditions (Rabalais et al. 2002). Dead zones can be found all over the world where excess nutrient delivery to waterways is prevalent (Dodds et al. 2008, Rabalais et al. 2002). In the US, at least 17% of estuarine water bodies are affected by hypoxia due to excess nutrients. These areas include some of the largest dead zones in the world, including northern parts of the Gulf of Mexico, the Chesapeake Bay and the Oregon coast (USEPA: Office of Research and Development 2010).

When implementing management practices to reduce nutrient runoff, geographic areas must be analyzed at the watershed level (Groffman et al. 2004, King et al. 2007). Within these watersheds, runoff can be split into 3 different classifications: urban, agricultural and forest (King et al. 2007). While row-crop agriculture is the largest source of nutrient runoff (USEPA: Nonpoint Source Control Branch 2005), urban ecosystems and the turf contained within them also contribute significantly (King et al. 2007). Runoff from urban ecosystems can originate from many different sources including lawns, parks, golf courses and industrial and commercial areas (King et al. 2007).

There are 15,890 golf courses and resorts in the US. Most of these are distributed in the eastern part of the country. States with the most golf courses include Florida, California, New York, Michigan and Texas (ngf.org). Most golf courses are intensively managed and drained in order to keep a well-maintained turf. These management techniques include considerable inputs of water and fertilizer, which leads many to presume that golf courses are a major source of nutrients in runoff (King et al. 2007). The amount of nutrients necessary to create satisfactory golf course turf is based on many factors including turf species and age, soil type, clipping removal, irrigation intensity, intensity of traffic and prevalent weeds and diseases (Thomas 2007). With all of these factors it is hard for turf managers to apply optimal amounts of fertilizer, usually resulting in applications that are larger than necessary. Based on surveys of US golf courses, it has been estimated that 101,096 tons of nitrogen were applied to 1,311,000 acres (154 lb N/acre or 28 kg N/ha); while 36,810 tons of phosphate were applied to 1,131,000 acres (65 lb P/acre or 12 kg P/ha) in 2006 alone (GCSAA 2009).

Recent scientific investigations show that nutrients are leaving golf courses through water runoff. A five-year study by King et al. (2007) on storm event runoff from a Texas golf course, found that more nutrients were leaving the golf course than were entering it. However, only phosphorus concentrations were large enough to exceed USEPA standards. A 20-year literature review by Baris et al. (2009) found similar results. They concluded that 95% (n=1683) of nitrate nitrogen and 86.5% (n=1429) of total phosphorus measurements exceeded the USEPA standards. Both studies suggest that nutrient runoff from golf courses, most notably phosphorus, can be of concern especially during storm events.

Many studies have examined methods to reduce the amount of nutrients entering waterways from golf courses. The use of grass buffer strips is the most notable and proven technique for nutrient reduction (USGA 2007, Moss et al. 2005). Other techniques, such as the use of retention ponds, have mixed reviews. Mallen et al. 2002 found that nutrient concentrations were greater at the pond outflow compared to the inflow. Davis and Lydy (2002) as well as Mallin and Wheeler (2000) found different results. Both studies concluded that retention ponds could significantly reduce nutrient concentrations of streams. Overall, it seems unclear as to whether or not retention ponds are an effective source of nutrient reduction.

The objectives of this study are two-fold. The first objective aims to determine if two retention ponds have an effect on stream nutrient concentrations. The second aims to determine the fate of nutrients in runoff as it travels through grass buffer strips.

METHODS AND MATERIALS

Study Site

The Millbrook Golf and Tennis Club (MGTC) (41° 46' 27.44" N 73°41' 32.57" W) is an 18-hole golf course in the village of Millbrook in Dutchess County, New York. The 22-ha course is adjacent to SR 343 and Church St. on the south side of Millbrook. Located in the Hudson River watershed, the course has one small stream that runs from east to west across the golf course property. Before entering the golf course, the stream weaves through a small wood before running through a culvert beneath the Church St. and SR 343 intersection. After leaving the golf course property, the stream meets with Wappinger Creek, 6 km downstream, and finally the Hudson River. The stream has a width of 1-2 meters for most of its reach on the golf course property. Vegetated buffer strips of varying lengths are located adjacent to the stream for almost the entire reach. The stream transects the heart of the golf course, with many fertilized fairways located immediately to the edge of the buffer strip or stream. Of the 600 meters of stream all but 180 m on the north side and 80 m on the south side are adjacent to a fairway. The elevation drops 20 meters over the span of the stream on the course property, resulting in a downward slope of about 3%.

Two retention ponds, with a minimal section of stream between them, are located on the west side of the golf course (at approximately 400 m). The eastern pond is twice the area of the western pond (approximately 0.072 ha and 0.036 ha respectively) and was the primary pond analyzed in this study.

Soil on the MGTC property is dominated by Dutchess-Cardigan complex (DwC) and to a smaller degree Nassau-Cardigan (NwD) complex. DwC are characterized as well drained and likely to transmit water at a rate of 1.54 to 5.03 cm/hr. NwD drain less efficiently and transmit water at a lower rate, up to 0.15 cm/hr. NwD soils are located in areas of high slope (15-20 percent) while DwC is located in areas with a smaller slope (5-16%. NwD soils are located in one pocket on the south side of the stream in the middle of the property. This pocket encompasses a steep hill with a pocket of woods at the crest of the hill (Table 1).

Fertilizers were applied early in the growing season (May 5^{th}, 2011) on the fairways. Approximately 2000 lbs of Duration CR (24-0-12), sulfur coated urea and sulfate of potash (particle size of SGN 190) fertilizer was applied to 10 acres of fairways with a Lely tow behind spreader. No phosphorus was applied.

Longitudinal Sampling

In order to determine the nutrient concentrations in different reaches of the stream, longitudinal sampling was conducted at various times throughout the summer. Two preliminary sets of water samples were collected at 12 different sites along the reach of the stream at the beginning of the summer of 2011 after fertilizer was applied (Figure 2). One sample set was collected at base flow conditions (June 7 2011) while the other was collected at the end of a storm event (June 9 2011). After this preliminary sampling, two more baseline collections were made (July 5 2011 and July 26 2011) at five sites (Figure 3). Water samples were taken to the Cary Institute lab and measured for ammonium, nitrate and phosphorus as well as magnesium, chloride, calcium, potassium, sodium and sulfate.

Lysimeters

Vegetated buffer strips along the stream were analyzed for their ability to remove nutrients. In this study, lysimeters, consisting of PVC pipe (2.54 cm diameter) with holes in the bottom, were placed approximately 18-25 cm into the ground to collect water moving from fairways to the stream channel. Caps were placed over each lysimeter to prevent rainwater from mixing with the groundwater. Three vegetated buffer strips, adjacent to fertilized fairways, were chosen on the golf course property. The three sample locations were labeled by orientation: west, middle and east (figure 4). Five lysimeters were placed at two sites (west and middle) and six at the third (east). Lysimeters were placed in the vegetated buffer strip in a line perpendicular to the stream in equal intervals. This allowed for groundwater at different positions in the buffer strip to be measured for nitrate, ammonia and phosphate. Water for sampling was removed using a syringe and tube. Samples were collected after rain events (July 9, 26 and August 10 of 2011) in order to ensure that there would be enough of the sample for lab analysis. After filtering sediments from samples, they were chilled until they could be analyzed for nitrogen, phosphorus and ammonia concentrations.

Denitrification Enzyme Assays

Denitrification enzyme assays (DEA) were conducted on both buffer strip soil cores and pond sediments to determine the rate of denitrification in these locations. All DEA samples were collected on August 9 2011. Four pond sediment samples were removed from the primary pond using a multi-stage sludge and sediment sampler. Three soil cores were removed from each of the three-lysimeter/buffer strip locations using a manual soil corer (7 cm diameter). Soil cores and sediments were then measured for their rate of denitrification (ng N/g soil/hour) using the acetylene inhibition method as described by Groffman et al (1999). Soil cores were taken from a depth of 17-20 cm. The bottom 5 cm of soil (5 g of fresh soil) was removed and placed into 125-mL Erlenmeyer flasks containing 10-mL of DEA media (KNO_3, glucose and Chloramphenicol). The flasks were capped with rubber serum stoppers. Anaerobic conditions were created by a series of evacuations and flushings with N_2. Next acetylene (5 mL) was added to each flask, which was immediately placed on a shaker at 125 rpm. Samples (9 mL) were taken at both the 30 minute mark as well as the 90 minute mark. The shaker was not on for the last 60 minutes of the analysis.

RESULTS

Longitudinal sampling

The two preliminary sample sets both had 12 samples, with each one set separately being collected after a rain event and the other during base line conditions. The longitudinal samplings show multi-reach water sample analysis for nitrogen, ammonia and phosphorus. Base flow sampling showed nitrate concentrations ranging between 0.48 - 1.19 mg/L. The highest concentration was found where the stream first entered the golf course property from upslope properties. Concentrations stayed relatively consistent until the stream met the first pond. Sampling at the outlet of the second pond showed a 2/3 decrease (from 0.96 mg/L to 0.39 mg/L) in nitrate concentrations compared to sampling at the pond inlet. Phosphorus concentrations showed a very similar pattern (decrease from 0.011 mg/L to 0.002 mg/L). Samples collected downstream from the ponds were consistently lower in nitrate (0.39 mg/L – 0.48 mg/L) (Figure 5).

Storm flow sampling was similar to base line flow sampling. The decrease in concentrations was less dramatic than during the base line, but a decrease was still evident. The largest nitrate concentration was again located where the stream entered the golf course property (0.91 mg/L) while the lowest was where the stream left the golf course property (0.38 mg/L). The decrease in nitrate from the beginning to the end of the pond was 0.25 mg/L. Phosphorus again decreased in similar fashion as the stream flowed through the pond (0.0050 mg/L)(Figure 6).

After preliminary sampling two smaller sample sets were gathered during base flow conditions and analyzed for their concentrations of the same nutrients. Each sample set included five samples located in equal intervals throughout the reach of the stream. The results of these sample sets had similar values and trends as the preliminary samples (Figures 7 and 8). Initial concentrations of nitrate where the stream meets the golf course property contained approximately 0.9 mg/L (0.99 and 0.90 mg/L). Both data sets also showed a decrease in nitrate (Δ 0.64 and 0.20) as the stream flowed through the pond. Phosphorus concentrations decreased as stream water passed through the pond in one of the base line sets, while drastically increasing in the other from below measurability to 0.32 mg/L, the highest phosphate concentration of all the longitudinal sampling.

Lysimeter Sampling

Three sets of water samples were collected from each of the three sets of lysimeters. Water samples were collected after a rain event to ensure a sufficient amount of water for sampling. Lysimeter sample nutrient concentrations were highly variable with no clear patterns or trends in each buffer strip. Instead, the data are best examined for the change in nutrient concentrations from the beginning of the buffer strip (lysimeter closest to the golf course) to the end (lysimeter closest to the stream). The west location had an increase in nitrate concentrations twice with a large decrease in the final sample set (Δ 0.28 mg/L). The middle lysimeter location had one increase (0.2 mg/L) and two decreases in nitrate concentrations (0.08 mg/L and 0.24 mg/L) as waters percolated through the buffer strip. The east lysimeter location also had one increase (0.07 mg/L) and two decreases (0.18 and 0.29 mg/L) (Figure 9).

DEA

Rates of denitrification (ng N/ g soil/hour) were measured in both pond sediments from the primary pond as well as from soil cores from each buffer strip (Figure 10). Potential denitrification rates in four pond sediment samples were relatively high with a range of 60.48 – 220.35. Three sediment cores were collected from each buffer strip. The west location had potential DEA values of 1.47, 2.99 and 6.11. The middle location had values of 3.27, 2.00 and 2.03, and the east location had values of 1.17, 0.52 and 1.35 (Figure 10).

DISCUSSION

Ponds

In all longitudinal sampling scenarios there was a decrease in nitrate concentrations as the stream flowed through the pond. These differences varied based on the sample set. The results of the DEA`s show that there are potentially high rates of denitrification occurring in the pond sediments. Denitrification is among various potential mechanisms that might remove nitrate from stream waters passing through these ponds. The data suggest that the pond is having an effect on nitrate concentrations, most likely through denitrification in pond sediments. Despite the lack of concrete proof of a connection, denitrification and/or assimilatory uptake seem to be the best explanation(s) for the decrease in nitrogen. The data suggest that denitrification is a strong candidate as the source of nitrate removal. Alternatively, the data also suggests the potential for assimilatory uptake as a potential source of nitrate removal. Decreases in phosphorus in longitudinal sampling suggest that assimilatory uptake may be an alternative cause for nitrate reduction. In all but one collection period, phosphorus concentrations decreased as the stream traveled through the pond (baseline 2, Figure 8); however, most phosphorus decreases were relatively small. Further research would be needed in order to determine the exact source of nitrate removal; however, it is important to conclude that the ponds are having an effect on nitrate concentrations.

Buffer Strips

The data collected from the buffer strips were highly variable with no clear trends. It was initially hypothesized that there would be a gradual decrease in nitrate concentrations in each buffer strip as sampling moved closer to the stream; however, this wasn't the case in almost all of the sample sets. Some sets had spikes or dips in the middle of the buffer strips that were higher or lower than the samples near the stream. . When examining the overall effect the buffer strip is having on nutrient concentrations, the changes were also highly variable. Of the 9 sets of samples taken (3 from each buffer strip) there were four overall increases in nitrate concentrations and five overall decreases in nitrate concentrations from the fairway to the stream. This suggests that the buffer strips are not acting efficiently to remove nitrogen from runoff.

There are a few potential explanations for the lack of a decrease in nitrate as sampling got closer to the stream. First, it is possible that there was not enough nitrate present for denitrification to occur. The lack of nitrate could cause denitrifying microbes to go dormant, this would explain the relatively consistent nitrate concentrations throughout the buffer strips. Another explanation could be the lack of anoxic conditions in the soil of the buffer strips. This again would cause any denitrifying microbes to become dormant; however, this seems less likely considering the relatively low levels nitrate concentrations.

CONCLUSIONS

This study shows that the nutrient concentrations in the runoff of fertilized golf courses and other lands are effectively reduced when the runoff waters pass through small ponds. Creation and maintenance of small ponds should be encouraged as part of golf course management practices.

ACKNOWLEDGMENTS

We thank lab technicians Denise Schmidt, Linda Grapel and Milada Vomela for their help with the use of the Analytical lab facilities. A special thanks also to Peter Groffman as well as Lisa Martel and Robin Schmidt for their help with conducting DEA assays.

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APPENDIX

TABLE 1. Soil mapping units and percents of total area located in the study area at the MGTC.

Soil mapping unit	Dominant texture	Extent of unit (ha)	Percent of total area
Dutchess-Cardigan complex	Loamy till	17.6	76.2%
Hoosic gravelly loam, near level	Sandy and gravelly	0.6	2.5%
Hoosic gravelly loam, hilly	Sandy and gravelly	0.1	0.4%
Nassau-Cardigan complex	Channery loamy till	4.8	20.8%

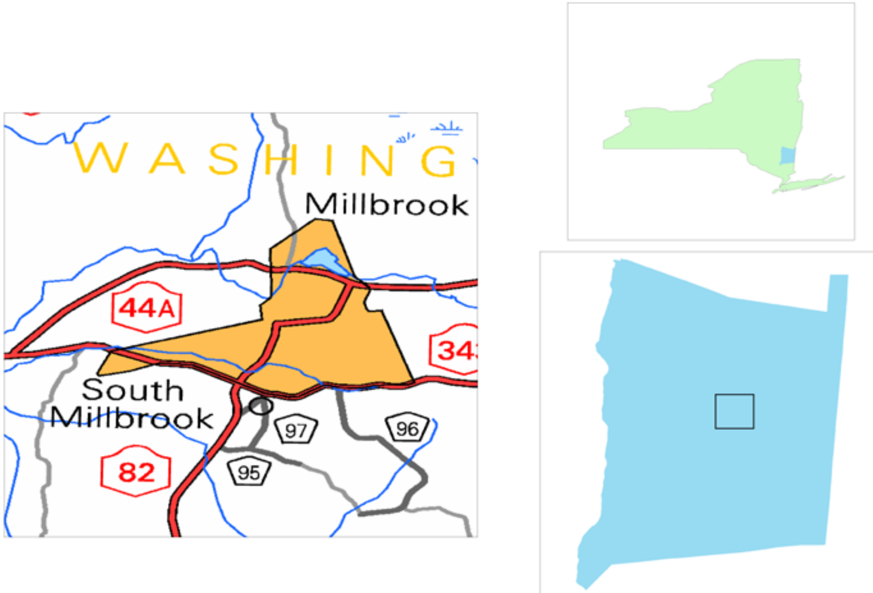

FIGURE 1. Location of the Millbrook Golf and Tennis Club in Dutchess County, south of Millbrook, NY.

FIGURE 2. Locations of 12 preliminary samples sites. Samples were collected early in the summer of 2011 and analyzed for phosphorus, ammonia and nitrate.

FIGURE 3. Location of 5 baseline samples collected throughout the summer of 2011. Samples were analyzed for phosphorus, ammonia, and nitrate.

FIGURE 4. Location of three lysimeter sample sites. Each location had either 5-6 lysimeters placed in the buffer strips.

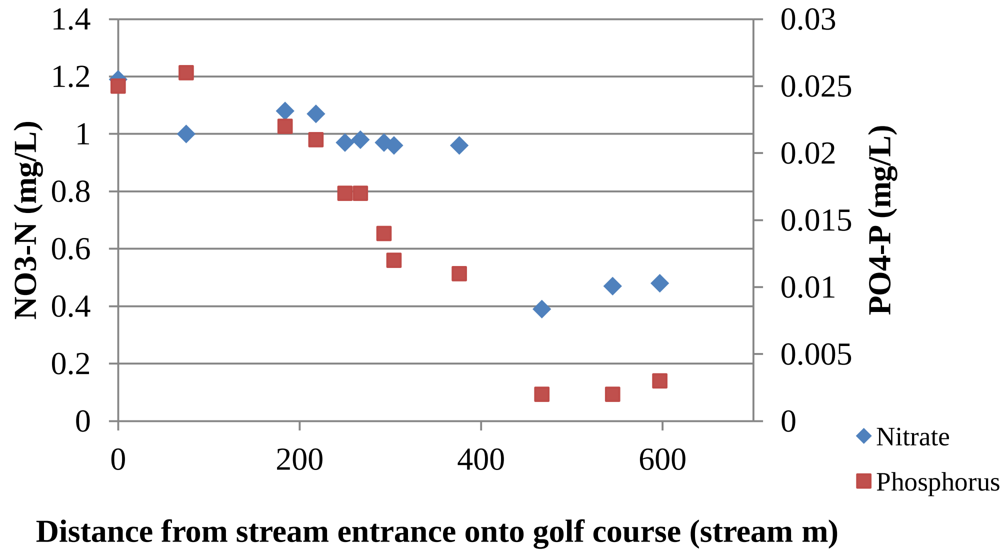

FIGURE 5. Longitudinal sampling concentrations for preliminary baseline data set.

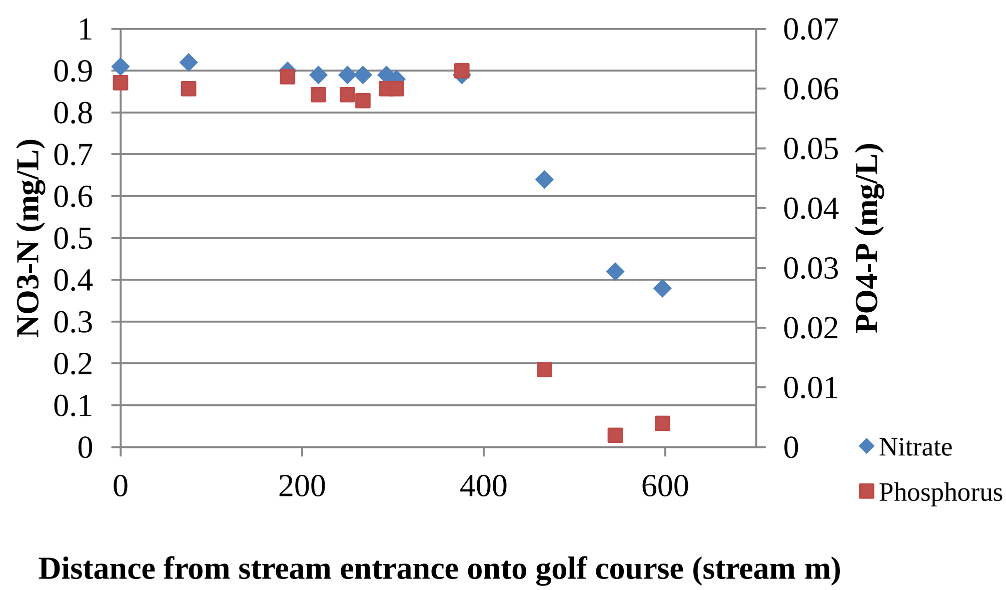

FIGURE 6. Longitudinal sampling concentrations for preliminary storm event data set.

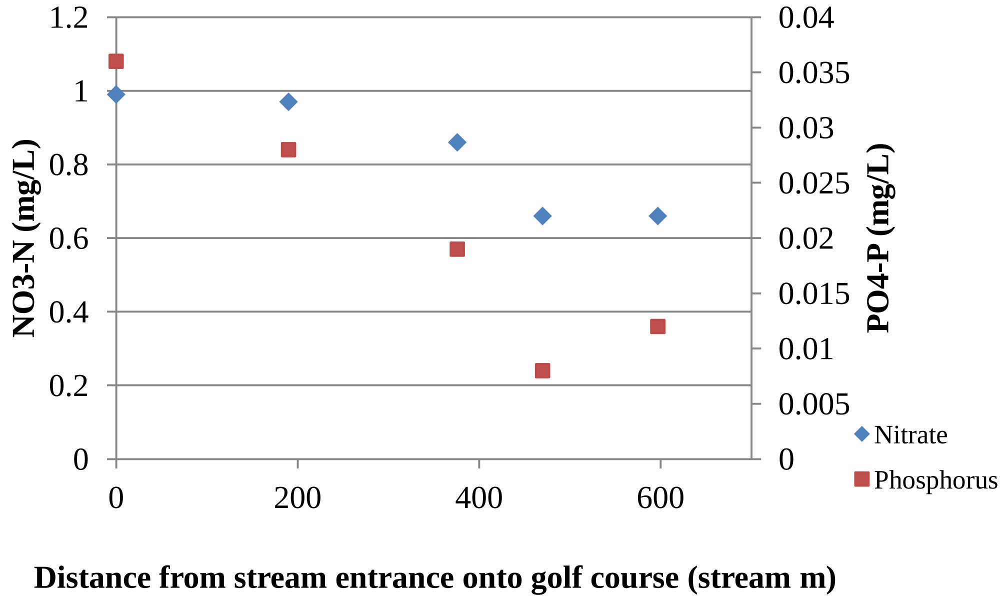

FIGURE 7. Ratio of nitrate and phosphorus concentrations to chloride for baseline longitudinal sample set 1.

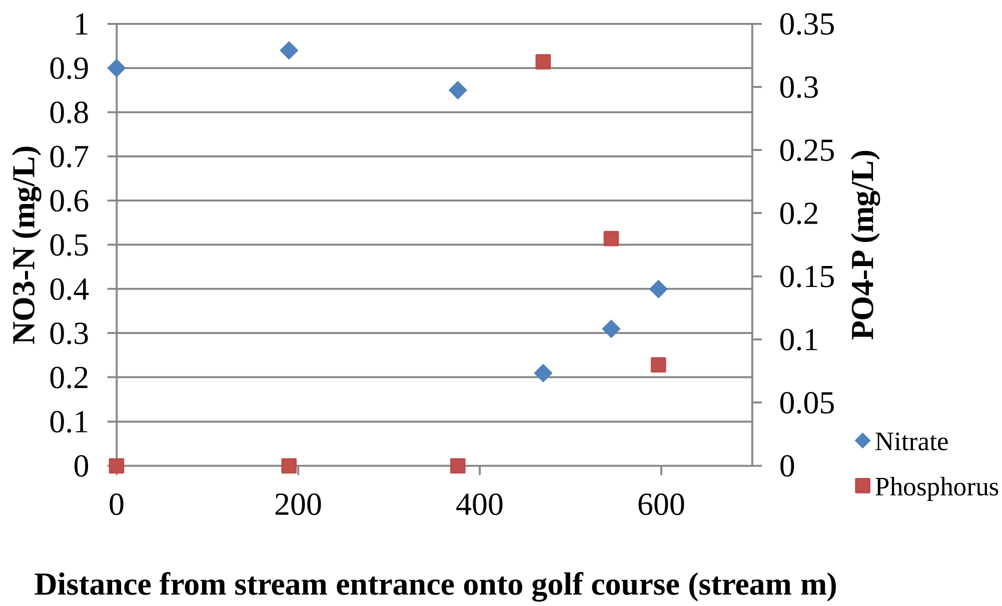

FIGURE 8. Ratio of nitrate and phosphorus concentrations to chloride for baseline longitudinal sample set 2.

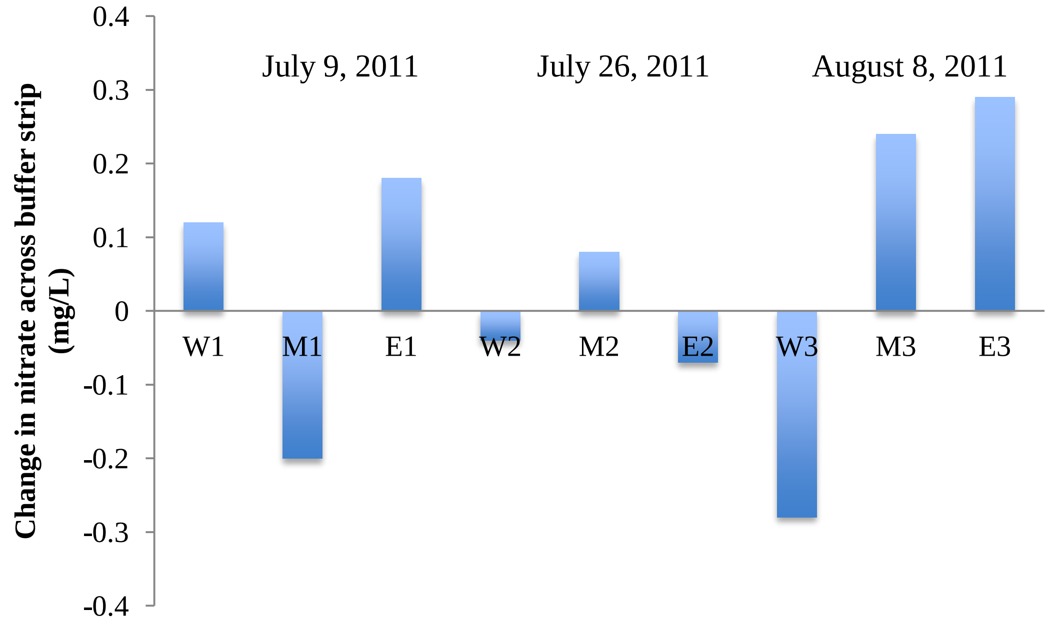

FIGURE 9. Change in nitrate across buffer strips collected on three different dates. Positive changes indicate a decrease in nitrate. Negative changes indicate an increase in nitrate.

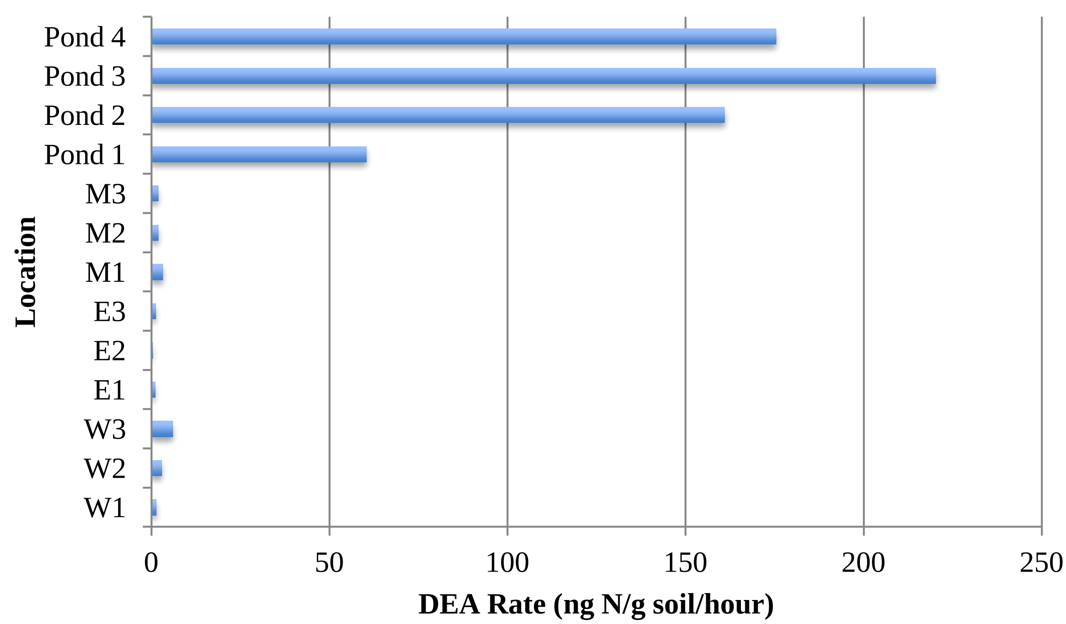

FIGURE 10. DEA rates from various locations in soil cores from vegetated buffer strips and sediment cores from ponds.