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Short communication

Controlling nitrogen release from farm ponds with a subsurface outflow device: Implications for improved water quality in receiving streams

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ABSTRACT

The retention of nutrients in farm ponds has many potential benefits, including reduction of nitrogen and phosphorus (promoters of eutrophication) in receiving streams. The aim of this study was to evaluate the efficacy of a commercial subsurface pond outflow control device (Pond Management System^{TM}) on nutrient retention in farm ponds. Four ponds of similar size and water chemistry in the upper Tar River basin of North Carolina, USA were studied; three were equipped with the pond outflow control device and one was retained without a device (normal surface outflow) that served as a reference site. Water samples were collected monthly from each pond at 0.3 m intervals from the surface to 2.1 m at a fixed station adjacent to the pond standpipe and from the pond outflow pipe from March to October 2005. The water samples were analyzed for total Kjeldahl nitrogen (N), total phosphorus (P), chlorophyll *a*, and a suite of other physicochemical variables. In ponds with the subsurface outflow device, the mean N concentrations in the outflow were substantially less (6.2–20.7%) than concentrations at the pond surface. Concentrations of N in the outflow were similar to N concentrations at intermediate pond depths (0.9–1.5 m), the depth of the outflow devices, indicating water was drawn from these depths and that N was being retained in the surface layers of the pond. Also, mean water temperatures were 1.1–1.9 °C cooler at intermediate depths compared to the surface, suggesting potential application of the outflow device for minimizing warm water outflows to receiving streams. These results provide evidence that under these conditions a subsurface pond outflow device can reduce nutrient release to receiving streams, thereby increasing overall stream water quality.

1. Introduction

Agriculture, urban activities, and atmospheric deposition are all major sources of nitrogen (N) and phosphorus (P) to aquatic ecosystems (Carpenter et al., 1998). Recent agricultural research, policy, and regulation have focused on the development and implementation of best management practices (BMPs) such as controlled drainage, riparian buffers and land

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and livestock waste management to limit nutrient influx into surface waters (Borin et al., 2005; Dukes and Evans, 2006; Gassman et al., 2006). Farm ponds are surface water bodies in agricultural settings that serve as an important source of water for livestock, irrigation, fire protection, recreational fishing and even fish production. Because of the proximity to the many agricultural activities that use or generate excess nutrients, farm ponds are often among the first aquatic systems to retain, sequester, and cycle nutrients like N and P.

Many studies have documented the process of eutrophication, the over-enrichment of water bodies including lakes and farm ponds with N and P (Carpenter et al., 1998; Smith, 1998), yet none, to our knowledge, have evaluated the retention of nutrients in farm ponds as a potential BMP to limit nutrient release to receiving streams. When most farm ponds are built, the outlet is constructed in such a way that only the upper surface layers of water are discharged (USDA, 1997). This surface discharge allows the nutrient and phytoplankton rich surface layers to be released to the receiving stream, thereby contributing to downstream eutrophication.

The aim of this study was to investigate a simple solution, the installation of a commercially available subsurface outflow device, to retain nutrients within farm ponds and to assess its potential benefits to water quality in the receiving streams.

2. Materials and methods

The subsurface outflow control device called the Pond Management System™ (E. W. Ventures, Raleigh, NC, USA; United States Patent No. 6,142,705) was evaluated in this study. The device is constructed from heavy gauge aluminum pipe, can be custom designed to fit over the diameter of any existing pond standpipe (e.g., outflow structure), and can be tailored to a length that achieves a subsurface outflow in a pond of any depth. Outflow devices used in this study had an exterior diameter of 30.5 cm and were 1.5 m long (Fig. 1). The top had an adjustable air relief valve secured to a heavy gauge aluminum plate, which was welded to the pipe. Aluminum stabilizers were welded to the inside of the pipe to keep the device aligned and secure on the pond standpipe. A set of crossbars inside the pipe 30.5 cm from the top allowed the device to rest on the pond standpipe without flow restriction, while preventing debris and other obstructions from clogging the standpipe opening. The device operates by drawing water through the bottom of the pipe. The effective subsurface depth from which water was drawn in this study was 1.2 m below the pond surface. When the valve at the top is in the open position (as was the situation during this study), the device maintains the water level in the pond at the height of the standpipe. When the valve is in the closed position, a siphon is created and the pond can be drained to the depth of the bottom of the device.

Four ponds of similar size (2.8–6.5 ha) in the upper Tar River basin of North Carolina, USA were selected for study. Ponds 2–4 were equipped with the pond outflow control device and Pond 1 was retained without a device (normal surface outflow) that served as a reference site. The maximum water depth of the four ponds ranged from 3 to 5 m.

Water samples (500 ml) were collected monthly by boat from each pond at 0.3 m intervals from the surface to 2.1 m with a water sampler at a fixed station adjacent to the pond standpipe (within 4–6 m) and by hand from the pond outflow pipe from March to October 2005. Temperature, dissolved oxygen (DO), pH, and conductivity were measured monthly at

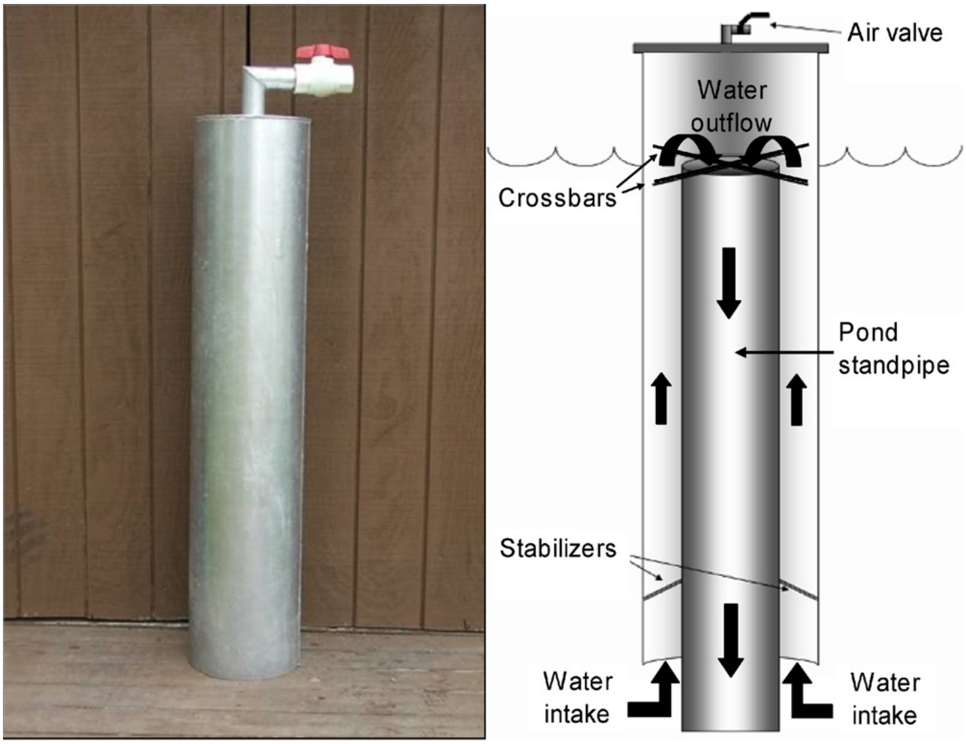

Fig. 1 – Photograph (left) and schematic diagram (right) of the Pond Management System™ outflow control device.

each station and water depth with a calibrated multiprobe meter (YSI Model 556 MPS, Yellow Springs Instruments, Yellow Springs, OH, USA). Secchi depth measurements of water clarity were also taken monthly at each station. All water samples were collected in 500-ml translucent or amber [chlorophyll *a* (Chl *a*) only] Nalgene® bottles and transported on ice to the laboratory within 6 h of collection for processing. Water samples for N and P analysis were decanted into 20-ml glass scintillation vials, preserved to $pH < 2$ with concentrated HCl, and stored at 4 °C until analysis. Water samples were analyzed within 24 h of collection for alkalinity and hardness by standard titration methods (APHA, 1995). Total Kjeldahl nitrogen and total phosphorus were analyzed with standard methods (APHA, 1995) by the Analytical Service Laboratory in the Department of Soil Science at North Carolina State University. Samples were analyzed for Chl *a* with standard methods (APHA, 1995) by the Center for Applied Aquatic Ecology at North Carolina State University. A rigorous quality assurance program demonstrated the validity of the analytical chemistry data generated in this study. Of the water samples analyzed for N and P, 20% were analyzed in duplicate and analyses included certified reference materials from Spex CertiPrep, Inc. (Metuchen, NJ, USA). These analyses yielded concentrations of N and P within the certified concentration range in all determinations.

For the purpose of this report, only the N data are presented in detail. The data for all other variables measured are presented in summary form. To evaluate the efficacy of the device for retaining N in surface water and discharging subsurface water from the depth of the device (1.2 m), the monthly measured N concentrations from each pond were grouped and averaged into three strata: surface (0.0–0.3 m), intermediate (0.9–1.5 m), and deep (1.8–2.1 m). The average N concentrations in the surface and intermediate strata were compared to the measured N concentration from the outflow pipe. From these data, the overall percent decrease of N in the outflow relative to the surface could be determined, representing the amount of N retained in the ponds (hereafter referred to as N retained). In addition, the percent decrease of N in the outflow of experimental ponds was plotted against the overall mean N concentration to assess any potential correlation with relative pond productivity. Average temperature at the pond surface and the intermediate depth (1.2 m) was calculated from March to October and plotted to detect any temperature change.

3. Results

The overall mean physicochemical characteristics of water measured monthly from March to October at the four ponds were similar except for Pond 1, which was slightly more productive than the others, as indicated by higher Chl *a*, N and P concentrations and shallower secchi depth (Table 1).

The concentrations of N measured monthly in each pond showed that the pond outflow device effectively controlled the discharge depth of water from the ponds. The N concentration measured in water from the outflow pipe was similar to the N concentration at the depth from which the outflow water was drawn in each of the four ponds (Fig. 2). Pond 1, which had no

Table 1 – Mean and range (in parentheses) of physicochemical characteristics of water measured monthly at all depths from the four test ponds from March to October 2005.

Pond	Temperature (°C)	Dissolved oxygen (mg/l)	pH	Conductivity (μS/cm)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	Total Kjeldahl nitrogen (mg/l)	Total phosphorus (mg/l)	Chlorophyll *a* (μg/l)	Secchi depth (cm)
1	22.9 (10.2–30.7)	8.2 (4.0–15.5)	7.7 (6.5–8.9)	62 (33–90)	23 (20–28)	19 (16–26)	2.1 (1.4–3.1)	0.17 (0.1–0.27)	54 (42–79)	56 (36–69)
2	23.1 (10.0–31.2)	10.0 (7.3–12.3)	8.2 (7.0–9.2)	64 (35–96)	20 (14–22)	18 (12–22)	1.4 (0.7–1.7)	0.04 (0.01–0.08)	28 (8–43)	104 (91–127)
3	23.1 (10.0–31.4)	8.9 (5.5–11.9)	7.6 (6.9–8.6)	54 (29–82)	20 (14–32)	22 (16–42)	1.8 (1.4–2.3)	0.06 (0.03–0.10)	30 (16–42)	69 (51–84)
4	23.5 (10.2–31.4)	10.0 (5.8–12.2)	7.4 (6.3–9.1)	49 (27–87)	18 (12–22)	20 (14–24)	1.3 (0.7–1.7)	0.03 (0.01–0.07)	31 (8–78)	102 (61–152)

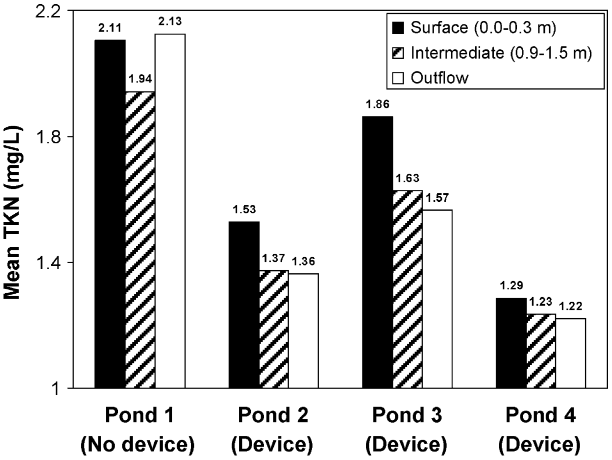

Fig. 2 – Mean total Kjeldahl nitrogen (TKN) concentrations in the surface, intermediate and outflow pipe waters from the four test ponds during March to October 2005.

device installed and was a surface outflow discharge, had comparable N concentrations between the surface stratum (2.11 mg/l) and the water from the outflow pipe (2.13 mg/l), indicating that water from the surface stratum was being discharged. In the three ponds (Ponds 2–4) with the subsurface outflow device installed (water was discharged from an intermediate depth), the measured N concentrations in the intermediate stratum were nearly identical to those measured in water sampled from the outflow pipe, whereas the surface concentrations were always greater than those of the outflow.

The monthly N concentration measurements also showed that the use of the pond outflow control device resulted in substantial retention of N within the test ponds. The subsurface water discharged through the outflow pipes of the three ponds with the device installed (Ponds 2–4) had about 6–21% lower N concentration during March through July, the period of greatest primary production in the ponds, than water in the surface stratum of the water column (Fig. 3A). The same relative trend was observed for the entire eight month study period (March–October), in which N concentration in the outflow was reduced about 5–16% (Fig. 3B). In contrast, Pond 1, which had no outflow control device installed, showed no difference in N concentration between the outflow and the surface stratum of the water column (i.e., 0% retained) throughout the study period.

By effectively controlling the discharge depth of water from the ponds (determined by device depth; confirmed by N measurements), the pond outflow control device may also have potential for limiting release of high temperature surface waters to receiving streams. The mean water temperatures were 1.1–1.9 °C cooler at intermediate depths compared to the surface (Fig. 4).

4. Discussion

The Pond Management System^{TM} subsurface outflow device effectively controlled the discharge depth of water from the test ponds in our study, thereby reducing the release of N in the outflow water to the receiving stream. Overall, we found that the amount of N released was reduced up to 21% in ponds

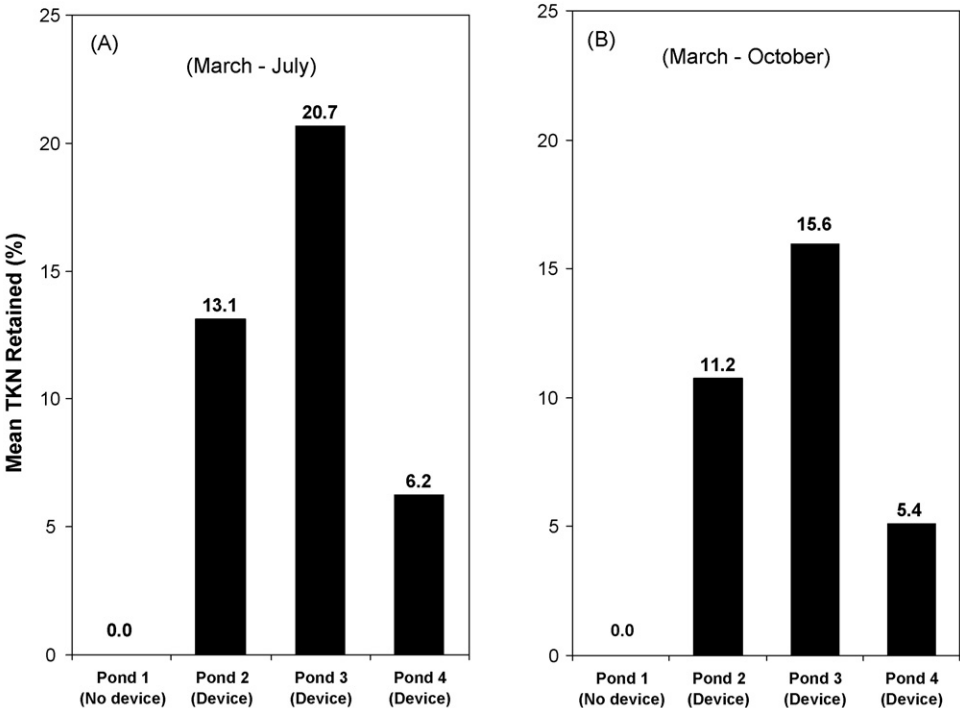

Fig. 3 – Mean percentage of total Kjeldahl nitrogen (TKN) concentration retained in the four test ponds during March to July (A), the period of greatest pond productivity, and March to October (B) 2005, the entire study period. Retention of TKN was based on the difference of measured concentrations at the surface relative to concentrations measured in the outflow.

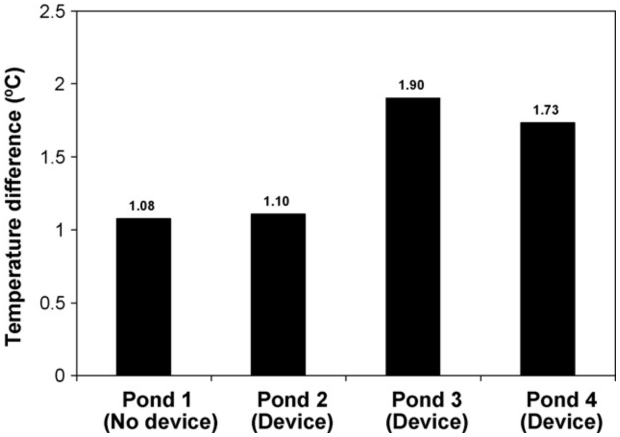

Fig. 4 – Mean temperature difference between the surface and 1.2 m depth in the four test ponds during March to October 2005.

with the device, even in the relatively nutrient poor systems studied here. The proportion of N retained may be even greater in more productive systems. For example, when we examined the relation between the percentage reduction in outflow N concentration and the mean N concentration across all depth strata (an indicator of overall pond productivity) in the ponds with the devices installed, there was a strong positive correlation ($R^2 = 0.99$, $P < 0.01$), suggesting that ponds with greater productivity could potentially retain greater proportions of N. This is likely due to an increased difference between surface and intermediate-depth N concentrations resulting from higher overall productivity. Because phytoplankton tend to concentrate in the upper meter of the water column (Lopes et al., 2005) and as greater concentrations of nutrients are present in the pond, the trend of increased N in the upper stratum becomes more dominant. Consequently, as the photic zone becomes shallower, greater nutrient stratification is likely.

Our finding that N concentration in the outflow was nearly identical to the intermediate-depth N concentration from ponds with devices installed was expected because the device was drawing water from the intermediate-depth range (0.9–1.5 m). It is important to note, however, that while the outflow N concentration was the same as the surface N concentration for Pond 1 (a typical surface outflow reference pond), the intermediate-depth N concentration was less than the surface, verifying the decreased N concentration in the intermediate stratum and suggesting that had there been a subsurface outflow device on Pond 1, a reduction in N released to the receiving stream would have occurred.

As expected, all four ponds exhibited a difference in mean temperature between the surface and 1.2 m (Fig. 4). The lower outflow temperatures resulting from intermediate depth discharge by the device could be very important in keeping warmer surface water in ponds from being discharged to receiving streams. As Strecker et al. (2004) demonstrated, shallow cold-water ecosystems can be destabilized by warm water, changing plankton dynamics and reducing water quality. This type of temperature difference would be even greater in systems with deeper withdrawal, particularly in larger ponds or lakes where mixing is less frequent, causing increased water stratification and warmer surface water. Thus, the device has potential for use in pond and lake settings where maintaining the integrity of cool or cold-water receiving streams is important for downstream biota.

The retention of nutrients in farm ponds has many potential benefits, including reduction of N and P (promoters of eutrophication) in receiving streams. Additionally, ponds managed for fishing, like those studied here, are sometimes fertilized to increase overall pond productivity and fish carrying capacity (Rice et al., 1999). The increased retention of nutrients in these types of systems by the subsurface outflow device would reduce the cost and effort of pond fertilization. Conversely, the retention of nutrients in farm ponds by these types of devices may contribute to increased eutrophication within farm ponds over time, depending on the rates of nutrient input and removal. This could potentially increase the risk of detrimental effects within the ponds such as low dissolved oxygen concentrations, fish kills, and harmful algal blooms (Carpenter et al., 1998; Smith, 1998). Such problems can be mitigated by controlling nutrient inputs to the pond or increasing export of nutrients in surface water through uses such as irrigation of crops, where the spraying of nutrient rich water on plants would be a benefit (e.g., decreased fertilizer application).

5. Conclusion

The Pond Management System^{TM} was originally designed and marketed to provide pond managers and farmers with drawdown capability for dam maintenance and aquatic weed control, protection of the outflow pipe from clogging by trash and other debris, animal (e.g., beaver *Castor canadensis*, muskrat *Ondatra zibethicus*) control and other pond management needs. Our assessment of this device for retaining nutrients in farm ponds has shown that it should represent a potential BMP for improving water quality (e.g., decreasing nutrients and high temperature water) in receiving streams. Other types and designs of subsurface outflow control devices (USDA, 1997) should yield similar benefits to water quality; however, because of the additional capabilities (e.g., drawdown, anti-clogging, animal damage control) of the subsurface outflow device tested in this study, it should provide a simple, yet effective contribution to both pond and nutrient management. Additional research is needed with subsurface outflow devices to assess their long-term within-system function and effects on receiving stream water quality.

REFERENCES

APHA, 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC.

Borin, M., Vianello, M., Morari, F., Zanin, G., 2005. Effectiveness of buffer strips in removing pollutants in runoff from a cultivated field in North-East Italy. Agric. Ecosyst. Environ. 105, 101–114.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smithf, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Appl. 8, 559–568.

Dukes, M.D., Evans, R.O., 2006. Impact of agriculture on water quality in the North Carolina middle coastal plain. J. Irrig. Drain. E-ASCE. 132, 250–262.

Gassman, P.W., Osei, E., Saleh, A., Rodecap, J., Norvell, S., Williams, J., 2006. Alternative practices for sediment and nutrient loss control on livestock farms in northeast Iowa. Agric. Ecosyst. Environ. 117, 135–144.

Lopes, M., Bicudo, C., Ferragut, M., 2005. Short term spatial and temporal variation of phytoplankton in a shallow tropical oligotrophic reservoir, southeast Brazil. Hydrobiologia 542, 235–247.

Rice, J.A., Noble, R.L., Curry, R.L. (Eds.), 1999. Pond Management Guide. Publ. No. AG-424. North Carolina Cooperative Extension Service, North Carolina State University, Raleigh, NC, USA, p. 29.

Smith, V.H., 1998. Cultural eutrophication of inland, estuarine, and coastal waters. In: Pace, M.L., Groffman, P.M. (Eds.), Successes, Limitations, and Frontiers in Ecosystem Science. Springer-Verlag, New York, NY, USA.

Strecker, A.L., Cobb, T.P., Vinebrooke, R.D., 2004. Effects of experimental greenhouse warming on phytoplankton and zooplankton communities in fishless alpine ponds. Limnol. Oceanogr. 49, 1182–1190.

USDA, 1997. Ponds—Planning, Design, Construction. United States Department of Agriculture, Natural Resources Conservation Service, Agriculture Handbook No. 590, Washington, DC, USA.