Assessing the Soil Nitrate-Nitrogen and Extractable Soil Phosphorus Status of the Spring Lake Watershed

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ABSTRACT

Nitrate-nitrogen and phosphate fertilizers are used worldwide including the Midwestern United States in agricultural operations to increase crop yields. Substantial amounts of fertilizer nitrates and phosphates, both solid phase and solution phase, may be lost from the soil to nearby aquatic systems. Nitrates and phosphates may also contaminate lakes and rivers from animal wastes or native N and P bearing materials. Increased nitrogen and phosphorus in aquatic systems may exacerbate eutrophication. Eutrophication is currently negatively impacting Spring Lake in McDonough County, Illinois. This lake is a major drinking water source for the city of Macomb, Illinois and the surrounding region. Systematic soil samples were taken from the Spring Lake watershed in areas affected by soil erosion to determine the soluble nitrate and phosphate content of the soil. The surface (0 - 5 cm) soil nitrate-nitrogen content was found to average 12.9 mg NO_3^--N/kg soil across all sites; while the extractable soil phosphorus was found to average 353 mg extractable P/kg soil across all sites. Both values indicate that soil erosion and runoff from these sites could negatively impact Spring Lake through increased N and P loading of the water of Spring Lake. The N and P loading of natural water bodies frequently increases eutrophication to hypereutrophic levels. The principal effect of increased eutrophication of Spring Lake is to decrease the potential of the lake as a bio-habitat and to reduce the use of the lake as a drinking water source.

INTRODUCTION

Spring Lake is located in McDonough County, Illinois, and is the main source of drinking water for the Macomb, Colchester, Bardolph, and Tennessee communities in the western Illinois region (Moorhouse, 2007). Spring Lake was built in 1927 with a surface area of approximately 80 acres. By 1947 the lake had lost half of its water storage capacity. This necessitated the dredging of the lake in 1951 to increase the water storage capacity. The continuous decline in the water storage capacity of Spring Lake led to the construction of a second dam, which expanded the lake to its present approximate size of 237 acres. The Illinois Environmental Protection Agency (IEPA) analyses of lake water samples prior to 2007 caused Spring Lake to be classed as "impaired." The impairment classification was triggered by excess phosphorus, nitrogen, and sediments. The impairments were so severe that Spring Lake was considered "high priority" by the IEPA.

Parts of Spring Lake may become eutrophic as excessive amounts of dissolved nitrogen and phosphorus allow algae growth to produce algal blooms during summer months (Moorhouse, 2007). As the algae die, they descend to the hypolimnon layer of the lake, and other organisms including bacteria, fungi, plankton species and other organisms consume the algae (Pearl, 2009). The consumption of the algae by other organisms requires that the consuming organisms increase their oxygen consumption for respiration. This process may partially deplete the deeper, hypolimnic water-layer of Spring Lake of dissolved oxygen, and leave the hypolimnon anoxic. The anoxia may be exacerbated as the influx of dissolved nitrogen and phosphorus to Spring Lake increases. Phosphorus is commonly the nutrient that limits algal growth and controls the subsequent oxygen status of fresh water bodies. Ideally, phosphorus concentration of water entering a lake should be less than 0.05 mg P L^{-1}, however an algae bloom can occur at concentrations as low as 0.02 mg P L^{-1} (Emsley and Hall, 1976). Studies have shown that nitrates contaminate aquatic systems throughout the year (Chesnaux et al., 2007). Although nitrate is not a limiting nutrient for eutrophication in aquatic system, it should be less than 10 mg NO_3^--N/L in drinking water (Daniels and Mesner, 2010; Liukkonen, 2002).

The Spring Lake watershed (Figure 1) encompasses approximately 12,966 acres (Moorhouse, 2007). The majority of the watershed is used for crop production, principally corn and soybean production. Eroded soil particles from the watershed cause sediment to build within the lake. Sediment build up decreases the water storage capacity of Spring Lake.

The highest priority for the Spring Lake Watershed Committee was to locate areas of high concentrations of phosphorus and nitrogen in the watershed (Moorehouse, 2007). The sites for sampling were chosen based on predictions of the highest soil erosion values using the Revised Universal Soil Loss Equation (RUSLE) (Renard, et al., 1997). The RUSLE was used to predict long term averages in annual rates of soil erosion (Moorehouse, 2007). The RUSLE is:

$$A = (R)(K)(LS)(C)(P)$$

The equation components include: potential average annual soil loss in tons per acre per year (A); rainfall erosivity factor (R); the soil erodibility factor (K); the length-slope factor (LS); and crop management factors (C and P) that were provided by the Soil and Water Conservation District (SWCD).

The objective of this research was to determine the sites within the Spring Lake watershed most likely to damage Spring Lake by increasing the eutrophication rate. To achieve this objective, sites most likely to be erosion hazards were selected. The soils at the selected sites were then extensively sampled and analyzed to determine the concentration of nitrate-nitrogen (NO_3^--N) and extractable P.

MATERIALS AND METHODS

Sites for soil sampling (Figure 2) were chosen based on previous erosion protection measures and predictions of the highest soil erosion values using the Revised Universal

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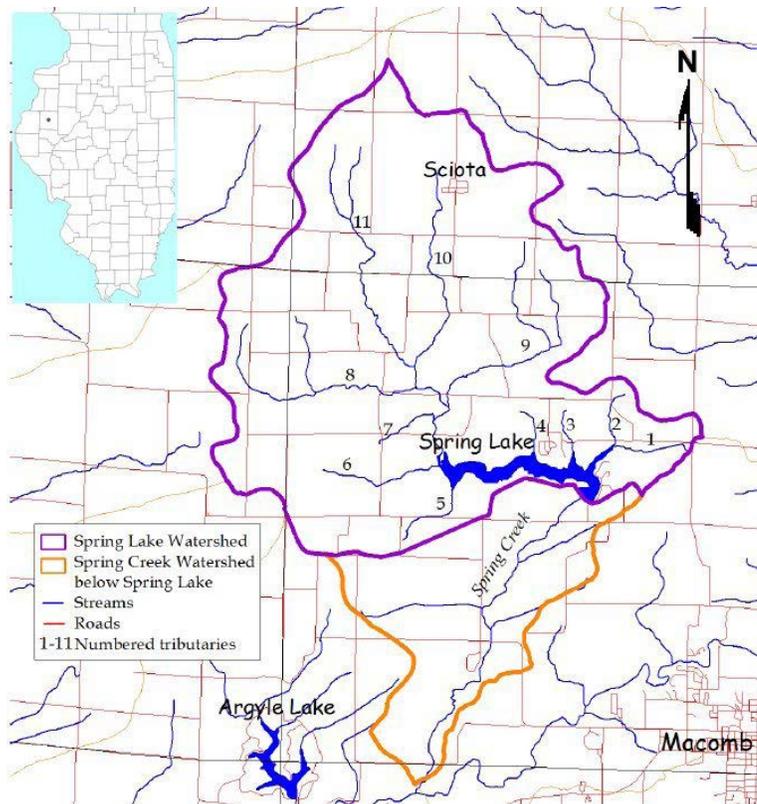
Figure 1. Map of the boundries of the Spring Lake watershed in McDonough Country, Illinois (Moorhouse, 2007).
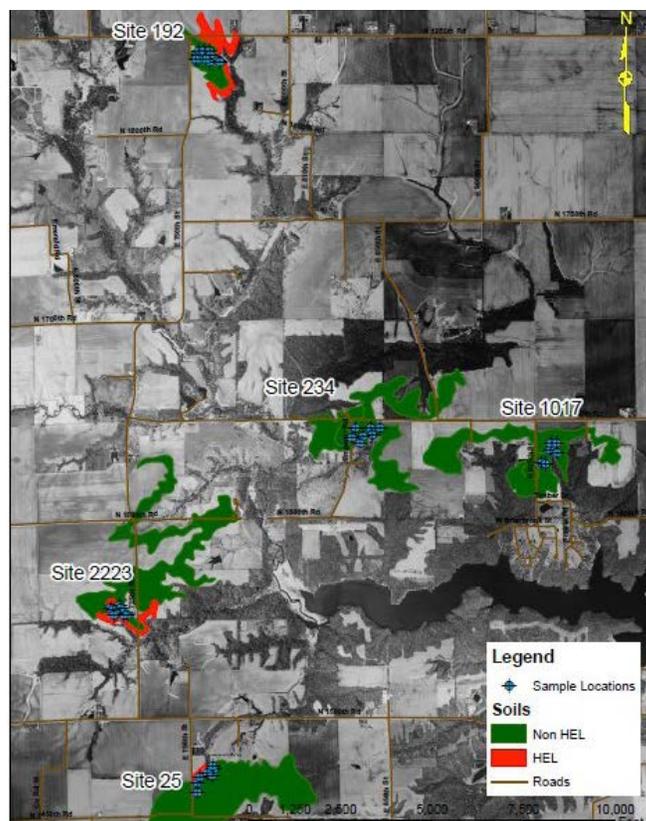
Figure 2. Site designations and individual sites sampled and analyzed for soil NO_3^- and soil PO_4^{3-} content by depth from the Spring Lake watershed in McDonough Country, Illinois from September 28, 2010 to October 26, 2010.

Soil Loss Equation. Six sites were selected for analysis, and the soil classification of the soils of each were determined (Table 1). Between six and eight locations within each site were sampled. Each core sample was taken to a depth of 15 cm during Fall, 2010. Each core sample was divided into three 5.0 cm segments. The samples were returned to laboratories at Western Illinois University, air dried, ground, and sieved in standard preparation for soil analysis. Air dry moisture of each soil sample was determined (Topp, 2002) and utilized to calculate subsequent soil weights.

The NO_3^--N content of the soil was determined using a NO_3^- ion selective electrode technique (Mulvaney, 1996). Ten grams of the soil sample was added to 50 mL of water and mixed for one minute on an orbital shaker. The slurry was filtered and 20 mL of the filtrate was added to a beaker with 2 mL of 2 M $(NH_4)_2SO_4$. A NO_3^- specific electrode was immersed in the mixed solutions and the NO_3^- content determines with a pH-millivolt meter. This procedure was repeated three times for each sample.

Soil P was extracted with Mehlich-3 extraction techniques (Mehlich, 1984). The Mehlich-3 extractant is composed of acetic acid (CH_3CO_2H), ammonium nitrate (NH_4NO_3), ammonium fluoride (NH_4F), nitric acid (HNO_3), and ethylenediaminetetraacetic acid (EDTA). The acetic acid component buffers the solution to pH = 2.5. The Mehlich-3 extractant is useful for extracting available P from acidic, neutral, and slightly basic soils (Sawyer and Mallarino, 1999).

Five grams of each soil sample were extracted with a 25 mL aliquot of the Mehlich-3 extractant. The sample-extractant slurries were shaken on an orbital shaker for five minutes. The samples were filtered and the extracts were transferred to polypropylene test tubes. Ten mL of each of the extracts were then tested for P concentration using the Vanadomolybdophosphoric Acid Method (Kuo, 1996). The extractable soil P content for each was then calculated for all soil samples taken from the Spring Lake watershed.

All data were analyzed using the Statistical Analysis System (version SAS-9.3) (SAS Institute Inc., Cary, NC, USA, 2010). Analysis of variance (ANOVA) using F-tests was conducted for both soil NO_3^--N and soil extractable P of each sample within each sites at each depth, and all sample x depth combinations. An example of this for the surface 5 cm of Site 25 is depicted in Figure 3. The model for the ANOVA was designed to test the main effects of site and depth, as well as the interaction of site with depth for both soil NO_3^--N and extractable P. The probability level chosen for all statistical tests was 5% (α = 0.05) (Steele and Torrie, 1980). Fisher's least significant difference (LSD) values were calculated for all means found to be significantly different.

RESULTS AND DISCUSSION

Overall Statistical Results. Analysis of variance indicated that soil NO_3^--N was found to have significantly different means

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Table 1. Soil sampling sites, number of samples, soil order, soil series, surface texture, and taxonomic classification of the soil samples collected in the Spring Lake watershed.

Site	Number Samples	Soil Order	Soil Series	Surface Texture	Taxonomic Classification
25	7	Alfisols	Hickory	Silt Loam	fine-loamy, mixed, active, mesic Typic Hapludalfs
19N	6	Alfisols	Greenbush	Silt Loam	fine-silty, mixed, superactive, mesic Mollic Hapludalfs
			Elco	Silt Loam	fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs
19S	6	Alfisols	Greenbush	Silt Loam	fine-silty, mixed, superactive, mesic Mollic Hapludalf
			Clarksdale	Silt Loam	fine, smectitic, mesic Udollic Endoaqualfs
234	7	Mollisols	Ipava	Silt Loam	fine, smectitic, and mesic Aquic Argiudolls
1017	6	Alfisols	Keomah	Silt Loam	fine, smectitic, mesic Aeric Endoaqualfs
			Clarksdale	Silt Loam	fine, smectitic, mesic Udollic Endoaqualfs
2223	8	Mollisols	Ipava	Silt Loam	fine, smectitic, and mesic Aquic Argiudolls
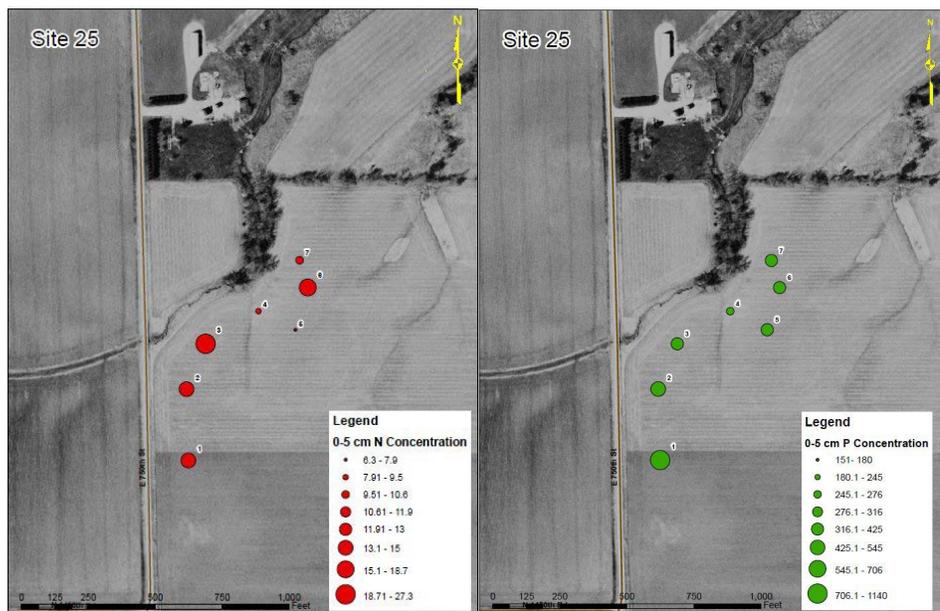
Figure 3. Sampling locations within Site 25 analyzed for NO_3^- and PO_4^{3-} content by depth from September 28, 2010 to October 26, 2010.

Table 2. Average soil NO_3^- concentrations at sampling sites within the Spring Lake watershed in McDonough County, Illinois.

| Depth (cm) | Site with Mg NO_3^--N/kg soil | | | | | | |
	25	19N	19S	234	1017	2223	Mean
0-5	13.6	16.6	13.8	8.7	13.3	12.1	12.9
5-10	10.5	9.6	8.6	8.3	9.2	7.4	8.9
10-15	9.3	7.3	6.2	8.5	7.8	6.6	7.6
Mean	11.1	11.2	9.5	8.5	10.1	8.7	

LSD(0.05) to compare two depth means at the same site = 3.9
LSD(0.05) to compare two depth means in different sites = 7.3

Table 3. Average soil PO_4^{3-} concentrations at sampling sites within the Spring Lake watershed in McDonough County, Illinois.

| Depth (cm) | Site with extractable P/kg soil | | | | | | |
	25	19N	19S	234	1017	2223	Mean
0-5	485	316	263	408	215	380	353
5-10	269	210	155	213	145	146	190
10-15	232	169	101	184	148	118	159
Mean	331	231	171	269	169	217	

LSD(0.05) to compare two depth means at the same site = 97
LSD(0.05) to compare two depth means in different sites = 182

among the main effects, sites and depth. Additionally, the interaction of site with depth (site x depth) produced significantly different means for soil NO_3^--N. The probability of the F-test value was greater than 0.01% for soil NO_3^--N by site and depth, and for the site x depth interaction.

Significant differences in the ANOVA of soil extractable P were observed for the main effects, site and depth variables, similar to the statistical analysis of soil NO_3^--N means. The interaction of site with depth (site x depth) produced significantly different means for soil extractable P, also similar to the trends observed with soil NO_3^--N. The F-test value was greater than 0.01% for the main effects and for the site x depth interaction for extractable soil P.

Soil Nitrate-Nitrogen Concentrations. The surface of the sites was estimated to be the greatest hazard to Spring Lake because of the potential for erosion of solid phase N as well as dissolved N. The soil NO_3^--N in the surface (0 - 5 cm) of all sites ranged from 8.7 to 16.6 mg NO_3^--N/kg soil (Table 2). During the spring and summer months there is an upward movement of water in the soil (Sands, 2009). When the soil moisture reaches the surface of the soil, the water evaporates and leaves behind the nitrate. Since samples were taken post-harvest, this is a possible explanation for a high nitrate concentration found in the surface of the soil. The 19N and 19S sites, the two with steepest slopes and highest erosion potential, had the two highest concentrations of surface soil NO_3^--N. Site 236 had the lowest surface soil NO_3^--N at 8.7 mg NO_3^--N/kg soil.

Similarities among sites included decreasing soil NO_3^--N with depth (Table 2). The surface (0 - 5 cm) always contained the greatest soil NO_3^--N. The deepest zone sampled (10 - 15 cm) always contained the least soil NO_3^--N except in site 234. Site 234 had only minimal differences among the three sampling depths. The reason for this anomaly is not known.

The mean soil NO_3^--N concentration for each site, across all depths, indicated little difference among the sites (Table 2). The site with the greatest soil NO_3^--N was 19N at 11.2 mg NO_3^--N/kg soil, while site 234 contained the least nitrate (8.5 mg NO_3^-

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-N/kg soil) soil. The consistency among the different sites was probably due to the post-harvest sampling period. At this time, it is assumed that the developing crops had abstracted all the soil N they could assimilate, and this left the soil in a minimal N condition and at a low point in soil NO_3^--N. Spring Lake could then be subject to substantial inputs of dissolved NO_3^-N, if soil NO_3^--N were substantially greater during the late spring and early summer after N-fertilizer applications. Increased soil NO_3^--N from fertilization combined with heavier rainfall events during spring and summer would increase both the hazard of eroding solid phase soil N and dissolving soluble soil N.

The mean soil NO_3^--N concentration for each depth, across all six sites, indicated substantial differences among depths (Table 2). The mean soil NO_3^--N concentration was greatest in the surface (0 - 5 cm); followed by the intermediate depth (5 - 10 cm); and the lowest soil NO_3^--N concentration was found in the deepest sampling zone (10 - 15 cm). Soil NO_3^--N concentration values decreased by 4.0 mg NO_3^--N/kg soil from the surface to the middle sampling zone. The decrease continued from the middle to deepest sampling zone by 1.3 mg NO_3^--N/kg soil. It should be noted that, in the analysis for the individual sites, the two deepest sampling depths never significantly differed in soil NO_3^--N concentration.

Nitrate is soluble and moves as a dissolved component of water both through the soil profile, and laterally with runoff water and eroded soil particles. The direction of major surface flow within the Spring Lake watershed is toward Spring Lake, hence, the runoff and water flow may arrive at Spring Lake. The high values of soil NO_3^--N (greater than 10 mg NO_3^--N/L according to Daniels and Mesner, 2010; Liukkonen, 2002) in the Spring Lake watershed have the potential to contaminate the lake, groundwater and drinking water.

Soil Phosphorus Concentrations. The surface of the sites was estimated to be the greatest hazard to Spring Lake because of the potential for erosion of solid phase P as well as dissolved P. The extractable soil P in the surface (0 - 5 cm) of all sites ranged from a high of 408 mg extractable P/kg

soil to a low of 215 mg of extractable P/kg soil (Table 3). Extractable soil P was much greater in the surface than in the deeper sampling zones. Phosphorus tends to be immobile in soils (Emsley and Hall, 1976). Consequently, broadcast P-fertilizers that are not consumed by growing plants tend to remain in the surface of soils where they are applied. Phosphate fertilizers penetrate the soil very slowly, only averaging 5 cm of downward movement per month until immobilized through adsorption or precipitation.

The soil samples utilized in this study were taken post-harvest; therefore the concentrations found should have been low due to plant uptake, precipitation of P and adsorption of phosphates by soil particles. The reported optimum range of extractable soil P levels is only 40 - 50 mg extractable P/kg soil (Daniels et al., 1998). The surface (0 - 5 cm) soil extractable P concentrations found in the sites tested range from a low of 215 mg extractable P/kg soil to a high of 485 mg extractable P/kg soil (Table 3). The lowest mean concentration of soil extractable P found was found in site 1017, and was still over four times the amount considered optimum. The greatest concentrations found (site 25) averaged 485 mg extractable P/kg soil, approximately ten times the expected levels.

The extractable soil P for the two deeper depths, 5 to 10 cm and 10 to 15 cm, was not significantly different at any of the six sites (Table 3). Other similarities among sites included decreasing extractable soil P with depth. The surface (0 - 5 cm) always contained the greatest extractable soil P. The deepest zone sampled (10 - 15 cm) always contained the least soil extractable soil P except in site 1017. Site 1017 had approximately equivalent extractable soil P in the two deepest depths. The reason for this single irregularity is not known. Since the mobility of soil P is limited, it is reasonable to assume that the greatest amounts of soil extractable P found in the surface 0 - 2 cm is due to crop fertilization.

Differences among sites were pooled to allow comparisons among sites and depths (Table 3). The mean soil extractable P concentration for each site, across all depths, indicated substantial difference among the sites. The site with the greatest soil P was

25 with 331 mg extractable P/kg soil, while site 19S contained the least P (171 mg extractable P/kg soil). The lack of consistency among the different sites was surprising due to the post-harvest sampling period. At this time, it is assumed that the developing crops had abstracted all the soil P they could assimilate, and should have depleted the soil of P. Spring Lake could then be subject to substantial inputs of sediment laden with P, if soil P were substantially greater during the late spring and early summer after P-fertilizer applications. Increased soil P from fertilization combined with heavier rainfall events during spring and summer would increase the hazard of eroding solid phase soil P.

The mean extractable soil P concentration for each depth, across all six sites, indicated substantial differences among depths (Table 3). The mean extractable soil P concentration was greatest in the surface (0 - 5 cm); followed by the intermediate depth (5 - 10 cm). The deepest sampling depth (10 - 15 cm) produced a mean extractable soil P concentration slightly less than the intermediate sampling zone. Extractable soil P concentrations decreased by 163 mg extractable P/kg soil from the surface to the middle sampling zone. The decrease from the middle to deepest sampling zone was much less at 31 mg extractable P/kg soil. It should be noted that, in the analysis of the individual sites, that the two deepest sampling depths never significantly differed in extractable soil P concentration.

The preponderance of soil phosphorus is insoluble and therefore immobile as a dissolved phase. Most soil phosphorus movement occurs as sediments generated from eroded soil particles. The direction of stream flow within the Spring Lake watershed is toward Spring Lake; hence, sediment loaded runoff water may find its way to Spring Lake. The high values of extractable soil P (optimum is 40 - 50 mg extractable P/kg soil according to Daniels, et al., 1988) in the Spring Lake watershed have the potential to contaminate the lake and increase the rate of eutrophication.

CONCLUSIONS

Soil NO_3^--N and extractable soil P concentrations found in sites deemed to be erosion hazards in the Spring Lake watershed were determined. While differences were

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observed among the different sites, all but a few of the concentrations were found to be great enough to be threatening to the drinking water quality of Spring Lake. This was particularly true in the surface (0 - 5 cm) of the soils. Surface soil NO_3^--N concentrations were great enough to present serious risks in the drinking water quality of groundwater and Spring Lakes, as well as contributing to the eutrophication of the lake. Surface soil extractable P was very high. Erosion of soils that create sediments extremely high in soil extractable P is certain to contribute to the eutrophication of Spring Lake and thereby reduce water quality.

To reduce the N and P hazards evident from these studies, best management practices have been implemented as directed by the Illinois Environmental Protection Agency and the McDonough County Soil and Water Conservation District. Nutrient management plans have been required and implemented from landowners in the Spring Lake watershed to reduce application rates of fertilizer N and P. Sixty new water and sediment control basins are being installed at strategic locations to reduce water runoff and sediment loading of streams that feed Spring Lake. One grade stabilization structure will be installed to hold erodible soil in place. Almost 900 m of new terraces are being installed to slow runoff water and thereby reduce soil erosion. Slightly over two hectares of new waterways will be fitted into current waterways to slow water feeding Spring Lake. An underdetermine area of new wetlands will be constructed to act as a buffer zone preventing sediments and contaminants from entering Spring Lake.

Projected pollutant load reductions should slow or alleviate the eutrophication of Spring Lake once the improved practices are implemented. It is predicted that sediment inputs will be reduced by almost 830,000 kg/year (911 ton/year). Phosphorus has a projected reduction of 614 kg of P/year, and nitrogen reduction to Spring Lake is projected to be 236 kg N/year.

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