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WATER QUALITY ASSESSMENT OF PRAIRIE CREEK RESERVOIR TRIBUTARIES IN DELAWARE COUNTY, INDIANA

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ABSTRACT. Prairie Creek Reservoir (PCR) is located in east-central Indiana within a predominantly agricultural watershed. The reservoir serves as a secondary source of drinking water for the city of Muncie and provides numerous recreational amenities. Previous studies focused on water quality in the reservoir, which led to local land management decisions. The current study was conducted to obtain baseline physical and chemical data for the five major tributaries of PCR, and to determine how agricultural, residential and commercial land use impacts water quality via tributary sub-watersheds. Water temperature, dissolved oxygen, and pH were measured; additionally, concentrations of total N, nitrate-N, ammonia-N, and phosphorus (P) species were analyzed. Dissolved oxygen concentrations were below Indiana Administrative Code (IAC) guidelines; total P and particulate P concentrations differed significantly ($p < 0.05$) between several tributaries, while total N and nitrate-N concentrations did not significantly differ. Of the five tributaries, Shave Tail Creek and Carmichael Ditch generated the greatest nutrient loads and were therefore ranked the worst tributaries in terms of overall water quality. It is recommended that best management practices be implemented at Shave Tail Creek and Carmichael Ditch to improve reservoir water quality.

Keywords: Eutrophication, nutrients, monitoring, streams, reservoir

INTRODUCTION

As of 2014, 43% of all lakes and reservoirs in the United States were classified as impaired for their designated uses (US EPA 2016). Nutrients are listed as the primary factor contributing to impairment, and agriculture is the foremost source of impairment. Commercial agricultural fertilizers inadvertently promote biological productivity in water that drains agricultural lands. An estimated 66% of nitrogen in the Mississippi River Basin originates from cultivated crops, mostly corn and soybean, grown within the Mississippi River watershed (USGS 2014). Runoff from livestock feedlots also contributes substantial N and P to surface waters (Burkholder et al. 2007). Animal manures may contain 2–5% N and P, depending on type of livestock raised (Hansen 2006; Buob & Homer no date). Such manures are often applied as a fertilizer to agricultural fields; therefore, intensive land application may result in N- and P-enriched surface runoff. Furthermore, soil-bound P may be lost via erosion (Quinton et al., 2001; Mullins 2009; Domagalski & Johnson 2013).

Cultural eutrophication of water bodies, the result of excess nutrients, reduces drinking water quality, increases sedimentation and algal blooms, and lowers or depletes dissolved oxygen (DO) concentrations. Eutrophication restricts commercial and recreational uses of water sources, reduces property values, and increases costs of water treatment for domestic consumption (Dodds & Welch 2000; US EPA 2002; Søndergaard et al. 2003; Carpenter 2005; Chislock et al. 2013; USGS 2013, 2014; Redmond et al. 2014).

Water bodies may experience eutrophication from nutrients released from domestic and municipal sources as well as from agricultural practices. Petrovic (1990) found that a small quantity of fertilizer nitrogen leaches from established turf to groundwater. Erickson et al. (2001) reported that plantings of mixed species (e.g., ornamentals) experienced ten times greater losses of nitrate than did areas planted to grass. Such landscapes may include large open spaces like parks, ornamental gardens, golf courses, as well as smaller plantings such as home gardens. Despite their prevalence, little is known about fertilizer losses from such managed landscapes (Amador et al. 2007).

Water quality in some portions of Indiana has degraded between 2002 and 2010. The US Environmental Protection Agency (US EPA

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2016) observed that 86% of assessed lakes/reservoirs support full body contact and 81% support use for a public water supply. For streams/rivers only 63% support full body contact and 79% support use for a public water supply. The eastern corn belt region (Ecoregion 55) extends across east-central Ohio through central Indiana and includes the Prairie Creek Reservoir watershed. The region has among the highest levels of eutrophication compared to any other Indiana ecoregion. The main causes of water quality degradation are agricultural and industrial runoff (US EPA 2016).

Management of eutrophication is a complex issue and may include artificial mixing and oxygenation, sediment removal, sediment aeration, covering of sediment, phosphorus inactivation, use of algicides, light reduction, macrophyte control, and ecoremediation (Svirčev et al., 2008). In those areas most affected by nutrient pollution, best management practices (BMPs) may serve to protect water quality (US EPA 2002, 2005, 2010).

In Delaware County, Indiana, Prairie Creek Reservoir (PCR) covers 1200 acres and contains 7.2 billion gallons of water (D-MMPC 2007). The reservoir serves as a secondary source of drinking water for the City of Muncie and provides recreational amenities such as boating, fishing, and camping. The reservoir and its surrounding riparian land are owned by the Indiana-American Water Company that leases it for recreational purposes to the Muncie Department of Parks and Recreation. The Delaware Muncie-Metropolitan Commission developed a Prairie Creek Reservoir Master Plan to address future land development within the watershed, enhance park and reservoir value, and protect water quality (D-MMPC 2007; Popovičová 2008). In 2012, the City of Muncie renewed the reservoir lease for 100 years (Dick 2012).

PCR is significantly affected by agricultural land use and has shown signs of degradation (D-MMPC 2007; Popovičová 2008). Recent studies (Cescon 1997; Goward 2004; Fiallos Celi 2008; Popovičová & Fiallos Celi 2009) have recorded obvious signs of eutrophication and reduction in DO levels during summer months. Dissolved oxygen concentrations reached anoxic levels that persisted from June through September and often reached 50% of the depth at monitored sites (Popovičová & Fiallos Celi 2009).

To prevent further degradation of reservoir water quality, The Indiana Department of Environmental Management (IDEM 2004) is recommending implementation of BMPs within the watershed to reduce non-point source pollution. Previous studies, however, have not conducted monitoring and assessment of reservoir tributaries, which is essential for implementation of BMPs. Analysis of reservoir tributaries and the reservoir outflow for nitrate-N, ammonia-N, total N, particulate P and total P, and physico-chemical parameters such as temperature and DO levels can aid in implementing future land management practices to safeguard reservoir water quality.

The purpose of the reported research is to investigate water quality for the five tributaries of the PCR watershed. The ultimate goal is to determine how land use affects water quality (i.e., nutrient concentrations and loads) in PCR. Data regarding water quality of the major tributaries were collected in order to support future management decisions.

EXPERIMENTAL METHODS

Study location.—Prairie Creek Reservoir Watershed, located in Delaware County, Indiana, is classified as gently rolling and contains small lakes, prairie pothole lakes, and wetlands. The watershed is composed mainly of Crosby and Miamian soil series, both of which experience poor drainage. The watershed is dominated by agricultural land use (72%), green space (18%), and residential development (6%) (IDEM 2004). The reservoir has five major tributaries, i.e., Carmichael Ditch, Shave Tail Creek, James Huffman Ditch, Cemetery Run, and Cecil Ditch, draining 44 km^2 (17 mi^2) of New Castle Till Plains (Table 1; Fig. 1) (IDEM 2004). These streams obtain water primarily from groundwater sources and precipitation. Riparian zones are observed to be dominated by woody to herbaceous vegetation. Stream bottoms consist primarily of a silt to gravel substrate. Silty bottoms have been encountered in multiple tributaries suggesting bank erosion with streams acting as sinks for sediment.

Sample collection and analysis.—Weekly sampling and monitoring was performed at each tributary and reservoir outflow from June through October 2014. A SONTEK Flow Tracker (SONTEK, San Diego, CA) measured discharge of each stream using US Geological Survey protocols (USGS 2010). A Hydrolab DS5 Sonde (Hydrolab Inc., Austin, TX) was used to measure pH, temperature, DO, and turbidity in-situ. Water samples for nutrient

Table 1.—Tributary sub-watershed characteristics of Prairie Creek Reservoir, Delaware County, Indiana.

Location	Stream length (m)	Drainage area (ha)	Land use	Percentage of land use
Outfall	1,869	n/a	n/a	n/a
Carmichael Ditch	2,849	517	Agriculture	49%
			Commercial	46%
			Residential	5%
Shave Tail Creek	7,508	799	Agriculture	53%
			Residential	41%
			Commercial	6%
Huffman Ditch	5,336	767	Agriculture	72%
			Commercial	16%
			Residential	12%
Cemetery Run	2,402	162	Agriculture	98%
			Residential	2%
Cecil Ditch	2,345	311	Agriculture	100%

determination were collected from the center of each tributary using a grab sample technique. Samples were collected in acid-washed glass containers, transported on ice, and analyzed within 24 hours of collection. Samples were analyzed for nitrate-N using the Cadmium Reduction Method 8039; ammonia-N by the Ammonia Salicylate Method 8155; total N by the Persulfate Digestion Method 10070; particulate and soluble orthophosphate by the Ascorbic Acid Method 8048 (Reactive Phos Ver3); and total P by the Acid Persulfate Digestion Method (Hach 2015). A Hach DR/2400 Spectrophotometer (Hach, Inc., Loveland, CO) was used to determine concentrations of each analyte. One field duplicate, one lab blank, a field blank, and a laboratory fortified blank with deionized H_2O were used for quality control purposes.

The effects of location (fixed factors) for each water quality parameter (dependent variable) were determined by the use of nonparametric statistics including Spearman's rho, Kruskal-Wallis, and multiple comparisons analysis. The level of statistical significance was set at $\alpha = 0.05$. Statistical analyses were performed using Minitab® 16.2.4 statistical software (Minitab Inc., State College, PA) on a Windows-based PC.

Ranking tributaries.—A stream quality ranking system was established based on total quantity of nutrients (kg/y), with scores from 1 (best) to 6 (worst). The final ranking was determined by adding the scores for each nutrient parameter; the tributary having the highest total value was designated as the poorest quality tributary.

RESULTS AND DISCUSSION

Discharge.—The greatest discharge was measured at the outflow (0.2 m^3/s) (6.89 ft^3/s) (Table 2). The Indiana-American Water Company controls the release of water at this location. Discharge varied throughout the sampling period from 0.01 to 0.2 m^3/s. It is expected that groundwater contributes to all tributaries due to the high water table in this watershed (NRCS 2013). Shave Tail Creek had the highest discharge rate compared to the other tributaries (0.04 m^3/s) (Table 2). Carmichael Ditch had the second highest discharge (0.03 m^3/sec), while Cemetery Run had the lowest (0.01 m^3/sec). It was observed that the latter stream experienced reservoir backflow.

Table 2.—Discharge (m^3/s) measured at Prairie Creek Reservoir tributaries in 2014 (June to October). * = Significant difference at $p < 0.05$.

Location	*n*	Mean ± std dev.	Min.	Max.
Outfall	13	0.20 ± 0.44	8.5×10^{-4}	1.60
Carmichael Ditch*	18	0.03 ± 0.03	1.4×10^{-3}	0.12
Shave Tail Creek	8	0.04 ± 0.02	0.03	0.11
Huffman Ditch	18	0.02 ± 0.02	4.5×10^{-3}	0.09
Cemetery Run	17	0.01 ± 0.008	-2.8×10^{-3}	0.03
Cecil Ditch*	17	0.01 ± 0.01	4.2×10^{-3}	0.05

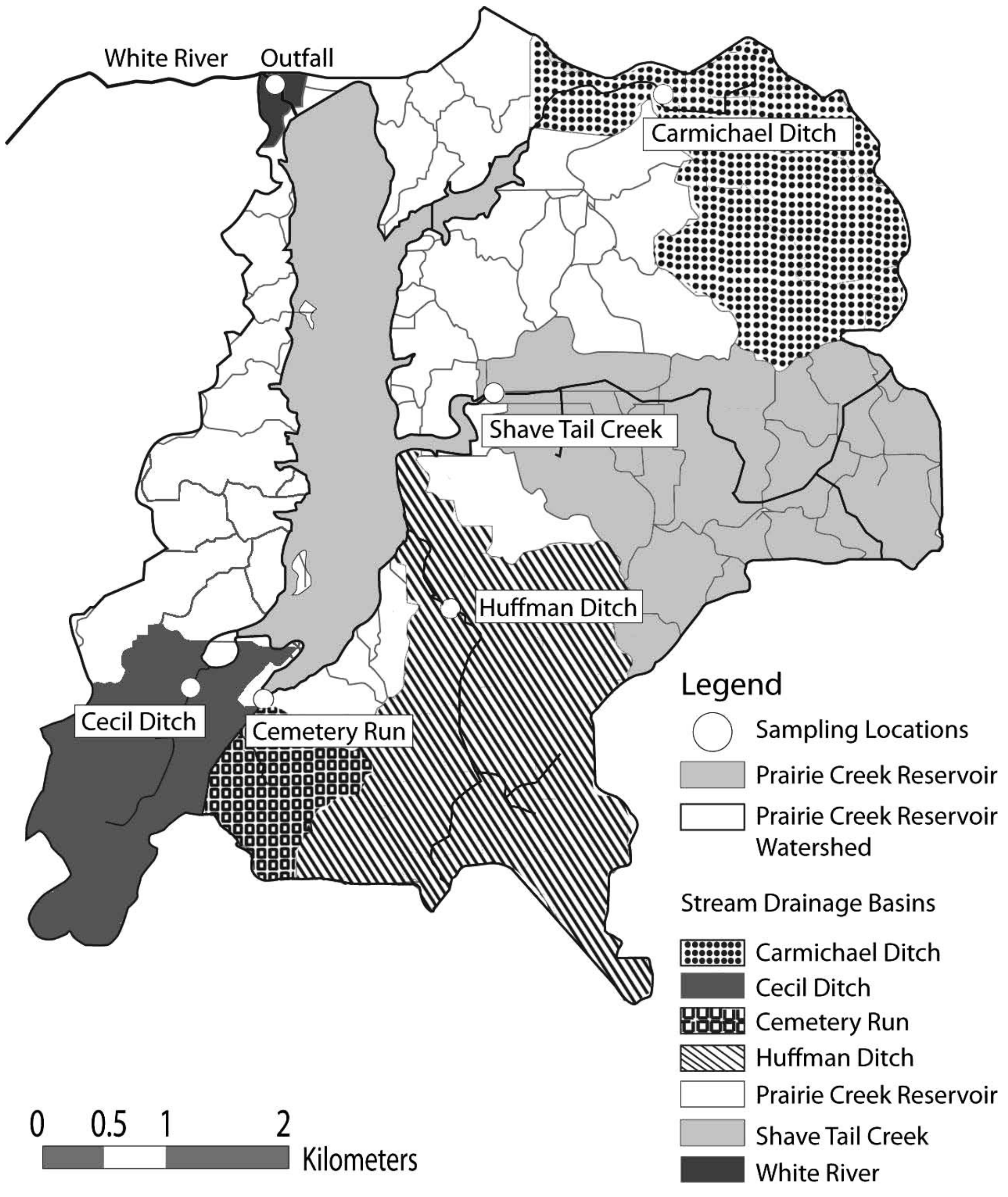

Figure 1.—Prairie Creek Reservoir, Delaware County, Indiana: sampling locations and tributary sub-watersheds.

June was the only month that had a higher mean precipitation (0.58 cm) (0.23 in.) than average for 1994–2014 (0.41 cm) (0.16 in.). It was expected that nutrient concentrations would be lower due to higher discharge rates for this month. July and September mean precipitation for 2014 was 0.25 and 0.2 cm, respectively, and was slightly less than mean precipitation for 1994–2014 (0.3 and 0.28 cm, respectively); nutrient concentrations were expected to be higher than normal concentrations (NWS 2014).

Physico-chemical characteristics.—*Reservoir outflow*: The reservoir outflow had the highest mean temperature (19.9° C) followed by Cemetery Run (17.2° C) (Table 3). The high temperature at the outflow is likely due to the

Table 3.—Physico-chemical parameters (mean ± standard deviation) measured at Prairie Creek Reservoir tributaries in 2014 (June through October). * = DO concentrations below Indiana Administrative Code (IAC) Standards; BDL = below detectable limits.

Parameter	Outfall	Carmichael Ditch	Shave Tail Creek	Huffman Ditch	Cemetery Run	Cecil Ditch
pH	7.63 ± 0.53	6.68 ± 0.26	7.16 ± 0.34	7.42 ± 0.26	7.46 ± 0.33	7.12 ± 0.41
n	9	9	9	9	9	9
median	7.53	6.69	7.22	7.47	7.51	7.23
range	7.0 - 8.4	6.16 – 7.0	6.55 - 7.7	6.8 - 7.8	6.93 - 8.1	6.22 - 7.60
DO (mg/L)	5.69 ± 3.66	3.23 ± 2.54*	2.48 ± 2.36*	2.94 ± 1.66*	3.53 ± 3.21*	2.69 ± 2.34*
n	9	9	9	9	9	9
median	5.85	3.17	2.92	3.08	3.64	2.45
range	BDL - 11.22	BDL - 6.65	BDL - 5.91	BDL - 5.23	BDL - 10.98	BDL - 5.55
Turbidity (NTU)	21.73 ± 12.67	28.28 ± 10.78	20.42 ± 7.4	38.24 ± 44.07	24.39 ± 8.14	20.32 ± 5.71
n	6	7	6	7	7	6
median	16.35	24.7	22	19.3	28.4	19.2
range	14.8 - 47.2	18.6 - 49.9	10.5 - 29.7	8.6 - 135.2	8 - 30.3	13.6 - 30
Temperature (° C)	19.92 ± 5.29	15.87 ± 3.95	15.73 ± 4.14	16.31 ± 3.19	17.24 ± 5.33	16.12 ± 4.49
n	9	9	9	9	9	9
median	20.23	16.73	17.92	17.43	18.25	17.18
range	12.1 - 25.85	10.07 - 20.96	9.8 - 20.12	10.22 - 19.25	8.81 - 25.74	9.37 - 21.29
Specific Conductivity (µS/cm)	324.4 ± 132.6	687.1 ± 116.5	647.4 ± 75.9	665.7 ± 60.0	577.8 ± 162.9	777.1 ± 32.2
n	8	9	8	9	8	7
median	349.5	690.6	667.3	670.5	643.8	780.8
range	0.1 - 471.9	410.2 - 814.9	460.8 - 685.5	532.6 - 766.5	339.5 - 754.9	738.7 - 833.6

Table 4.—Nutrient concentrations (mean ± standard deviation) for Prairie Creek Reservoir tributaries in 2014 (June through October). BDL = below detectable limits.

Parameters (mg/L)	Outfall	Carmichael Ditch	Shave Tail Creek	Huffman Ditch	Cemetery Run	Cecil Ditch
Nitrate-N	0.45 ± 0.21	1.15 ± 1.11	0.67 ± 0.43	1.07 ± 0.8	0.58 ± 0.32	1.02 ± 0.76
n	15	15	15	15	4	15
Median	0.4	0.7	0.6	0.8	0.55	0.9
Range	0.2 - 0.9	BDL - 4.2	0.2 - 1.6	0.2 - 3.2	0.1 - 1.4	BDL - 2.7
Ammonia-N	0.04 ± 0.05	0.05 ± 0.02	0.04 ± 0.06	0.01 ± 0.02	0.02 ± 0.02	0.04 ± 0.03
n	17	17	17	17	17	17
Median	0.03	0.05	0.02	0	0.03	0.03
Range	BDL - 0.14	BDL - 0.07	BDL - 0.24	BDL - 0.08	BDL - 0.07	BDL - 0.1
Total N	0.66 ± 0.84	1.61 ± 1.5	1.2 ± 1.33	1.44 ± 1.3	0.68 ± 1.04	1.55 ± 1.81
n	15	15	15	15	14	15
Median	0.2	1.3	0.9	1	0.2	0.9
Range	BDL - 2.3	BDL - 4.7	BDL - 4.4	BDL - 4	BDL - 3.6	BDL - 5.4
Soluble PO_4^{3-}	0.03 ± 0.03	0.08 ± 0.08	0.1 ± 0.13	0.08 ± 0.07	0.05 ± 0.03	0.08 ± 0.1
n	18	18	18	18	17	18
Median	0.02	0.07	0.08	0.07	0.05	0.06
Range	BDL - 0.10	BDL - 0.32	BDL - 0.61	BDL - 0.24	BDL - 0.11	BDL - 0.1
Particulate P	0.01 ± 0.02	0.03 ± 0.06	0.01 ± 0.02	0.02 ± 0.04	0.00 ± 0.00	0.01 ± 0.00
n	18	18	18	18	18	17
Median	BDL	BDL	BDL	BDL	BDL	BDL
Range	BDL - 0.12	BDL - 0.15	BDL - 0.05	BDL - 0.14	BDL - 0.01	BDL - 0.05
Total P	0.04 ± 0.06	0.09 ± 0.09	0.13 ± 0.15	0.09 ± 0.08	0.06 ± 0.07	0.04 ± 0.05
n	18	18	18	18	18	18
Median	BDL	0.06	0.06	0.05	0.05	0.01
Range	BDL - 0.19	BDL - 0.28	BDL - 0.60	BDL - 0.22	BDL - 0.22	BDL - 0.16

reservoir being exposed to direct sunlight. Specific conductivity at the outflow (324.4 μS/cm) was lowest compared to the tributaries.

The reservoir outflow had the highest pH (7.6) and DO concentration (5.69 mg/L). The high DO concentration may be a result of agitation and subsequent aeration of water discharging directly from the reservoir. pH and DO concentrations for this location were lower than those measured by Goward (2004) (7.97 and 9.06 mg/L, respectively). The lower pH and DO concentration measured in the current study may be attributed to decomposition of organic matter (Cooke et al. 2005; Jørgensen et al. 2005).

Tributaries: Carmichael Ditch had the lowest pH (6.68) and second-highest specific conductivity (687.1 μS/cm), possibly a result of algal productivity and decomposition, and mineralization of detritus; Cecil Ditch had highest specific conductivity (780.8 μS/cm) (Table 3). Fertilizer runoff likely contributed to high conductivity readings.

Nutrient concentrations.—Carmichael Ditch had the highest concentrations of total N (1.61 mg/L), nitrate-N (1.15 mg/L), and ammonia-N (0.05 mg/L) (Table 4); however, ammonia-N and nitrate-N concentrations for this sub-watershed were lower than concentrations measured a decade earlier (0.095 and 1.4 mg/L, respectively) (Goward 2004). Concentrations of nitrate-N were $<$ 0.7 mg/L in the outflow for Shave Tail Creek and Cemetery Run (Table 4).

Cecil Ditch had the highest mean concentrations of nitrite (0.78 mg/L) followed by Shave Tail Creek (0.68 mg/L) (data not shown). Nitrite concentrations were highest during warm summer months; this may be generated from nitrate-rich groundwater that discharges to the surface and is ultimately transformed via denitrification (USGS 2009, 2011).

According to the Indiana Administrative Code (IAC), concentrations of N species were within acceptable limits; however, the presence of dense algal growth in Carmichael Ditch suggests that IAC limits may be too high. Leaching from surface soil, use of tile drains, bank erosion, and stormwater runoff may have contributed to

Table 5.—Spearman correlations for tributary parameters (*r*).

Parameter	Outfall	Carmichael Ditch	Shave Tail Creek	Huffman Ditch	Cemetery Run	Cecil Ditch
Nitrate vs. Discharge	−0.64	0.77	−0.24	0.37	−0.10	0.00
Ammonia vs. Discharge	−0.22	−0.13	0.56	0.59	−0.19	0.14
Total N vs. Discharge	−0.22	0.43	−0.16	0.18	0.10	0.32
Particulate P. vs. Discharge	−0.10	−0.02	−0.08	0.13	−0.25	−0.13
Soluble P vs. Discharge	0.37	0.76	0.20	0.44	−0.17	−0.09
Total P vs. Discharge	−0.18	0.66	−0.23	0.63	0.02	0.06
pH vs. Discharge	0.88	−0.33	−0.66	0.61	0.42	0.22
Dissolved Oxygen vs. Discharge	0.82	0.30	−0.66	0.73	0.75	0.39
Specific Conductivity vs. Discharge	−0.09	0.11	0.72	−0.50	−0.38	0.63
Stream Turbidity vs. Discharge	0.73	−0.34	1.0	−0.58	0.62	−0.27
Total Phosphorus vs. Turbidity	−0.43	−0.20	−0.34	−0.16	−0.81	−0.70
Particulate Phosphorus vs. Turbidity	−0.20	−0.24	−0.11	0.81	−0.89	−0.58
Soluble Orthophosphate vs. Turbidity	0.31	0.27	0.43	−0.37	0.21	0.02
Nitrite vs. Discharge	−0.31	−0.05	−0.32	0.10	−0.37	0.30
Nitrite vs. pH	0.53	0.41	0.92	0.62	−0.30	0.25
Nitrite vs. Dissolved oxygen	0.30	−0.62	0.55	0.70	−0.17	0.48
Nitrite vs. Turbidity	−0.12	−0.48	−0.29	−0.87	0.48	−0.36
Nitrite vs. Total N.	−0.29	0.01	−0.29	−0.21	−0.21	−0.17

elevated N concentrations (Mullin 2009; Domagalski & Johnson 2013).

Shave Tail Creek had the highest total P concentration (0.13 mg/L) (Table 3), which may be caused by fertilizer runoff, soil erosion, and disturbance of the creek bed by cattle (Goward 2004). This sub-watershed consists predominantly of agricultural fields (53%). Several tributaries had similar total P concentrations compared to 2011 data (0.06 mg/L) (UWRWA 2011). Soluble orthophosphate concentrations were highest at Shave Tail Creek (0.1 mg/L) and particulate P was highest at Carmichael Ditch (0.03 mg/L) (Table 3).

Comparison of tributary properties.—Shave Tail Creek had significantly ($p < 0.05$) higher discharge and total N and P concentrations compared to Carmichael Ditch, Cemetery Run, and Cecil Ditch (Tables 2 & 4). Ammonia-N concentrations were significantly different between Carmichael Ditch and Huffman Ditch ($p = 0.02$); however, ammonia-N comprises a relatively minor fraction of total N, which did not significantly differ throughout the watershed ($p = 0.13$).

Prairie Creek Reservoir Watershed (PCRW) had lower concentrations of ammonia-N and nitrate-N (0.05 and 1.15 mg/L) (Table 4) compared to nearby Buck Creek (0.07 and 2.3 mg/L, respectively) and Killbuck Creek (0.14 and 2.4 mg/L, respectively) watersheds (Goward 2004). Soluble orthophosphate concentrations measured 0.08 mg/L each for Carmichael Ditch, Huffman Ditch, and Cecil Ditch in the PCRW, which were twice the value of Buck Creek (0.04 mg/L) but an order of magnitude less than for Killbuck Creek (0.75 mg/L) (Goward 2004).

The PCRW is less developed compared to Buck Creek and Killbuck Creek watersheds — residential use comprised 15.4 and 12.9 %, respectively, compared to 6 % for PCRW (Goward 2004; UWRWA 2011). Agricultural land use predominates in the PCRW (72%) (Goward 2004; UWRWA 2011). PCRW has the highest percentage of green space (19%) compared to the other watersheds (Buck Creek, 13% and Killbuck Creek, 7%). This may account for PCRW having better water quality than the other watersheds (Goward 2004; UWRWA 2011).

Correlations.—Concentrations of nitrate-N were strongly correlated with discharge at Carmichael Ditch ($r = 0.77$) (Table 5). Total P had a moderately positive correlation with discharge at both Carmichael Ditch ($r = 0.66$) and Huffman Ditch ($r = 0.63$).

The outflow had a moderately negative correlation with ammonia-N concentration and pH ($r = - 0.63$) and a strong negative correlation with DO level ($r = - 0.83$) (data not shown). Carmichael Ditch had a strongly negative correlation between ammonia-N and DO ($r = - 0.75$) which may have been caused by denitrification and respiration of algae throughout the sampling period (Cooke et al. 2005; Jørgensen et al., 2005). The outflow had a

Table 6.—Nutrient loads contributed by each tributary and exported to the White River. Numbers represent kg/y.

Nutrient	Outfall	Carmichael Ditch	Shave Tail Creek	Huffman Ditch	Cemetery Run	Cecil Ditch
Nitrate-N	2790	667	953	631	188	388
Ammonia-N	265	268	60	83	81	138
Total N	4066	942	1698	849	212	577
Total P	59	14	50	14	6	4

strongly positive correlation ($r = 0.88$) and Huffman Ditch a moderately positive correlation ($r = 0.61$) for pH and discharge (Table 5). Higher rates of discharge could incorporate greater quantities of DO, reduce concentrations of CO_2, and increase pH (Araoye 2009). Higher discharge rates are capable of carrying greater quantities of particulates and ions, which result in a positive correlation with turbidity (Table 5).

Ranking tributaries and best management practices.—Among the five tributaries, Shave Tail Creek contributed the greatest annual nutrient load (total N = 1698 kg/yr and total P = 50 kg/yr) (Table 6). Comparing the sum total nutrient loads for the tributaries to the outflow, it is evident that nutrient loads in PCR are increasing due to influx of total N and P from the watershed. This study did not establish a water budget for the watershed and cannot determine an accurate mass balance for the reservoir (Walker 1999; Fetter 2001); however, it is likely that the reservoir is acting as a nutrient sink for the watershed. Eutrophication of the reservoir could impair both aquatic biodiversity and drinking water quality for Muncie.

Shave Tail Creek and Carmichael Ditch were ranked the worst tributaries within the watershed in terms of water quality parameters (Table 7). In the Shave Tail Creek subwatershed, cattle were found to have direct access to the creek (Goward 2004). Additionally, the relatively high values for N and P may be due to greater commercial and residential development (Table 1). Petrovic (1990) concluded that only a modest quantity of fertilizer nitrogen ($< 10\%$) is typically lost from established turf. This finding is supported by Guillard & Kopp (2004). Jiang et al. (2000) have shown that turf sites retain 90% of accumulated N during the following year even if no vegetation is replanted. Erickson et al. (2001) reported that plantings of mixed species lost ten times more NO_3^- than did areas planted to grass. To assess fully the environmental impact of residential, institutional or municipal landscaping, however, all components of the landscape must be evaluated for their contribution to fertilizer losses (Amador et al. 2007). It is also possible that fewer management practices implemented for these subwatersheds allowed runoff and erosion of fertilizers and possibly septic runoff to enter the tributaries. Cecil Ditch had the lowest total P input which could be a direct result of having a riparian zone consisting largely of dense woody vegetation.

BMPs suggested for Shave Tail Creek and Carmichael Ditch include soil analysis preplanting of turf grass, ornamental, and agricultural crops (Hartz 2006) to determine soil N and P concentrations. This would allow for accurate determination of fertilizer application rates (Hartz 2006; Hartz & Smith 2009). Another

Table 7.—Ranking of reservoir outfall and tributaries based on nutrient loads. Rank: 1 = best quality, 6 = worst quality.

Parameter	Outfall	Carmichael Ditch	Shave Tail Creek	Huffman Ditch	Cemetery Run	Cecil Ditch
Ammonia	5	6	1	3	2	4
Total N	6	4	5	3	1	4
Particulate PO_4^{3-}	6	4	5	3	1	2
Soluble PO_4^{3-}	6	3	5	4	1	4
Total P	6	3	5	4	2	1
Total score	35	24	26	20	8	17
Overall rank[a]	6	4	5	3	1	2

suggested BMP is to regularly monitor soil N levels, which would provide a basis for determining accurate fertilizer application rates.

The use of cover crops could reduce nutrient loss from soils by rotating shallow-rooted crops with deep-rooted crops (Hartz 2006; Smukler et al. 2012). It is further recommended to implement catchment ponds where feasible so that runoff could be recycled onto lawns and fields (Smukler et al. 2012). The installation of vegetative buffer strips and constructed wetlands could be the best option for future land management practices due to current bank instability (US EPA 2005; MDNR 2007a, b). US EPA (2005) recommends at least a 100-foot buffer strip to efficiently remove 50% of the nutrients that may enter a stream.

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