An analysis of lakes and streams in the Barbee and Chapman lake chains in Kosciusko County, Indiana

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Executive Summary

The general purposes of this project were to give an overall assessment of lakes and streams of both the Barbee and Chapman lake chains as well as to establish baseline conditions for the Barbee lake chain before installation of a public sewer system. To accomplish these purposes, extensive lake and stream sampling efforts were conducted. Stream sampling for physical and chemical parameters occurred biweekly from September 2012 through August 2013 for each of the 13 stream sampling sites. Stream sites were also measured for *E. coli* on 10 separate occasions during June-August 2013. Stream invertebrates and streambank erosion were evaluated using the Hoosier Riverwatch methodology. In-lake sampling for physical and chemical parameters was conducted monthly during June-August 2013 for the seven lakes of the Barbee lake chain and for the two lakes of the Chapman lake chain. To establish a near-shore baseline *E. coli* snapshot, 59 representative sites were sampled around the shorelines of the lakes on July 2, 2013. Shoreline erosion was evaluated by visual survey of lake shoreline as well.

Several important results were identified in the present study. About half of all shoreline in the Barbee and Chapman lake chains was composed of concrete seawalls. Though relatively small proportions of the lake chain shorelines were eroding, the high occurrence of concrete seawalls across the chains likely allowed eroded sediment that was present to be continually transported around the lakes during windy conditions and times of high boat traffic. Lakes generally showed higher nutrient concentrations in bottom waters compared to surface waters indicating a combination of algae uptake near the surface and internal loading of nutrients to the lake from the sediment near the bottom. Lake *E. coli* samples were all well below the EPA human health threshold of 235 cfu/100 mL while stream *E. coli* samples were over the health threshold more than 60% of the time. The Barbee streams showed high loads of sediments, phosphorus, and nitrogen in the dominant loading streams (Grassy Creek and Putney Ditch) relative to the largest loading stream (Crooked Creek) in the Chapman chain.

The highest priority for future work is a follow-up study repeating the same methodologies and study sites once the sewer system installation is complete. Most previous management recommendations by earlier diagnostic studies of each lake chain are still valid presently. Agriculture is common in both lake chain drainage areas, so agricultural best management practices are likely the most effective management tool to improve and protect Barbee and Chapman lakes. To be sure, an analysis of current agricultural practices followed by a study to determine the most effective best management practice implementation strategy is warranted.

Project Purpose

The general purposes of this project were to give an overall assessment of lakes and streams of both the Barbee and Chapman lake chains as well as to establish baseline conditions for the Barbee lake chain before implementation of a public sewer system. The overall assessment included stream analysis of nutrients, sediments, *E. coli*, habitat, shoreline erosion, and biological monitoring. For lakes, analysis included nutrients, sediments, *E. coli*, and erosion. These present analyses as well as previous research allowed for description of recent trends, characterization of current conditions, identification of water quality problems, and recommendation of future efforts. This project is meant to be the pre-construction portion of a two part research study to explore impacts of public sewer system implementation on lake water quality in the Barbee lake chain. Since no public sewer construction is planned for the Chapman lake chain, it is included in this study as the control.

Project Description

Study sites

The Barbee and Chapman lake chains are located in the glacial lakes area of northern Indiana in Kosciusko County. The lakes are part of the Tippecanoe watershed (HUC 05120106) which drains into the Wabash River near Lafayette, Indiana. For the purposes of the present study, the Barbee lake chain (HUC 051201060105) included Banning, Irish, Little Barbee, Big Barbee, Kuhn, Sechrist, and Sawmill lakes as well as the following streams: Putney Ditch (inflow to Little Barbee), Heron Creek (inflow to Kuhn), Rattlesnake Creek (inflow to Kuhn), Shoe Creek (inflow to Banning), Grassy Creek outflow (outflow from Sawmill), Grassy Creek inflow (inflow to Big Barbee), and McKenna Creek (inflow to Irish) (Figure 1).

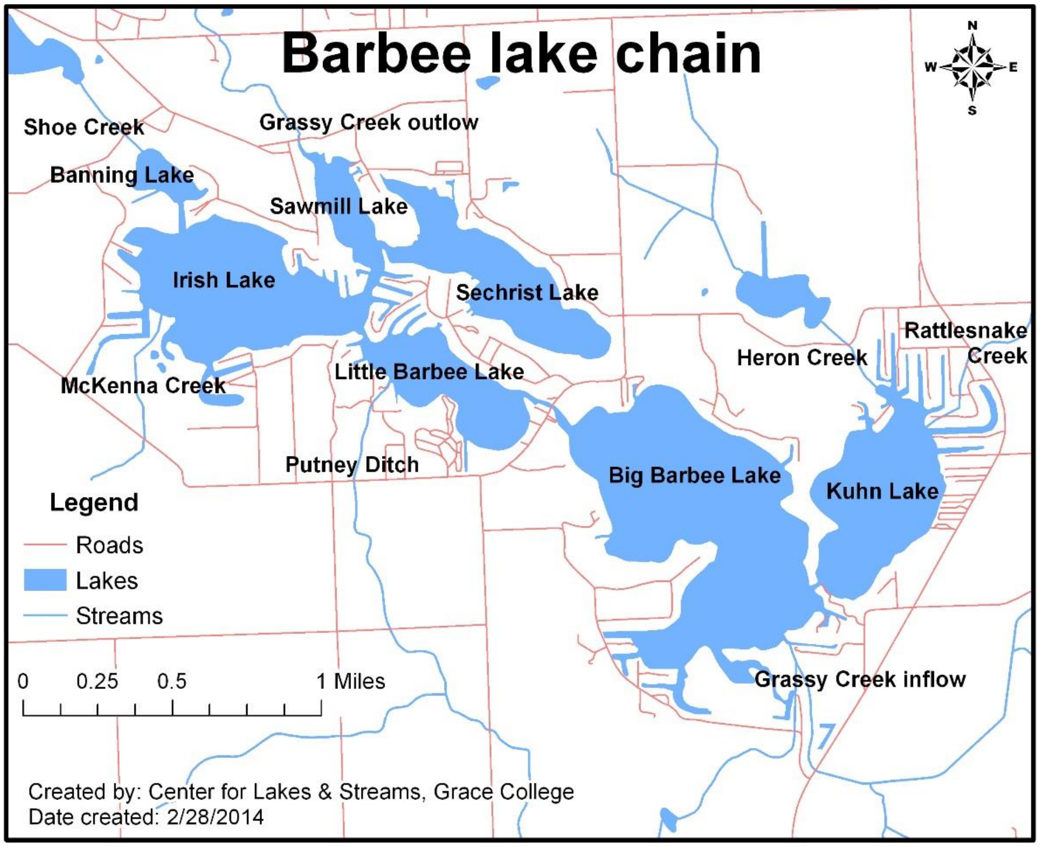

Figure 1: Map showing Barbee lake chain, including locations of seven lakes and seven streams included in present study. Substrate

The Chapman lake chain (HUC 051201060205) included Big Chapman Lake and Little Chapman Lake along with the following streams: Heeter Ditch (outflow from Little Chapman), Arrowhead Drain (inflow to Little Chapman), Highland Drain (inflow to Little Chapman), Crooked Creek (inflow to Big Chapman), Gunter Creek (inflow to Big Chapman, may also be known as C27 Creek or Island Park Drain), and Lozier's Creek (inflow to Little Chapman)(Figure 2). Sampling sites for lakes were located in the deepest hole in each lake. Sampling sites for streams were typically chosen near a road crossing as close to lake as possible (Table 1).

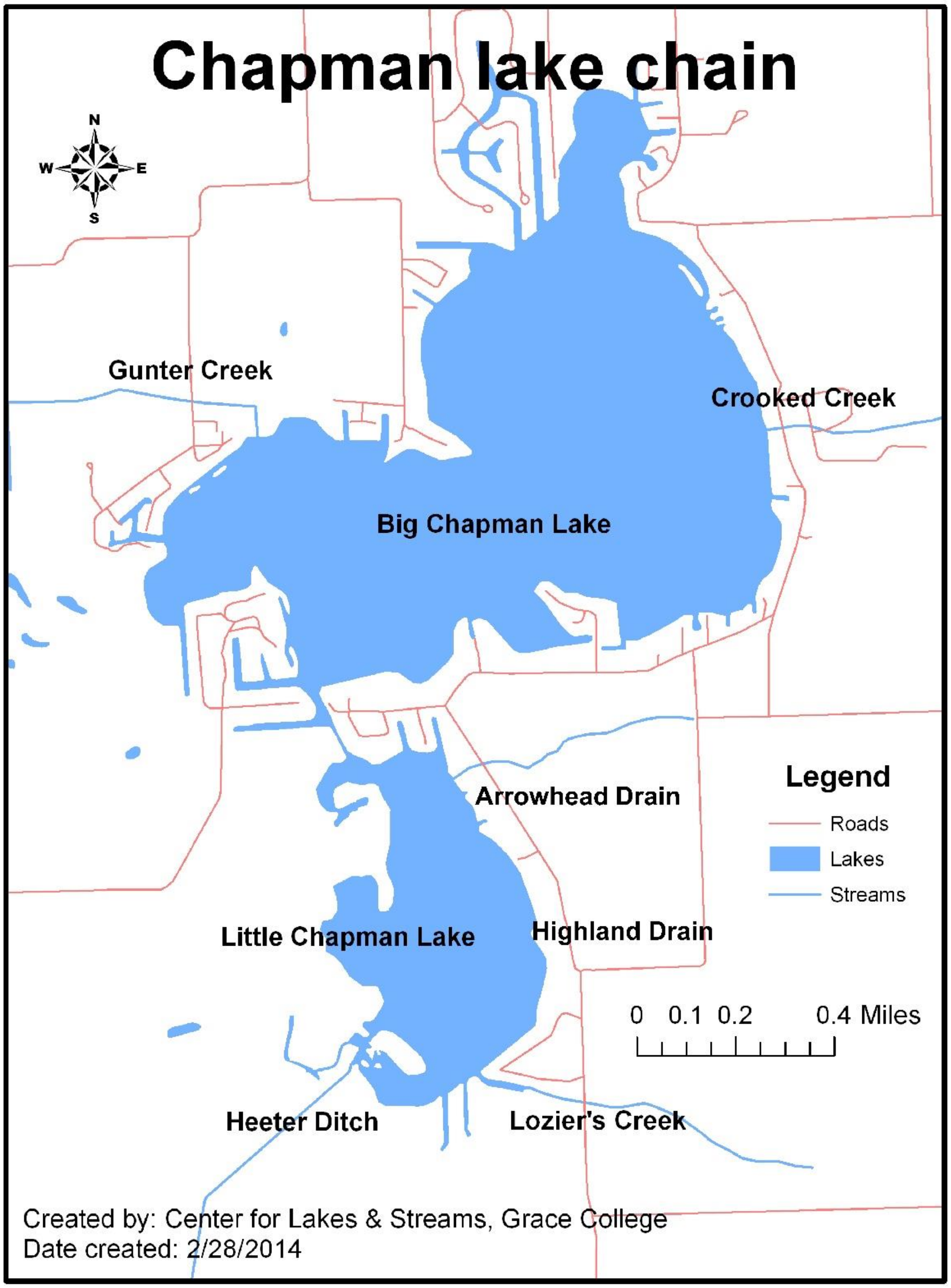

Figure 2: Map showing Chapman lake chain, including locations of two lakes and six streams included in present study.

Table 1: Name, description and location of all stream sampling sites included in the present study.

Stream Name	Lake Connection	Latitude	Longitude
Putney Ditch	Inflow to Little Barbee	N41.29075	W085.72512
Heron Creek	Inflow to Kuhn	N41.29257	W085.69530
Rattlesnake Creek	Inflow to Kuhn	N41.29000	W085.68784
Shoe Creek	Inflow to Banning	N41.30325	W085.74172
Grassy Creek outflow	Outflow from Sawmill	N41.30283	W085.73053
Grassy Creek inflow	Inflow to Big Barbee	N41.28219	W085.67894
McKenna Creek	Inflow to Irish	N41.28841	W085.74072
Heeter Ditch	Outflow from Little Chapman	N41.26042	W085.80141
Highland Drain	Inflow to Little Chapman	N41.27203	W085.78557
Arrowhead Drain	Inflow to Little Chapman	N41.27716	W085.78881
Crooked Creek	Inflow to Big Chapman	N41.28570	W085.77659
Gunter Creek	Inflow to Big Chapman	N41.28802	W085.79990
Lozier's Creek	Inflow to Little Chapman	N41.26725	W085.78497

Sampling Methods

Stream Sampling

Stream sampling for physical and chemical parameters occurred biweekly from September 2012 through August 2013 for each of the 13 stream sampling sites (Table 1). At each site, water flow was measured with an OTT MF Pro flow meter by taking water velocity and depth measurements across the stream cross section. A Hydrolab Quanta multiprobe was used to measure water temperature, pH, dissolved oxygen, and specific conductivity at each stream site. A water sample was collected at each site for later laboratory analysis of several nutrient and background water quality parameters as well.

The same 13 stream sites were measured for *E. coli* on 10 separate occasions during June-August 2013. This consisted of a sample collected in the field using sterile technique and later lab analysis. These samples allowed two separate 30-day geometric means to be calculated for each stream site.

Stream invertebrates and streambank erosion were evaluated using the Hoosier Riverwatch methodology (Riverwatch data sheets included in Appendix A). First, the stream habitat was evaluated using the Citizens Qualitative Habitat Evaluation Index (CQHEI), which included a second individual score for the bank erosion component. Third, stream invertebrates were studied using the Pollution Tolerance Index Rating (PTIR) to check relative amounts of identified invertebrates as tolerant or intolerant of pollution.

Lake Sampling (nutrients, E. coli, shoreline erosion)

In-lake sampling for physical and chemical parameters was conducted monthly during June-August 2013 for the seven lakes of the Barbee lake chain and for the two lakes of the Chapman lake chain. At each site a Secchi disk depth measurement was made to determine water clarity. Next, a Hydrolab Quanta multiprobe was used to measure water temperature, pH, dissolved oxygen, and specific conductivity at each meter from the surface to the lake bottom. Finally, a Van Dorn sampler was used to collect water samples from 1 m below the water surface and from 1 m above the lake bottom to represent epilimnion (surface layer) and hypolimnion (bottom layer) samples, respectively. An integrated water sample from the surface to 2 m depth was taken as well. These water samples were collected for later laboratory analysis of several nutrient and background water quality parameters.

To establish a near-shore baseline *E. coli* snapshot, 59 representative sites were sampled around the shorelines of the lakes on July 2, 2013 (Table 2; Field maps showing sampling locations included in Appendix B). Care was taken to capture shoreline diversity in sampling to include shorelines on different sides of lake, different vegetation conditions, different densities and types of homes, and more coverage on larger lakes. Sampling sites were located away from inflowing streams since streams were sampled separately. These samples were collected near the Fourth of July holiday to represent a time of high usage of lake homes.

Table 2: Name, location and description of near-shore lake *E. coli* sampling sites.

Lake Name	ID	Coordinates	Distance from Shore/Landmarks
Kuhn Lake	KUH1	N41.28494 W085.69673	56.07 m from shore/center of lillypads
	KUH2	N41.28821 W085.69445	29.21 m from shore/ 36.65 m SE of pier 147 EMS B3
	KUH3	N41.28991 W085.69192	12.00 m from shore/ 26.14m NW of 82 EMS B6C Ln pier
	KUH4	N41.28651 W085.68995	37.24 m from shore/30.31 m SW of 45 EMS B10 Ln pier
	KUH5	N41.28310 W085.69114	32.55 m from shore/84.77 m SW of 47 EMS B18 Ln pier
	KUH6	N41.28049 W085.69590	28.72 m from shore/28.86 m N of 60 EMS B20B Ln pier
Big Barbee Lake	BBA1	N41.27925 W085.69900	32.37 m from shore
	BBA2	N41.27810 W085.70308	48.63 m N of vegetation
	BBA3	N41.27850 W085.70869	8.13 m from shore (corner)
	BBA4	N41.28114 W085.70557	20.78 m from shore at 27 EMS B28C Ln
	BBA5	N41.28409 W085.69908	31.32 m from vegetation
	BBA6	N41.28617 W085.69940	15.56 m from vegetation
	BBA7	N41.28811 W085.70249	28.22 m from shore/9.121 m SE of 49 EMS B1B Ln pier
	BBA8	N41.28245 W085.70808	20.96 m from shore/24 EMS B28B Ln property
	BBA9	N41.29058 W085.70784	27.78 m from shore
	BBA10	N41.28782 W085.71319	14.61 m from shore/70 EMS B70 Ln property
Little Barbee Lake	LBA1	N41.28886 W085.71617	7.529 m from shore/8 EMS B69 N property
	LBA2	N41.28903 W085.72054	18.32 m from shore/ 6402 E McKenna Rd Property
	LBA3	N41.29031 W085.72220	9.677 m from vegetation
	LBA4	N41.29169 W085.71947	11.80 m from shore/10.52 m SE of 177 EMS B61 Ln pier
	LBA5	N41.29375 W085.72179	center of points/13.16 m SE from shore (corner)
	LBA6	N41.29200 W085.72599	18.97 m from shore/5.258 m W of 88 EMS B33A Ln pier
Irish Lake	IRI1	N41.29391 W085.73859	27.28 m from vegetation

	IRI2	N41.29660	W085.74106	20.07 m from shore/52 EMS B38B Ln property
	IRI3	N41.29845	W085.74148	8.549 m from shore/ 11.71 m E of 310 EMS B38 Ln pier
	IRI4	N41.29929	W085.73630	4.131 m from shore/17.2 m NE of 225 EMS B40A Ln pier
	IRI5	N41.29770	W085.73158	16.07 m from shore/ 18.85 m W of 45 Ems B40A Ln
	IRI6	N41.29604	W085.72919	28.98 m from shore/23 EMS B40E Ln property
	IRI7	N41.29278	W085.73306	9.685 m from shore/50 EMS B36A Ln/Halfway down pier
	IRI8	N41.29249	W085.73566	7.793 m from shore/1 EMS B37 Ln property
Sechrist Lake	SEC1	N41.29665	W085.72059	33.81 m from shore/21.75 m N of 48 EMS B61L Ln pier
	SEC2	N41.29488	W085.71920	35.20 m from shore/274 EMS B60 LN property
	SEC3	N41.29291	W085.71097	22.39 m from shore/53 EMS B48A Ln property
	SEC4	N41.29553	W085.71435	39.29 m from shore/129 EMS B48 LN property
	SEC5	N41.29816	W085.71823	25.13 m from shore/4351 N Sullivan Rd property
	SEC6	N41.30033	W085.72356	38.45 m S of 115 EMS B43 Ln/ 60.34 m N of 22 EMS B42E Ln
Banning Lake	BAN1	N41.30086	W085.73979	56.04 m N of vegetation
	BAN2	N41.30212	W085.73985	30.23 m SE of shore/12.23 m SE from 37 EMS B39W Ln pier
	BAN3	N41.30145	W085.73859	30.53 m SW of shore/19.35 m SW from 5645 E 450 N pier
	BAN4	N41.30031	W085.73718	20.21 m SW of point/27.22 m NW of 10 EMS B40A 1 Ln pier
Sawmill Lake	SAW1	N41.30034	W085.72694	21.39 m from shore/11.23 m SW of 109 EMS B42 Ln pier
	SAW2	N41.30216	W085.72981	11.99 m from shore/8.096 m SE of 5949 E 450 N pier
	SAW3	N41.30017	W085.72945	18.63 m from shore/12.11 m SE of 98 EMS B40 Ln
	SAW4	N41.29796	W085.72798	18.75 m from shore/9.368 m E of 20 EMS B40C Ln
Big Chapman Lake	BCH1	N41.28881	W085.79105	5.874 m from shore/296 EMS C28 Ln
	BCH2	N41.29244	W085.78688	21.15 m SE from shore/159 EMS C29A1 Ln
	BCH3	N41.29638	W085.78347	34.64 m S of vegetation/100.8 m E from vegetation
	BCH4	N41.29097	W085.78064	43.46 m SW of shore/741 Chapman Lake Dr shore
	BCH5	N41.28546	W085.77799	41.80 m W of shore/12.07 m N of 991 Chapman Lake Dr pier
	BCH6	N41.28145	W085.78342	5.09 m E of shore/20 EMS C17A Ln property
	BCH7	N41.28079	W085.78519	8.578 m S of 23 EMS C17 B Ln pier
	BCH8	N41.28130	W085.79608	39.98 m E of shore
	BCH9	N41.28243	W085.80031	52.04 m N of shore /125 EMS C24D Ln
	BCH10	N41.28574	W085.79256	36.86 m S of point/19 EMS C28F Ln
Little Chapman Lake	LCH1	N41.27736	W085.79198	14.91 m S of shore/30 EMS C19B Ln property
	LCH2	N41.27203	W085.78716	24.19 m W of shore/2103 Chapman Lake Dr property
	LCH3	N41.26837	W085.78940	31.79 m NW of point/74 EMS C23 Ln property
	LCH4	N41.26768	W085.79186	68.27 m N of vegetation/53.34 S of vegetation/53.36 m SW of point
	LCH5	N41.27110	W085.79401	24.18 m NE of vegetation
	LCH6	N41.27436	W085.79254	6.992 m E of vegetation

Shoreline erosion was evaluated by visual survey of lake shoreline from a boat. Each lake shoreline was divided into sections that could be visually inspected from a different vantage point on the lake (Field maps included as Appendix C). The eroded versus protected shoreline along with categories of cement seawall, glacial stone, beach, grass, and natural were estimated for each section. These sections were then scaled up to the entire individual lake shorelines and then the two lake chains as well.

Lab Analysis

Water samples obtained in the field for later lab analysis were stored in the dark near 2° C until returning to Grace College each day. Samples were continually kept at 2° C in the dark at Grace College and through transport to analytical laboratories. *E. coli* samples were transported to the Kosciusko County Health Department for analysis within 24 hours of field sampling. Stream and lake samples for nutrient and background water quality analysis were transported to the National Center for Water Quality Research at Heidelberg University for analysis within 7 days of field sampling. Analyzed parameters included suspended solids, conductivity, chloride, fluoride, sulfate, silicon dioxide, total phosphorus (TP), soluble reactive phosphorus, total nitrogen (TN), total Kjeldahl nitrogen, ammonia, nitrate, and nitrite.

Data Analysis

Field data was written on field log sheets (Field data sheets included in Appendix D) and immediately recorded electronically throughout project to avoid any loss of data. Data was always checked twice for accuracy when transferred from field log sheets to computer spreadsheets.

Project Tasks

Hydrology and Lake Habitat Quality

Water budgets for both the Barbee and Chapman lake chains were estimated and discussed in great detail previously (Richardson and Jones, 2000; Giolitto and Jones, 2001). These budgets show water residence times for each lake which approximates the average amount of time a given drop of water spends in the lake before leaving through the outflowing stream (Table 3). Sechrist Lake in the Barbee lake chain as well as Big Chapman from the Chapman lake chain have much longer residence times compared to the other lakes. Sawmill Lake has the shortest residence time in the Barbee lake chain. Sechrist and Big Chapman have small watershed sizes relative to their water volumes, so they might be less sensitive to land uses up in the surrounding drainage area but more sensitive to the use of the lake and its immediate shoreline. Sawmill and the other lakes with short residence times are dominated by the stream inflows and outflows such that these lakes are extremely sensitive to the watersheds surrounding them. The faster residence time might also allow for quicker flushing of materials out of the lake during different seasons as well as they are almost acting as widened parts of the streams that flow through them.

Table 3: Lake water budgets (from Richardson and Jones, 2000; Giolitto and Jones, 2001).

	Residence time	
Lake	(in years)	(in days)
Kuhn	0.37	135
Big Barbee	0.14	52
Little Barbee	0.02	8.2
Irish	0.05	18.9
Banning	0.25	89.8
Sechrist	4.3	1,571
Sawmill	0.008	2.9
Big Chapman	2.07	756
Little Chapman	0.35	128

Erosion from lake shorelines has additional impacts on the lakes of the Barbee and Chapman lake chains. Lake shorelines were predominantly protected in both lake chains, though the Barbee chain had proportionally more shoreline classified as eroding compared to the Chapman chain (Table 4). Within the Chapman chain the two individual lakes had similarly small eroding shoreline proportions, while the Barbee chain had much more variation among lakes from 4% eroding around Kuhn and Big Barbee and up to 34% around Little Barbee. Shoreline classifications in both lake chains were similar with about half of all shoreline in each lake chain being composed of concrete seawalls (Table 4). Naturally vegetated shorelines were the next most common in both lake chains followed by grass lawns, glacial stone, and sand beaches. Individual lakes showed great variation in shoreline classifications for both lake chains with Kuhn having highest proportion of concrete seawalls (58%), Sawmill having most grass lawn shorelines (45%), and Banning having the largest proportion in natural vegetation (72%). Though relatively small proportions of the Barbee and Chapman lake chain shorelines were eroding, the high occurrence of concrete seawalls across the chains likely allowed eroded sediment that was present to be continually transported around the lakes during windy conditions and times of high boat traffic.

Table 4: Lake shoreline erosion and classifications from present study.

	Name	Shoreline Length (m)	Shoreline Erosion (%)		Shoreline Classification (%)				
			Eroding	Protected	Concrete	Stone	Beach	Grass	Natural
Individual Lakes	Kuhn	8165	4	96	58	5	2	6	29
	Sechrist	4770	19	81	45	17	3	32	4
	Sawmill	2354	30	70	40	5	5	45	5
	Big Barbee	10587	4	96	50	7	1	6	37
	Irish	12087	7	93	50	0	3	9	38
	Banning	1621	5	95	10	2	0	16	72
	Little Barbee	5971	34	66	42	7	1	41	9
	Big Chapman	51510	7	93	57	7	0	15	21
	Little Chapman	23791	3	97	40	10	0	10	40
Lake Chains	Barbee Chain	45555	12	88	48	5	2	17	28
	Chapman Chain	75301	6	94	52	8	0	13	27

Streambank erosion from inflowing streams also has the potential for increased sediment levels in the Barbee and Chapman lake chains. Like with individual lakes, individual streams associated with each lake chain had widely different streambank conditions related to erosion (Table 5). Overall, the surveyed streambanks flowing into the Chapman lake chain were eroding more than streambanks in inflowing streams to the Barbee lake chain. Within the Chapman lake chain, both Big Chapman and Little Chapman had a mix of combination and raw classifications. The Barbee lake chain had a stable streambank classification for Heron Creek flowing into Kuhn as well as a raw classification for Grassy Creek flowing into Big Barbee. Though this data is limited to surveyed sites in each stream, the Chapman lake chain may be more susceptible to streambank erosion transporting sediments into the lakes compared to the Barbee lake chain. However, since Grassy Creek is the major inflowing stream in the Barbee lake chain and it had a streambank classification of raw, Big Barbee Lake may be particularly vulnerable to sediment loading in relation to other lakes of the Barbee lake chain.

Table 5: Stream site bank erosion classifications from present study.

Stream Name	Lake Connection	Bank Erosion Classification
Putney Ditch	Inflow to Little Barbee	Combination
Heron Creek	Inflow to Kuhn	Stable
Rattlesnake Creek	Inflow to Kuhn	Combination
Shoe Creek	Inflow to Banning	Combination
Grassy Creek outflow	Outflow from Sawmill	Combination
Grassy Creek inflow	Inflow to Big Barbee	Raw
McKenna Creek	Inflow to Irish	Stable/Combination
Heeter Ditch	Outflow from Little Chapman	Raw
Highland Drain	Inflow to Little Chapman	Raw
Arrowhead Drain	Inflow to Little Chapman	Combination
Crooked Creek	Inflow to Big Chapman	Combination
Gunter Creek	Inflow to Big Chapman	Raw
Lozier's Creek	Inflow to Little Chapman	Raw

Lake Littoral Zone and Stream Habitat

Lake littoral zones have been previously studied and reported on in great detail in previous reports (Ewolt, 2010; Giolitto and Jones, 2001; Richardson and Jones, 2000; Scribailo and Alix, 2013). A lake's littoral zone is the area near the shoreline where rooted plants can be found since it is shallow enough for plants to absorb sunlight. Based on the morphometry, or shape, of a lake bottom, lakes can have different relative sizes of littoral zones and therefore different opportunities for plant growth (Table 6; Giolitto and Jones, 2001; Richardson and Jones, 2000). When comparing each lake chain, there is a remarkable similarity of both having just less than half of their surface area being made up of shallow littoral zones of less than 10 ft (3 m) depth. However, there is much variation in relative littoral zone extents within the Barbee (31-76%) and Chapman (30-52%) lake chains. Big Barbee (31%) and Little Chapman (30%) have relatively small littoral areas and therefore rooted plants have less of an impact on these lakes compared to lakes with relatively large littoral areas such as Banning (76%) or Kuhn (64%).

Not only are the relative sizes of littoral zones important for lake ecosystems, but also the diversity of species found in those shallow areas of the lakes. Previous research has shown different numbers of species during spring and summer vegetation sampling (Table 6; Ewolt, 2010; Scribailo and Alix, 2013). Lakes in the Barbee and Chapman chains have few invasive species compared to native species, but these invasive species have still been identified as problematic in previous studies. Eurasian water-milfoil (*Myriophyllum spicatum*) and curly-leaved pondweed (*Potamogeton crispus*) are considered the two most problematic invasive species in both the Chapman lake chain (Scribailo and Alix, 2013) and in the Barbee lake chain (Ewolt, 2010). Coontail (*Ceratophyllum demersum*) was the dominant native species in the Barbee lake chain while both coontail and stonewort (*Chara sp.*) were the most common native species in the Chapman lake chain.

Table 6: Spring and summer vegetation sampling results for lake littoral zones (from Ewolt, 2010; Scribailo and Alix, 2013).

		Littoral Zone	Littoral Zone	Number of species			
				Native		Invasive	
	Name	(acres)	(%)	Spring	Summer	Spring	Summer
Individual Lakes	Kuhn	87	64	14	18	1	1
	Sechrist	43	41	10	15	2	2
	Sawmill	19	53	7	5	2	2
	Big Barbee	94	31	12	10	2	2
	Irish	102	56	11	12	2	1
	Banning	13	76	6	7	2	1
	Little Barbee	28	38	4	4	2	1
	Big Chapman	260	52	13	11	3	2
	Little Chapman	42	30	6	8	2	1
Lake Chains	Barbee Chain	386	45				
	Chapman Chain	302	47				

Stream habitat, including physical and biological indicators in the stream, is also important to the littoral and other areas of these lakes because it is an indicator of the water quality of incoming water. Results of the QHEI as part of the Hoosier Riverwatch methodology showed wide variation in total index scores and in individual components of these physical characteristics (Table 7). For bottom substrate, the streams around the Chapman lake chain had the highest (Arrowhead Drain and Lozier’s Creek) and lowest (Heeter Ditch and Gunter Creek) scores of both lake chains. High substrate scores were based on larger sized bottom particles and fewer silts and clays to smother larger particles being common throughout the stream. Gunter Creek flows through a wetland area such that its bottom substrate resembled a wetland more so than a stream channel. Chapman and Barbee lake chains had similar average bottom substrate scores. Fish cover measures the degree of hiding places for fish in the streams. These scores were fairly consistent across stream sites except for Gunter Creek which had little fish cover. Stream shape evaluates the degree of human alteration of the stream channel such as straightening the channel or bridge construction. These scores were quite favorable for the Barbee and Chapman streams, indicating streams sites showing meandering stream channels were present. In fact, Heron Creek had a maximum possible score on this QHEI component. Stream riparian area was scored based on riparian width, land use, shade, and erosion. Lots of variation was shown in this component with poor riparian conditions for Putney Ditch and Heeter Ditch and great riparian conditions at McKenna Creek and Heron Creek sites. Variation in stream depth and velocity was another QHEI component which showed much variation among stream sites, but similar averages for Barbee and Chapman lakes chains when all stream sites are taken as a group in each case. The presence of riffles and runs was the component where average scores were most different between the Barbee and Chapman lake chains. The Barbee lake chain had much worse scores for this component as five of the seven stream sites in this chain had no riffles and runs present. Total QHEI scores were similar for Barbee and Chapman streams and were in the category of "enough positive habitat features available to attain Warm Water Habitat" conditions. Individual stream sites ranged from the worst QHEI total score category (Putney Ditch, Shoe Creek, Heeter Ditch, and Gunter Creek) to the top category (Heron Creek, Grassy Creek inflow, McKenna Creek, Arrowhead Drain, Crooked Creek, and Lozier's Creek).

Table 7: QHEI results using the Hoosier Riverwatch methodology as part of present study.

Lake Chain	Stream	Total	Bottom Substrate	Fish Cover	Stream Shape	Riparian Area	Depth & Velocity	Riffles/ Run
Barbee	Putney Ditch	43	8	10	11	6	8	0
	Heron Creek	70	16	10	20	19	1	4
	Rattlesnake Creek	56	11	10	14	16	5	0
	Shoe Creek	48	11	8	12	16	1	0
	Grassy Creek outflow	63	16	14	12	12	9	0
	Grassy Creek inflow	73	19	16	15	15	8	0
	McKenna Creek	80	18	12	17	19	4	11
Chapman	Heeter Ditch	47	6	12	15	6	8	0
	Highland Drain	65	8	12	17	10	5	13
	Arrowhead Drain	88	20	16	17	17	5	13
	Crooked Creek	82	19	12	17	13	9	12
	Gunter Creek	32	0	2	12	14	4	0
	Lozier's Creek	78	21	12	17	15	5	8
Barbee	Average	62	14	11	14	15	5	2
Chapman	Average	65	12	11	16	12	6	8

Stream habitat was also evaluated biologically by utilizing the PTIR scores as well as counts of individual organisms in each pollution tolerance group according to the Hoosier Riverwatch methodology. The stream sites ranged widely in PTIR scores from "excellent" rating for Grassy Creek outflow to "bad" ratings for McKenna Creek, Crooked Creek, and Lozier's Creek (Table 8). According to this data there were also three stream sites with "good" ratings (Heron Creek, Grassy Creek inflow, and Arrowhead Drain) and five that had "fair" ratings (Putney Ditch, Rattlesnake Creek, Shoe Creek, Heeter Ditch, and Highland Drain). Average PTIR scores for each lake chain showed the Barbee lake chain as having a healthier biological community in the surrounding streams compared to the Chapman lake chain.

Table 8: Pollution tolerance index ratings (PTIR) and tolerance category results using the Hoosier Riverwatch methodology as part of present study. PTIR results are considered excellent for scores greater than or equal to 23, good for scores of 17 to 22, fair for scores of 11 to 16, and bad for scores less than or equal to 10. Numbers included for each category and stream are the total number of individual organisms collected.

Lake Chain	Stream	PTIR	# Intolerant	# Moderately intolerant	# Fairly tolerant	# Very tolerant
Barbee	Putney Ditch	16	7	4	0	24
	Heron Creek	19	2	38	70	43
	Rattlesnake Creek	14	5	15	1	6
	Shoe Creek	13	0	51	1	40
	Grassy Creek Outflow	27	4	115	6	22
	Grassy Creek Inflow	21	130	12	16	0
	McKenna Creek	8	9	6	0	9
Chapman	Heeter Ditch	11	2	2	13	7
	Highland Drain	16	0	12	5	6
	Arrowhead Drain	17	2	5	100	104
	Crooked Creek	9	0	100	7	7
	Gunter Creek	12	1	21	0	5
	Lozier's Creek	7	0	10	100	4
Barbee	Averages	17	22	34	13	21
Chapman	Averages	12	1	25	38	22

Counts were recorded for individual organisms as well and categorized into intolerant, moderately intolerant, fairly tolerant, and very tolerant groups in regards to water pollution. Grassy Creek inflow had had many more insects from the group that were intolerant to pollution (mayfly nymphs and right-handed snails) compared to any other stream site (Table 8). This stream site had relatively high QHEI scores as well which likely contribute to a healthy organism community. The Barbee lake chain streams had a much higher average number of intolerant organisms collected compared to the Chapman lake chain. Another strong stream site according to organism counts was Grassy Creek outflow which had a high number of moderately intolerant organisms. Stream sites with the most fairly tolerant and very tolerant organisms were in the Chapman lake chain which led to the Chapman lake chain having higher average numbers of organisms per steam site for these two pollution tolerance categories.

Lake Nonpoint Source Pollution

The lakes and streams of the Barbee and Chapman lake chains were extensively sampled for nutrients, sediments, *E. coli*, and general water quality measures to identify sources of nonpoint source pollution and evaluate overall health of these ecosystems.

For lakes, samples were collected in the epilimnion (top layer) and hypolimnion (bottom layer) of the lake. General water quality measures showed typical values for lakes in northern Indiana (Tables 9 and 10). There was variation in water clarity as measured by the Secchi disk, showing lakes with more surface water inflow (streams) had less clarity because of more nutrients promoting algae growth and more sediments to reduce clarity. Lake epilimnion layers had higher water temperatures and oxygen concentrations due to sunlight warming surface water and algae producing oxygen.

Table 9: Average general water quality measures for lake epilimnion (top layer).

	Name	Secchi Disk (ft)	Temperature (deg C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% sat)	pH	Conductivity (mS/cm)
Individual Lakes	Kuhn	7.6	24.7	8.2	101.9	8.4	0.451
	Sechrist	6.7	25.4	8.4	105.1	8.6	0.415
	Sawmill	2.9	24.7	9.9	122.9	8.5	0.441
	Big Barbee	2.9	24.2	9.6	117.4	8.5	0.463
	Irish	2.8	25.0	10.7	133.5	8.7	0.418
	Banning	4.4	24.7	6.1	75.9	7.9	0.433
	Little Barbee	2.8	24.4	10.3	127.3	8.5	0.460
	Big Chapman	7.0	26.4	8.2	105.2	8.4	0.437
	Little Chapman	3.0	26.6	10.2	131.3	8.8	0.390
Lake Chains	Barbee Chain	3.8	24.7	9.2	113.7	8.4	0.438
	Chapman Chain	5.0	26.5	9.2	118.3	8.6	0.414

Table 10: Average general water quality measures for lake hypolimnion (bottom layer).

	Name	Temperature (deg C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% sat)	pH	Conductivity (mS/cm)
Individual Lakes	Kuhn	14.3	0.9	9.3	7.6	0.499
	Sechrist	7.9	0.2	1.9	7.6	0.466
	Sawmill	12.3	0.2	1.9	7.5	0.549
	Big Barbee	9.9	0.1	1.0	7.6	0.553
	Irish	10.6	0.2	1.9	7.6	0.509
	Banning	20.2	1.3	14.7	7.5	0.425
	Little Barbee	16.1	1.2	12.3	7.6	0.501
	Big Chapman	10.6	0.1	1.2	7.4	0.527
	Little Chapman	13.0	0.3	2.5	7.4	0.491
Lake Chains	Barbee Chain	13.1	0.6	6.2	7.6	0.500
	Chapman Chain	11.8	0.2	1.9	7.4	0.509

Nutrients and sediments in lakes varied as expected as well. Lakes generally showed higher nutrient concentrations in hypolimnion compared to epilimnion indicating a combination of algae uptake near the surface and internal loading of nutrients to the lake from the sediment near the bottom (Tables 11 and 12). Higher epilimnion nitrate concentrations in Big Barbee, Little Barbee, and Sawmill lakes indicates strong external nitrogen loading to these lakes. Little Chapman and Little Barbee showed the highest phosphorus concentrations in the hypolimnion of any of the other lakes in the present study, indicating that these lakes have the strongest internal loading of phosphorus.

Table 11: Average nutrient and sediment concentrations for lake epilimnion (top layer).

	Name	Suspended Sediments (mg/L)	Soluble Reactive Phosphorus (mg P/L)	Total Phosphorus (mg P/L)	Ammonia (mg N/L)	Nitrite (mg N/L)	Nitrate (mg N/L)	Total Kjehldahl Nitrogen (mg N/L)	Total Nitrogen (mg N/L)
Individual Lakes	Kuhn	3.1	0.005	0.05	0.06	0.01	0.13	0.79	0.92
	Sechrist	1.9	0.004	0.03	0.02	0.01	0.11	0.74	0.86
	Sawmill	4.3	0.004	0.06	0.05	0.07	1.25	1.34	2.65
	Big Barbee	7.9	0.003	0.05	0.05	0.10	1.76	1.34	3.19
	Irish	6.0	0.004	0.05	0.06	0.06	0.69	1.24	1.98
	Banning	9.2	0.005	0.05	0.04	0.01	0.03	0.96	1.00
	Little Barbee	9.5	0.003	0.06	0.06	0.08	1.90	1.43	3.41
	Big Chapman	1.2	0.004	0.03	0.05	0.00	0.02	0.66	0.69
	Little Chapman	8.7	0.003	0.05	0.00	0.00	0.00	0.96	0.96
Lake Chains	Barbee Chain	6.0	0.004	0.05	0.05	0.05	0.84	1.12	2.00
	Chapman Chain	4.9	0.003	0.04	0.03	0.00	0.01	0.81	0.83

Table 12: Average nutrient and sediment concentrations for lake hypolimnion (bottom layer).

	Name	Suspended Sediments (mg/L)	Soluble Reactive Phosphorus (mg P/L)	Total Phosphorus (mg P/L)	Ammonia (mg N/L)	Nitrite (mg N/L)	Nitrate (mg N/L)	Total Kjehldahl Nitrogen (mg N/L)	Total Nitrogen (mg N/L)
Individual Lakes	Kuhn	2.8	0.003	0.02	0.21	0.01	0.07	0.70	0.78
	Sechrist	8.4	0.101	0.18	1.00	0.00	0.00	2.13	2.13
	Sawmill	5.7	0.139	0.24	1.45	0.01	0.05	2.76	2.82
	Big Barbee	5.7	0.060	0.15	0.65	0.09	1.12	1.64	2.85
	Irish	2.2	0.093	0.19	0.91	0.03	0.31	1.90	2.23
	Banning	8.4	0.005	0.07	0.08	0.01	0.04	1.19	1.23
	Little Barbee	5.8	0.165	0.32	1.41	0.05	0.36	2.26	2.66
	Big Chapman	5.1	0.004	0.06	1.01	0.00	0.01	2.31	2.31
	Little Chapman	15.0	0.156	0.32	1.97	0.00	0.01	4.41	4.42
Lake Chains	Barbee Chain	5.6	0.081	0.17	0.82	0.03	0.28	1.80	2.10
	Chapman Chain	10.0	0.080	0.19	1.49	0.00	0.01	3.36	3.36

Lake *E. coli* samples were collected along shorelines of each lake to develop a baseline of *E. coli* levels for later reference (Table 13). All samples collected were well below the EPA human health threshold of 235 cfu/100 mL such that there were no *E. coli* concerns identified for these nine lakes with this snapshot sampling effort. This was despite sampling only two days before the 4^{th} of July holiday when lake homes were likely being heavily used.

Table 13: Average near-shore lake *E. coli* levels from July 2, 2103.

	Name	*E. coli* (cfu/100 ml)
Individual Lakes	Kuhn	18.2
	Sechrist	7.9
	Sawmill	14.4
	Big Barbee	14.5
	Irish	10.0
	Banning	13.7
	Little Barbee	15.3
	Big Chapman	41.1
	Little Chapman	13.6
Lake Chains	Barbee Chain	13.4
	Chapman Chain	27.3

Stream sampling results were impacted by drought conditions. Over the study period of September 2012 through August 2013, drought conditions lingered in the first several months of the study. Many stream sites only had water flow during the last six months of the study period. Therefore, total loading from stream sites over the year-long study period may not be indicative of typical annual loads for these streams, but relative contributions of these streams and concentrations observed are likely more representative. With these weather conditions, it was not possible to analyze seasonal differences in stream loading which would have been another beneficial aspect to this study.

General water quality measures for streams showed wide variation among stream sites (Table 14). In the Barbee chain, the average outflow from Grassy Creek was slightly higher than the average inflow from all of the inflowing streams combined, indicating that groundwater flow through springs in the lakes is occurring at a relatively small rate. However, in the Chapman chain, the average outflow through Heeter Ditch is much higher than the sum of the average inflowing streams which likely indicates a much more important groundwater contribution to this lake chain compared to the Barbee chain. Average water temperatures and pH values were similar across streams and lake chains. Average dissolved oxygen levels were similar in Barbee streams compared to Chapman streams, but there was wide variation among individual streams. Gunter Creek which flows into Big Chapman and Shoe Creek which flows in Banning had very low oxygen levels. Both of these streams had very low flow rates compared to most other streams, so a lack of turbulent water flow could explain the low oxygen levels. Conductivity levels were much higher in the Chapman streams compared to the Barbee streams which could indicate more salt runoff from local streets, but it is not at a level to warrant concern.

Table 14: Average general water quality measures for streams.

Lake Chain	Stream	Flow (cms)	Temperature (deg C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% sat)	pH	Conductivity (mS/cm)
Barbee	Putney Ditch	0.105	15.4	11.3	113.1	8.3	630
	Heron Creek	0.018	16.8	6.3	59.3	7.7	529
	Rattlesnake Creek	0.014	17.5	6.8	68.2	7.8	622
	Shoe Creek	0.001	16.7	3.3	26.7	6.9	311
	Grassy Creek Outflow	0.563	14.6	11.3	110.6	8.2	478
	Grassy Creek Inflow	0.330	13.8	9.4	84.4	7.7	564
	McKenna Creek	0.001	17.8	8.7	93.0	8.3	644
Chapman	Heeter Ditch	0.141	18.7	8.1	83.9	7.8	537
	Highland Drain	0.002	13.4	9.2	87.9	7.9	685
	Arrowhead Drain	0.006	13.1	11.0	101.0	8.0	674
	Crooked Creek	0.033	12.5	10.9	100.3	8.1	684
	Gunter Creek	0.002	19.0	0.6	6.3	7.0	680
	Lozier's Creek	0.004	18.3	6.6	70.2	7.8	674
Barbee	Averages	0.147	16.1	8.1	79.3	7.8	540
Chapman	Averages	0.031	15.8	7.7	74.9	7.8	656

Nutrients and sediments across stream sampling sites showed strong variation (Table 15). Average suspended sediments ranged from only 2.5 mg/L in Heron Creek flowing into Kuhn Lake up to 94.0 mg/L in Shoe Creek which flowed into Banning Lake. The relatively small flow of Shoe Creek likely negates any negative effect on Banning Lake from this sediment transport. Sediments were also seen to be typically higher in inflowing streams compared to the outflowing streams indicating that many sediments likely settle out in these lakes. This same pattern was observed for total phosphorus and total nitrogen indicating uptake of these nutrients in the lakes as expected.

Table 15: Average nutrient and sediment concentrations for streams.

Lake Chain	Stream	Suspended Sediments (mg/L)	Soluble Reactive Phosphorus (mg P/L)	Total Phosphorus (mg P/L)	Ammonia (mg N/L)	Nitrite (mg N/L)	Nitrate (mg N/L)	Total Kjehldahl Nitrogen (mg N/L)	Total Nitrogen (mg N/L)
Barbee	Putney Ditch	12.9	0.050	0.184	0.037	0.024	4.64	0.75	5.42
	Heron Creek	2.5	0.003	0.023	0.028	0.001	0.02	0.77	0.79
	Rattlesnake Creek	20.6	0.012	0.067	0.060	0.010	0.67	1.40	2.08
	Shoe Creek	94.0	0.102	1.677	0.262	0.004	0.18	2.94	3.12
	Grassy Creek Outflow	4.0	0.020	0.065	0.067	0.017	0.48	0.84	1.34
	Grassy Creek Inflow	16.7	0.013	0.091	0.094	0.044	1.85	1.16	3.06
	McKenna Creek	5.3	0.009	0.031	0.022	0.014	7.99	0.36	8.36
Chapman	Heeter Ditch	6.0	0.004	0.044	0.111	0.011	0.46	0.97	1.44
	Highland Drain	6.6	0.036	0.063	0.035	0.003	2.59	0.33	2.92
	Arrowhead Drain	18.6	0.035	0.101	0.048	0.017	4.53	0.62	5.17
	Crooked Creek	16.2	0.033	0.094	0.061	0.021	3.86	0.78	4.66
	Gunter Creek	7.2	0.035	0.115	0.107	0.001	0.01	3.16	3.17
	Lozier's Creek	41.2	0.021	0.118	0.037	0.023	6.23	0.57	6.83
Barbee	Averages	22.3	0.030	0.305	0.082	0.016	2.26	1.18	3.45
Chapman	Averages	16.0	0.027	0.089	0.066	0.013	2.95	1.07	4.03

Stream *E. coli* samples were collected to develop a baseline of *E. coli* levels for later reference (Table 16). Samples collected were over the EPA human health threshold of 235 cfu/100 mL more than 60% of the time such that there are many *E. coli* concerns identified for these nine lakes related to inflowing streams. In the Barbee chain, Putney Ditch is the largest concern since it has relatively high water flow and high *E. coli* levels. Though the Chapman streams had higher overall average *E. coli* levels, their relatively low flow rates lead to a lack of strong warrant for concern.

Table 16: *E. coli* levels from two 30-day geometric mean analyses. All streams are lake inflows except Grassy Creek Outflow and Heeter Ditch which are the only outflowing streams.

Lake Chain	Stream	July Mean (cfu/100 ml)	August Mean (cfu/100 ml)
Barbee	Putney Ditch	700	432
	Heron Creek	267	172
	Rattlesnake Creek	295	339
	Shoe Creek	1339	1200
	Grassy Creek Outflow	13	56
	Grassy Creek Inflow	263	209
	McKenna Creek	1100	1078
Chapman	Heeter Ditch	93	79
	Highland Drain	1783	1180
	Arrowhead Drain	1587	1653
	Crooked Creek	602	681
	Gunter Creek	257	102
	Lozier's Creek	953	804
Barbee	Averages	568	498
Chapman	Averages	879	750

As stated above, annual stream loading estimates for sediments and nutrients were uncertain due to drought conditions over the study period, but some interesting observations could be made despite this. The Barbee streams showed high loads of sediments, phosphorus, and nitrogen in the dominant loading streams (Grassy Creek and Putney Ditch) relative to the largest loading stream (Crooked Creek) in the Chapman chain (Figures 3-8). Future efforts to control sediment and nutrient loading to these two lake chains should consider these major loading streams as top priorities.

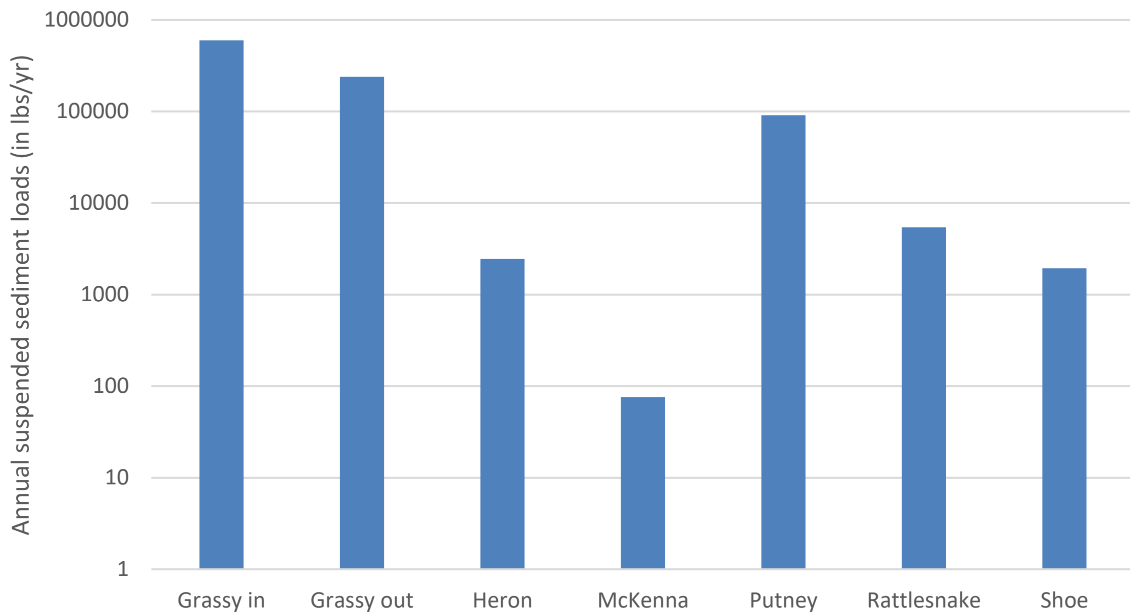

Figure 3: Annual suspended sediment loads (in lbs/yr) for Barbee stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

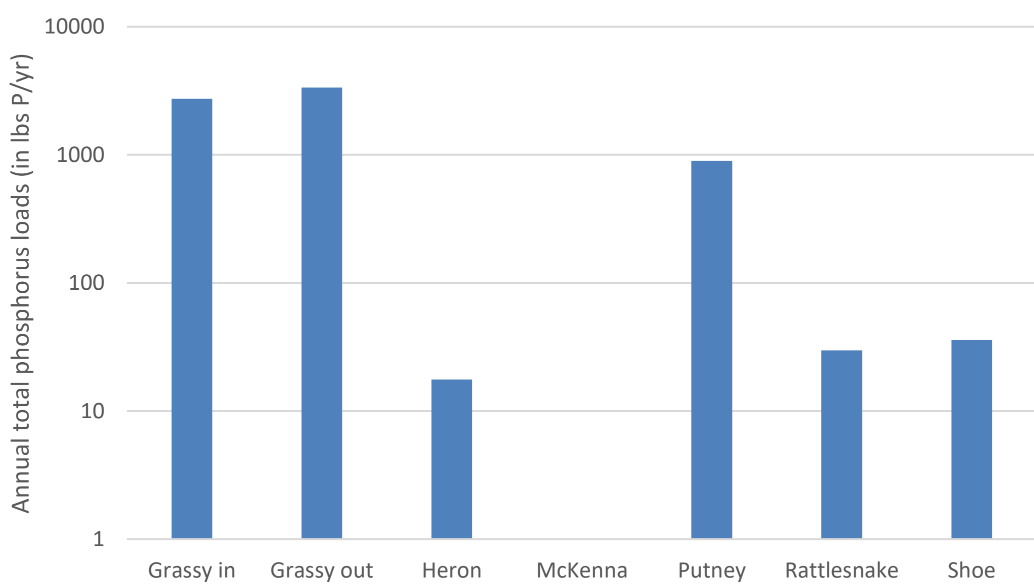

Figure 4: Annual total phosphorus loads (in lbs P/yr) for Barbee stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

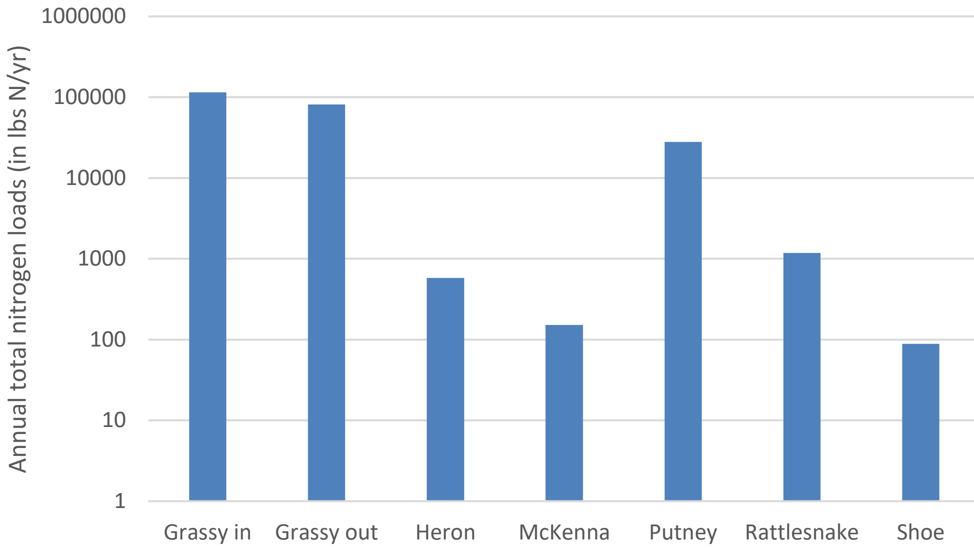

Figure 5: Annual total nitrogen loads (in lbs N/yr) for Barbee stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

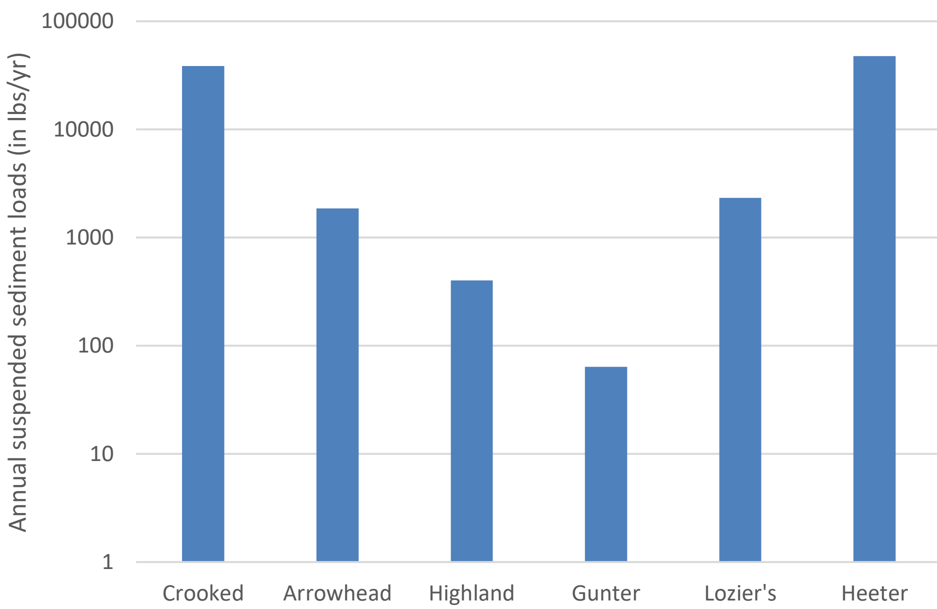

Figure 6: Annual suspended sediment loads (in lbs/yr) for Chapman stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

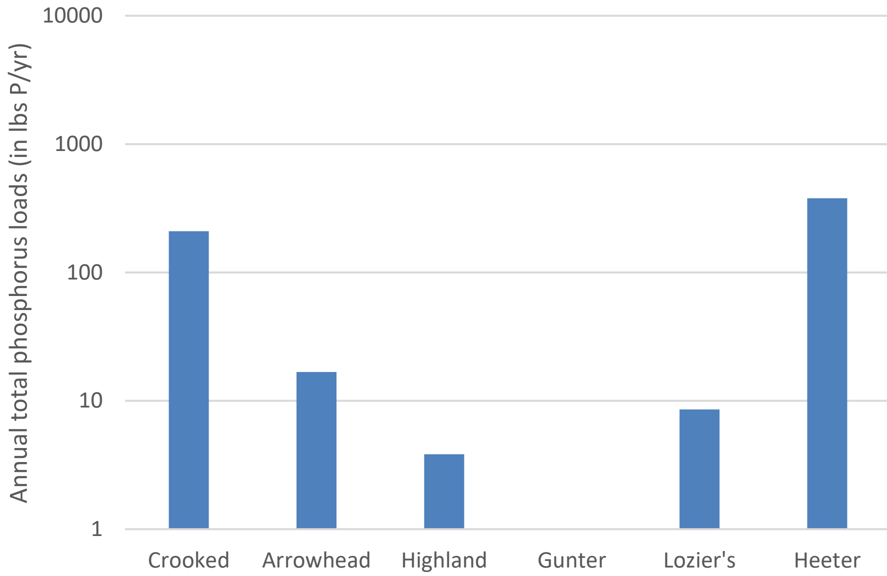

Figure 7: Annual total phosphorus loads (in lbs P/yr) for Chapman stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

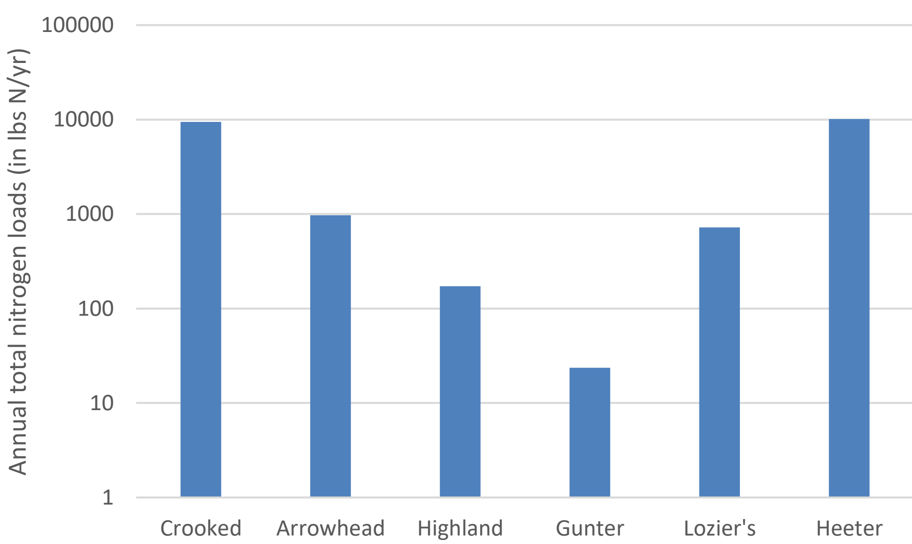

Figure 8: Annual total nitrogen loads (in lbs N/yr) for Chapman stream sites. Note that scale on vertical axis is logarithmic to show smaller and larger loads on same figure.

Recent trends

Several trends and connections were observed in data from the present study as well as in comparison to previous research on the Barbee and Chapman lakes and streams. In the Barbee Lake chain, Kuhn and Sechrist lakes had the highest water clarity. Sechrist Lake has a relatively small watershed size (Richardson and Jones, 2000). This lessens opportunities for nutrients to get into the lake which would grow algae and reduce clarity, and it also lessens opportunities for sediments to enter the lake which would also reduce clarity. Kuhn Lake only had 4% of its shoreline susceptible to erosion and had a relatively large littoral zone (Ewolt, 2010) such that rooted plants have a chance to outcompete algae for available nutrients. These factors could have caused better clarity as well with fewer sediments in the water and less algae. Big Barbee, Little Barbee, and Sawmill lakes had much lower water clarity measures. Big Barbee and Little Barbee lakes had high nutrient levels in the surface water which could have led to high algae populations. These nutrients likely came from Putney Ditch and Grassy Creek which were the inflowing streams with the largest loading of sediments and nutrients. Sawmill Lake also had high nutrient levels in the surface layer which likely led to increased algae growth, reducing water clarity. As stated above, the relatively short residence time of Sawmill Lake makes it more sensitive to inflowing water.

In the Chapman lakes, Big Chapman had the higher water clarity. Like Sechrist Lake in the Barbee chain, Big Chapman Lake has a relatively small watershed size (Giolitto and Jones, 2001). As mentioned above, there is also a large groundwater contribution. These two factors lead to less chance for nutrients and sediments to enter the lake through inflowing streams, increasing lake water clarity. Little Chapman Lake had a substantially lower water clarity compared to Big Chapman Lake. This was likely due to higher phosphorus levels in the surface water which was connected to more algae.

Trends over time were also observed in the Barbee and Chapman lake chains. In the Barbee chain, total phosphorus levels in the surface lake layer have remained mostly consistent from 1990 to 2013 in all the lakes except Kuhn Lake. In Kuhn Lake, total phosphorus was 0.012 mg/L in 1990 (Richardson and Jones, 2000) and had risen to 0.050 by 2013 in the present study. As in the earlier Barbee diagnostic study (Richardson and Jones, 2000), our present research confirms that Grassy Creek and Putney Ditch are major contributors to sediments and nutrients to the Barbee lake chain. The Chapman lakes showed some increase in surface layer total phosphorus concentrations from the early 1990's to 2000 (Giolitto and Jones, 2001), and concentrations from the present study are similar to those observed in 2000. Crooked Creek was confirmed as the highest contributor of sediments and nutrients to the Chapman lakes as well.

Future work

Since the primary purpose of this present study is to establish baseline conditions for the Barbee lake chain before implementation of a public sewer system, a follow-up study repeating the same methodologies and study sites is the highest priority for future work. The Chapman lake chain will need to be included in the follow-up study since it serves as the control for the research. The Center for Lakes & Streams will monitor the progress of the public sewer system construction and usage to determine a suitable time for the follow-up study. Care will be taken to avoid any potential residual construction impacts by delaying the follow-up study as needed, so as to properly analyze a well-functioning and established sewer system.

A secondary purpose of the present study was to provide an overall assessment of the Barbee and Chapman lakes and streams to offer management recommendations. Richardson and Jones (2000) previously made several specific management recommendations for the Barbee lakes and streams which are still valid. Several agencies and organizations have already been working towards these recommendations such as the Barbee Lake Property Owners Association, the Natural Resources Conservation Service, the Kosciusko County Soil and Water Conservation District, and the Tippecanoe Watershed Foundation, but even more efforts are warranted. Since the drainage area of these lakes is mostly agricultural, further adoption of agricultural best management practices is critical for improvement of the Barbee lake chain. An extensive analysis of current best management practices in this drainage area should be completed followed by a feasibility and implementation study to develop a plan for strategic implementation of new practices. These would likely include a conservation system including no-till, cover crops, nutrient management, targeted wetland restoration, two-stage ditches, and edge-of-field filter strips. The present study also demonstrates particular concern for Kuhn Lake. It had the highest water clarity of any of the nine lakes in the study, and it also is increasing in surface total phosphorus levels the most. While the primary focus should be on the streams contributing the most to the Barbee chain (Grassy Creek and Putney), separate efforts should be undertaken to address loading from Rattlesnake and Heron Creeks as well as nutrient loading from around the lake itself.

Chapman lakes and streams have also had efforts towards improvement by Chapman Lakes Conservation Association, the Chapman Lakes Foundation, the Natural Resources Conservation Service, and the Kosciusko County Soil and Water Conservation District. Previous management recommendations by Giolitto and Jones (2001) are also still valid presently. The most common land use in the Chapman lakes drainage area was agriculture, so agricultural best management practices are likely the most effective management tool to improve and protect Big Chapman and Little Chapman lakes. To be sure, an analysis of current agricultural practices followed by a study to determine the most effective best management practice implementation strategy is warranted. This may include several practices already identified in the earlier diagnostic study (Giolitto and Jones, 2001), including bank and channel erosion techniques and wetland restoration since bank erosion in stream channels was identified as a problem in the present study. More recently adopted practices such as cover crops and two-stage ditches likely have promise in the Chapman lakes drainage area as well. These improvements should be focused on the Crooked Creek drainage area since this stream was identified by the present and previous diagnostic study as being most critical to lake improvement.

Conclusion

Several important results were identified in the present study. About half of all shoreline in the Barbee and Chapman lake chains was composed of concrete seawalls. Though relatively small proportions of the lake chain shorelines were eroding, the high occurrence of concrete seawalls across the chains likely allowed eroded sediment that was present to be continually transported around the lakes during windy conditions and times of high boat traffic. Both lake chains had just less than half of their surface area being made up of shallow littoral zones where rooted plants grew. Lakes in the Barbee and Chapman chains have few invasive species of rooted plants compared to native species, but these invasive species are still problematic. Eurasian water-milfoil (*Myriophyllum spicatum*) and curly-leaved pondweed (*Potamogeton crispus*) are considered the two most problematic invasive species in both the Chapman lake chain and in the Barbee lake chain. Stream QHEI results showed wide variation in total index scores and in individual components of these physical characteristics. Lakes generally showed higher nutrient concentrations in hypolimnion compared to epilimnion indicating a combination of algae uptake near the surface and internal loading of nutrients to the lake from the sediment near the bottom. Lake *E. coli* samples were collected along shorelines of each lake, and all samples collected were well below the EPA human health threshold of 235 cfu/100 mL such that there were no *E. coli* concerns identified within these nine lakes with this snapshot sampling effort. However, stream *E. coli* samples were collected and were over the health threshold more than 60% of the time such that there are many concerns identified related to inflowing streams. The Barbee streams showed high loads of sediments, phosphorus, and nitrogen in the dominant loading streams (Grassy Creek and Putney Ditch) relative to the largest loading stream (Crooked Creek) in the Chapman chain.

Since the primary purpose of this present study is to establish baseline conditions for the Barbee lake chain before implementation of a public sewer system, a follow-up study repeating the same methodologies and study sites is the highest priority for future work. A secondary purpose of the present study was to provide an overall assessment of the Barbee and Chapman lakes and streams to offer management recommendations. Previous management recommendations by earlier diagnostic studies of each lake chain are still valid presently. The most common land use in both lake chain drainage areas was agriculture, so agricultural best management practices are likely the most effective management tool to improve and protect Barbee and Chapman lakes. To be sure, an analysis of current agricultural practices followed by a study to determine the most effective best management practice implementation strategy is warranted. This strategy may include several practices already identified in the earlier diagnostic study and would likely include a conservation system including no-till, cover crops, nutrient management, targeted wetland restoration, two-stage ditches, and edge-of-field filter strips.

References

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Updated Feb. 2020 to correct an issue with stream names.