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NUTRIENT CHEMISTRY OF MICHIGAN’S MAUMEE RIVER TRIBUTARIES
BEAN CREEK AND ST. JOSEPH RIVER WATERSHEDS
HILLSDALE AND LENAWEE COUNTIES
2016-2018

MAY 2020

MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
WATER RESOURCES DIVISION

LIMNOTECH

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Great Lakes
RESTORATION

Cover Photos:

Photographs from the study watersheds during wet weather conditions: East Branch St. Joseph River (Station C - *top left*); Lime Lake Inlet (Station N - *top right*); Laird Creek (Station E - *bottom left*); and Lime Creek (Station I and its automated sampler - *bottom right*).

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INTRODUCTION

While harmful algae blooms were mostly absent in Lake Erie from the 1980s until the mid-late 1990s, the Western Lake Erie Basin has frequently experienced persistent and intense cyanobacteria blooms in recent years (State of Michigan, 2018; Wilson et al., 2019; National Oceanic and Atmospheric Administration-Great Lakes Environmental Research Laboratory [NOAA-GLERL], 2019). The Maumee River system, which drains southern Michigan, northeastern Indiana, and northwestern Ohio (Greeman, 1994), is one of the largest contributors of nutrients (e.g., total phosphorus [TP] and dissolved reactive phosphorus [DRP]) that feed algae blooms and anoxic regions within Lake Erie (Annex 4 Objectives and Targets Task Team [Annex 4 OTTT], 2015; Maccoux et al., 2016; Muenich et al., 2016). Modeling efforts have been made on parameters such as phosphorus and various best management practices (BMP) in the Maumee River watershed (Scavia et al., 2016) and its Bean/Tiffin subwatershed (Limnotech, 2013); actual water quality sampling in the region, prior to this study, has been limited. This report summarizes a three-year study to gather water samples and other information to enhance the State of Michigan’s understanding of stream nutrient conditions in its portion of the Maumee River watershed. It includes methods used, key results observed, and conclusions made during the study. More detailed information (e.g., introduction, background, study areas, various forms of phosphorus, figure creation, road crossings, latitude/longitude, STORET numbers, sampling, equipment, methods, flow measurement efforts, results, and statistics computation) are presented in Appendix I.

The primary objectives of this study were to:

1) Monitor nutrient concentrations (especially TP and DRP[1]) throughout Michigan’s portion of the upper Maumee River watershed (mainly the St. Joseph River and Bean Creek watersheds), particularly near where those rivers leave Michigan and flow into Ohio, under a variety of spring[2] flow conditions.
2) Identify subwatersheds where nutrient concentrations (especially TP and DRP) are high relative to other subwatersheds within Michigan’s St. Joseph River and Bean Creek watershed areas.
3) Make this information available to help prioritize subwatersheds where future nutrient reduction efforts should be focused.

METHODS OVERVIEW

Water quality samples and streamflow measurements were collected under a variety of spring flow conditions throughout the St. Joseph River and Bean Creek (i.e., upper Tiffin River) watersheds. While low flow stream conditions were sometimes sampled, an effort was made to capture wet-weather events to characterize conditions when nutrients concentrations and loads were expected to be higher. Grab sample techniques were used at 16 locations in 2016, and then increased to 20 locations in 2017-2018. In addition to grab sampling, 5 of these locations were sampled more intensively during some storm events using automated samplers.

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[1] In this report, EGLE, Water Resources Division, recognizes that while DRP, soluble reactive phosphorus, and dissolved orthophosphate values are not exactly the same, they are often considered to be closely approximate.

[2] “Spring” was defined as March 1-July 31 by the Annex 4 OTTT (2015) and was the season prioritized for research, per the State of Michigan (2018) and Annex 4 OTTT (2015), as opposed to a full calendar year or “water year” (October 1-September 30) time frame (Appendix II).

In 2016, water chemistry analysis was limited to phosphorus (TP and DRP for grab samples; TP only for samples collected by automated samplers). In 2017-2018, more parameters were added (i.e., nitrate, nitrite, ammonia, total Kjeldahl nitrogen, and total suspended solids for both grab and automated sampling; total orthophosphate for automated samplers). Note that orthophosphate, not DRP, was added to the automated sampler analysis in 2017-2018 due to filtering timeframe restrictions for DRP (40 CFR 136). All water sample parameters were analyzed by the Michigan Department of Environment, Great Lakes, and Energy (EGLE[3]), Environmental Laboratory, in Lansing, Michigan, except for turbidity (measured only in 2016), which was analyzed by EGLE staff (Jeff Varricchione) using a Hach turbidimeter at the EGLE equipment warehouse in Lansing, Michigan. Additional water quality parameters (water temperature, specific conductance, pH, and dissolved oxygen) were measured in the field using YSI sondes during all years.

RESULT HIGHLIGHTS AND DISCUSSION

Sampling Locations

Sampling locations are shown in Figure 1 and listed in Tables 1-3.

Note regarding stream names:

1) There are two Silver Creeks (i.e., Stations F and G in the St. Joseph River watershed and Station K in the Bean Creek watershed).
2) There is a St. Joseph Creek (Station L) in the Bean Creek watershed.

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[3] EGLE was known as the Michigan Department of Environmental Quality (MDEQ) prior to April 2019.

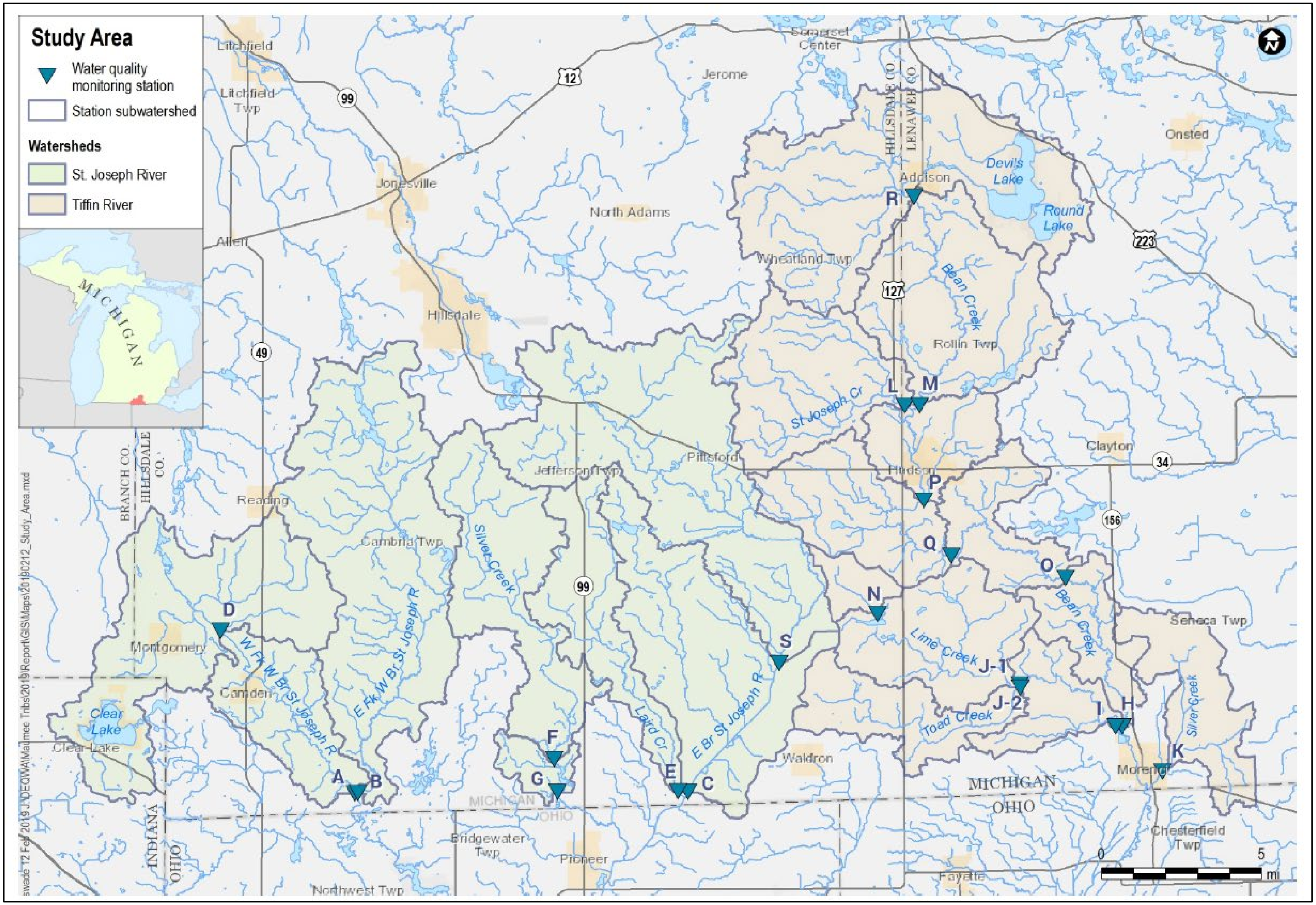

Figure 1. Upper Maumee River Tributaries – (St. Joseph River and Bean Creek-Tiffin River) watersheds and monitoring locations map (Appendix I).

Highlights of Results from this Study

Tables and figures in this section summarize key information (Appendix I) such as ranking of phosphorus concentrations and instantaneous loads[4] plus important land use characteristics (Tables 1, 2, and 3; Figures 2-8) among the various study site locations (stations) and their respective cumulative subwatersheds.

Because the number of sampling stations and parameters analyzed were more limited in 2016, and because large storms (especially during grab sampling events) were better captured in 2017-2018 sampling (Appendix I; Figures 3-1 and 3-2), the emphasis of this report is on the 2017-2018 data. Large storm events are of great interest because, especially for nonpoint source particulate pollutants, it "is not uncommon for 80 to 90% or more of the annual load to be delivered during the 10% of the time with the highest fluxes" (i.e., snowmelt and storm runoff events) (Richards, 1998).

Grab Samples

In 2016, TP concentrations among the 16 sampling locations were generally similar except for Station F (Silver Creek, St. Joseph River watershed) and Stations O and H (mainstem Bean Creek) (Appendix III). Stations F, O, and H had lower concentrations relative to other stations during all grab sampling events in that year (the highest of which was 0.098 mg/L at Station F [Silver Creek] on June 23, 2016). The largest TP concentrations observed during 2016 grab sampling events were at Station A (West Fork West Branch St. Joseph River on June 23, 2016) and Station I (Lime Creek on July 14, 2016) with concentrations of 0.320 mg/L and 0.310 mg/L, respectively. In comparison, likely due to the improved capture of larger storm events, the largest concentrations measured in 2017-2018 were much higher (more than 6 times higher) than the largest concentrations in 2016. The two highest concentrations were 2.1 mg/L and 1.3 mg/L at Station K (Silver Creek; Bean Creek watershed; March 1, 2018) and Station J-2 (Toad Creek; March 1, 2018), respectively (Figure 2).

Many of the stations that generally had low TP concentrations in 2016 also had low DRP concentrations relative to other stations that year: Silver Creek (Stations F and G; St. Joseph River watershed) and mainstem Bean Creek (Stations O and H). Differences in DRP between 2016 and 2017-2018 were not as stark as for TP. The largest DRP concentration in 2016 grab sampling events was 0.130 mg/L at Station I (Lime Creek on July 14, 2016); the largest concentration in 2017-2018 was 0.200 mg/L at Station J-2 (Toad Creek on March 1, 2018), which was only 1.5 times higher than the largest value in 2016.

The grab sampling data collected between 2017-2018 at all 20 stations appeared to show a pattern of where the highest relative DRP and TP concentrations were occurring during this study (Tables 1 and 2; Figures 2-8). (Note that there were some tied rankings within Tables 1 and 2.) Certain subwatersheds had many of the top rankings for 75th percentile and 100th percentile (i.e., maximum) DRP and TP concentrations (Tables 1 and 2). The Lime Creek

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[4] Samples collected during times of increased runoff provide valuable information with respect to nutrient loading. However, only very coarse, instantaneous load estimates are discussed in this report for between-station comparison purposes since it is generally recommended there be a higher frequency of flow and nutrient sampling in order to accurately estimate loads for time scales such as seasonal [e.g., spring] or annual [e.g., Richards, 1998; Betanzo et al., 2015; Reutter, 2016; USEPA, 2018]. When examining these instantaneous loading rates, they should only be viewed as snapshots in time within the study area, and are likely not comparable to seasonal or annual loading rates estimated by other studies or organizations (e.g., in other parts of the Lake Erie watershed).

(Stations J-2, N, J-1, and I) and Silver Creek (Station K) subwatersheds of Bean Creek watershed were all ranked between 1st and 7th out of 20 stations. In fact, Station K had the highest TP value observed in this study, 2.1 mg/L, regardless of whether the sample was collected by grab or automated technique (Tables 2 and 3). Patterns were a little less clear in the St. Joseph River watershed, but Stations S and C (East Branch) and D and A (West Branch) also had some high-ranking concentrations (i.e., in the top 7). Patterns for stations having the lowest relative concentrations across the study region were a little clearer. Stations F and G (both in Silver Creek, upstream and downstream of Merry Lake) in the St. Joseph River watershed, and Stations R and H in the mainstem Bean Creek watershed, generally had the lowest ranked 75th percentile and 100th percentile DRP and TP concentrations in the study (with the exception of the 100th percentile TP concentration for Station F, which ranked 13th overall) (Tables 1 and 2; Figures 2-8). Other mainstem Bean Creek stations (M, O, P, and Q) and St. Joseph Creek (Station L in the Bean Creek watershed) generally had relatively lower 75th percentile and 100th percentile concentrations of DRP and TP (i.e., ranked $\geq$ 11th).

The Lime Creek and Silver Creek (Bean Creek watershed) stations mentioned above for high phosphorus concentrations generally were not ranked the highest for average instantaneous loads, although Stations J-1 and J-2 did rank 5th and 6th for DRP load and 5th and 7th for TP load. Since instantaneous load is the product of *flow* times *concentration*, most streams having a lower ranking for instantaneous loads was a result of them being smaller-order streams with relatively small flows.

Table 1. Overall summary and ranking of grab-sample dissolved reactive phosphorus (DRP) concentrations, loadings, and key cumulative subwatershed land characteristics among the study stations. A rank of #1 meant having the highest concentration, instantaneous load, or land characteristic, and bold font was used to highlight stations with the highest-ranked values. L.R., %ile, and t indicate (instantaneous) loading rate[4], percentile, and tie-in-ranking, respectively. Data summarized in this table are for years 2017-2018 for comparability reasons since only 16 of the 20 "grab" stations were sampled in 2016.

Watershed	Station	River Name	75th %ile (mg/L)	75th %ile [Rank]	100th %ile (mg/L)	100th %ile [Rank]	Avg. L.R. (lbs./day)	Avg. L.R. [Rank]	% Agricultural Land (%)	% Agricultural Land [Rank]	Total Area of Documented, Potential Manure Spreading Fields **	% Area Comprised of Manure Spreading Fields (%)**	% Area Comprised of Manure Spreading Fields [Rank]**	Has Biosolids Land Application Sites	Has WWTPs or WWSLs	% Being Low Permeability Soils (C, C/D, D) (%)	% Being Low Permeability Soils (C, C/D, D) [Rank]	Subwatershed Avg. Slope (%)	Subwatershed Avg. Slope [Rank]	Total Area Draining to Station (acres)	Total Area Draining to Station [Rank]
		Parameter:	**DRP**	**DRP**	**DRP**	**DRP**	**DRP**	**DRP**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumulative**	**Cumu-lative**	**Cumulative**	**Cumulative**	**Cumulative**
		Sampling Event Type:	**Grab**	**Grab**	**Grab**	**Grab**	**Grab**	**Grab**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**	**Subwatershed**
BEAN-TIFFIN	J-2	Toad Creek	**0.130**	**[1] t**	**0.200**	**[1]**	**26**	**[6]**	**85%**	**[3]**	**1,277**	**16%**	**[5]**	Yes***		**96.6**	**[1]**	3.0	[18]	7,955	[19]
BEAN-TIFFIN	K	Silver Creek	**0.130**	**[1] t**	**0.150**	**[3]**	15	[12] t	**86%**	**[2]**	**2,311**	**27%**	**[3]**			**85.8**	**[3]**	2.0	[20]	8,446	[18]
BEAN-TIFFIN	N	Lime Lake Inlet	**0.110**	**[3]**	**0.170**	**[2]**	4	[18] t	**88%**	**[1]**	**783**	**35%**	**[2]**	Yes***		**77.5**	**[5]**	2.5	[19]	2,245	[20]
ST. JOSEPH	S	E. Br. St. Joseph River	**0.084**	**[4]**	**0.140**	**[4]**	24	[7]	56%	[17]	1,148	4%	[13] t	Yes***	Yes***	35.1	[17]	**5.9**	**[1] t**	30,466	[9]
BEAN-TIFFIN	J-1	Lime Creek	**0.083**	**[5]**	**0.110**	**[7] t**	**27**	**[5]**	**80%**	**[4]**	**5,063**	**36%**	**[1]**	Yes***	Yes***	**84.0**	**[4]**	3.6	[16]	13,893	[15]
BEAN-TIFFIN	I	Lime Creek	**0.072**	**[6]**	**0.110**	**[7] t**	21	[9]	**80%**	**[4]**	**7,124**	**26%**	**[4]**	Yes***	Yes	**87.0**	**[2]**	3.5	[17]	27,271	[11]
ST. JOSEPH	B	E. Fk. W. Br. St. Joseph River	0.054	[7]	0.083	[11]	23	[8]	65%	[7]	0	0%	[20]			42.0	[14]	4.8	[15]	31,108	[8]
ST. JOSEPH	C	E. Br. St. Joseph River	0.052	[8]	**0.120**	**[5] t**	**52**	**[1]**	63%	[9]	3,824	7%	[12]	Yes	Yes	54.0	[7]	5.0	[13] t	51,116	[5]
ST. JOSEPH	D	W. Fk. W. Br. St. Joseph River	0.046	[9] t	**0.120**	**[5] t**	13	[14]	61%	[10]	411	2%	[15] t	Yes***	Yes***	42.7	[12]	5.0	[13] t	22,606	[12]
ST. JOSEPH	A	W. Fk. W. Br. St. Joseph River	0.046	[9] t	0.090	[9]	20	[10]	59%	[12]	445	1%	[17] t	Yes	Yes***	53.8	[8]	**5.5**	**[5] t**	31,692	[7]
BEAN-TIFFIN	Q	Bean Creek	0.038	[11]	0.050	[14]	**40**	**[2]**	58%	[15]	9,281	12%	[9]	Yes***	Yes	40.1	[15]	5.4	[8] t	77,518	[3]
ST. JOSEPH	E	Laird Creek	0.037	[12]	0.089	[10]	9	[15]	**67%**	**[6]**	61	1%	[17] t			**62.5**	**[6]**	5.2	[12]	10,275	[17]
BEAN-TIFFIN	P	Bean Creek	0.036	[13]	0.038	[19]	17	[11]	56%	[17]	7,490	11%	[10]	Yes	Yes***	36.4	[16]	5.4	[8] t	67,002	[4]
BEAN-TIFFIN	L	St. Joseph Creek	0.031	[14] t	0.067	[12]	6	[17]	64%	[8]	**1,777**	**13%**	**[6] t**	Yes***		32.8	[19]	**5.5**	**[5] t**	13,448	[16]
BEAN-TIFFIN	O	Bean Creek	0.031	[14] t	0.053	[13]	**36**	**[3]**	58%	[15]	**11,047**	**13%**	**[6] t**	Yes***	Yes	43.2	[11]	**5.5**	**[5] t**	84,438	[2]
BEAN-TIFFIN	M	Bean Creek (Fitts Creek*)	0.031	[14] t	0.046	[15]	15	[12] t	54%	[19]	4,002	9%	[11]	Yes***	Yes***	33.6	[18]	5.4	[8] t	47,059	[6]
BEAN-TIFFIN	H	Bean Creek	0.027	[17]	0.040	[18]	**30**	**[4]**	59%	[12]	**12,018**	**13%**	**[6] t**	Yes	Yes	45.0	[10]	5.4	[8] t	90,291	[1]
BEAN-TIFFIN	R	Bean Creek	0.024	[18]	0.045	[16]	7	[16]	51%	[20]	1,034	4%	[13] t	Yes***		28.8	[20]	**5.6**	**[4]**	28,825	[10]
ST. JOSEPH	G	Silver Creek	0.021	[19]	0.044	[17]	---	---	59%	[12]	311	2%	[15] t	Yes***		48.1	[9]	**5.7**	**[3]**	17,826	[13]
ST. JOSEPH	F	Silver Creek	0.020	[20]	0.037	[20]	4	[18] t	60%	[11]	159	1%	[17] t	Yes***		42.3	[13]	**5.9**	**[1] t**	15,694	[14]

* Some maps [e.g., DeLorme, 2009] name the outlet from Devils Lake that then enters Addison Millpond as Fitts Creek, while some other sources name an even longer stretch of this stream as Fitts Creek. For example, the hydrography layer of the Michigan Geographic Framework (Version 17a) names the reach beginning as the outlet from Devils Lake down to the stream's eventual confluence with St. Joseph Creek near Beecher Road, as "Fitts Creek." USGS topographic maps (1962, 2017), however, name the stream from Devils Lake all the way down to the stream's eventual confluence with St. Joseph Creek as Bean Creek; the present report uses this naming convention.

** Manure spreading fields included in the tables and figures in this report are all potential manure application fields[8] listed in the Comprehensive Nutrient Management Plan as of January 18, 2019.

*** Biosolid sites or Wastewater Treatment Plant (WWTP)/Wastewater Sewage Lagoon (WWSL) facilities were in the immediate subwatershed (as opposed to being anywhere in the cumulative subwatershed) of that station.

Table 2. Overall summary and ranking of grab-sample total phosphorus (TP) concentrations, loadings, and key cumulative subwatershed land characteristics amongst the study stations. A rank of # 1 meant having the highest concentration, instantaneous load, or land characteristic, and bold font was used to highlight stations with the highest-ranked values. L.R., %ile, and t indicate (instantaneous) loading rate[4.], percentile, and tie-in-ranking, respectively. Data summarized in this table are for years 2017-2018 for comparability reasons since only 16 of the 20 "grab" stations were sampled in 2016.

Watershed	Station	River Name	75th %ile (mg/L)	75th %ile [Rank]	100th %ile (mg/L)	100th %ile [Rank]	Avg. L.R. (lbs./day)	Avg. L.R. [Rank]	% Agricultural Land (%)	% Agricultural Land [Rank]	Total Area of Documented, Potential Manure Spreading Fields **	% Area Comprised of Manure Spreading Fields (%)**	% Area Comprised of Manure Spreading Fields [Rank]**	Has Biosolids Land Application Sites	Has WWTPs or WWSLs	% Being Low Permeability Soils (C, C/D, D) (%)	% Being Low Permeability Soils (C, C/D, D) [Rank]	Subwatershed Avg. Slope (%)	Subwatershed Avg. Slope [Rank]	Total Area Draining to Station (acres)	Total Area Draining to Station [Rank]
		Parameter:	TP	TP	TP	TP	TP	TP	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative
		Sampling Event Type:	Grab	Grab	Grab	Grab	Grab	Grab	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed
BEAN-TIFFIN	J-2	Toad Creek	**0.645**	**[1] t**	**1.300**	**[2]**	152	[7]	**85%**	**[3]**	**1,277**	**16%**	**[5]**	Yes***		**96.6**	**[1]**	3.0	[18]	7,955	[19]
BEAN-TIFFIN	N	Lime Lake Inlet	**0.645**	**[1] t**	**0.910**	**[4]**	25	[19]	**88%**	**[1]**	**783**	**35%**	**[2]**	Yes***		**77.5**	**[5]**	2.5	[19]	2,245	[20]
BEAN-TIFFIN	K	Silver Creek	**0.443**	**[3]**	**2.100**	**[1]**	145	[8]	**86%**	**[2]**	**2,311**	**27%**	**[3]**			**85.8**	**[3]**	2.0	[20]	8,446	[18]
BEAN-TIFFIN	J-1	Lime Creek	**0.423**	**[4]**	**0.870**	**[5]**	**165**	**[5]**	**80%**	**[4]**	**5,063**	**36%**	**[1]**	Yes***	Yes***	**84.0**	**[4]**	3.6	[16]	13,893	[15]
BEAN-TIFFIN	I	Lime Creek	**0.418**	**[5]**	0.450	[12]	98	[13]	**80%**	**[4]**	**7,124**	**26%**	**[4]**	Yes***	Yes	**87.0**	**[2]**	3.5	[17]	27,271	[11]
ST. JOSEPH	C	E. Br. St. Joseph River	**0.403**	**[6]**	0.600	[9]	**293**	**[1]**	63%	[9]	3,824	7%	[12]	Yes	Yes	54.0	[7]	5.0	[13] t	51,116	[5]
ST. JOSEPH	E	Laird Creek	0.360	[7]	0.740	[7]	83	[14]	**67%**	**[6]**	61	1%	[17] t			**62.5**	**[6]**	5.2	[12]	10,275	[17]
ST. JOSEPH	S	E. Br. St. Joseph River	0.328	[8]	0.630	[8]	121	[11]	56%	[17]	1,148	4%	[13] t	Yes***	Yes***	35.1	[17]	**5.9**	**[1] t**	30,466	[9]
ST. JOSEPH	D	W. Fk. W. Br. St. Joseph River	0.315	[9]	**0.830**	**[6]**	135	[9]	61%	[10]	411	2%	[15] t	Yes***	Yes***	42.7	[12]	5.0	[13] t	22,606	[12]
ST. JOSEPH	A	W. Fk. W. Br. St. Joseph River	0.233	[10]	**1.000**	**[3]**	**155**	**[6]**	59%	[12]	445	1%	[17] t	Yes	Yes***	53.8	[8]	**5.5**	**[5] t**	31,692	[7]
BEAN-TIFFIN	P	Bean Creek	0.198	[11]	0.290	[16]	131	[10]	56%	[17]	7,490	11%	[10]	Yes	Yes***	36.4	[16]	5.4	[8] t	67,002	[4]
BEAN-TIFFIN	O	Bean Creek	0.178	[12]	0.490	[11]	**266**	**[3]**	58%	[15]	**11,047**	**13%**	**[6] t**	Yes***	Yes	43.2	[11]	**5.5**	**[5] t**	84,438	[2]
BEAN-TIFFIN	Q	Bean Creek	0.175	[13]	0.380	[14]	**277**	**[2]**	58%	[15]	9,281	12%	[9]	Yes***	Yes	40.1	[15]	5.4	[8] t	77,518	[3]
BEAN-TIFFIN	L	St. Joseph Creek	0.163	[14]	0.330	[15]	29	[18]	64%	[8]	**1,777**	**13%**	**[6] t**	Yes***		32.8	[19]	**5.5**	**[5] t**	13,448	[16]
ST. JOSEPH	B	E. Fk. W. Br. St. Joseph River	0.160	[15]	0.500	[10]	108	[12]	65%	[7]	0	0%	[20]			42.0	[14]	4.8	[15]	31,108	[8]
BEAN-TIFFIN	H	Bean Creek	0.143	[16]	0.240	[18] t	**187**	**[4]**	59%	[12]	**12,018**	**13%**	**[6] t**	Yes	Yes	45.0	[10]	5.4	[8] t	90,291	[1]
BEAN-TIFFIN	M	Bean Creek (Fitts Creek*)	0.128	[17] t	0.250	[17]	80	[15]	54%	[19]	4,002	9%	[11]	Yes***	Yes***	33.6	[18]	5.4	[8] t	47,059	[6]
ST. JOSEPH	G	Silver Creek	0.128	[17] t	0.240	[18] t	---		59%	[12]	311	2%	[15] t	Yes***		48.1	[9]	**5.7**	**[3]**	17,826	[13]
ST. JOSEPH	F	Silver Creek	0.099	[19]	0.390	[13]	40	[16]	60%	[11]	159	1%	[17] t	Yes***		42.3	[13]	**5.9**	**[1] t**	15,694	[14]
BEAN-TIFFIN	R	Bean Creek	0.098	[20]	0.140	[20]	32	[17]	51%	[20]	1,034	4%	[13] t	Yes***		28.8	[20]	**5.6**	**[4]**	28,825	[10]

* Some maps [e.g., DeLorme, 2009] name the outlet from Devils Lake that then enters Addison Millpond as Fitts Creek, while some other sources name an even longer stretch of this stream as Fitts Creek. For example, the hydrography layer of the Michigan Geographic Framework (Version 17a) names the reach beginning as the outlet from Devils Lake down to the stream's eventual confluence with St. Joseph Creek near Beecher Road, as "Fitts Creek." USGS topographic maps (1962, 2017), however, name the stream from Devils Lake all the way down to the stream's eventual confluence with St. Joseph Creek as Bean Creek; the present report uses this naming convention.

** Manure spreading fields included in the tables and figures in this report are all potential manure application fields[8] listed in the Comprehensive Nutrient Management Plan as of January 18, 2019.

*** Biosolid sites or WWTP/WWSL facilities were in the immediate subwatershed (as opposed to being anywhere in the cumulative subwatershed) of that station.

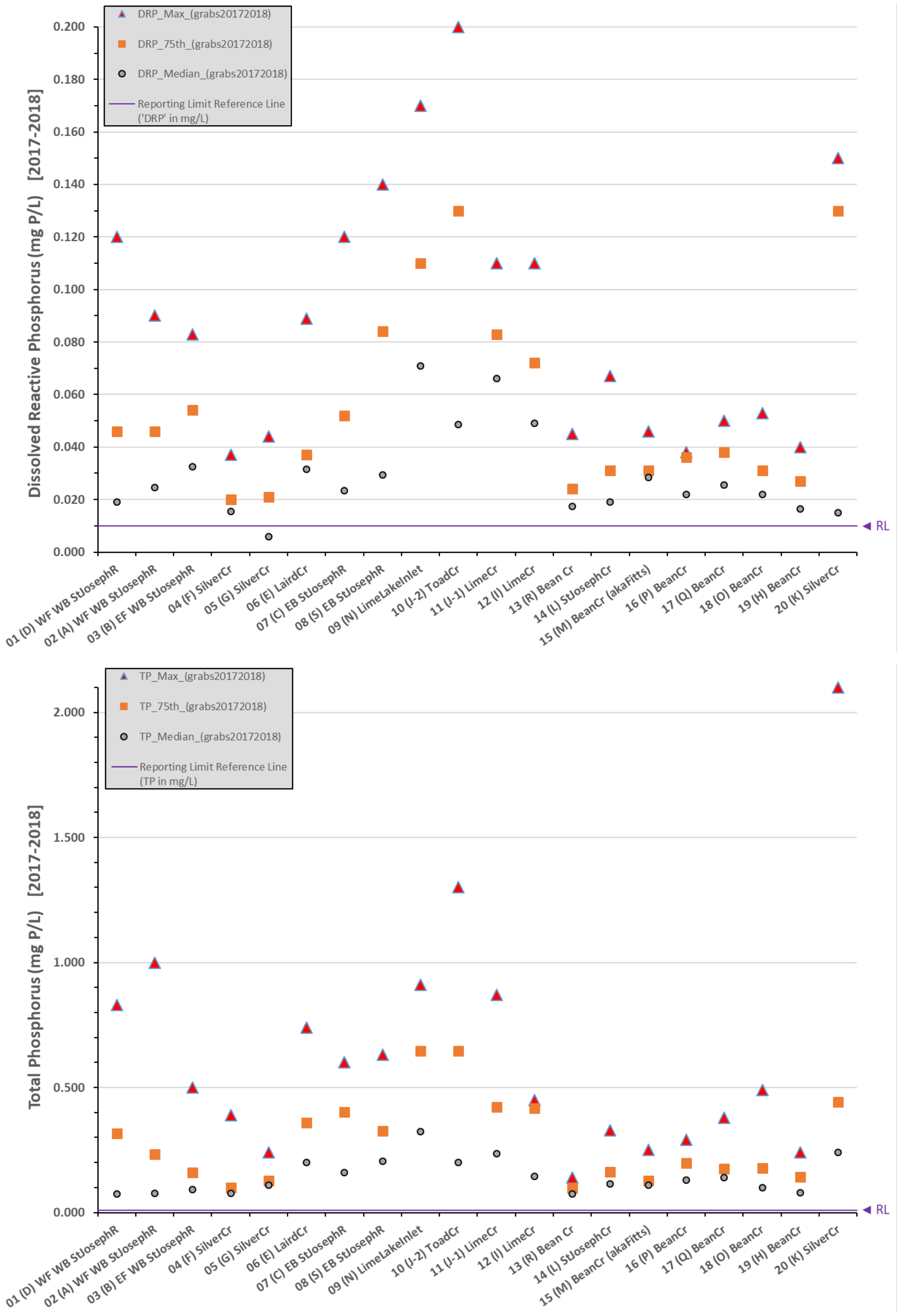

Figure 2. Statistical summary of dissolved reactive phosphorus (top) and total phosphorus (bottom) results from 2017-2018 grab sampling. Sites, ordered from left to right, are moving roughly from west to east across the study area.

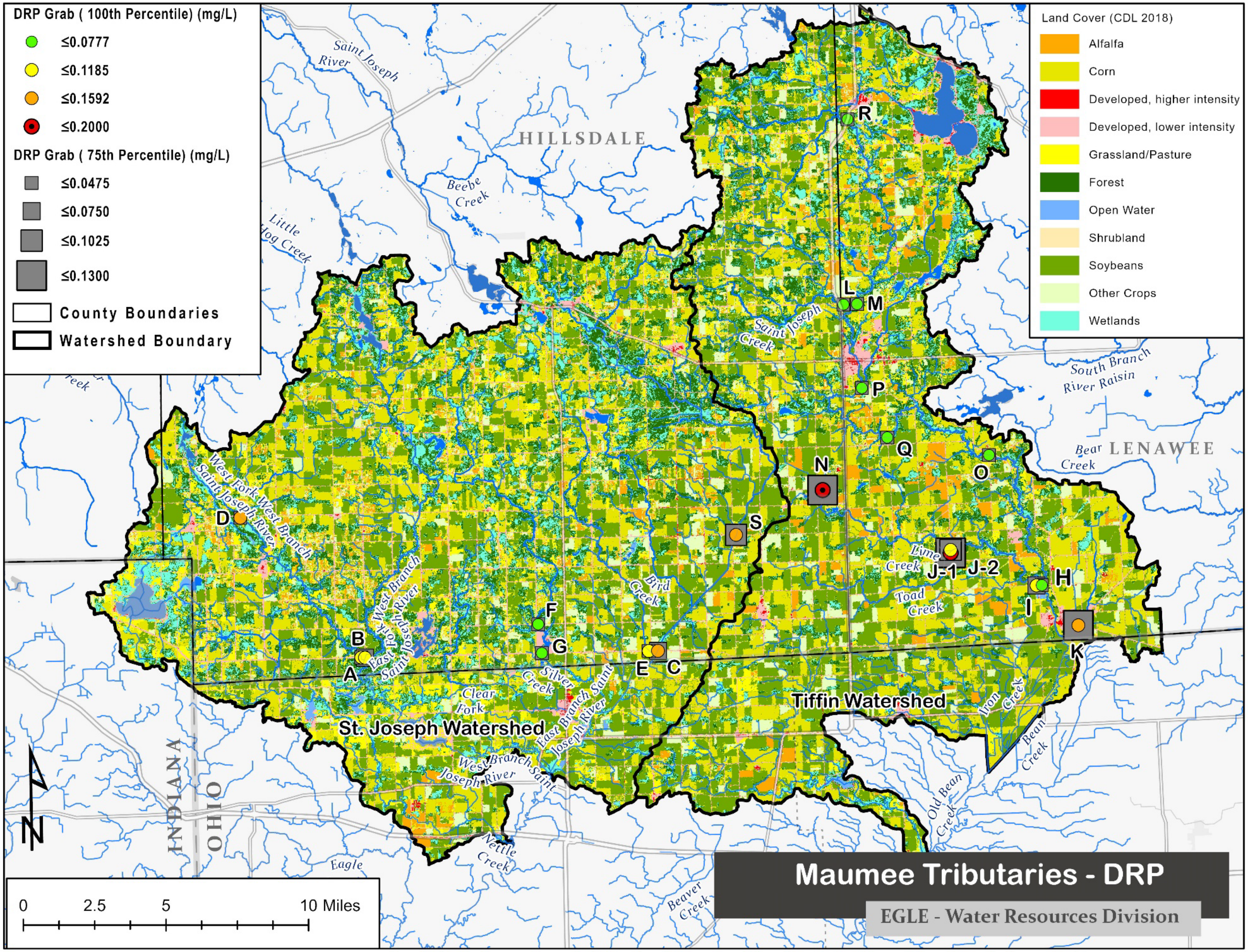

Figure 3. Map of 75th percentile and 100th percentile DRP values for 2017-2018 relative to land cover (U.S. Department of Agriculture [USDA], 2019) in the St. Joseph River and Bean Creek-Tiffin River watersheds.

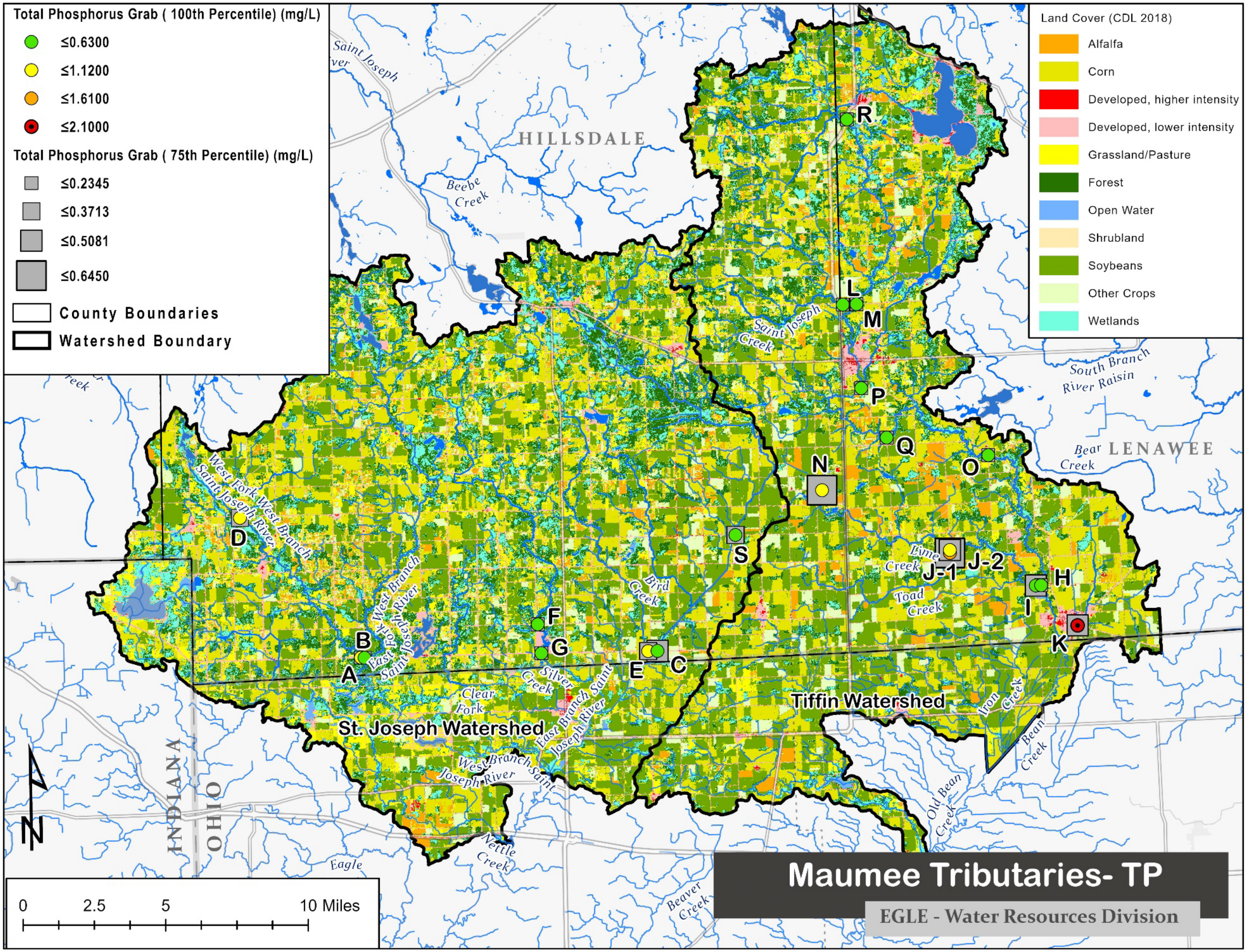

Figure 4. Map of 75th percentile and 100th percentile TP values for 2017-2018 relative to land cover (USDA, 2019) in the St. Joseph River and Bean Creek-Tiffin River watersheds.

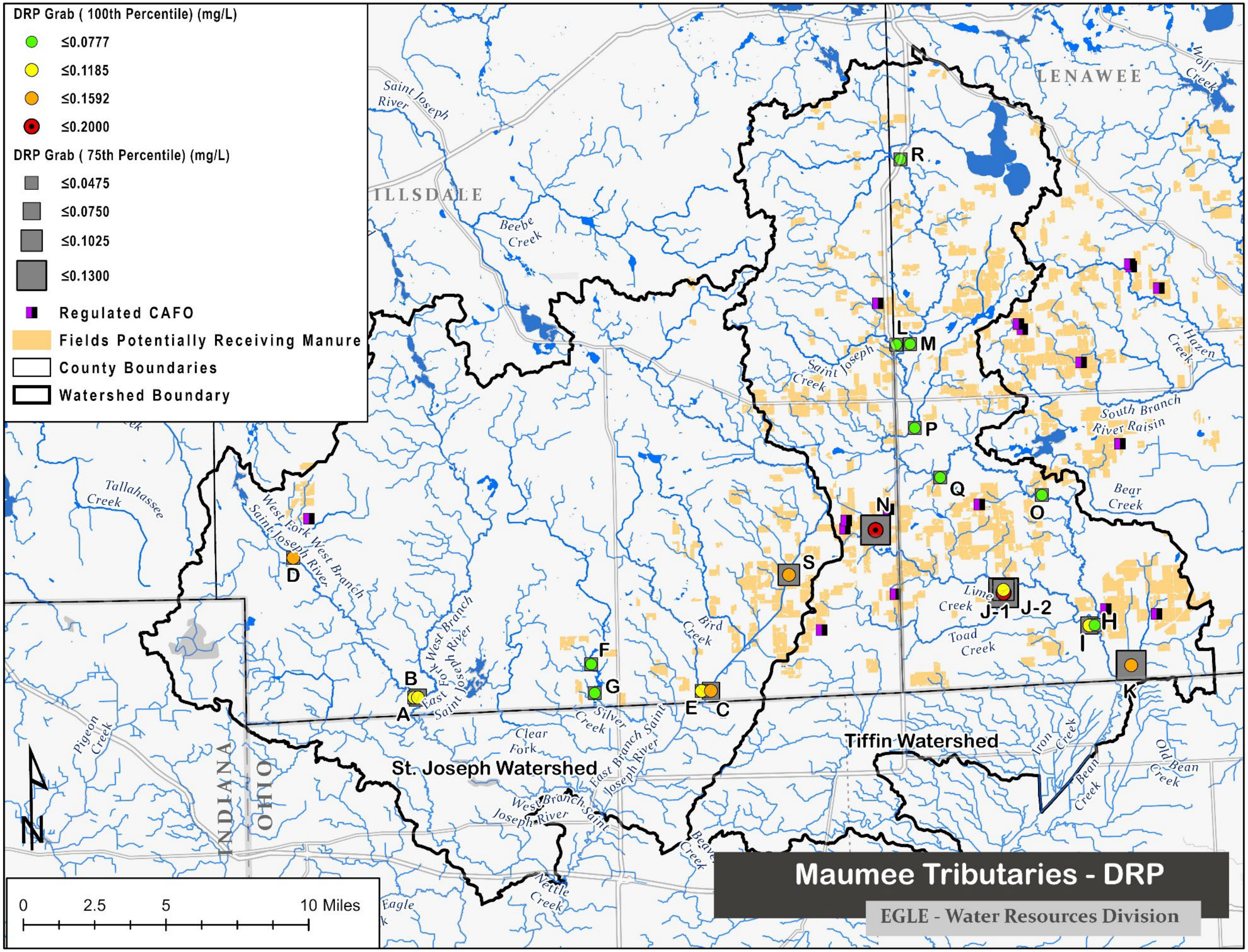

Figure 5. Map of 75th percentile and 100th percentile DRP values for 2017-2018 relative to potential manure spreading fields[8].

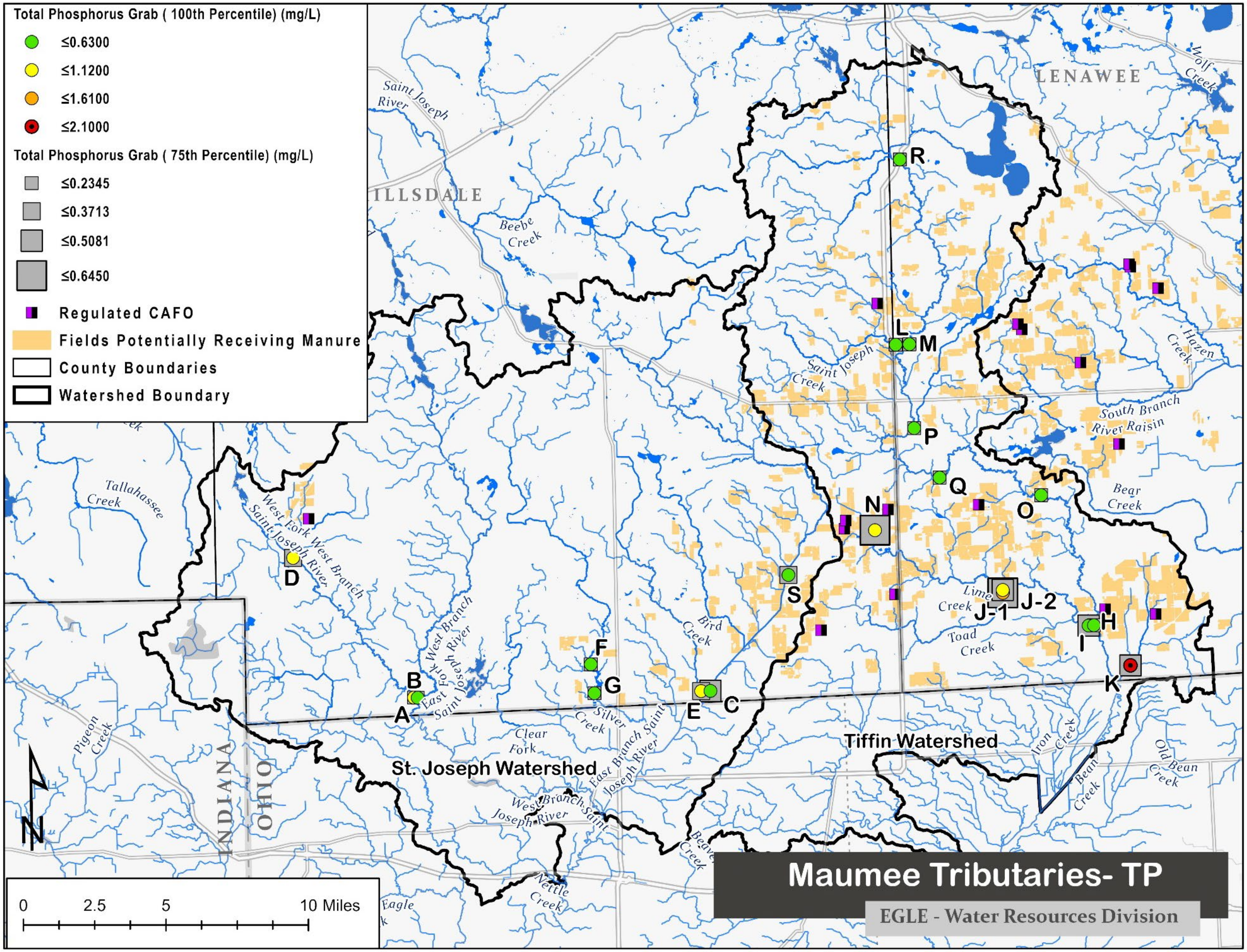

Figure 6. Map of 75th percentile and 100th percentile TP values for 2017-2018 relative to potential manure spreading fields[8].

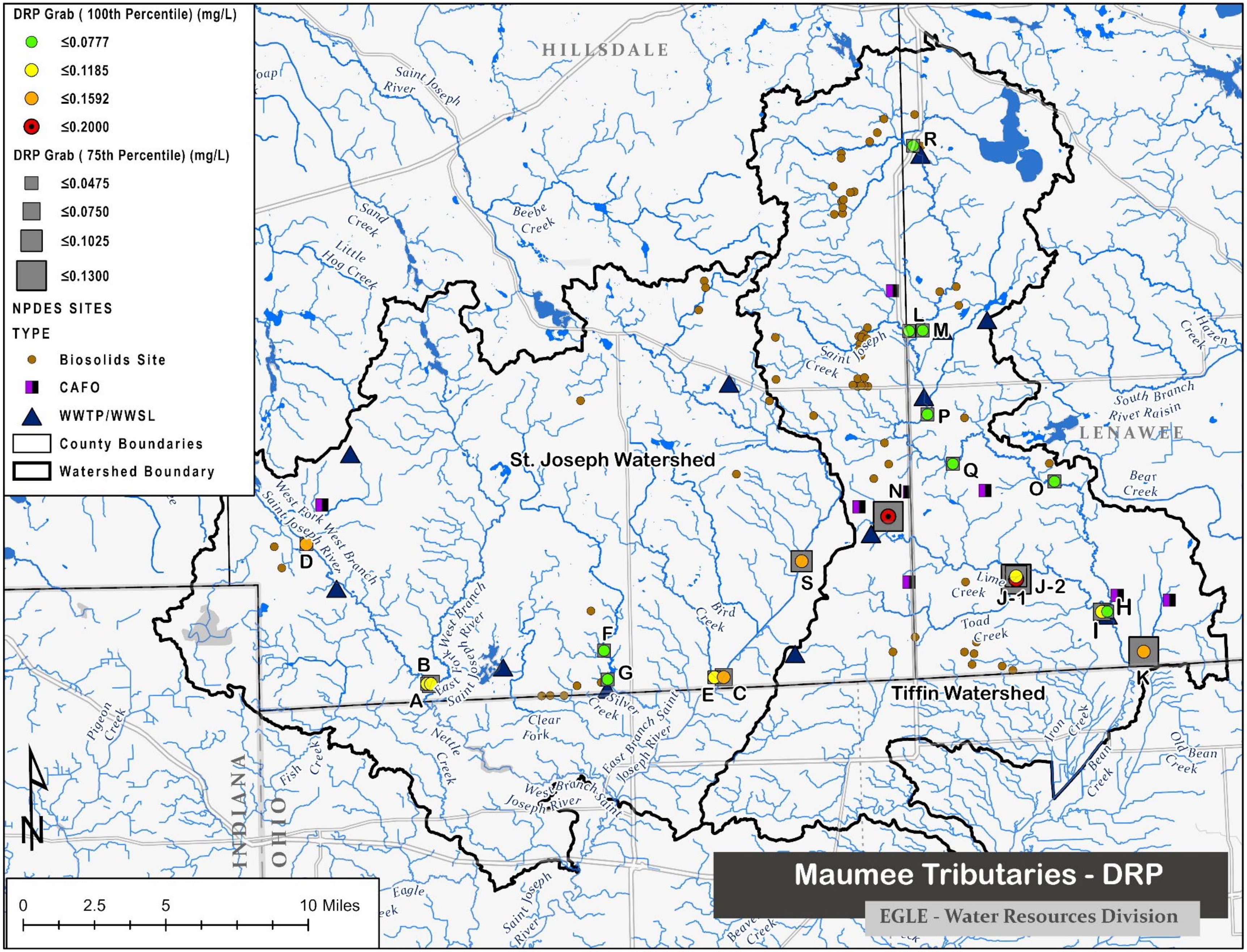

Figure 7. Map of 75th percentile and 100th percentile DRP values for 2017-2018 relative to National Pollutant Discharge Elimination System (NPDES) facilities (e.g., biosolids application sites, Concentrated Animal Feeding Operations [CAFO] facilities, and WWTPs/WWSLs).

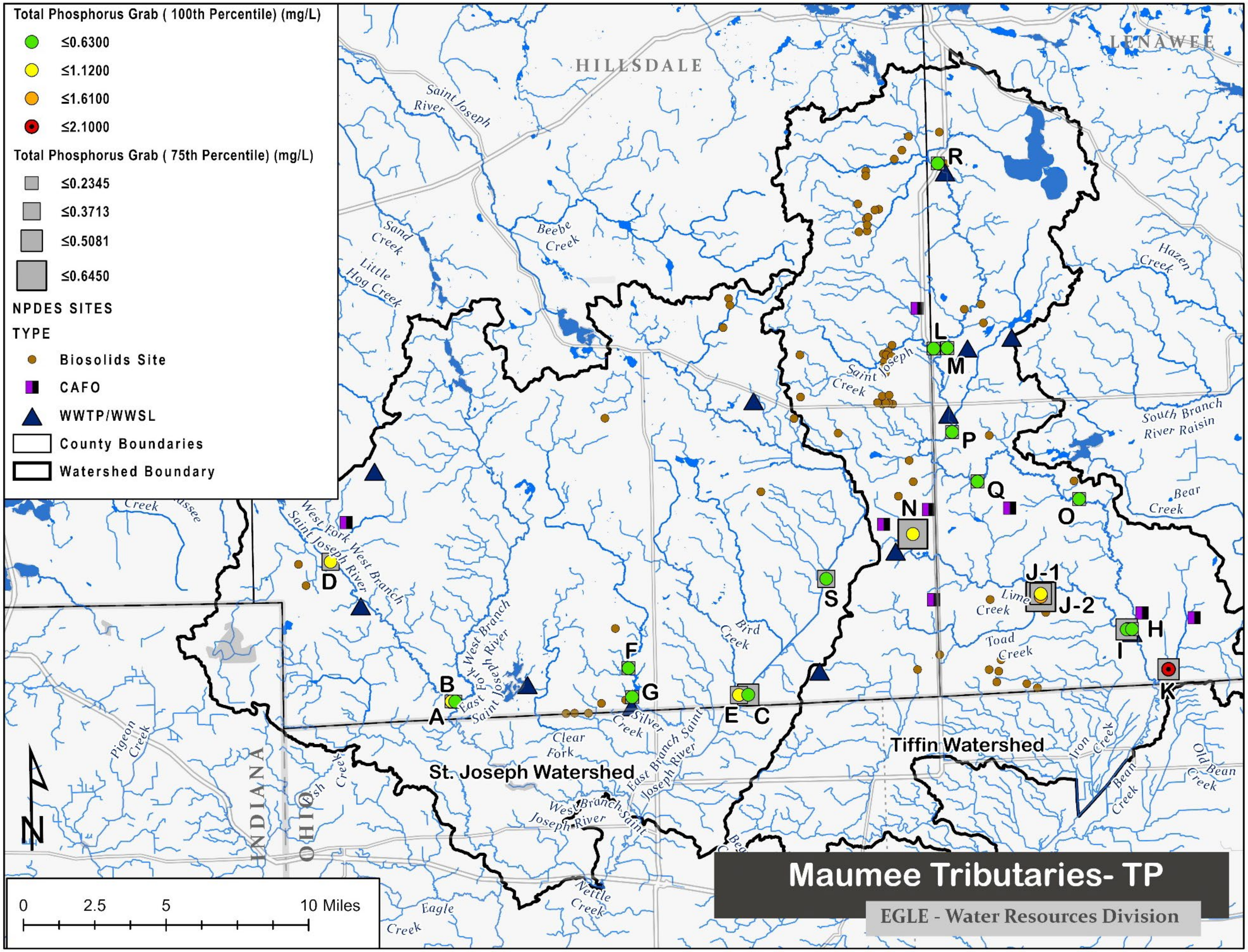

Figure 8. Map of 75th percentile and 100th percentile TP values for 2017-2018 relative to NPDES facilities (e.g., biosolids application sites, CAFOs, and WWTPs/WWSLs).

Automated-Sampler Samples

Overall, patterns were less apparent for data collected with automated samplers (Table 3; Section 4.2 of Appendix I), which were set up to collect samples during the rise, peak, and fall of storm hydrographs in an attempt to capture the highest concentrations possible. Station H had the lowest concentrations of total orthophosphate and TP, while concentrations at the other four automated stations were generally higher (except for maximum TP concentrations at Station B). Maximum concentrations of total orthophosphate at automated Stations A, B, C, and I were all ≥ 0.200 mg/L compared to 0.075 mg/L at Station H. Maximum concentrations of TP at Stations A, C, and I ranged from 0.960 to 1.700 mg/L, while it was 0.720 mg/L at both Stations H and B.

Highest Phosphorus Values

For samples with relatively high phosphorus concentrations, regardless of using grab or automated techniques, it is possible that some were influenced not only by inorganic phosphorus but also by organic particulate matter (e.g., a stray piece of algae, detritus [decaying leaf or plant material], bacteria, plankton) (Carlson and Simpson, 1996; Jarvie et al., 2002; Munn et al., 2018).

Other Water Quality Parameters

The emphasis of this study was on phosphorus; however, results for other environmental variables, including various forms of nitrogen, total suspended solids, and parameters measured by sonde, can be found Appendix I. In general, nitrogen parameters tended to be highest in concentration at stations that had the highest phosphorous concentrations.

Flow Data

Flow data for this study are not covered here but are detailed in Appendices I and IV.

Table 3. Overall summary and ranking of autosampled (AutoS) phosphorus concentrations, loadings, and key cumulative subwatershed land characteristics among the intensive study stations. A rank of #1 meant having the highest concentration, instantaneous load, or land characteristic, and bold font was used to highlight stations with the highest-ranked values. L.R., %ile, and t indicate (instantaneous) loading rate[4], percentile, and tie-in-ranking, respectively. Data summarized in this table are for years 2017-2018 for total orthophosphate (T oP) and 2016-2018 for total phosphorus (TP). The Max. Average Loading Rate for automated samplers was the largest average loading rate computed for a particular site among the automated sampling events. Average loading rates for automated samplers were computed by taking the average of instantaneous loading rates computed for samples collected during a given wet-weather event.

Watershed	Station	River Name	Max Conc. (mg/L)	Max Conc. [Rank]	Max. Avg. L.R. (lbs./day)	Max. Avg. L.R. [Rank]	Max Conc. (mg/L)	Max Conc. [Rank]	Max. Avg. L.R. (lbs./day)	Max. Avg. L.R. [Rank]	% Agricultural Land (%)	% Agricultural Land [Rank]	Total Area of Documented, Potential Manure Spreading Fields **	% Area Comprised of Manure Spreading Fields (%)**	% Area Comprised of Manure Spreading Fields [Rank]**	Has Biosolids Land Application Sites	Has WWTPs or WWSLs	% Being Low Permeability Soils (C, C/D, D) (%)	% Being Low Permeability Soils (C, C/D, D) [Rank]	Subwatershed Avg. Slope (%)	Subwatershed Avg. Slope [Rank]
		Parameter:	T oP	T oP	T oP	T oP	TP	TP	TP	TP	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative
		Sampling Event Type:	AutoS	AutoS	AutoS	AutoS	AutoS	AutoS	AutoS	AutoS	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed	Subwatershed
BEAN-TIFFIN	I	Lime Creek	**0.240**	**[1] t**	**117**	**[3]**	**1.700**	**[1]**	**492**	**[3]**	**80%**	**[1]**	**7,124**	**26%**	**[1]**	Yes***	Yes	**87.0**	**[1]**	3.5	[5]
ST. JOSEPH	B	E. Fk. W. Br. St. Joseph River	**0.240**	**[1] t**	112	[4]	0.720	[4] t	315	[5]	**65%**	**[2]**	0	0%	[5]			42.0	[5]	4.8	[4]
ST. JOSEPH	A	W. Fk. W. Br. St. Joseph River	**0.230**	**[3]**	88	[5]	**0.960**	**[3]**	345	[4]	59%	[4]	445	1%	[4]	Yes	Yes***	**53.8**	**[3]**	**5.5**	**[1]**
ST. JOSEPH	C	E. Br. St. Joseph River	0.200	[4]	**173**	**[1]**	**1.200**	**[2]**	**1,259**	**[1]**	**63%**	**[3]**	**3,824**	**7%**	**[3]**	Yes	Yes	**54.0**	**[2]**	**5.0**	**[3]**
BEAN-TIFFIN	H	Bean Creek	0.075	[5]	**127**	**[2]**	0.720	[4] t	**1,150**	**[2]**	59%	[4]	**12,018**	**13%**	**[2]**	Yes	Yes	45.0	[4]	**5.4**	**[2]**

Watershed	Station	River Name	Total Area Draining to Station (Acres)	Total Area Draining to Station [Rank]
			Cumulative	Cumulative
		Sampling Event Type:	Subwatershed	Subwatershed
BEAN-TIFFIN	I	Lime Creek	27,271	[5]
ST. JOSEPH	B	E. Fk. W. Br. St. Joseph River	31,108	[4]
ST. JOSEPH	A	W. Fk. W. Br. St. Joseph River	31,692	[3]
ST. JOSEPH	C	E. Br. St. Joseph River	51,116	[2]
BEAN-TIFFIN	H	Bean Creek	90,291	[1]

* Some maps [e.g., DeLorme, 2009] name the outlet from Devils Lake that then enters Addison Millpond as Fitts Creek, while some other sources name an even longer stretch of this stream as Fitts Creek. For example, the hydrography layer of the Michigan Geographic Framework (Version 17a) names the reach beginning as the outlet from Devils Lake down to the stream's eventual confluence with St. Joseph Creek near Beecher Road, as "Fitts Creek." USGS topographic maps (1962, 2017), however, name the stream from Devils Lake all the way down to the stream's eventual confluence with St. Joseph Creek as Bean Creek; the present report uses this naming convention.

** Manure spreading fields included in the tables and figures in this report are the all potential manure application fields[8] listed in the Comprehensive Nutrient Management Plan as of January 18, 2019.

*** Biosolid sites or WWTP/WWSL facilities were in the immediate subwatershed (as opposed to being anywhere in the cumulative subwatershed) of that station.

Potential Sources of Excess Nutrients in the Bean Creek and St. Joseph River Watersheds

Due to intensive human activity, there are many potential sources of excess nutrient (e.g., phosphorus) pollution in the Bean Creek and St. Joseph River watersheds. A brief description of these sources is presented below.

There are small urban areas in the study watersheds, including Addison, Hudson, and Camden (Morenci is mostly downstream of the monitoring stations). Sources of phosphorus in urban (city and residential) runoff typically include nonpoint sources such as plant and leaf litter, soil particles, pet waste, fertilizer, atmospheric deposition of particles, and point sources such as WWTPs and WWSLs. Lawns and golf courses, along with impervious surfaces such as roads and parking lots and their associated drainage networks, typically account for the greatest nonpoint sources of phosphorus loading in those types of areas (Hobbie et al., 2017; Minnesota Stormwater Manual Contributors, 2018; Paul and Meyer, 2001). There are residential and commercial areas, a golf course (near Hudson), two WWTPs, and six WWSLs in the study watersheds. (For a list of WWTPs and WWSLs in the study watersheds, see Section 5.6 in Appendix I).

In more rural residential areas, septic systems (especially when aging and/or faulty) and illicit discharges, in addition to lawn fertilizer and WWSLs, can be sources of nutrients and *E. coli* bacteria[5] (MDEQ, 2017; Rippke, 2019; Michigan EGLE SepticSmart[6]; USEPA[7]).

Many parts of the Bean Creek and St. Joseph River watersheds are dominated by agricultural land uses. In their commentary, Wilson et al. (2019) discussed phosphorus contributions from the Maumee and Sandusky Rivers and that, together, these watersheds contribute the largest tributary loads of phosphorus to Lake Erie and the Great Lakes. Both watersheds are dominated by agriculture (>70%) and have approximately 88% to 93% of their phosphorus loads coming from nonpoint sources (based on data by the Ohio Environmental Protection Agency [2016, 2018]) – loads that are typically delivered as pulses during storm events (Wilson et al., 2019). The Bean Creek watershed management plan (Blonde and Cleland, 2019) noted that BMPs most effective in reducing loads during the months with the highest erosion potential (e.g., winter, early spring, late fall) should be given a higher priority.

Agricultural land use activities often include one or many of the following practices: row crops and associated fertilizer, livestock, the spreading of manure and biosolids on fields, tile drainage, and the removal of natural riparian vegetation, all of which can contribute excess nutrients such as phosphorus to stream and river systems by both overland and subsurface pathways (Carlisle et al., 2013; Capel et al., 2018).

As mentioned earlier, subsurface tile drains also need to be considered when planning efforts to reduce phosphorus loads. According to the USEPA-GLNPO (2018):

> "… a significant portion of the phosphorus that is contributing to the harmful algal blooms in Lake Erie originates from surface and subsurface losses of commercial and organic fertilizer applied to cropland. According to USDA researchers, soluble phosphorus loss is the greatest treatment need in the Western Basin, and the majority of soluble

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[5] To learn more about *E. coli* bacteria in Michigan, visit Michigan.gov/egleecoli.

[6] https://www.michigan.gov/egle/about/Organization/Drinking-Water-and-Environmental-Health/onsite-wastewater-management/SepticSmart

[7] epa.gov/septic; https://www.epa.gov/septic/about-septic-systems

phosphorus losses occur through subsurface tile drains (King et al., 2014 and Smith et al., 2014, USDA NRCS, 2016) …"

Land Use Characteristics and Associations with Phosphorus Concentrations in this Study

As mentioned above, there are a variety of land use activities and natural features in the study watersheds that could potentially contribute nutrients like phosphorus to the Bean-Tiffin and St. Joseph River watersheds (e.g., agricultural row-crop fields, spreading of manure or biosolids on fields, WWTPs, WWSLs, urban development; lower soil porosity or higher average slopes in some areas compared to other areas) (Appendix I [Chapters 5 and 6]). A determination of specific sources and locations exporting high amounts of phosphorus to local stream reaches was not within the scope of this study. Further, since each sampling location in this study reflected all runoff and other contributions upstream of them, the ability to discern a source of significant nutrient concentrations and loading was not within the scope of this study. Thus, only a broad-scale, coarse approach towards identification of potential sources in subwatersheds was performed here. A summary of many of those potential sources and features is presented below.

Similar to station-ranking for DRP and TP concentrations for grab samples, the Lime Creek (Stations J-2, N, J-1, and I) and Silver Creek (Station K) subwatersheds in the Bean Creek watershed had the top-5 ranked stations for percent cumulative lands used for agricultural purposes (Tables 1 and 2; Figures 3 and 4; and Chapter 5 of Appendix I). Ranked sixth was Station E (Laird Creek) in the St. Joseph River watershed. Likewise, the top-5 ranked stations with the greatest percent cumulative *potential* manure spreading fields[8] were either in the Lime Creek (Stations J-2, N, J-1, and I) or Silver Creek (Station K) subwatersheds of the Bean Creek watershed (Tables 1 and 2; Figures 5 and 6; and Chapter 5 of Appendix I). Tied for sixth were other Bean Creek watershed stations (H, L, and O). Station C (East Branch St. Joseph River) was the highest ranked (12) in the St. Joseph River watershed.

Biosolids application fields occur in most subwatersheds of the Bean Creek and St. Joseph River watersheds (Tables 1-3; Figures 7 and 8; and Chapter 5 of Appendix I); however, not enough data were available to quantify the acreage of fields where it was applied. (For additional information refer to Section 5.5 in Appendix I).

A number of subwatersheds in the Bean Creek and St. Joseph River watersheds have WWTPs (2) or WWSLs (6) in them (Tables 1-3; Figures 7 and 8; and Chapter 5 of Appendix I). Wastewater treatment regulates and reduces phosphorus loading to receiving waters substantially, but not entirely.

Ten of the 20 stations had $\geq$45% low permeability soils [cumulative soil type (C, C/D, or D) (Appendix I; USDA, 2009)]. These soil groups have low to very low infiltration rates and

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[8] The manure spreading fields displayed in Tables 1-3, Figures 5 and 6, and Appendix I (shown as orange-colored shading) represent all *potential* manure application fields listed in the Comprehensive Nutrient Management Plan, as of January 18, 2019, for regulated CAFOs only. There are numerous smaller, unregulated Animal Feeding Operations (AFO) in the region that are not shown on the figures and tables due to a lack of specific information on those locations. Additionally, note that some fields within the watershed may be managed by CAFOs with farmsteads outside of the watershed, and sometimes CAFO "manifested manure" waste applied to fields within the watershed is not shown on the maps. AFOs having characteristics, such as exceeding a certain number of animals, are considered to be large, medium, or small CAFOs, and are regulated by EGLE. *Manifested manure* is waste that is sold or transferred to another entity, other than the facility producing the waste.

moderately-high to high runoff potential (Appendix I; USDA, 2009). The top-5 ranked watersheds were all either in the Lime Creek or Silver Creek subwatersheds of Bean Creek (Tables 1 and 2).

Possible Influence of Land Characteristics, Flow Inputs, or Lag Times on Phosphorus Concentrations at Station H

While Station H on Bean Creek (which did not have the Lime Creek and Silver Creek [Station K] [all Bean Creek] subwatersheds upstream of it) had relatively large flows and ranked 4th for average instantaneous loads of DRP and TP, it also had relatively low DRP and TP concentrations overall (Tables 1 and 2). Factors that may help explain these lower relative phosphorus concentrations include the fact that the cumulative subwatershed for Station H (Bean Creek) had a lower percent agricultural land, percent area comprised of potential manure-spreading fields, and percent of its land being low-permeability soil types relative to the Lime Creek and Silver Creek stations (Tables 1 and 2). Other factors may also partly explain the differences between Station H and the other stations mentioned above (e.g., possible inputs of flow groundwater contributions or upstream tributary flow inputs; different storm pulse lag times among the different stations); however, they were not studied or examined as part of this project and are merely speculative at this point.

Influence of Precipitation Variability on Water Quality Data Collected for this Study

Rainfall amounts near stations during sampling events were often not uniform (Figure 9), making sampling under similar rainfall conditions logistically challenging. This can be seen in figures within Appendix I (Figures 3-4 for flow, Figures 12-13 for instantaneous TP loads, and Figures 15-16 for instantaneous DRP loads), which show that highest flows and instantaneous loading rates varied among stations from sampling event to sampling event.

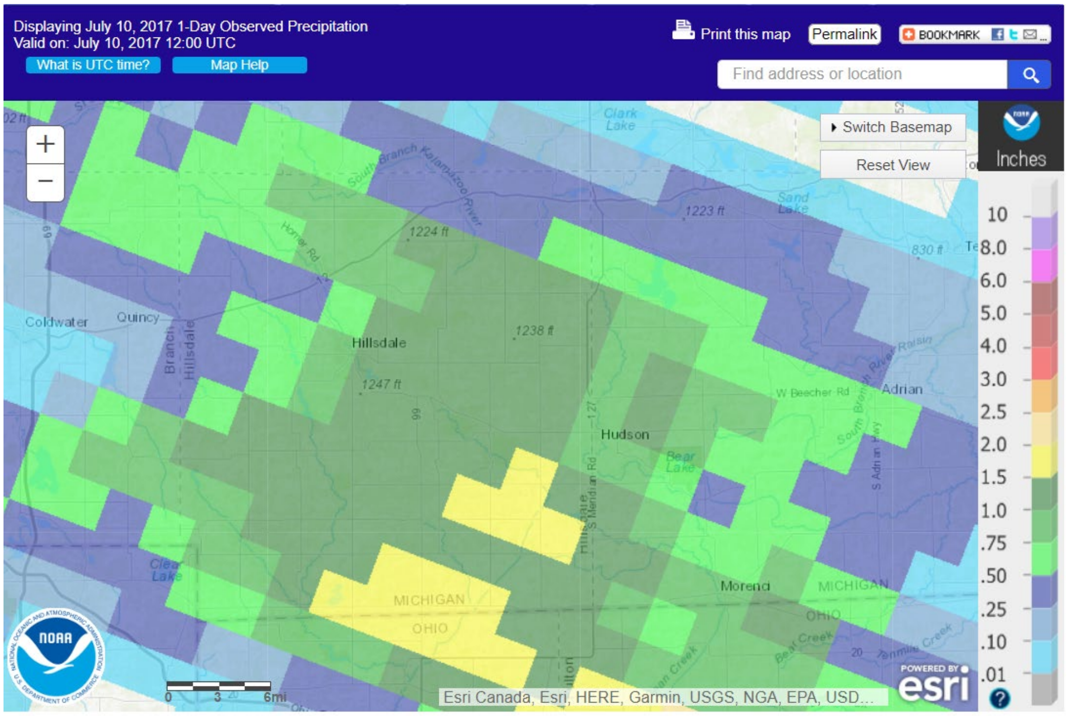

Figure 9. Distribution of rainfall across the study region on July 10, 2017. Image source: water.weather.gov/precip/.

Efforts to Evaluate and/or Reduce Nutrient Contributions to Michigan's Upper Maumee River Tributaries

Phosphorus trends and dynamics in the lake and its tributaries are complex[9], have changed over time, and remain the subject of much research. Following a period of significant reductions in eutrophication that occurred during the 1980s after implementation of phosphorus load reduction programs begun in the 1970s, Lake Erie began experiencing re-eutrophication in the 1990s, even though TP loads to the lake continued to slowly decline (Baker et al., 2014). Between 1991-2012, DRP export from nonpoint sources in the Maumee River increased dramatically while bioavailable particulate phosphorus[10] export declined slightly in the Maumee River (Baker et al., 2014; Jarvie et al., 2017). Baker et al. (2014) and Jarvie et al. (2017) concluded that increased nonpoint source loading of DRP is an important contributing

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[9] In addition to complex interactions between, and variability of, human activities (including point sources and agricultural practices), annual discharge, and climate (Baker et al., 2017), other factors may play a role (including invasive mussel species [Matisoff and Ciborowski, 2005]).

[10] "Bioavailable particulate phosphorus can settle out of the water column prior to releasing orthophosphate, and thus not directly support algal or cyanobacterial growth apart from subsequent contributions to internal phosphorus loading" (Baker et al., 2017).

factor to re-eutrophication in Lake Erie and that reducing phosphorus loading from agriculture sources should address not only particulate phosphorus but also DRP. In part of their paper, Baker et al. (2019) reviewed and commented on some challenges for DRP load reduction programs that exist including subsurface tile drainage systems for agricultural fields and utilization of no-till and reduced till cropping systems. These two practices have economic benefits for, and are popular with, farmers and/or agricultural professionals. Subsurface tile drainage systems in agricultural lands are a major pathway for DRP export from cropland, which results "in increased water yields from cropland, greater connectivity between cropland and stream systems, and increased DRP runoff." Utilization of no-till and reduced till cropping systems, which offer erosion control benefits in addition to economic advantages, also unintentionally "are often accompanied by increased runoff concentrations and loads of DRP because of a build-up of phosphorus soil test levels in the upper layers of the soil … and development of soil macropores, which support preferential flow of water from the surface to tile systems …" (Baker et al., 2019).

Muenich et al. (2016) evaluated how various scenarios of nutrient management strategies, reduction of fertilizer applications, utilization of vegetative buffers, and implementation of widespread cover crops and alternative cropping changes affected phosphorus loads in the Maumee River watershed. This information can assist in deciding which BMPs, or some combination of them, to apply to the landscape. The modeling done by Muenich et al. (2016) suggested a large amount of "Legacy P"[11] exists in the Maumee River watershed soils and that Legacy P will need to be taken into consideration as part of watershed management efforts.

Wilson et al. (2019) reviewed the effectiveness of recommended agricultural BMPs intended to reduce phosphorus and then paired that knowledge with behavioral data on likely adoption to identify how best to achieve the reduction target. The authors found that achieving phosphorus targets was feasible since a majority of the farming population in the Western Lake Erie Basin was willing to consider many of the recommended BMPs. However, they also concluded that farmers would need better cost-benefit information, site-specific decision support tools, and technical assistance to more rapidly adopt and execute the placement of recommended practices.

Watershed management plans have been developed for the Bean Creek and St. Joseph River watersheds (Blonde and Cleland, 2019; Sustainable Natural Resources Technologies, Inc., 2015). They provide important guidance for considering where and how to reduce excess nutrient runoff and subsurface drainage into these watersheds.

On a broader scale, Domestic Action Plans have been developed by the State of Michigan (2018) and USEPA-GLNPO (2018) for watersheds that drain into Lake Erie. Domestic Action Plans provide important guidance for considering where and how to reduce nutrient runoff and subsurface drainage into the Bean Creek and St. Joseph River watersheds (i.e., Michigan's portion of the Maumee River watershed) while also recognizing that an adaptive management approach will likely be needed as more monitoring and research is done over time. Because

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[11] *Legacy P in agricultural fields* is phosphorus that is present due to past land management (e.g., historical fertilizer applications) and continues to be remobilized and contribute to current loads. *Legacy P in streams* is phosphorus that was deposited in waterways in past years, some of which contributes to current loads (USEPA-GLNPO, 2018; Sharpley et al., 2013). Legacy sources are dynamic and variable. For example, phosphorus can cycle (transform) from a dissolved inorganic nutrient phase, be taken up by organisms and be incorporated into organic, living tissue (solids form), and then be re-mineralized after excretion or decomposition, all the while *spiraling* in a general downstream direction due to flow (especially when in the dissolved form) (Allan and Castillo, 2007).

these documents are written at a broader scale, they also provide guidance for other priority watersheds in Michigan’s portion of the Lake Erie basin, especially the Detroit River and River Raisin watersheds.

CONCLUSION

While this report points out locations to potentially target and prioritize for reduction of nutrient runoff and drainage, it is important to note that reductions occurring anywhere in these watersheds is likely to benefit local water quality conditions as well as downstream receiving waters (e.g., Maumee River and Lake Erie), so they are encouraged anywhere practicable.

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