MI/DEQ/WB-09/023

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER BUREAU
MARCH 2009

STAFF REPORT

E. COLI, TOTAL PHOSPHORUS, AND SOLUBLE REACTIVE PHOSPHORUS MONITORING IN THE PINNEBOG RIVER, PIGEON RIVER, AND SHEBEON DRAIN HURON COUNTY, MICHIGAN APRIL 29-SEPTEMBER 4, 2008

INTRODUCTION

The Saginaw Bay and Lake Huron coastal stream watersheds, also known as the Pigeon-Wiscoggin (HUC 04080103) and the Cherry-Willow (HUC 04080104) watersheds, are composed of numerous and relatively small perennial, intermittent, and ephemeral streams that flow directly to Lake Huron or Saginaw Bay. Many of these streams have no known name, exist without delineated tributaries, and flow only a few miles before reaching their confluence. The Pigeon and Pinnebog Rivers represent the largest of the areas drainage basins with both streams having a main channel length of approximately 40 miles.

The Pigeon, Pinnebog, and Shebeon watersheds are best described as highly altered watersheds, meaning that much of the tributary net that supports each stream is a composition of many named and unnamed county drains. Many of the tributaries to each respective stream are intermittent, and largely, surface runoff-dependent systems that respond quickly to precipitation events.

The Pigeon River, Pinnebog River, and Shebeon Drain watersheds are dominated by agricultural land use (Figure 1), which includes various sized animal feeding operations, a small amount of urban runoff, and both continuous and seasonal discharges from Wastewater Treatment Plants (WWTPs) and Wastewater Sewage Lagoons. Collectively, these watersheds offer a strong potential to discharge substantial amounts of nutrients to Saginaw Bay and the Great Lakes basin. In addition, large numbers of livestock and residential dwellings with individual septic systems exist in relative close proximity to these respective streams and their tributaries, and provide an additional potential for bacterial contamination.

The objectives of this study were to characterize changes in total phosphorus (TP) and soluble reactive phosphorus (SRP) export with changes in land use. In addition, this study determined *E. coli* water quality standard (WQS) compliance, and identified (to the best of our ability) portions of the watersheds that contribute *E. coli* to each respective waterway. To that end, specific land use types were targeted to investigate the potential for *E. coli* contamination.

APPLICABLE WQS FOR *E. COLI*

The designated use rule (Rule 100 [R 323.1100] of the Part 4 rules, WQS, promulgated under Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended) states that this water body be protected for total body contact recreation from May 1 through October 31 and partial body contact recreation year-round. The

target levels for these designated uses are the ambient *E. coli* standards established in Rule 62 of the WQS as follows:

> R 323.1062 Microorganisms.
> Rule 62. (1) All waters of the state protected for total body contact recreation shall not contain more than 130 E. coli per 100 milliliters (mL), as a 30-day geometric mean. Compliance shall be based on the geometric mean of all individual samples taken during five or more sampling events representatively spread over a 30-day period. Each sampling event shall consist of three or more samples taken at representative locations within a defined sampling area. At no time shall the waters of the state protected for total body contact recreation contain more than a maximum of 300 E. coli per 100 mL. Compliance shall be based on the geometric mean of three or more samples taken during the same sampling event at representative locations within a defined sampling area.
>
> (2) All surface waters of the state protected for partial body contact recreation shall not contain more than a maximum of 1,000 E. coli per 100 mL. Compliance shall be based on the geometric mean of 3 or more samples, taken during the same sampling event, at representative locations within a defined sampling area.

The target for sanitary wastewater discharges is:

> Rule 62. (3) Discharges containing treated or untreated human sewage shall not contain more than 200 fecal coliform bacteria per 100 mL, based on the geometric mean of all of five or more samples taken over a 30-day period, nor more than 400 fecal coliform bacteria per 100 mL, based on the geometric mean of all of three or more samples taken during any period of discharge not to exceed seven days. Other indicators of adequate disinfection may be utilized where approved by the Department.

The Pinnebog River Watershed

The Pinnebog River begins as a series of agricultural drains in southwest Colfax Township and flows north approximately 40 miles to its confluence with Saginaw Bay in Section 10 in Hume Township. The main branch of the river has an average slope of 4 feet per mile; however, most of this gradient is upstream from the village of Elkton in Oliver Township. The Pinnebog River from Elkton to Saginaw Bay has an average slope of approximately 0.6 feet per mile and a slope of only 0.1 feet per mile within 3 miles of Saginaw Bay. Significant tributaries to the Pinnebog include Bad Axe Creek, which begins as a series of agricultural drains southeast and southwest of the city of Bad Axe and flows northwest to its confluence with the Pinnebog in Section 13 of Chandler Township, all within Huron County. Other tributaries include the Elkton Drain, McMullen Drain, Nettle Run, Hill Drain, Southworth Drain, Oliver Drain, Cameron Drain, McClean Drain, and Musselman Drain. The Pinnebog River flows through land use that is dominated by agriculture. Approximately 64 percent of the basin is composed of cultivated crops followed by pasture/hay (12 percent) (Table 1, Figure 1).

Table 1. Land Use for the Pinnebog River Watershed, Huron County, Michigan.			
Land Use	**Acres**	**Square Miles**	**Percent**
Open Water	106.85	0.17	0.1%
Developed, Open Space	3537.90	5.53	4.1%
Developed, Low Intensity	2944.19	4.60	3.4%
Developed, Medium Intensity	408.71	0.64	0.5%
Developed, High Intensity	227.78	0.36	0.3%
Barren Land	130.05	0.20	0.2%
Deciduous Forest	4361.14	6.81	5.1%
Evergreen Forest	174.48	0.27	0.2%
Mixed Forest	245.06	0.38	0.3%
Scrub/Shrub	57.19	0.09	0.1%
Grassland/Herbaceous	730.78	1.14	0.9%
Pasture/Hay	10265.87	16.04	12.0%
Cultivated Crops	54930.33	85.83	64.0%
Woody Wetlands	7315.00	11.43	8.5%
Emergent Herbaceous Wetlands	374.31	0.58	0.4%
Total	**85809.66**	**134.08**	**100.0%**

The Pigeon River Watershed

The Pigeon River and Shebeon Creek are also located in Huron County; both are west of the Pinnebog River. The Pigeon River is formed from the Livingston and Appin Drains in southwest Sheridan Township and flows northward to its confluence with Saginaw Bay at Caseville, Michigan. The main portion of the Pigeon River has an average slope of approximately 4 feet per mile and has been heavily modified to support agricultural drainage. The primary land use in the watershed is cultivated crops (72 percent) followed by pasture/hay (10 percent) (Table 2, Figure 1).

Table 2. Land use in the Pigeon River Watershed, Huron County, Michigan.			
Land Use	**Acres**	**Square Miles**	**Percent**
Open Water	156.66	0.2	0.2%
Developed, Open Space	2589.56	4.0	2.6%
Developed, Low Intensity	3198.00	5.0	3.2%
Developed, Medium Intensity	224.31	0.4	0.2%
Developed, High Intensity	101.35	0.2	0.1%
Barren Land	116.40	0.2	0.1%
Deciduous Forest	4360.75	6.8	4.3%
Evergreen Forest	99.07	0.2	0.1%
Mixed Forest	214.68	0.3	0.2%
Scrub/Shrub	74.50	0.1	0.1%
Grassland/Herbaceous	772.72	1.2	0.8%
Pasture/Hay	9663.18	15.1	9.6%
Cultivated Crops	72645.01	113.5	72.1%
Woody Wetlands	5560.34	8.7	5.5%
Emergent Herbaceous Wetlands	922.57	1.4	0.9%
Total	**100699.10**	**157.34**	**100.0%**

The Shebeon Drain Watershed

The Shebeon Drain begins as a series of agricultural drains in northwest Tuscola County and flows north northwest to its confluence with Saginaw Bay approximately 6 miles north of Sebewaing. The main channel is apprroximately 19 miles long with an average gradient between 8 and 9 feet per mile. Virtually the entire length of Shebeon Drain and most of its respective tributaries are heavily modified to support agricultural drainage. The primary land use in the watershed is cultivated crops (79 percent) followed by pasture/hay (11 percent) (Table 3, Figure 1).

Table 3. Land use in the Shebeon Drain watershed, Huron County, Michigan.

Land Use	Acres	Square Miles	Percent
Developed, Open Space	367.26	0.57	2.1%
Developed, Low Intensity	634.64	0.99	3.6%
Developed, Medium Intensity	16.87	0.03	0.1%
Barren Land	40.16	0.06	0.2%
Deciduous Forest	222.70	0.35	1.3%
Evergreen Forest	2.79	0.00	0.0%
Mixed Forest	9.44	0.01	0.1%
Scrub/Shrub	1.73	0.00	0.0%
Grassland/Herbaceous	77.86	0.12	0.4%
Pasture/Hay	1838.77	2.87	10.5%
Cultivated Crops	13789.53	21.55	79.1%
Woody Wetlands	428.24	0.67	2.5%
Emergent Herbaceous Wetlands	6.42	0.01	0.0%
Total	**17436.40**	**27.24**	**100.0%**

All three of the targeted watersheds contain a very small percentage of low intensity residential development, presumably operating various forms of individual septic systems.

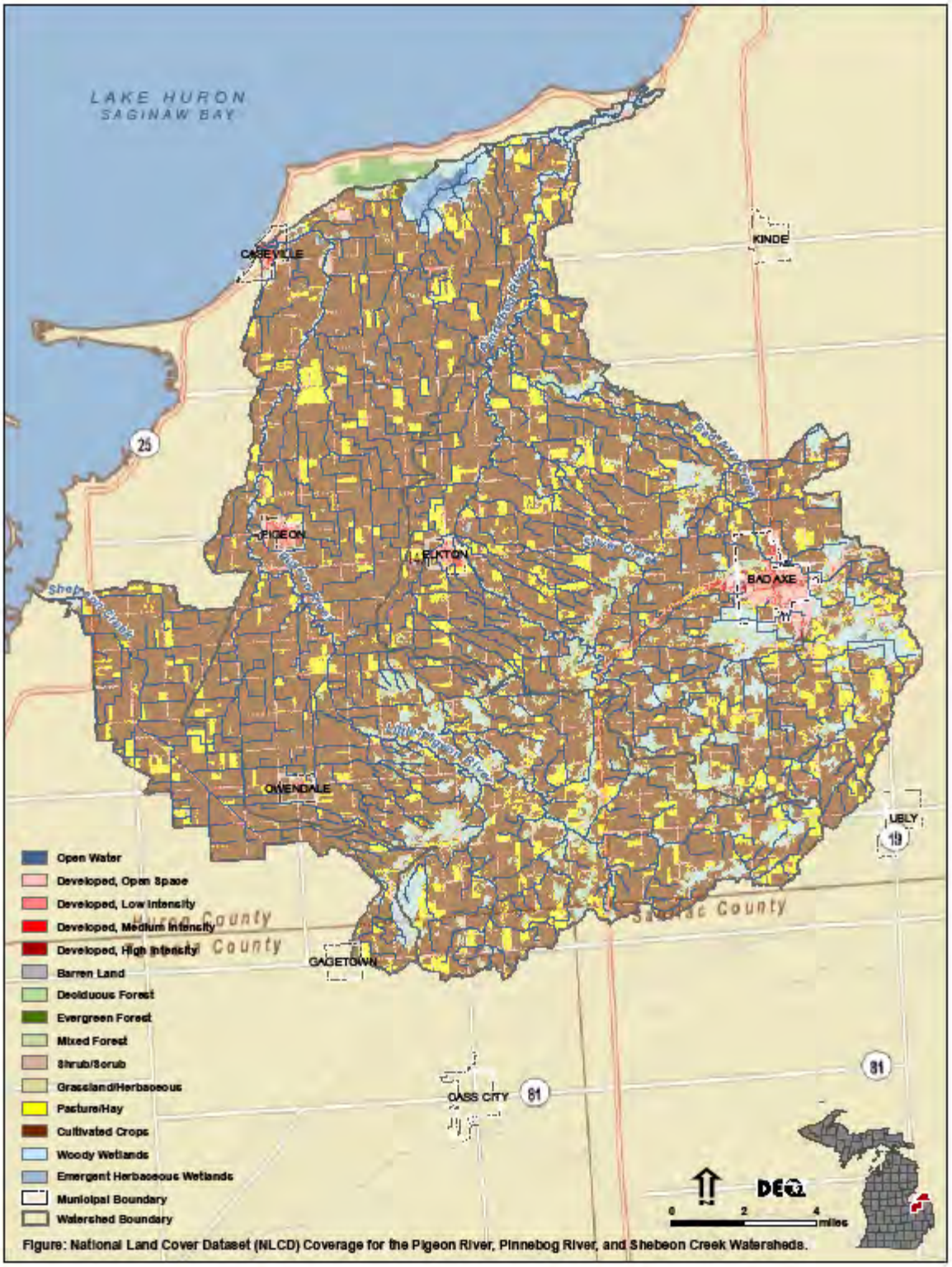

Figure 1. Land use for the Pinnebog River, Pigeon River, and Shebeon Drain watersheds.

MONITORING METHODS

Bi-Weekly Sampling

The Pinnebog River, Pigeon River, and Shebeon Drain sampling locations identified for this study are shown in Figure 2 and described in Table 4. Bi-weekly sampling for *E. coli*, TP, and SRP was conducted at the sampling stations beginning April 29, 2008. *E. coli* samples were to be collected for the first four sampling events only, as outlined in the approved Quality Assurance Project Plan (QAPP). However, the June 10, 2008, sampling event was considered a wet weather event, so an additional bi-weekly *E. coli* sampling event was conducted on June 23-24, 2008. Also, an additional *E. coli* sampling event was added on May 22, 2008, at the Pinnebog River sampling locations. Three samples (i.e., triplicate) were collected for *E. coli* at each sampling station, with the exception of Station PIN02 (Figure 2). The *E. coli* samples were delivered to In-House Water Lab in Howell, Michigan, so that *E. coli* analyses occurred within 8 hours of collection.

The TP and SRP samples were collected bi-weekly for the entire sampling period from April 29 to September 4, 2008. The TP and SRP samples were sent to the Michigan Department of Environmental Quality (MDEQ), Environmental Laboratory, in Lansing, Michigan for analysis. Results for SRP, which is mostly the inorganic fraction of a TP sample, are provided in the following sample results but not specifically discussed. TP samples were not collected from Station PIN02, upstream of the Bad Axe WWTP, until May 28, 2008.

Wet Weather Sampling

Wet weather sampling events were conducted on June 10 and August 3, 2008. These events were designed to target the rising limb of the hydrograph; however, given the diversity of stream size and therefore, sub-basin area, the specific point of the rising limb where sample collection occurred is unclear. Samples were collected from all locations for *E. coli*, TP, and SRP. Rainfall, as recorded at the Bad Axe WWTP, measured 0.63 and 0.35 inches on June 9 and June 10, respectively, and as 1.8 and 0.0 inches on August 2 and August 3, 2008, respectively. An additional rain event affected the Shebeon Drain watershed only, and is specifically discussed later in this report.

Bacterial Source Tracking (BST)

Samples were collected in the study area and analyzed for Human *Bacteroidetes* and *Enterococcus*, as well as Cow *Bacteroidetes* and *Enterococcus* biomarkers. Fecal *Bacteroidetes* are found in abundant amounts in feces of warm-blooded animals. They are considered a good indicator of recent fecal pollution because they are strict anaerobes (i.e., they do not survive long outside the host organism). *Enterococci* are benign bacteria when they reside in their normal habitat such as the gastrointestinal tracts of human and animals. Outside their normal habitat, *Enterococci* are pathogenic and may cause urinary tract and wound infections, and life-threatening diseases such as bacteraemia, endocarditis, and meningitis. *Enterococci* can survive for extended periods of time outside the body and can be used as indicators of human fecal contamination.

The samples were shipped overnight to Source Molecular Corporation in Florida for analysis. The biomarker analyses were not performed unless the *E. coli* results from In-House Water Labs indicated a geometric mean *E. coli* concentration greater than 300 *E. coli* per 100 ml. If the *E. coli* concentration was less than 300 *E. coli* per 100 ml as a geometric mean, the sample

was discarded by Source Molecular Corporation. The *Bacteroidetes* and *Enterococci* were then quantified in samples that were positive for the cow and human biomarkers.

Sampling Methods

At each sample location, samples were collected using a sampling pole from bridge crossings or the stream bank. Samples were collected in a manner that minimized the chance of sediment infiltrating the samples during collection. Care was also taken to not disturb resident bottom feeding fish to minimize bottom sediment resuspension. Water for TP and SRP analyses was collected just below the surface, as surface water may be enriched and may not be representative of the water column.

Once collected, the water was poured into sample bottles. SRP samples were filtered in the field, and all samples were placed in coolers with ice and kept at 4°C. Field blanks were collected every 20 samples (5 percent) by filling a sample bottle with distilled water at the site. Duplicates were collected every 10 samples (10 percent) by collecting a sufficient volume of water to alternately pour the water into the sample bottle and the duplicate bottle.

Stagnant water was not sampled. Dry streams and stagnant water conditions were noted on the field log sheets. Weather observations and other unusual stream conditions were also recorded on the log sheets (i.e., unusual turbidity, odor, no flow, high flow, etc.).

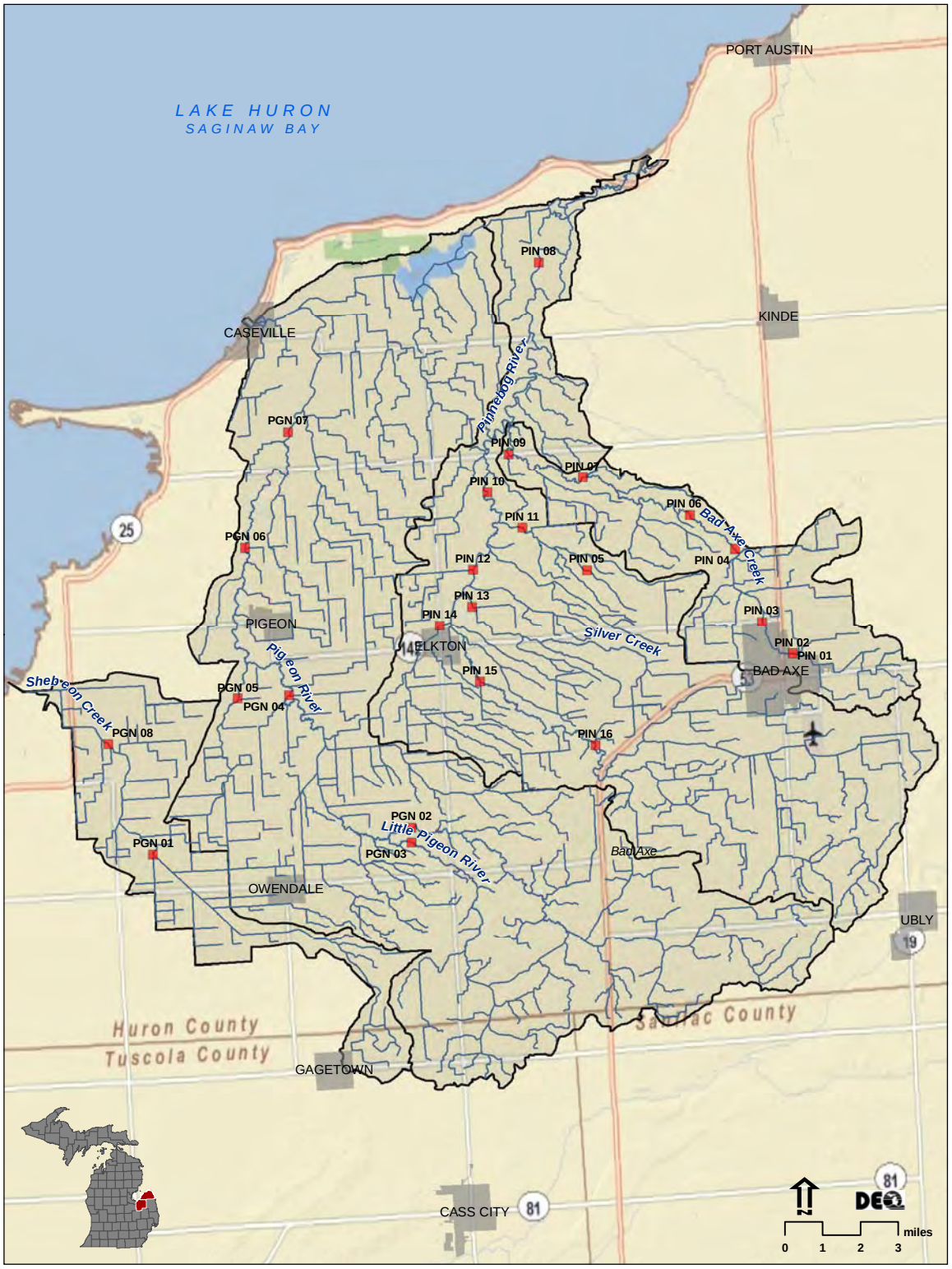

Figure 2. Sampling locations in the Pigeon River, Pinnebog River, and Shebeon Drain watersheds in Huron County, Michigan.

Table 4. Pinnebog River, Pigeon River, and Shebeon Drain watershed sampling stations.

Station	Water Body	Location	LAT	LONG
PIN-01	Bad Axe Drain	Whitelam Street – d/s of WWTP	43.810685	-82.994875
PIN-02	Bad Axe Drain	~ 150 ft u/s of WWTP	43.810685	-82.994875
PIN-03	Bad Axe Drain	Pigeon Road	43.823518	-83.010234
PIN-04	Bad Axe Drain	Berne Road	43.851572	-83.023029
PIN-05	McMullen Drain	Pinnebog Road	43.845761	-83.101767
PIN-06	Bad Axe Creek	Campbell Road	43.865367	-83.046497
PIN-07	Bad Axe Creek	Pinnebog Road	43.881483	-83.102509
PIN-08	Pinnebog River	Oak Beach Road	43.964310	-83.121786
PIN-09	Bad Axe Creek	Filion Road	43.891335	-83.141283
PIN-10	Pinnebog River	Crown Road	43.876659	-83.153460
PIN-11	McMullen Drain	Campbell Road	43.862858	-83.135291
PIN-12	Pinnebog River	Berne Road	43.847664	-83.162104
PIN-13	Nettle Run	Richardson Road	43.833408	-83.163541
PIN-14	Elkton Drain	Elkton Road	43.826389	-83.181082
PIN-15	Pinnebog River	Geiger Road	43.804256	-83.160477
PIN-16	Pinnebog River	Stein Road	43.778326	-83.101284
PGN-01	Shebon Creek	Canboro Road	43.742273	-83.336520
PGN-02	Pigeon River	Farver Road (north of Canboro)	43.749269	-83.199627
PGN-03	Pigeon River	Farver Road (south of Canboro)	43.743775	-83.199542
PGN-04	Schultz Drain	Geiger Road	43.801324	-83.262498
PGN-05	West Branch Ext. Pigeon River	Geiger Road	43.800816	-83.289313
PGN-06	Pigeon River	Campbell Road	43.858725	-83.283085
PGN-07	Pigeon River	Dunn Road	43.902673	-83.258128
PGN-08	Shebeon Creek	Haist Road	43.785029	-83.358686

Flow Measurements

Estimates of flow are required to calculate nutrient export (load); however, measuring flow at each sample location during each sampling event exceeded the resources available for this study. Therefore, flow reference curves were created in the affected watersheds following standard United States Geological Survey flow measurement protocols so that reasonable flow estimates could be extrapolated at each sampling site per sampling event. A flow reference curve is the correlation between stream flow (as cubic feet per second [cfs]) and stage height; the height of the water as measured from a specific point of reference. A measurement, referred to as a tapedown measurement, is taken from a specific reference point (i.e., a mark point on a bridge) to the surface of the water. Flow is then measured at this same location and associated with the tapedown measurement. This process is repeated for a range of flow events at each site until a correlation between the tapedown and the volume of water flowing at that measurement is established.

While flow reference curves allow for a relatively quick discharge calculation, they may be susceptible to error if channel form is altered near the reference point. Error can occur when:

- Channel form changes due to significant bed scouring.
- Excessive amounts of sediment are deposited in the channel.

- Excessive plant growth in the channel impedes flow.

Flow measurements can also be effected when:

- Water withdraw events such as irrigation temporarily decreases flow at a specific site.
- Intermittent discharges result in temporary surges in stream discharge.

Altered (dredged) channels can be highly susceptible to error because of unstable channel bed form. When nutrients are sufficient, an increase in solar exposure from the loss of mature riparian vegetation can produce a sharp increase in the quantity of plants and algae that can subsequently affect channel flow.

Tapedown (Stage) Measurements

The distance from an identified reference point to the water surface was measured at the time of sample collection at each location using a weighted steel measuring tape. The reference points were located and marked by MDEQ staff. There were no tapedown measurements taken at Station PIN02 because the samples were collected from the stream bank at this location, not at a bridge. Flows at Station PIN02 were calculated based on the flow at Station PIN01 (immediately downstream from Station PIN02) minus the volume of discharge from the Bad Axe WWTP.

SUMMARY OF SAMPLING RESULTS

Flow Sampling Results

Tapedown measurements and the flows associated with each sample location/sampling event are listed in Appendix A, Table 3. Reference curve data provided by the Hydrologic Studies Unit, Land and Water Management Division, MDEQ, are listed in Appendix C. Flow data strongly suggests that portions of these watersheds are losing systems, in that flow volume(s) actually decrease along the stream's longitudinal continuum in mid to late summer (i.e., Figure 3 from the Pigeon River).

Raw flow data from the Bad Axe Drain showed highly irregular flows throughout the sampling season. It is likely that much of this apparent error results from one or a combination of the potential sources of error listed above. Reference curve data from actual flow measurements in Bad Axe Creek (Figure 4) indicate a typical flow profile of steadily increasing flows from upstream to downstream during the early summer with a tendency to lose flow at the most

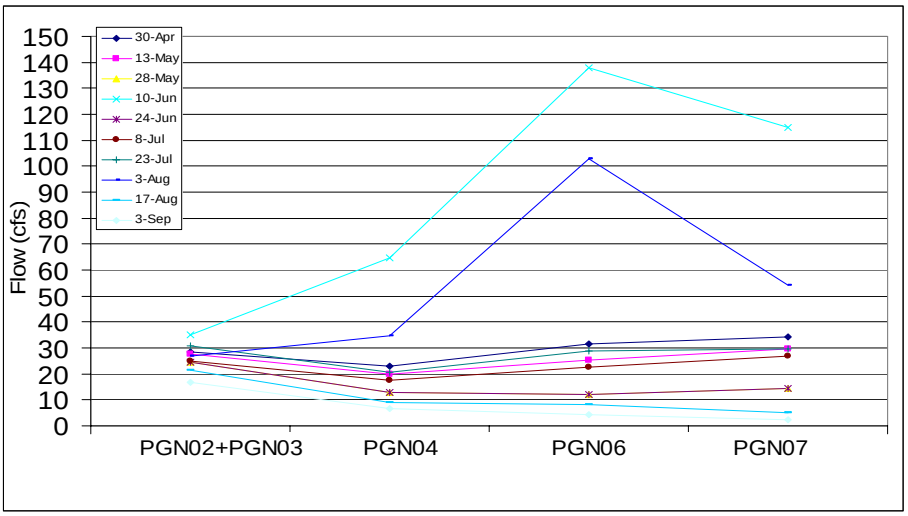

Figure 3. Flows from four sites on the Pigeon River, 2008.

downstream point in mid to late summer, a pattern relatively common to the rest of the watershed. Flows that deviated grossly from the expected flow pattern were replaced with extrapolated values that were most similar to actual flow measurements from sites immediately upstream and downstream from the site in question (i.e., Figure 4). The occasional use of extrapolated flow values was considered necessary to provide better estimates of phosphorus loads.

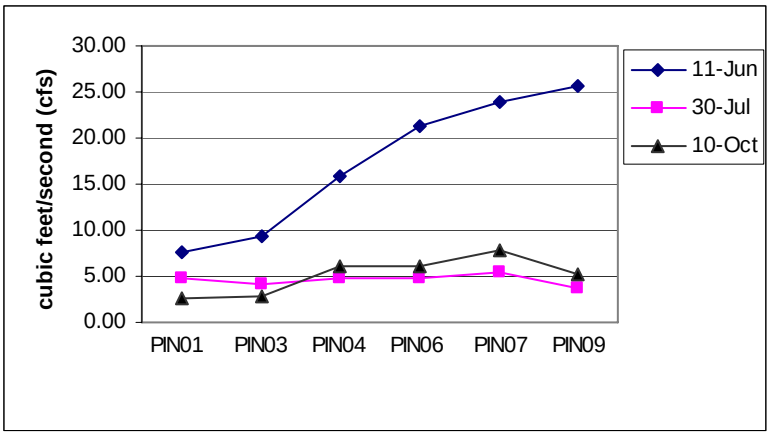

Figure 4. Reference curve data from the Bad Axe Drain, 2008.

E. COLI MONITORING RESULTS

Bi-Weekly Sampling

E. coli sampling was conducted in the Pinnebog River, Pigeon River, and tributaries on April 29/April 30; May 13/May 14; May 22 (Pinnebog River only); May 27/May 28; June 10; and June 23/June 24, 2008. The complete *E. coli* data set can be found in Appendix B. *E. coli* data summaries are presented by major watershed below.

Pinnebog River

The Pinnebog River was sampled 6 times at 5 locations between April and June 2008 (Table 5). Daily maximum concentrations ranged from 32 *E. coli* per 100 ml in April at Stein Road and May at Oak Beach Road to 2,183 *E. coli* per 100 ml in June at Stein Road. Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 11 of the 30 samples collected. The daily geometric mean WQS was exceeded at all stations on June 10, 2008 (Figure 5).

Table 5. Pinnebog River *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 – 300	301 – 1,000	1,001 – 10,000	> 10,000
PIN08 - Pinnebog River at Oak Beach Rd.	6	5	1	0	0
PIN10 - Pinnebog River at Crown Rd.	6	4	2	0	0
PIN12 - Pinnebog River at Berne Rd.	6	4	1	1	0
PIN15 - Pinnebog River at Geiger Rd.	6	3	3	0	0
PIN16 - Pinnebog River at Stein Rd.	6	3	2	1	0

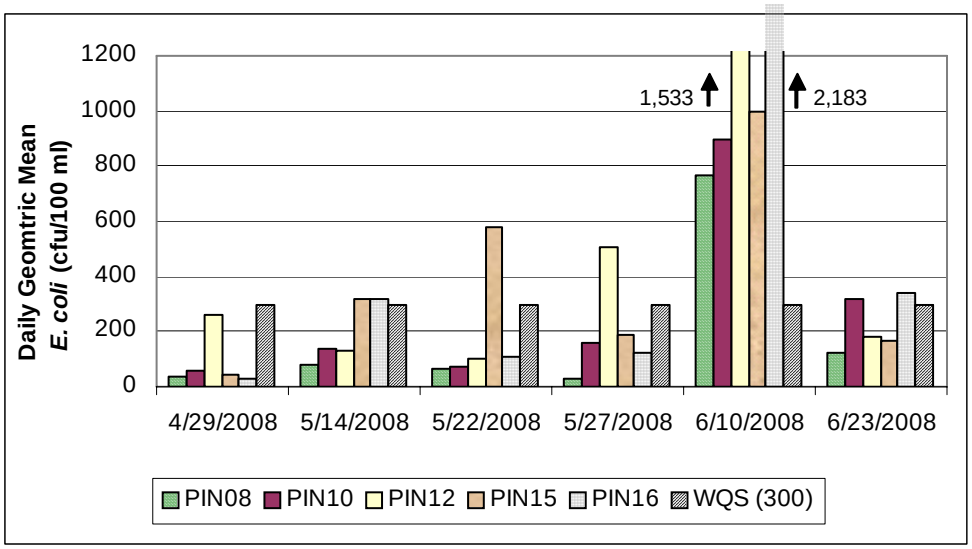

Figure 5. Daily Geometric Mean *E. coli* concentrations for the Pinnebog River, Huron County, Michigan, 2008.

Bad Axe Drain

The Bad Axe Drain was sampled 6 times at 3 locations between April and June 2008 (Table 6). Daily maximum concentrations ranged from 25 *E. coli* per 100 ml in April at Pigeon Road to 12,253 *E. coli* per 100 ml in May at Berne Road. Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 11 of the 18 samples collected (Figure 6).

Table 6. Bad Axe Drain *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0-300	301-1,000	1,001-10,000	> 10,000
PIN01 – Bad Axe Drain at Whitelam St – d/s of WWTP	6	3	1	2	0
PIN03 – Bad Axe Drain at Pigeon Rd.	6	3	1	2	0
PIN04 – Bad Axe Drain at Berne Rd.	6	1	3	1	1

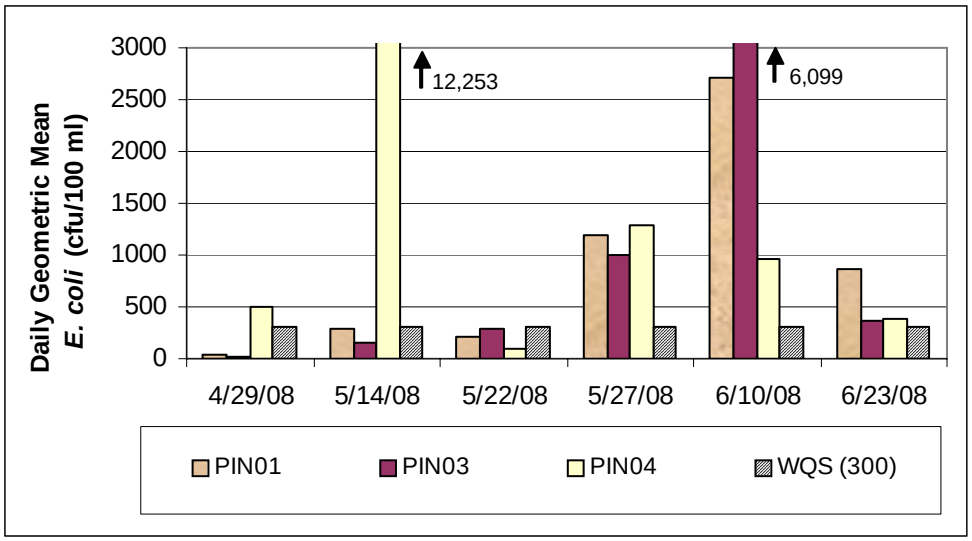

Figure 6. Daily Geometric Mean *E. coli* concentrations for the Bad Axe Drain, Huron County, Michigan, 2008.

Bad Axe Creek

The Bad Axe Creek was sampled 6 times at 3 locations between April and June 2008 (Table 7). Daily maximum concentrations ranged from 20 *E. coli* per 100 ml in April at Campbell Road to 3,979 *E. coli* per 100 ml in June at Campbell Road. Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 7 of the 18 samples collected (Figure 7).

Table 7. Bad Axe Creek *E. coli* concentrations at the locations indicated, April-June, 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 - 300	301 - 1,000	1,001 - 10,000	> 10,000
PIN06 – Bad Axe Creek at Campbell Rd.	6	3	1	1	1
PIN07 – Bad Axe Creek at Pinnebog Rd.	6	4	2	0	0
PIN09 – Bad Axe Creek at Filion Rd.	6	6	0	0	0

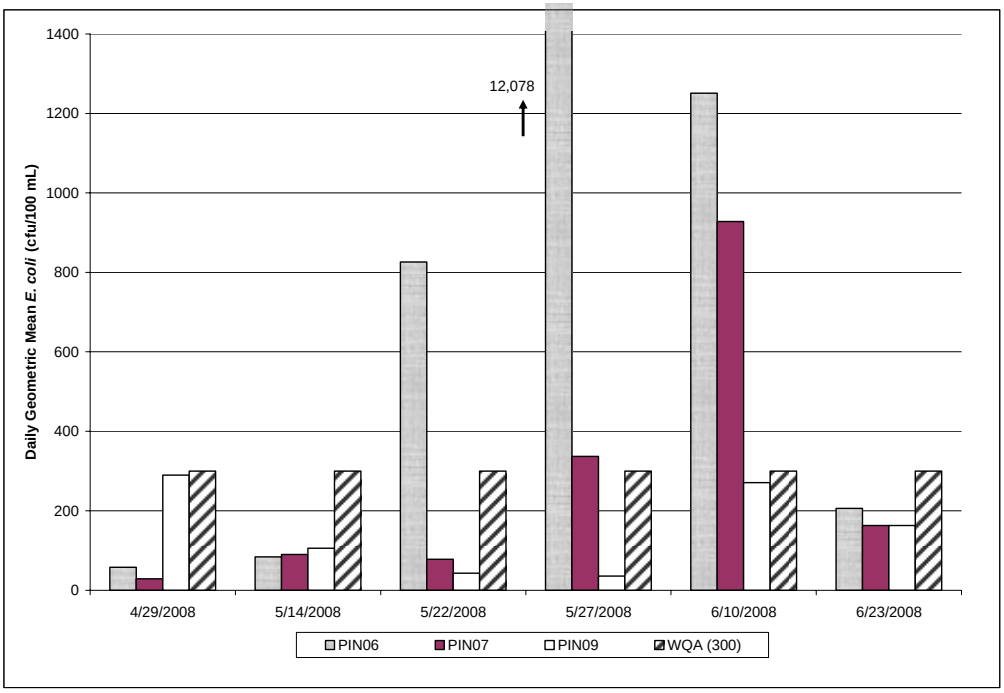

Figure 7. Daily Geometric Mean *E. coli* concentrations for the Bad Axe Creek, Huron County, Michigan, 2008.

McMullen Drain

The McMullen Drain was sampled 6 times at 2 locations between April and June 2008 (Table 8). Daily maximum concentrations ranged from 20 *E. coli* per 100 ml in April at Campbell Road to 12,078 *E. coli* per 100 ml in May at Pinnebog Road. Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 7 of the 12 samples collected (Figure 8).

Table 8. McMullen Drain *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 – 300	301 – 1,000	1,001 – 10,000	> 10,000
PIN05 – McMullen Drain at Pinnebog Rd.	6	1	3	2	1
PIN11 – McMullen Drain at Campbell Rd.	6	2	3	1	0

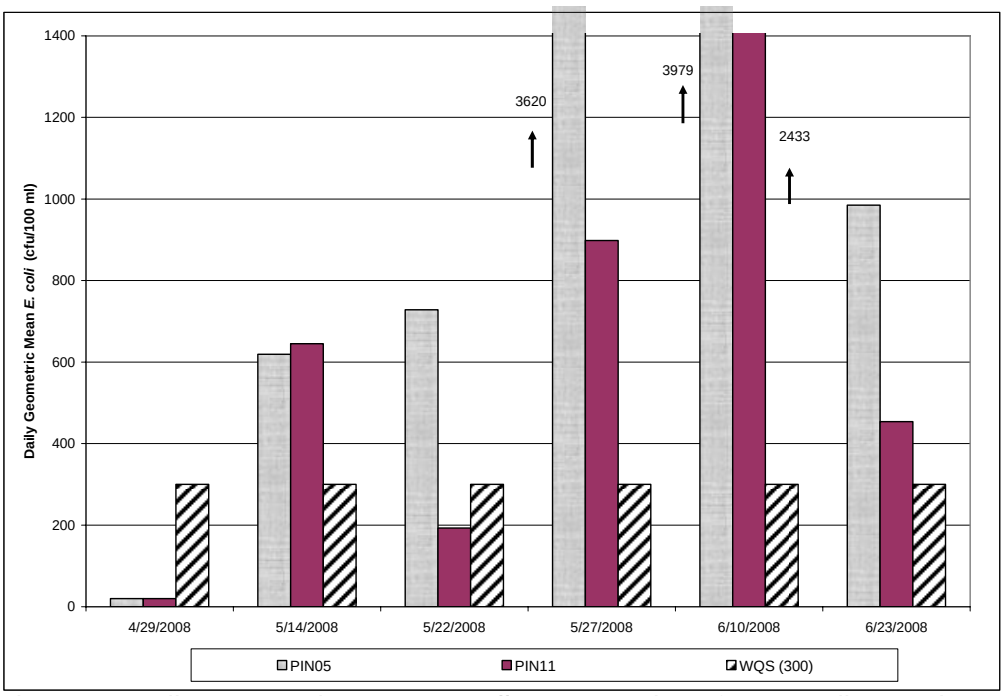

Figure 8. Daily Geometric Mean *E. coli* concentrations for McMullen Drain, Huron County, Michigan, 2008.

Pinnebog River Tributaries (Nettle Run and Elkton Drain)

Nettle Run and the Elkton Drain were sampled 6 times between April and June 2008 (Table 9). Daily maximum concentrations in Nettle Run ranged from 20 *E. coli* per 100 ml in May to 2,998 *E. coli* per 100 ml in June. Daily maximum concentrations in the Elkton Drain ranged from 43 *E. coli* per 100 ml in May to 3,796 *E. coli* per 100 ml in April. Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 3 of the 6 samples in Nettle Run and 5 of the 6 samples in the Elkton Drain (Figure 9).

Table 9. Nettle Run and Elkton Drain *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 - 300	301 – 1,000	1,001 – 10,000	> 10,000
PIN13 – Nettle Run at Richardson Rd.	6	3	2	1	0
PIN14 – Elkton Drain at Elkton Rd.	6	1	1	4	0

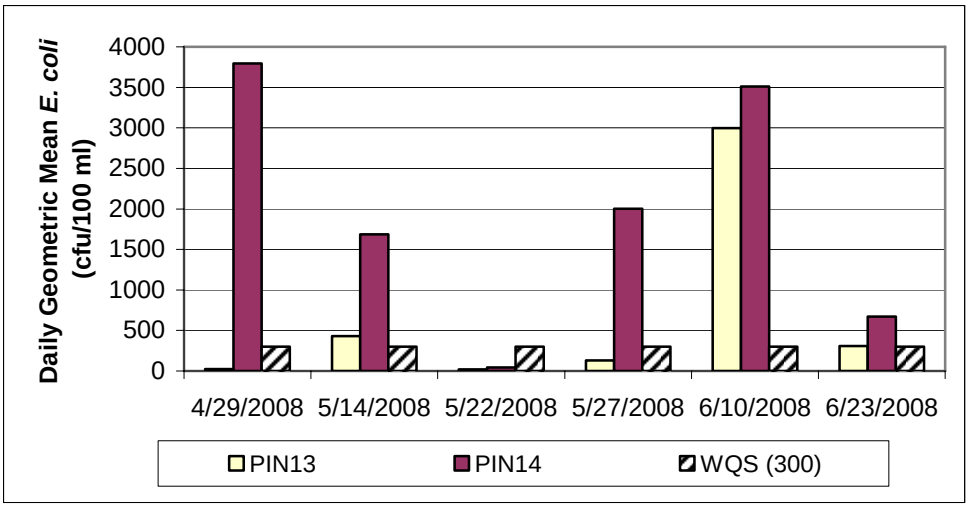

Figure 9. Daily Geometric Mean *E. coli* concentrations for Nettle Run and Elkton Drain, Huron County, Michigan, 2008.

Pigeon River

The Pigeon River was sampled 5 times at 4 locations between April and June 2008 (Table 10). Daily maximum concentrations ranged from 29 *E. coli* per 100 ml in April at Dunn Road to 1,151 *E. coli* per 100 ml in June at Farver Road (north of Canboro). Daily maximum *E. coli* concentrations exceeded the daily geometric mean total body contact recreation WQS of 300 *E. coli* per 100 ml in 6 of the 20 samples collected (Figure 10).

Table 10. Pigeon River *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 - 300	301 – 1,000	1,001 – 10,000	> 10,000
PGN02 - Pigeon River at Farver Rd. (N. of Canboro)	5	3	1	1	0
PGN03 - Pigeon River at Farver Rd. (S. of Canboro)	5	2	3	0	0
PGN06 - Pigeon River at Campbell Rd.	5	4	1	0	0
PGN07 - Pigeon River at Dunn Rd.	5	5	0	0	0

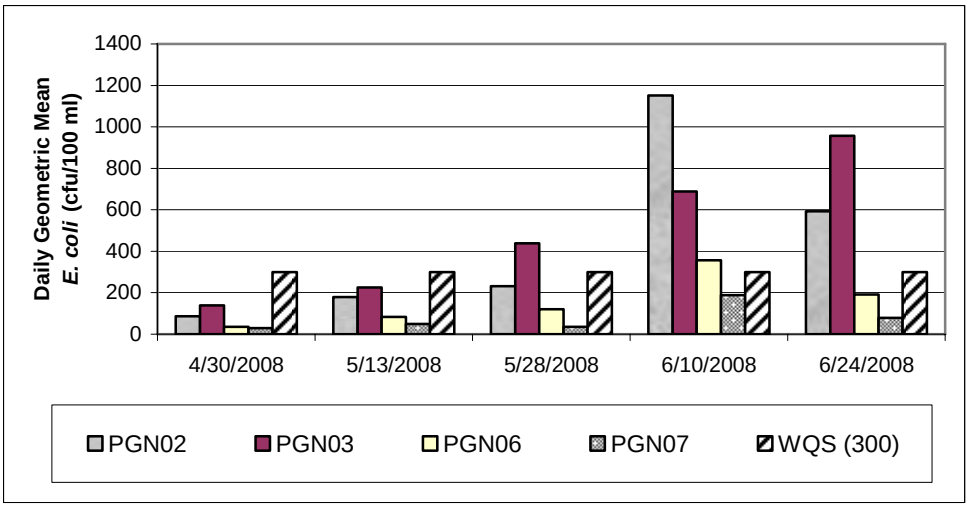

Figure 10. Daily geometric mean *E. coli* concentrations for the Pigeon River, Huron County, Michigan, 2008.

Shebeon Creek

Shebeon Creek was sampled 5 times at 2 locations between April and June 2008. A summary of *E. coli* concentrations can be found in Table 11. Daily maximum concentrations ranged from 20 *E. coli* per 100 ml in April at Canboro Road to 273 *E. coli* per 100 ml in June at Haist Road. Both stations on Shebeon Creek meet the daily maximum WQS of 300 *E. coli* per 100 ml for all 10 samples collected (Figure 11).

Table 11. Shebeon Creek *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 - 300	301 – 1,000	1,001 – 10,000	> 10,000
PGN01 - Shebeon Creek at Canboro Rd.	5	5	0	0	0
PGN08 - Shebeon Creek at Haist Rd.	5	5	0	0	0

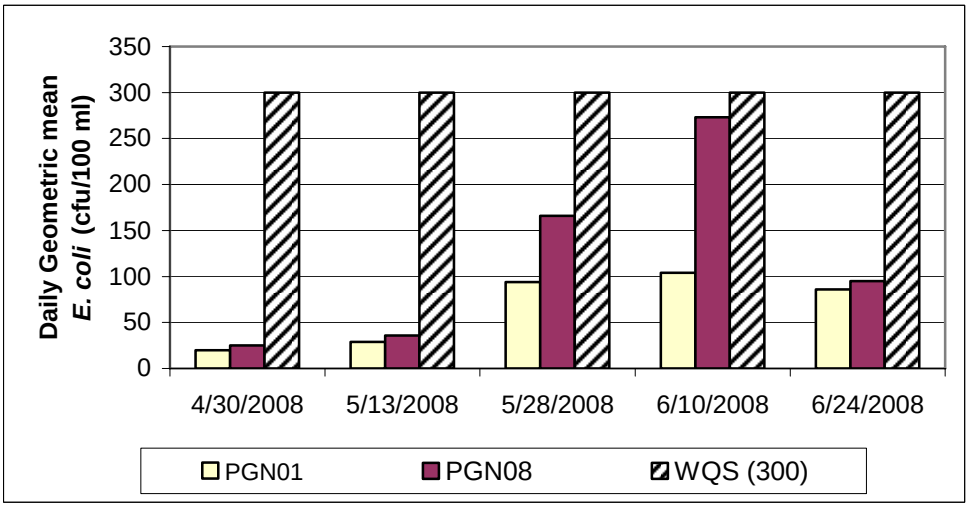

Figure 11. Daily Geometric Mean *E. coli* concentrations for Shebeon Creek, Huron County, Michigan, 2008.

Pigeon River Tributaries (Schultz Drain and the West Branch Extension Drain of the Pigeon River)

Schultz Drain and the West Branch Extension Drain of the Pigeon River were sampled 5 times between April and June 2008. A summary of *E. coli* concentrations can be found in Table 12. Daily maximum concentrations in the Schultz Drain ranged from 119 *E. coli* per 100 ml in April to 538 *E. coli* per 100 ml in June. Daily maximum concentrations in the West Branch Extension Drain of the Pigeon River ranged from 32 *E. coli* per 100 ml in April to 337 *E. coli* per 100 ml in June. Daily maximum *E. coli* concentrations exceeded the 300 *E. coli* per 100 ml total body contact WQS in 2 of the 5 samples in the Schultz Drain and in 1 of the 5 samples taken in the West Branch Extension Drain of the Pigeon River (Figure 12).

Table 12. Pigeon River tributaries (Schultz Drain and the West Branch Extension Drain of the Pigeon River) *E. coli* concentrations at the locations indicated, April-June 2008.

Sampling Sites	Total No. of Values	Daily Geometric Mean *E. coli* Range (cfu/100mL)			
		0 - 300	301 – 1,000	1,001 – 10,000	> 10,000
PGN04 - Schultz Drain at Geiger Rd.	5	3	2	0	0
PGN05 - West Branch Extension Drain of Pigeon River at Geiger Rd.	5	4	1	0	0

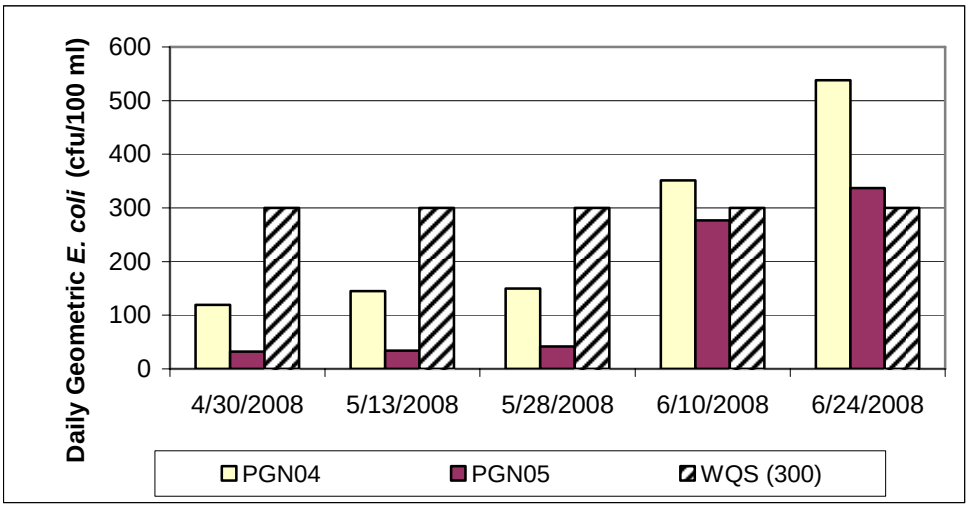

Figure 12. Daily Geometric Mean *E. coli* concentrations for tributaries of the Pigeon River (Schultz Drain and the West Branch Extension Drain of the Pigeon River), Huron County, Michigan, 2008.

Wet Weather

A wet weather sampling event was conducted on June 10, 2008. Exceedances of WQS were observed at all sampling stations on the Pinnebog River, Bad Axe Drain, McMullen Drain, Nettle Run, and Elkton Drain. Two of three stations on the Bad Axe Creek exhibited WQS exceedances during this sampling event (Figures 5-9).

WQS exceedances during wet weather appear to be less frequent in the Pigeon River watershed relative to the Pinnebog River watershed. For instance, Shebeon Drain and the West Branch Extension Drain of the Pigeon River met WQS on June 10, 2008. WQS exceedances were observed at 3 of 4 stations on the Pigeon River and on the Schultz Drain (Figures 10-12).

BST Sample Results

BST was conducted at selected sample locations to aid in identifying the potential sources of elevated *E. coli*. Two indicator organisms, *Bacteroidetes* and *Enterococcus*, were chosen due to their unique characteristics. Fecal *Bacteroidetes* are strict anaerobes (i.e., do not require oxygen) and can be indicative of recent fecal contamination when found in water. On the other hand, *Enterococcus* is able to survive for extended periods of time and can indicate longer term fecal pollution. When used together, these two fecal indicator organisms strengthen the validity of positive results in BST analyses.

Samples were collected and sent to Source Molecular Corporation for a two-step BST process using the fecal indicator organisms described above. In the first step, samples were analyzed for the presence of human and/or cattle fecal biomarkers (Table 13a). If positive results were found for either human or cattle sources of *E. coli*, specific analyses (i.e., Human *Bacteroidetes* "Quantification" ID™, Human *Enterococcus* "Quantification" ID™, Cow *Bacteroidetes* "Quantification" ID™, and Cow *Enterococcus* "Quantification" ID™) were used to quantify the approximate percentage of the biomarkers, by source, in the samples. Eleven of the 15 sample locations selected for BST analyses had positive results for human and/or cow fecal biomarkers. Quantification for samples testing positive for human and/or cattle biomarkers are presented in Table 13b.

When interpreting any BST result, it should be emphasized that only a small subset of samples were collected for this specialized analyses (i.e., one sample per station). A "negative" result should not exclude human and/or cattle contamination as a possible source of *E. coli* at a particular location. Such conclusions would require a comprehensive sample design and was beyond the scope of this project.

Table 13a. BST – Biomarker Identification Summary.

Location	**Cow *Bacteroidetes***	**Cow *Enterococci***	**Human *Bacteroidetes***	**Human *Enterococci***
Pinnebog River Watershed				
PIN01	Positive	positive	Positive	positive
PIN03	Negative	negative	Negative	positive
PIN04	Negative	negative	Negative	negative
PIN05	Positive	positive	Positive	positive
PIN06	Negative	negative	Negative	negative
PIN08	Negative	negative	Negative	negative
PIN10	Negative	negative	Positive	positive
PIN11	Negative	negative	Positive	positive
PIN13	Negative	negative	Positive	positive
PIN14	Negative	negative	Positive	positive
PIN15	Negative	negative	Negative	negative
PIN16	Negative	negative	Positive	positive
Pigeon River Watershed				
PGN02	Negative	negative	Negative	positive
PGN03	Negative	negative	Positive	Positive
PGN06	Negative	negative	Negative	negative

Table 13b. Quantification of *E. coli* samples by source (note: percentages are estimates only).

Sampling Sites	Human *Enterococcus* Biomarker Quantification (%)	Human *Bacteroidetes* Biomarker Quantification (%)	Cow *Enterococcus* Biomarker Quantification (%)	Cow *Bacteroidetes* Biomarker Quantification (%)
Pinnebog River				
PIN10	<10	<10	n/a	n/a
PIN16	100	<10	n/a	n/a
Bad Axe Drain				
PIN01	>80	>80	<10	<10
PIN03	10-30	n/a	n/a	n/a
PIN03	<10	<10	n/a	n/a
McMullen Drain				
PIN05	>80	>80	<10	<10
PIN11	<10	<10	n/a	n/a
Nettle Run				
PIN13	<10	10-30	n/a	n/a
Elkton Drain				
PIN14	<10	<10	n/a	n/a
Pigeon River				
PGN03	*	*	n/a	n/a
PGN02	10-30	n/a	n/a	n/a

> = greater than
< = less than
*biomarker detected but laboratory ratios rejected

TP and SRP Monitoring Summary Bi-Weekly Sampling

Bi-weekly sampling was conducted for TP and SRP for the entire sampling period from April 29 to September 4, 2008. The sample results for TP and SRP are included in Appendix A. Nutrient export, expressed as a load in pounds per day (lbs/day), was calculated in this monitoring effort to demonstrate the quantity of phosphorus that is contributed to a stream for downstream export at specific points along the river's continuum. It is, however, important to note that load is a calculated value based on the concentration of the parameter being sampled and the stream flow in the channel at the time of sampling. As such, the load values expressed below demonstrate differences in nutrient export with changes in land use and suggest areas where nutrient contributions to the stream(s) may be greater than in other areas. The data should not be used as a quantitative measure of chronic loading rates or as part of an annual nutrient budget for each respective waterway or Saginaw Bay.

The highest average TP and SRP concentrations in the Pinnebog River were reported at Station PIN14. Station PIN14 is on the Elkton Drain at Elkton Road, just downstream of the Village of Elkton. The highest average TP concentration on the Pigeon River was reported at Station PGN06 at Campbell Road. The highest average SRP concentration on the Pigeon River was found at Station PGN05, which is located on the West Branch Extension Drain of Pigeon River at Geiger Road.

The TP concentrations reported in the Pinnebog River watershed ranged from 0.014 milligrams per liter (mg/L) at Station PIN05 on June 23, 2008, to 0.99 mg/L at Station PIN14 on September 3, 2008. The TP concentrations reported on the Pigeon River range from 0.009 mg/L at Station PGN03 on April 30, 2008, to 0.54 mg/L at Station PGN06 on May 28, 2008.

The minimum SRP concentration reported in the Pinnebog River watershed was 0.001 mg/L, which was observed at Stations PIN05, PIN08, PIN09, PIN10, PIN11, PIN12, PIN13, and PIN16. The maximum SRP concentration reported was 0.5 mg/L at Station PIN13 on May 27, 2008. The SRP concentrations reported on the Pigeon River ranged from 0.001 mg/L at Station PGN03 on May 28, 2008, to 0.37 mg/L at Station PGN06 on May 14, 2008.

Wet Weather

Wet weather sampling events were conducted on June 10 and August 3, 2008, and analyzed for TP and SRP. When considering all TP concentrations collected during the study period, none of the 16 Pinnebog River sampling stations show the maximum TP concentration on the June 10, 2008, wet weather sampling event (Figure 4). However, the maximum TP concentration collected during the study period was detected at 5 of the 16 Pinnebog River sampling stations during the second wet weather event on August 3, 2008. When considering all TP concentrations collected during the study period, none of the 8 Pigeon River sampling stations show the maximum TP concentration on the June 10, 2008, wet weather sampling event (Figure 5). However, the maximum TP concentration was detected at 3 of the 8 Pigeon River sampling stations during the second wet weather event on August 3, 2008.

Pinnebog River

The main branch of the Pinnebog River was monitored at 5 specific locations (Figure 13). Station PIN16 was the most upstream location, Station PIN15 was immediately upstream of the village of Elkton while Station PIN12 was located downstream of Elkton. Station PIN10 provides an estimation of the nutrient load upstream from Bad Axe Creek while Station PIN 08 describes the nutrient load upstream from the bay. Significant tributaries to the Pinnebog River include Stations PIN13 and PIN14, which are immediately downstream from Elkton. The McMullen Drain containing Stations PIN05 and PIN11 confluences immediately upstream from Station PIN10 and Bad Axe Creek, which joins the Pinnebog River approximately 2 miles downstream from Station PIN10. Bad Axe Creek was monitored at 6 locations representing above and below the Bad Axe WWTP (Stations PIN02 and PIN01, respectively), downstream from the urban portion of the community of Bad Axe (Station PIN03), and downstream from a general area containing several Animal Feeding Operations between Station PIN03 and the streams confluence (Stations PIN04, PIN05, PIN07, and PIN09).

Flow data for all sites sampled in the Pigeon and Pinnebog Rivers and the Shebeon Drain are contained in Appendix C. Concentration values are in Appendix A; Tables 1a-4a. Figure 14 shows changes in concentration while Figure 15 graphically demonstrates changes in stream flow and the load of both TP and SRP. Changes in phosphorus export in the Pinnebog River were generally correlated with changes in flow with some exceptions while the concentration of phosphorus reflected changes in the rate of phosphorus loading to the stream channel. As an example, the concentration of phosphorus increased dramatically on May 27, 2008, downstream of the village of Elkton (Station PIN12) and then decreased by more than 50 percent at Station PIN10 (Figure 14). It is likely that the increase at Station PIN12 is from contributions from the tributaries represented by Stations PIN13 and PIN14. The concentration decrease seen at Station PIN10 is likely due to a combination of dilution from tributaries downstream from Station PIN12 and the loss of phosphorus due to biological uptake and adherence to sediment particulates (physical processes). The TP concentration then increases downstream from the confluence of Bad Axe Creek at Station PIN08 demonstrating that there is a significant source of phosphorus between Stations PIN10 and PIN08.

The change in phosphorus load (Figure 15) shows the actual amount of TP that is being exported downstream without the effects of dilution. The significant increase in the load of TP downstream from the village of Elkton at Station PIN12 is consistent with the change in TP concentration. The decrease in load seen at Station PIN10 reinforces the likelihood that phosphorus was lost to biological and physical processes and that the reduction is not due to

dilution. However, the increase seen at Station PIN08 clearly demonstrates that even though the concentration of TP was less at Station PIN08 than what was seen at Station PIN12, the actual amount of phosphorus in the channel was significantly higher, likely reflecting an increase in the amount of phosphorus added to the Pinnebog River from other sources. It should be noted that the phosphorus load from Bad Axe Creek was calculated at 18.5 lbs/day on the same date.

The greatest export value measured in the Pinnebog River at the most downstream station (PIN08) was approximately 245 lbs/day of phosphorus on June 10, 2008, while the lowest value was 9.7 lbs/day during base flow conditions on September 3, 2008.

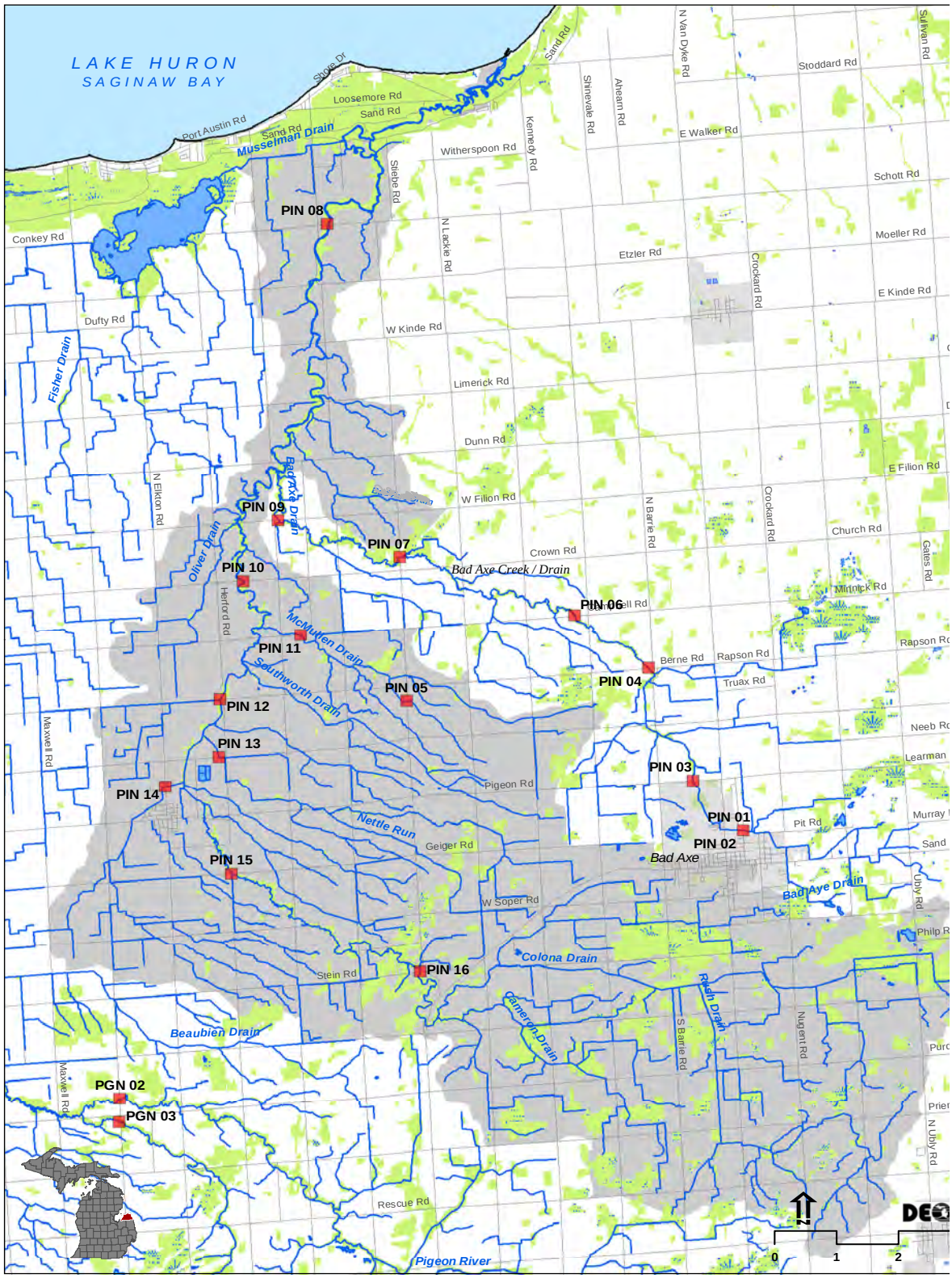

Figure 13. Sampling locations in the Pinnebog River watershed including Bad Axe Creek.

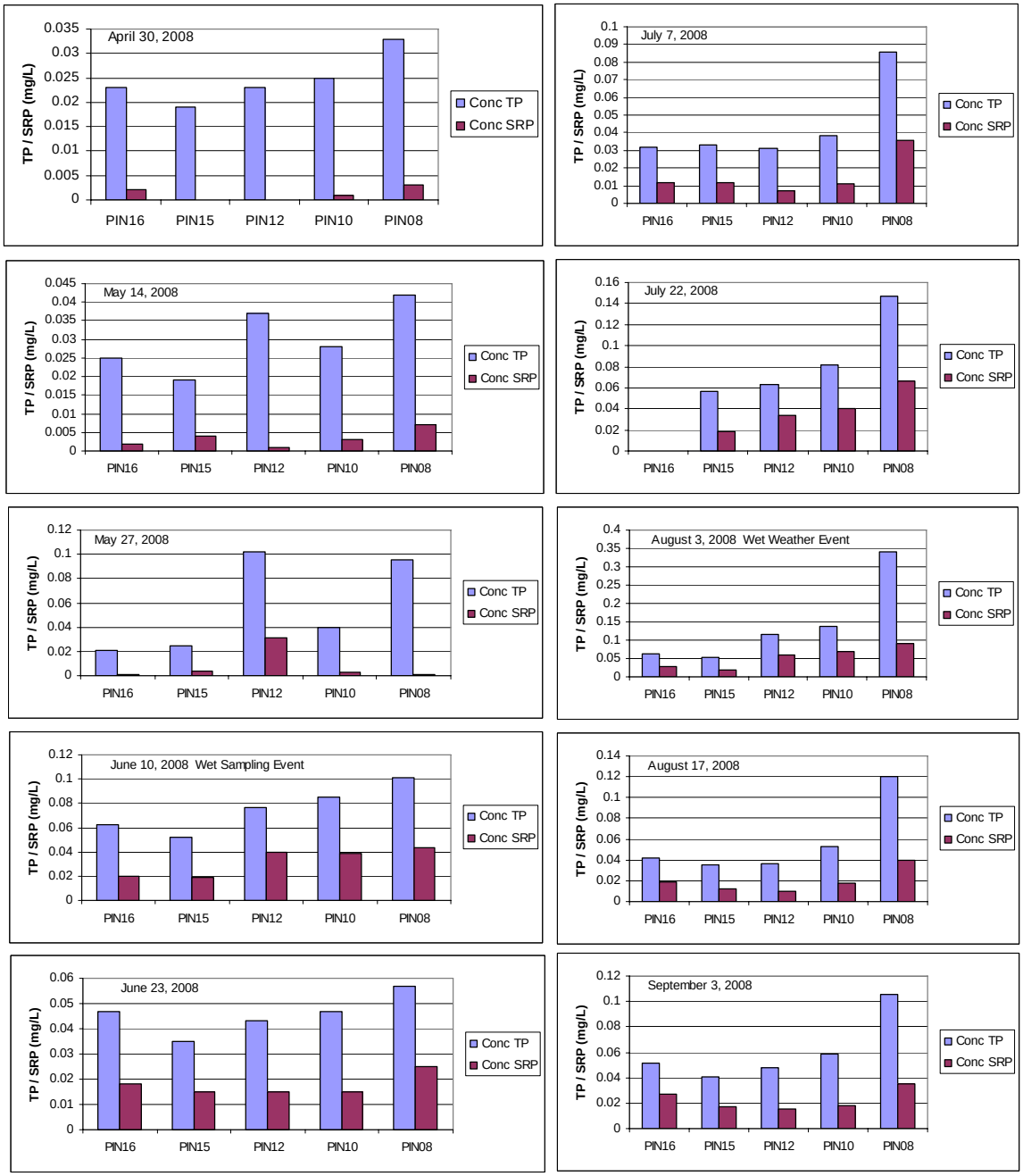

Figure 14. TP and SRP concentrations in the Pinnebog River, April 30-September 3, 2008.

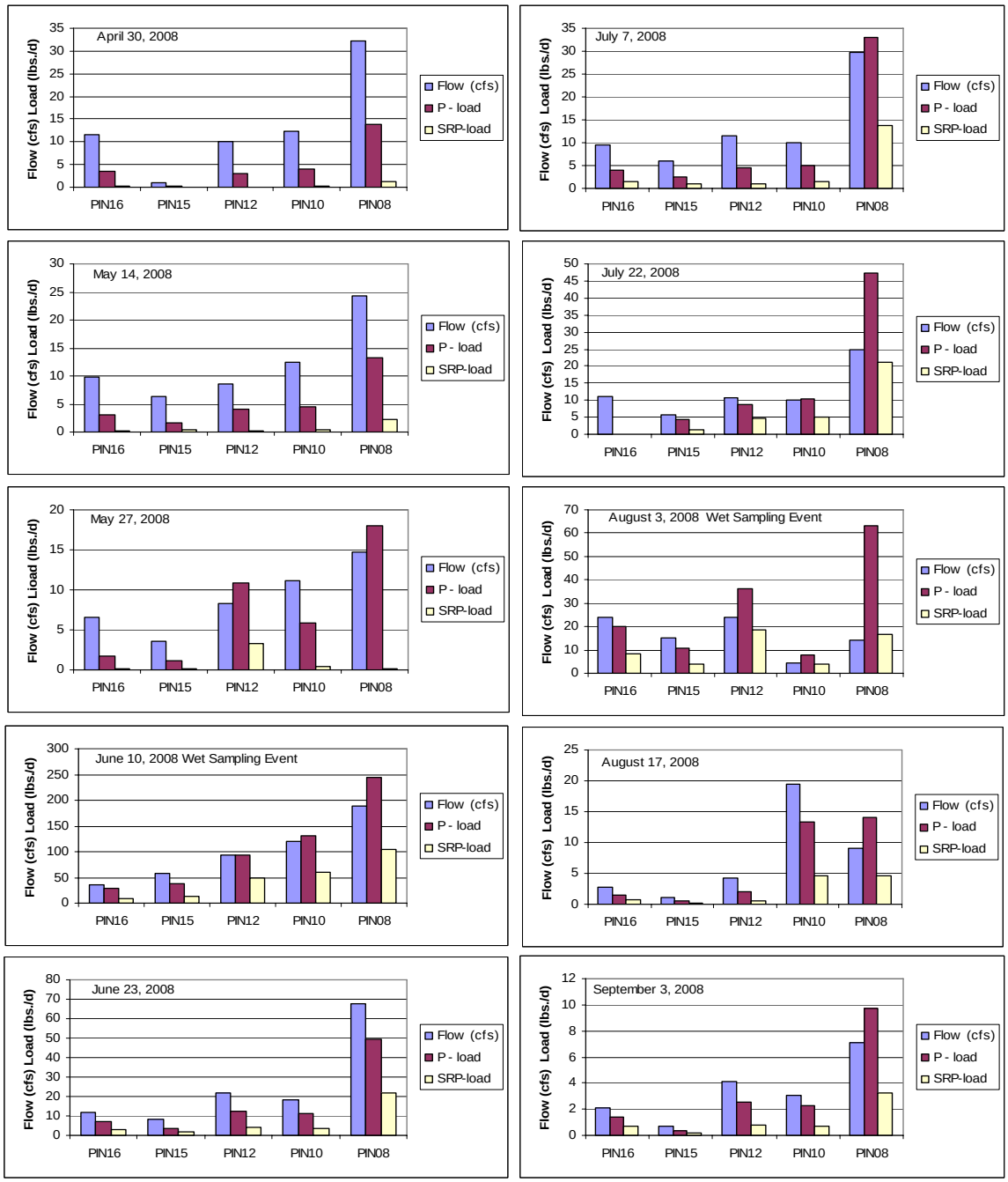

Figure 15. Flow, and the export of TP and SRP as lbs/day in the Pinnebog River, April 29-September 3, 2008.

Bad Axe Creek (Bad Axe Drain)

Bad Axe Creek (Figure 13) begins as a series of agricultural drains immediately east of the city of Bad Axe and flows northwest to its confluence with the Pinnebog River. The stream (also referred to as the Bad Axe Drain in the headwater region) receives the discharge from the city's WWTP and a seasonal discharge from a lagoon system, all located within an urban land use

area. As the stream flows northwest it passes through primarily row crop agricultural land use and in the proximity of several Animal Feeding Operations.

Concentrations of TP and SRP in Bad Axe Creek (Figure 16) were relatively high compared to most streams of similar size. Concentrations typically spiked downstream from the WWTP (Station PIN01) and were then reduced 1.65 miles downstream at Station PIN03 before elevating again at Station PIN04. The TP concentration spike at Station PIN01 is likely the influence of the Bad Axe WWTP. A reduction in concentration between Stations PIN01 and

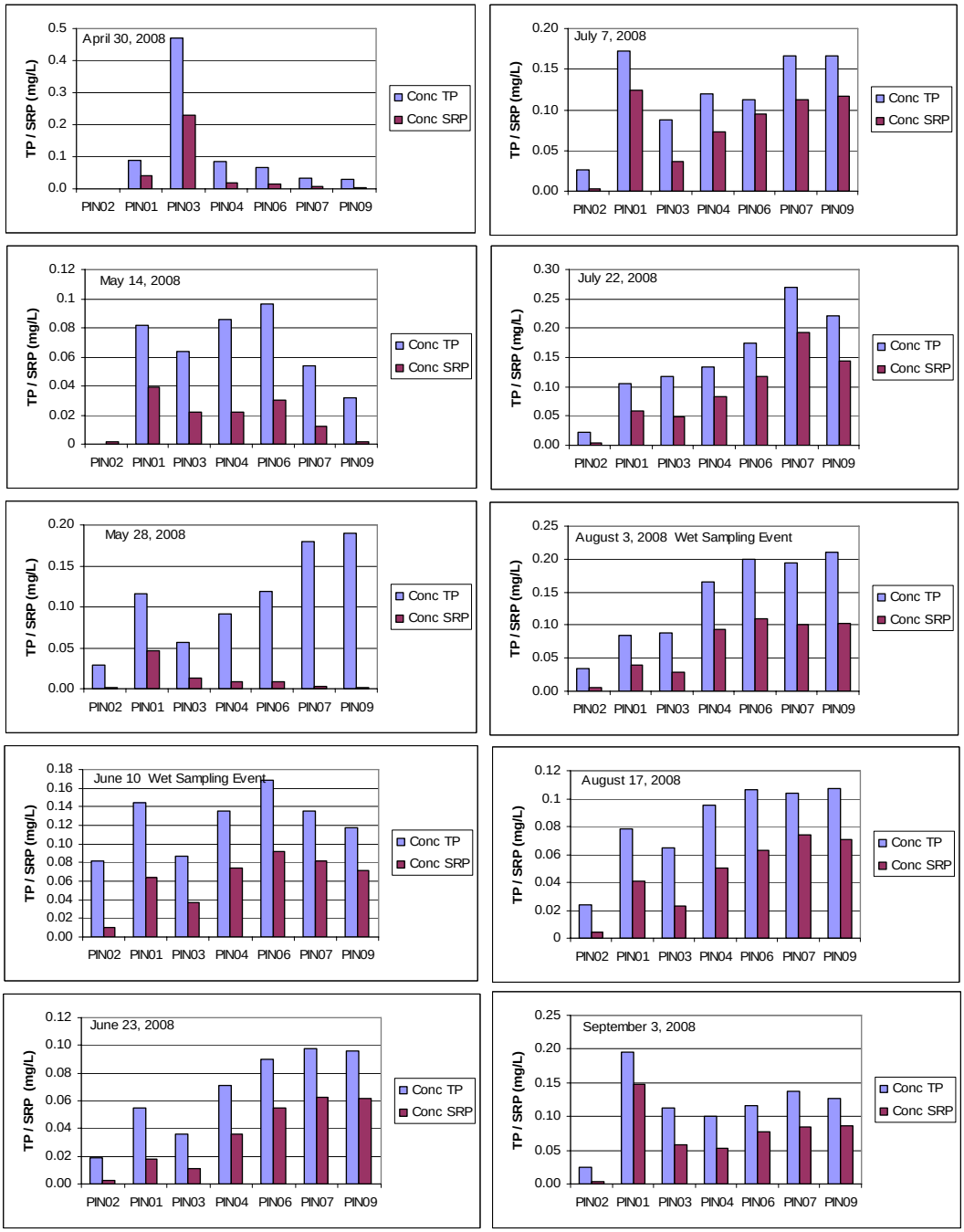

Figure 16. TP and SRP concentrations in Bad Axe Creek, April 30-September 3, 2008.

PIN03 was common during the course of this study with the exception of a TP spike on April 29, 2008, at Station PIN03. It was later determined that the April 29 sampling event occurred as the Colfax Township Waste Water Sewage Lagoon, located approximately one mile upstream from Station PIN03, was discharging. In general, phosphorus concentrations increased between Stations PIN03 and PIN09 with a corresponding increase in phosphorus export (i.e., Figure 17).

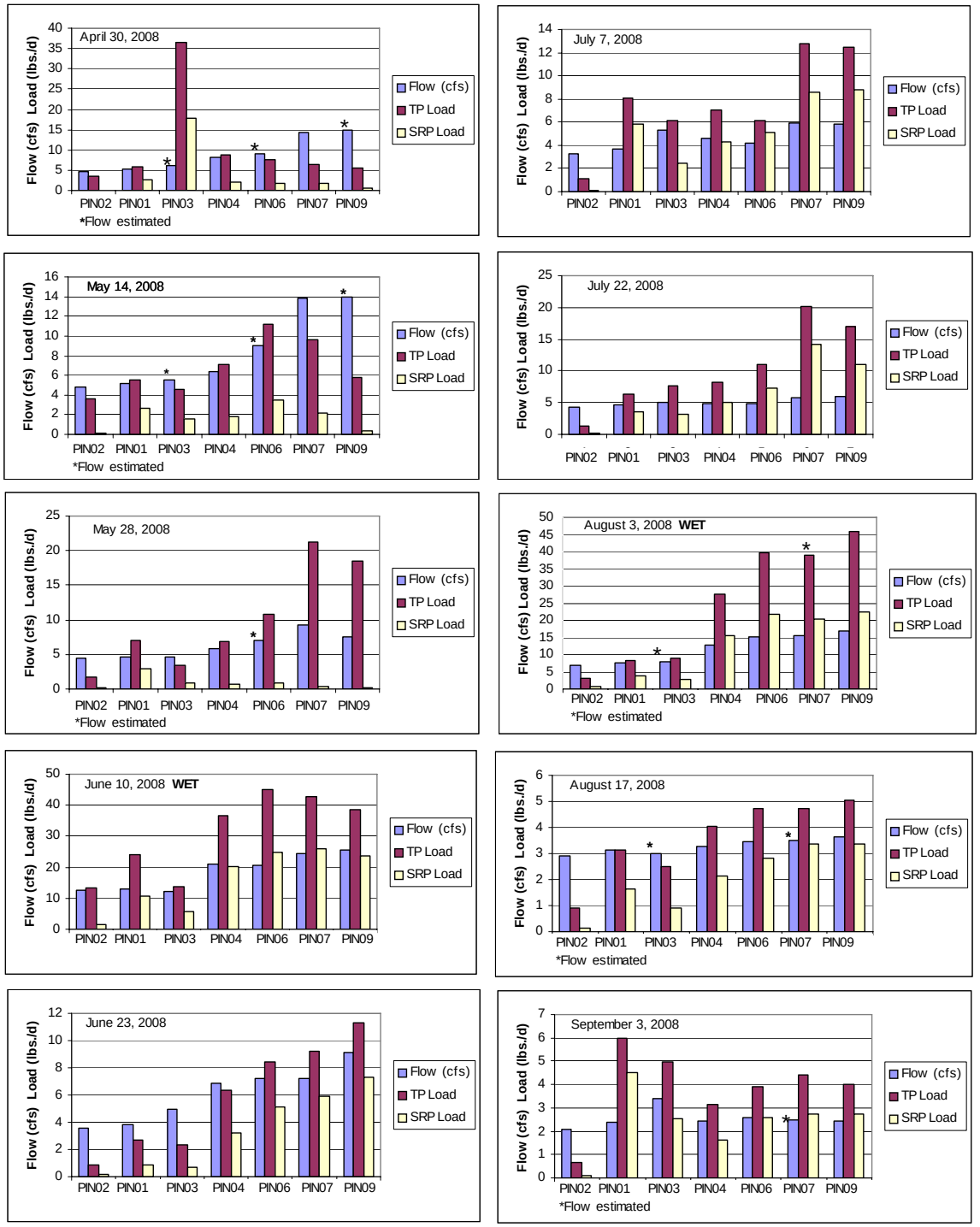

Figure 17. Flow, and the export of TP and SRP as lbs/day in Bad Axe Creek/Drain, April 30-September 3, 2008.

Additional tributaries to the Pinnebog River were monitored by Stations PIN05 and PIN11 on the McMullen Drain, Station PIN13 on Nettle Run, and Station PIN14 on the Elkton Drain (Figures 18 and 19).

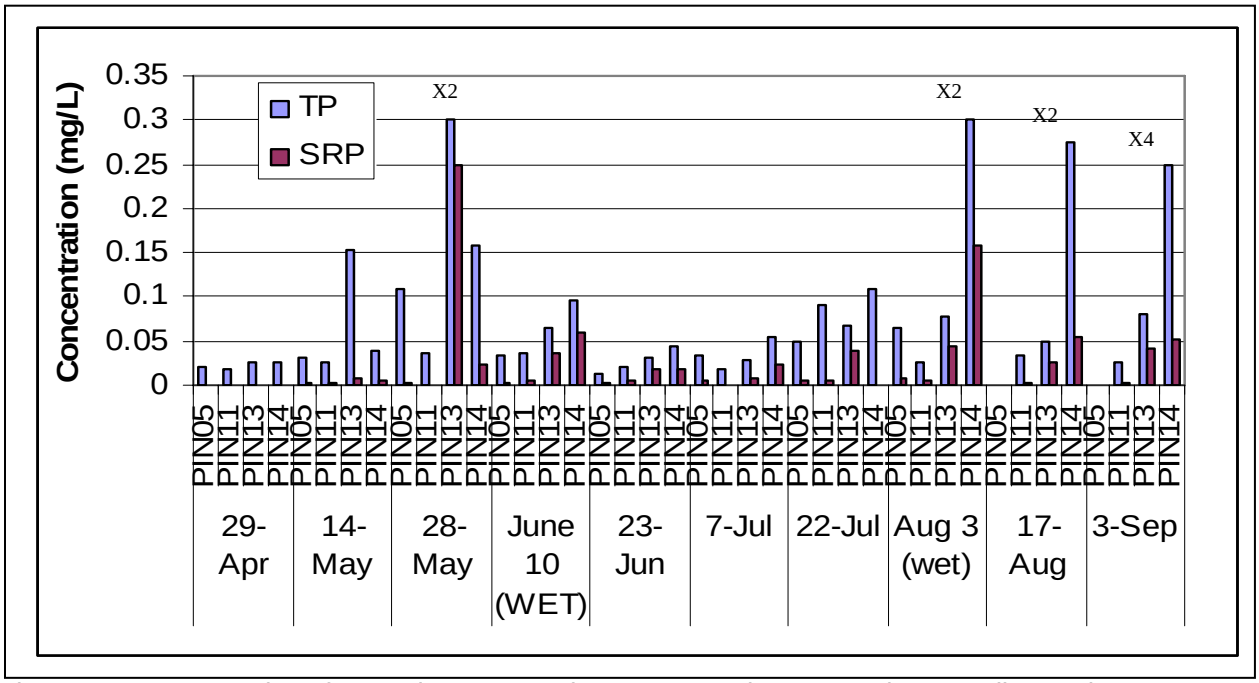

Figure 18. Concentration of TP and SRP at Stations PIN05 and PIN11 on the McMullen Drain, Station PIN13 on Nettle Run, and Station PIN14 on the Elkton Drain, April 29-September 3, 2008. Note that the values indicated at Station PIN13 on May 28, August 3, August 17, and September 3 are reduced to protect the scale of the other monitoring events. The values shown should be multiplied by the values indicated to provide the actual sample result found.

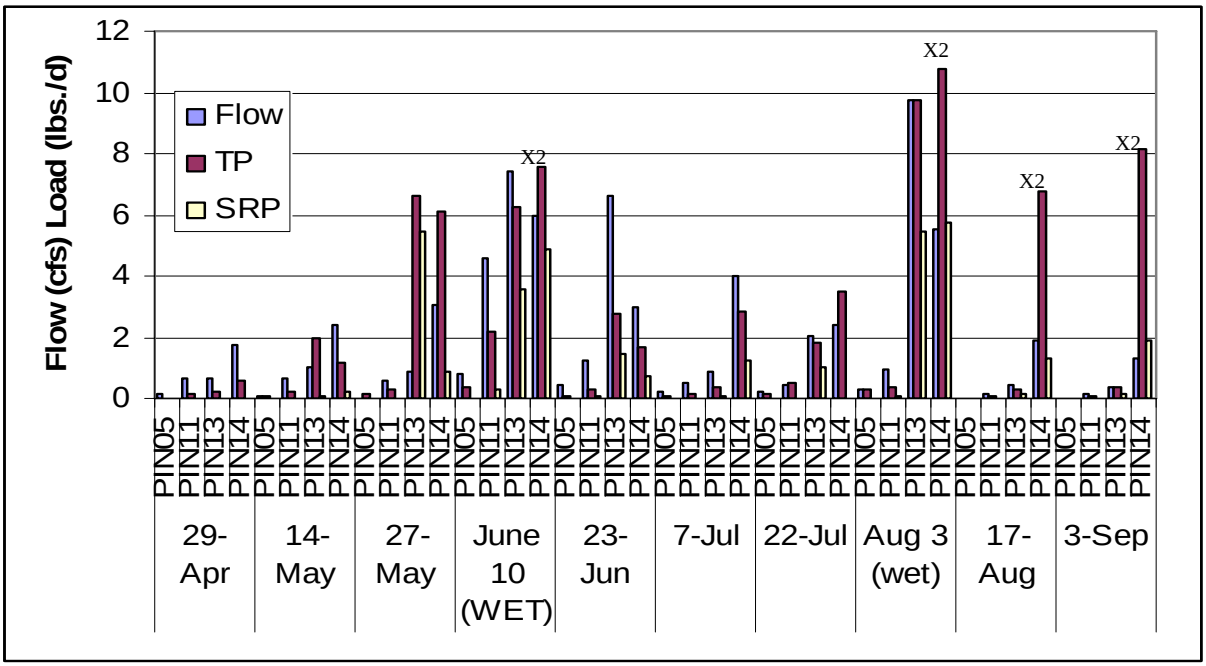

Figure 19. Flow and the load of TP and SRP at Stations PIN05 and PIN11 on the McMullen Drain, Station PIN13 on Nettle Run, and Station PIN14 on Elkton Drain, April 29-September 3, 2008. Note that the values indicated at Station PIN14 for June 10, August 3, August 17, and September 3 are reduced to protect the scale of the other monitoring events. The values shown should be multiplied by two (2) to provide the actual sample value found.

Pigeon River

Sampling locations in the Pigeon River (Figure 20) begin in the west branch Pigeon River (Station PGN03) and the main branch Pigeon River (Station PGN02). An additional data point is provided in the data tables and figures as Station "02+03." This data point reflects the additive values from sampling Stations PGN02 and PGN03 and is added to provide a point of comparing phosphorus and flow in upper portions of the Pigeon River where the west branch and main branch of the Pigeon River confluence.

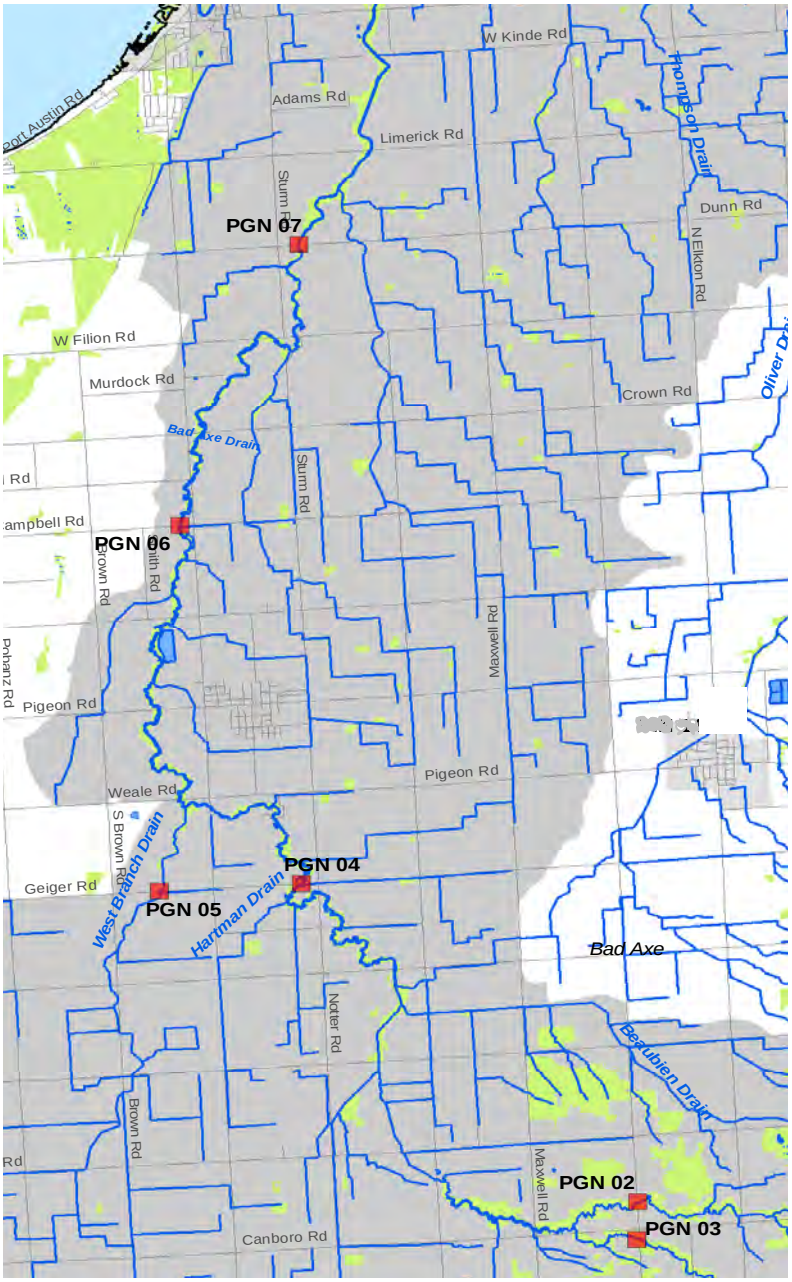

Figure 20. Sampling locations in the Pigeon River watershed, 2008.

Flow at Station PGN04 consistently decreased from the upper reaches during dry weather sampling events, suggesting that a portion of the channel between 02+03 and PGN04 acts as a losing stream. Flow increased predictably between these same two points during wet weather events. Flow also decreased in the downstream reaches (Station PGN07) in late August and September. The loss of flow in the lower Pigeon River is consistent with biological surveys that reported low flows or even no flow in the lower Pigeon River in late summer.

Phosphorus concentrations in the Pigeon River (Figure 21) were highly variable from late April to September. Phosphorus concentrations were elevated downstream from the village of Pigeon in late April and early May; however, concentrations were not remarkable compared to other sampling locations from late May to early September. It should be noted that the ratio of TP to SRP was relatively high on many sampling dates and locations. Soluble reactive phosphorus represents the form of phosphorus that is most available for biological uptake. Ratios of TP to SRP exceeding 2:1 strongly suggest that the biological community is either unavailable for phosphorus uptake or that the community is

saturated with no further SRP uptake possible. Phosphorus export (Figure 22) was correlated with stream flow and predictably high during wet weather events.

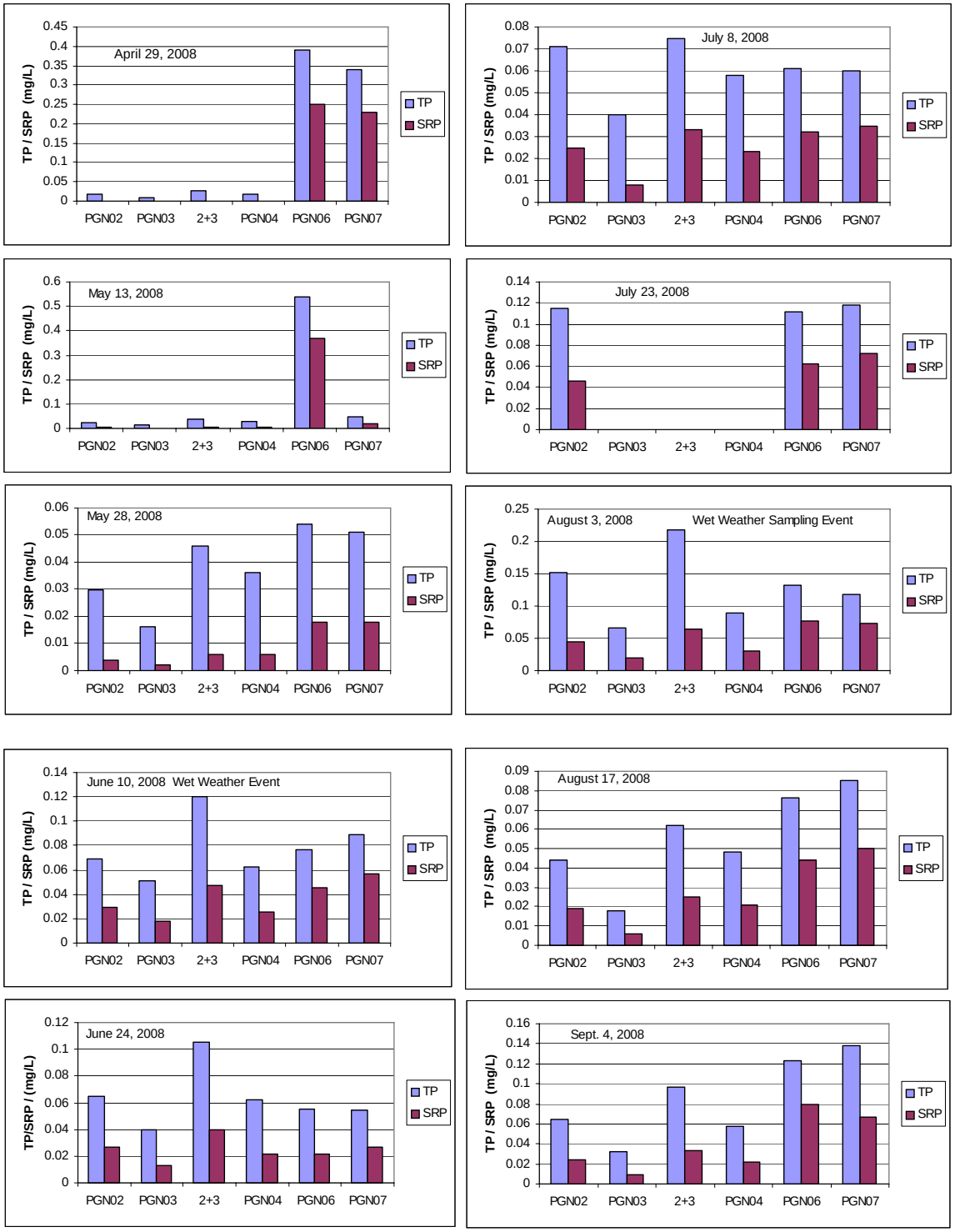

Figure 21. TP and SRP concentrations in the Pigeon River, April 30-September 4, 2008.

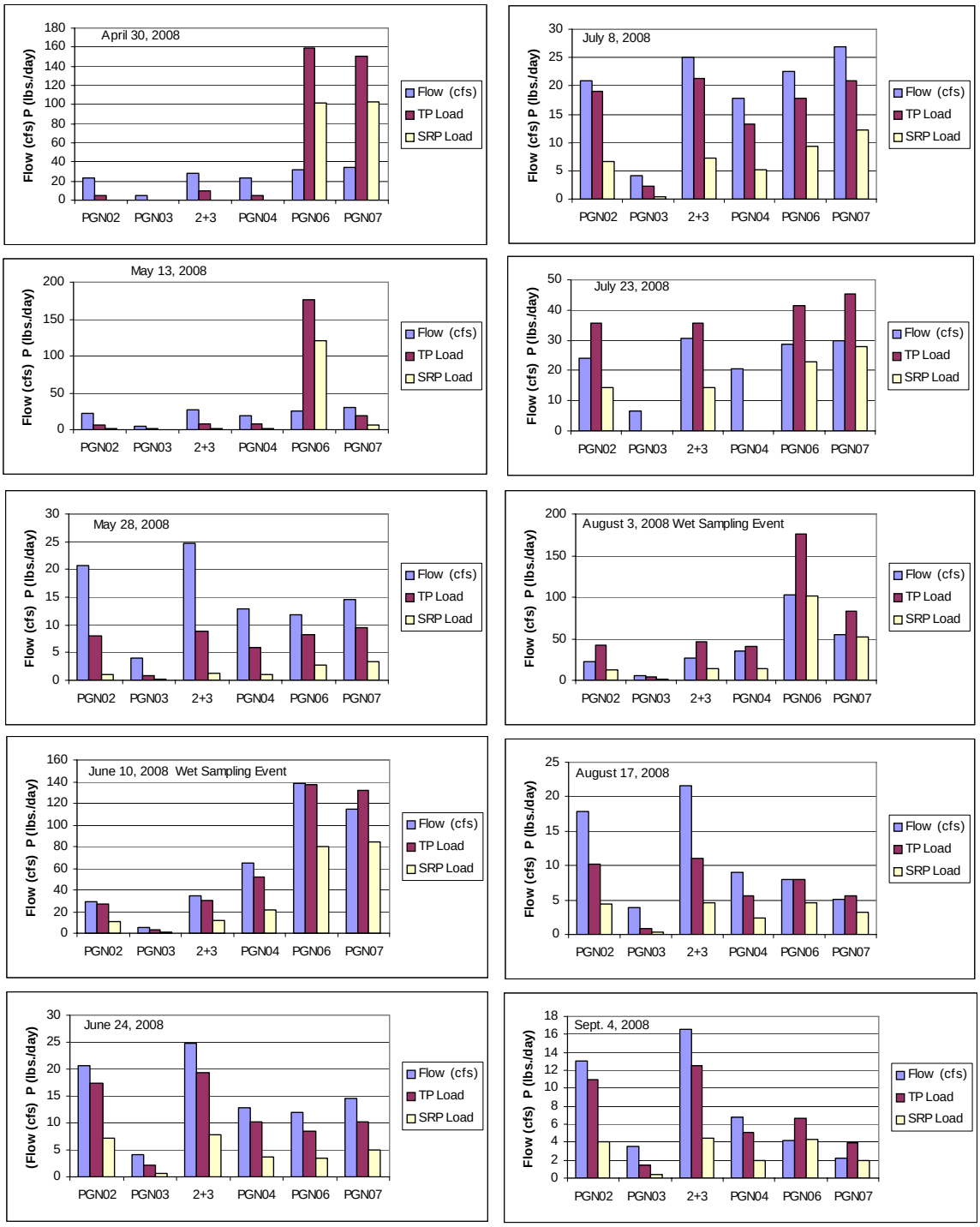

Figure 22. Flow, and the TP and SRP load (as lbs/day) in the Pigeon River, April 30-September 4, 2008.

The West Branch Extension Drain joins the Pigeon River approximately one mile south of the village of Pigeon between Stations PGN04 and PGN07. Based on flow, the West Branch Extension Drain is a relatively minor component of the total flow in the Pigeon River, but consistently held one of the highest TP concentrations of the streams sampled (Figures 23 and 24).

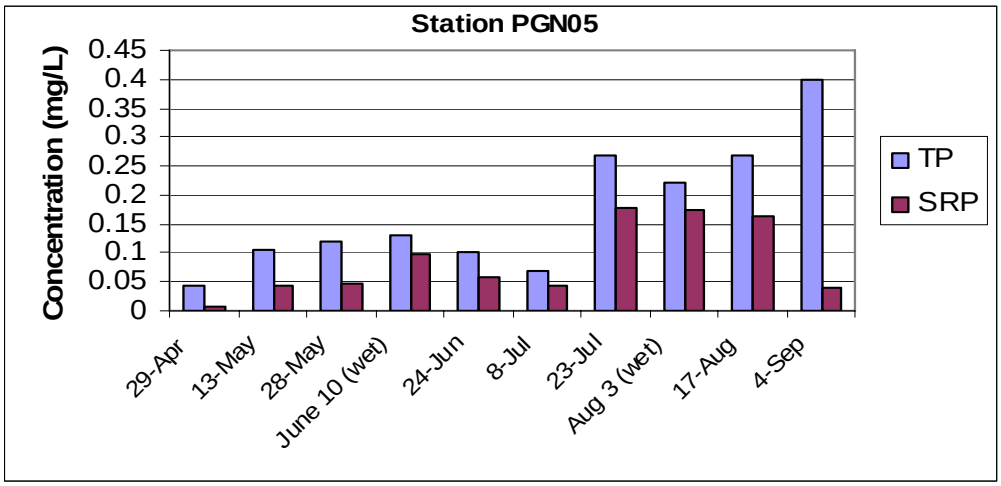

Figure 23. TP and SRP concentrations at Station PGN05 from April 29-September 4, 2008.

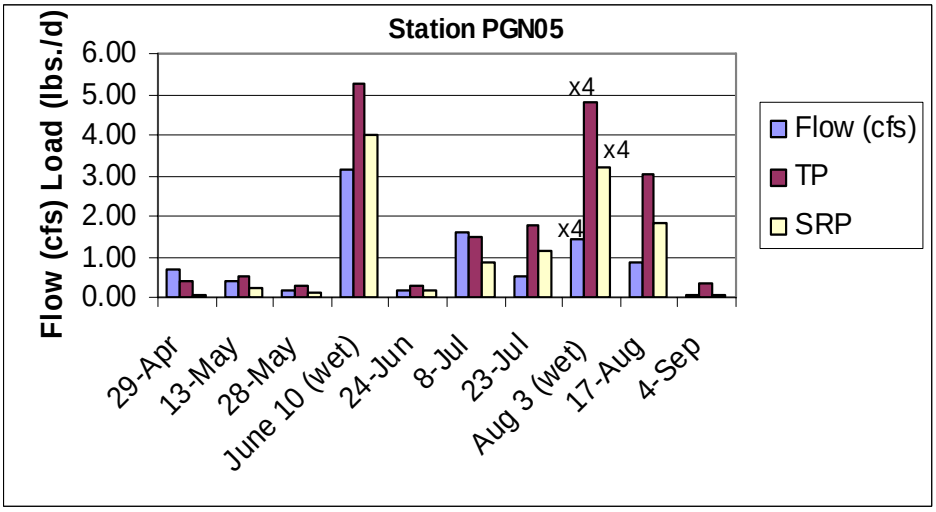

Figure 24. Flow and the TP and SRP load (as lbs/day) at Station PGN05, April 30-September 4, 2008. Note that the values indicated for August 3, 2008, are reduced to protect the scale of the other nine monitoring events. Values given should be multiplied by 4 to provide the actual sample value found on August 3.

Shebeon Drain

The Shebeon Drain (Figure 25) was monitored at only 2 locations as land use in the watershed was relatively monotypic. Flows at the downstream station (PGN08) were typically less than the upstream station (PGN01); however, the overall difference in flow volume (as cfs) was negligible. There was 1 significant sampling anomaly that occurred on July 23, 2008, when field crews found the drain in a flooded condition while the other streams involved with this study were at expected seasonal levels. Apparently a significant portion of the Shebeon Drain watershed was hit with a small but intense rain event that resulted in very high flows. Flow increased from 6 cfs on July 8, 2008, to 225 cfs on July 23, 2008, at Station PGN08 resulting in a corresponding phosphorus load of approximately 500 lbs/day, the largest phosphorus load measured at any site during the course of this study (Figures 26 and 27).

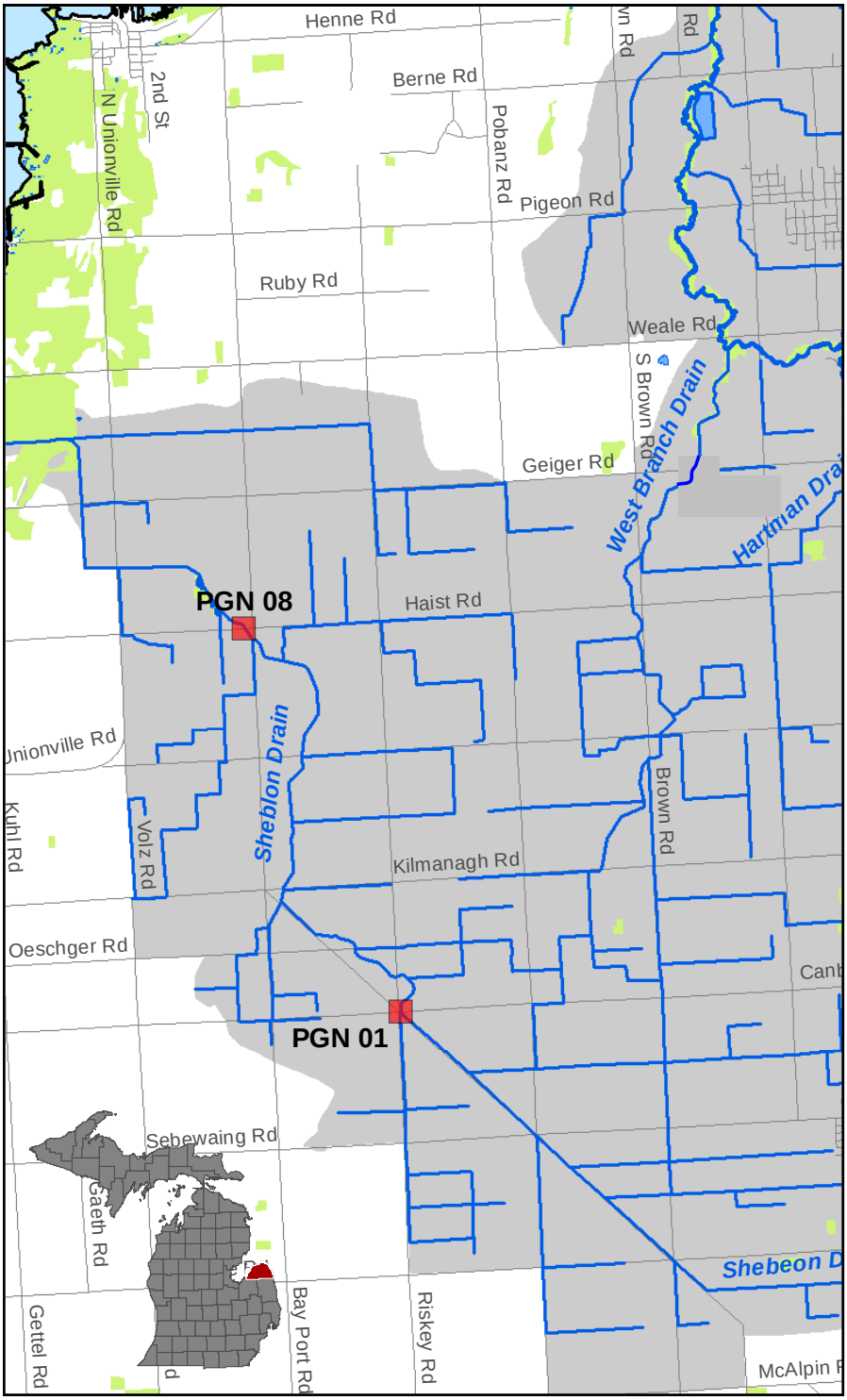

Figure 25. Sampling locations in the Shebeon Drain watershed, April 29-September 4, 2008.

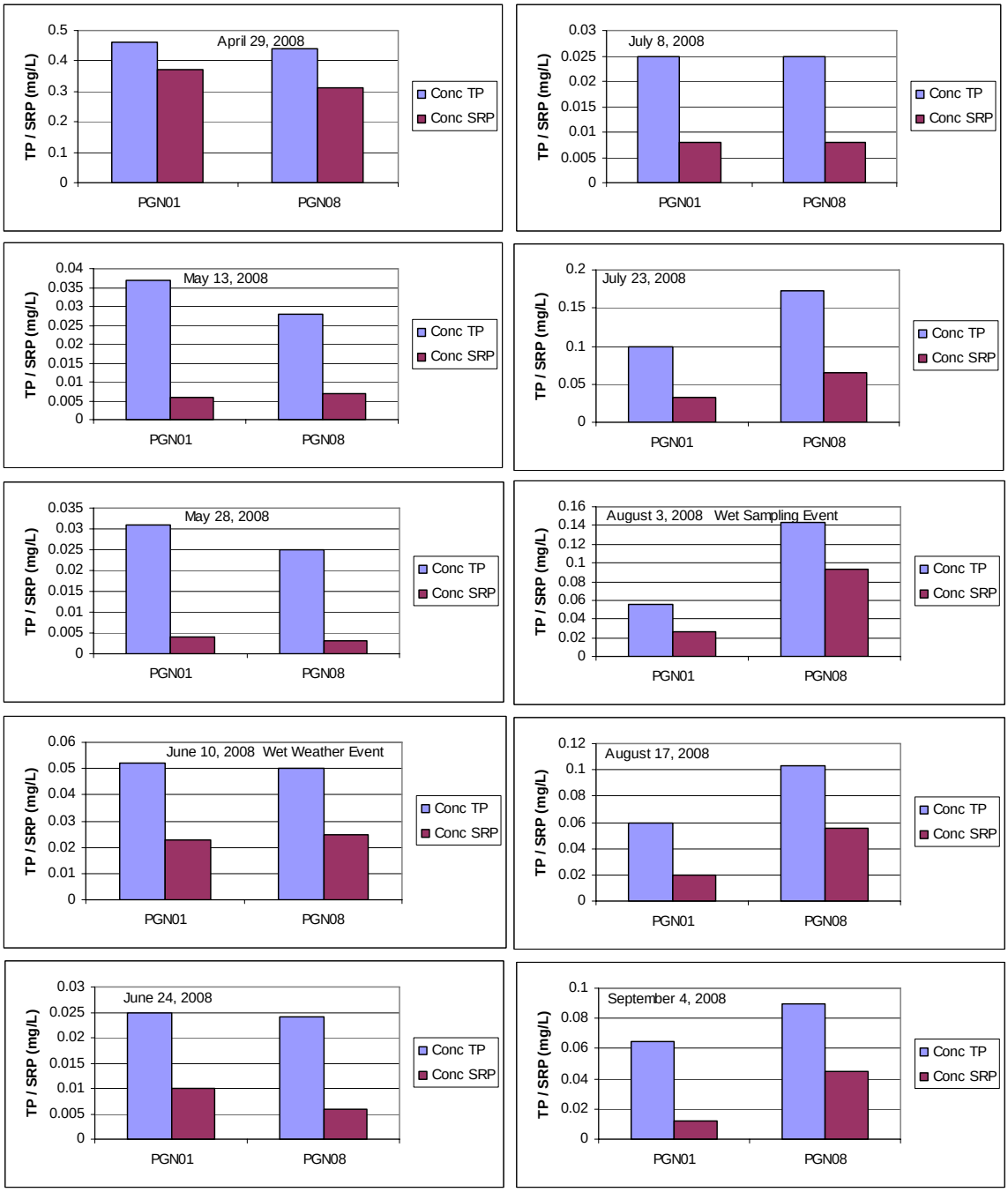

Figure 26. TP and SRP concentrations in the Shebeon Drain, April 30-September 4, 2008.

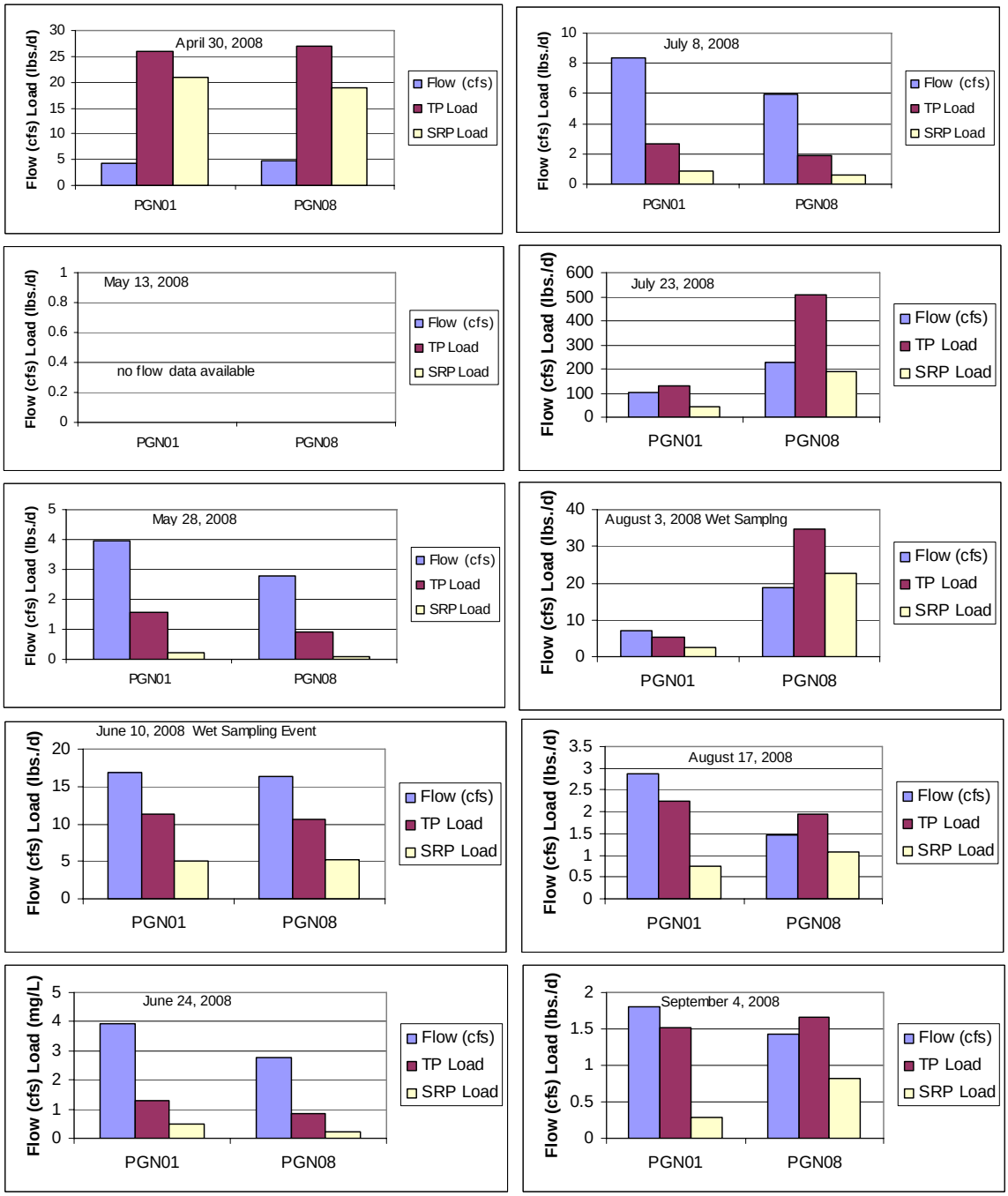

Figure 27. Flow, and the TP and SRP load (as lbs/day) in the Shebeon Drain, April 30-September 4, 2008.

Discussion

Phosphorus concentrations in the targeted watersheds were highly variable throughout the course of this study effort. Although ambient concentrations of TP were often relatively normal, the data suggest areas where nutrient availability may be exceptional. The expected TP concentration in rivers and streams that flow through the lake plain soils along Michigan's southeastern counties would typically range from 0.015 to 0.040 mg/L with SRP concentration less than 0.01 mg/L. Phosphorus concentrations in the main channel portions of the Pigeon and Pinnebog Rivers were not remarkable in April and May; however, concentrations began to increase as summer base flow conditions were approached. Samples taken during wet weather sampling contained TP concentrations that were predictably high, but did not exceed the expected concentration range for typical high water events. Ambient TP concentrations in some of the tributaries sampled, especially from Bad Axe Creek, range from high to exceptionally high and also demonstrated the greatest degree of concentration variability. In general, phosphorus concentrations increased in the Pigeon and Pinnebog Rivers from upstream to downstream. In addition, flow data collected in 2008 is consistent with historical reports and flow measurements that strongly suggest that the downstream (northern) portions of the Pigeon and Pinnebog Rivers are loosing systems, in that flow volumes decrease in the lower (northern) portions of the watershed. The loss of flow was most severe in the Pigeon River with some historical data suggesting zero flow during exceptionally dry summers.

Nutrient export (as load) generally correlates with flow as increases in flow volume are typically associated with the conditions that facilitate the movement of nutrients along soil surfaces and in shallow groundwater. As such, higher flow volumes contact larger nutrient sources available in overland flow (runoff) and groundwater resulting in an increase in nutrient load. Increases in nutrient load in the absence of an increase in flow can often indicate an additional source, typically anthropogenic, to the stream channel.

The relationship between flow and nutrient (as phosphorus) load in all of the targeted watersheds was relatively typical as the phosphorus load was mostly correlated with flow volumes as expected. However, spikes in phosphorus loads, not associated with flow events, were captured during data collection, and may suggest portions within each respective basin where nutrient sources are well above expected background sources.

The TP load at Station PGN06 (immediately downstream from the village of Elkton) in the Pigeon River was inconsistent with flow data (Figure 28) at four separate monitoring events, suggesting an anthropogenic source upstream from this monitoring point.

The relationship between phosphorus export and flow in Bad Axe Creek/Drain was similar to the Pigeon River in that export was generally correlated with stream flow. However, ambient concentrations of phosphorus throughout the Bad Axe Creek were generally higher than TP concentrations found in the Pigeon River. Phosphorus export at 2 sampling locations (Table 29), Stations PIN06 and PIN07, was disproportionately higher on several sampling dates,

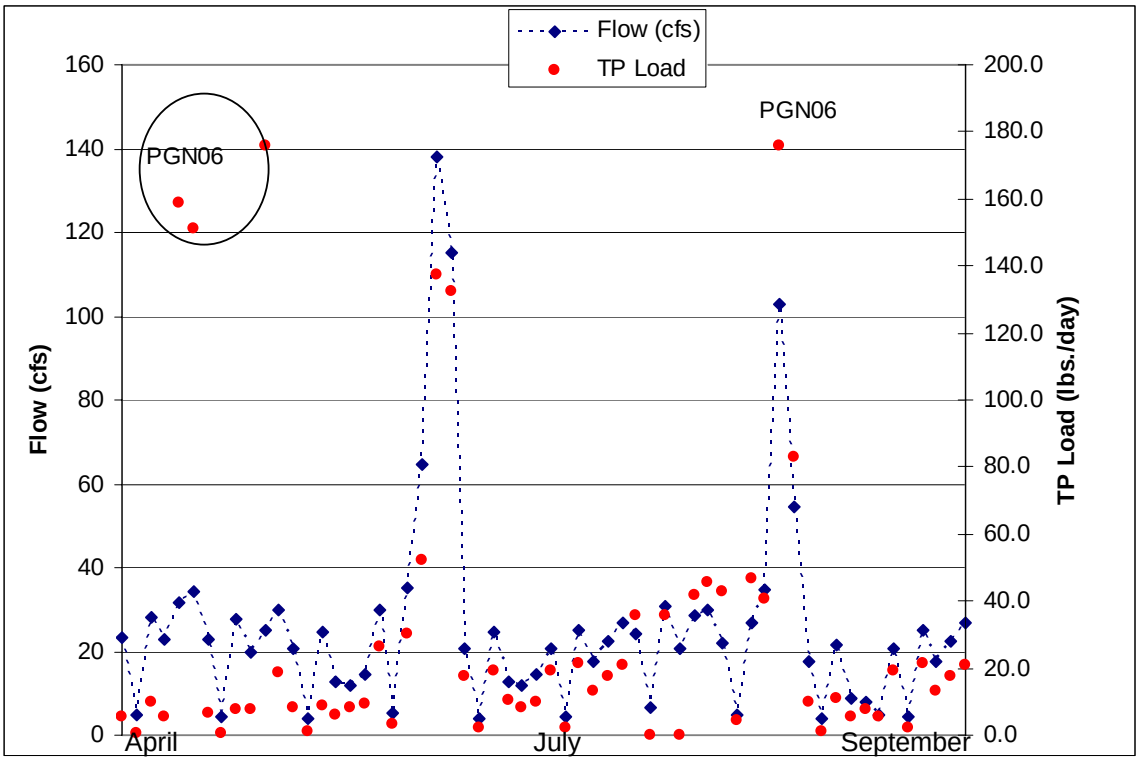

Figure 28. TP and flow data, April 30-September 3, 2008, in the Pigeon River.

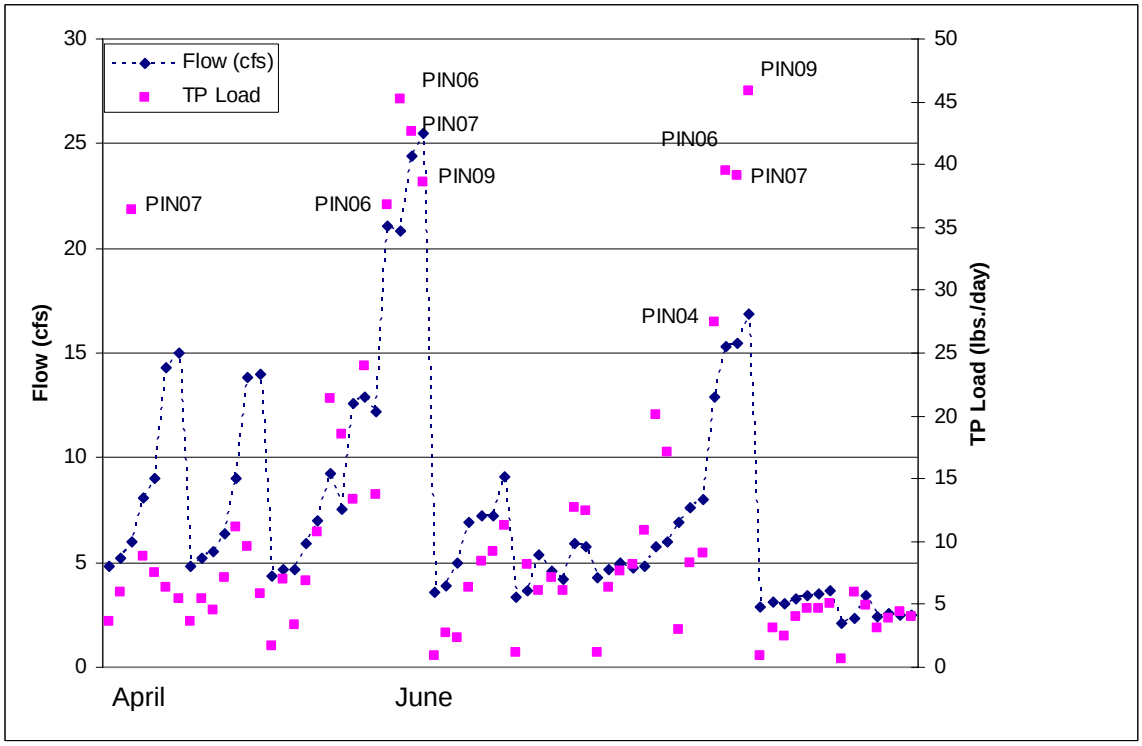

Figure 29. Flow and phosphorus export (load) in Bad Axe Creek from April 29-September 3, 2008.

again, suggesting that nutrients were much more available to the channel upstream from these sampling locations than at other points along the stream's continuum. The relationship between flow and TP export in the Pinnebog River appeared to be ordinary (Figure 30) as there were no obvious exceptions in the flow/export relationship.

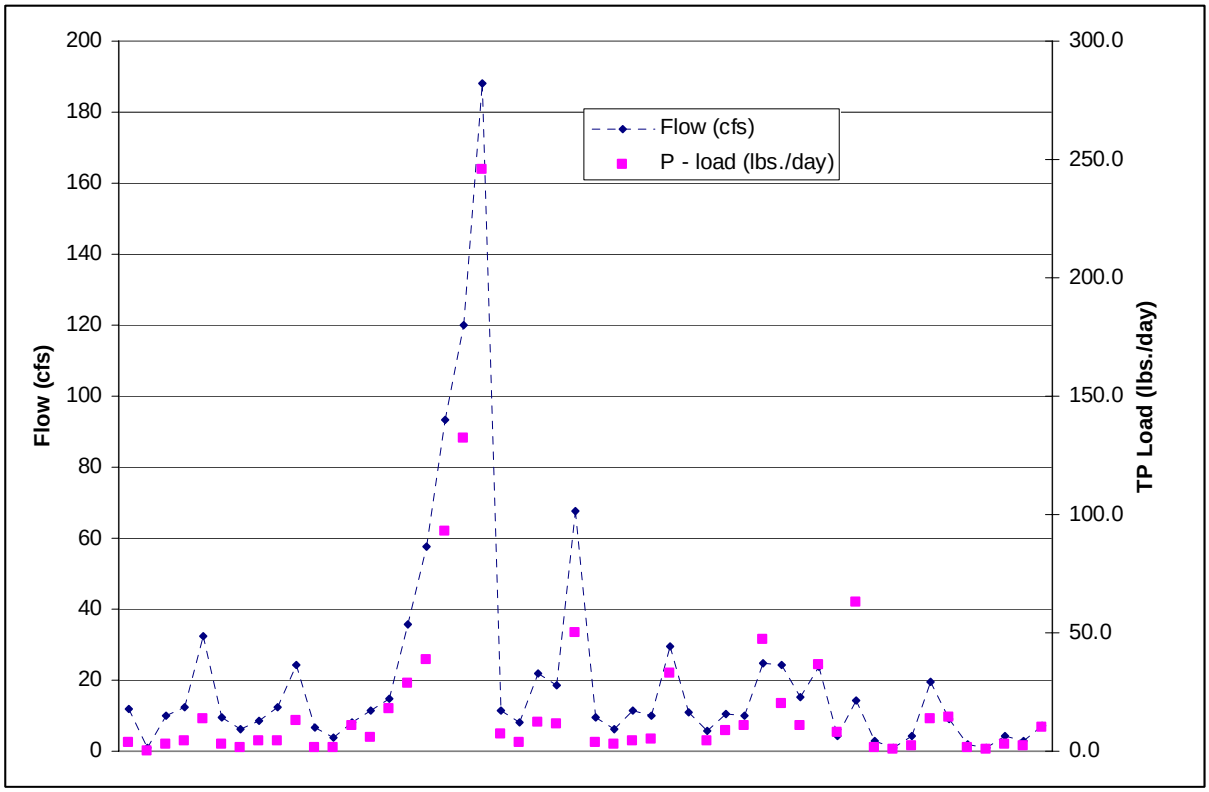

Figure 30. Flow and TP export (load) in the Pinnebog River from April 30-September 3, 2008.

Quality Assurance/Quality Control Sampling Results

Phosphorus Sampling

Duplicate samples were collected at a frequency of 10 percent. Fifty-three of the 56 sample/duplicate pairs had a relative percent difference less than 30 percent as required by the QAPP. Equipment blanks were collected at a frequency of 5 percent. All of the equipment blank results were less than 50 percent of the reporting limit.

E. coli Sampling

Duplicate samples were collected at a frequency of 10 percent. All of the duplicate pairs were within the precision criteria as specified in the QAPP. Equipment blanks were collected at a frequency of 5 percent. *E. coli* was not detected in any of the field blank samples.

Report by: Jeffrey Cooper, Senior Aquatic Biologist
Christine Alexander, Senior Aquatic Biologist
Surface Water Assessment Section
Water Bureau