Mason and Pierson Drain Project

FINAL REPORT

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Introduction

Although White Lake (Muskegon County, MI) was recently removed from the list of Great Lakes Areas of Concern (AOCs), it is recognized that its “de-listing” does not mean that it is free of environmental issues. Rather, the de-listing recognized the improvements associated with contaminated sediment removal from sources such as Whitehall Leather Co. and Hooker Chemical Co. among others, and Great Lakes Restoration Initiative (GLRI)-funded activities related to habitat restoration. It is recognized that nonpoint source pollution, which results in excess nutrients entering the lake from the surrounding watershed, is also a source of water quality impairment to White Lake and has the potential to fuel algal blooms (Steinman et al. 2009). The White River was implicated in delivering 98% of the total phosphorus and 96% of the total nitrogen to White Lake in the 1960s (Freedman et al. 1979), but increased lakeshore development and year-round residential use in the past two decades have raised concerns about other nutrient inputs from the watershed (Steinman et al. 2009).

At the request of the Muskegon County Drain Commissioner’s Office, AWRI conducted a monitoring project to evaluate the general water quality characteristics of two drains that are tributaries to White Lake: Mason Drain, which enters White Lake from the south and Pierson Drain, which enters White Lake from the north. Pierson Drain was previously sampled by the Muskegon Conservation District (MCD) in 2012 and 2013, as part of an effort to gather more information on four subwatersheds of the White River that were deemed “severely critical” in the White River Management Plan. The MCD found that even among the severely critical watersheds they sampled, Pierson Drain stood out with very high levels of *E. coli* and total phosphorus, and poor habitat conditions (MCD 2013a, b). This prompted MCD to name Pierson Drain as a priority area for phosphorus reduction and BMP implementation, particularly in the heavily-farmed upper reaches (MCD 2013a). The Pierson Drain watershed is highly impacted by agriculture, which is believed to be the cause of its water quality problems (MCD 2013b).

In both drains, AWRI measured a suite of nutrient parameters, physical properties, and *E. coli* (Pierson Drain only) to provide a general assessment of the water quality in the drains, and determine if a more detailed investigation of water quality impairment is warranted. This report summarizes the monitoring effort and provides information to Muskegon County and the Drain Commissioner regarding the water quality status of the drains.

Methods

Site Description

Mason Drain is a small drain located on the southwest side of White Lake. Its key hydrologic features include: 1) a private retention pond at the southern end of the drainage district; 2) a private surface drain that flows from east to west before entering a golf course pond; 3) the golf course pond that is part of the County Drain; 4) a 12” subsurface pipe that extends south-north from the golf course to a point of discharge into White Lake, where it enters the lake through a drain pipe, both of which are part of the County Drain. Two sampling sites were established on Mason Drain: one site captured surface flow on the White Lake Golf Club property and one site was at the outfall of the subsurface drain into White Lake (Figure 1). Water samples were collected within the pipe at the outfall.

Pierson Drain is a larger drain, located on the northwest side of White Lake. It primarily drains agricultural land before widening into a lagoon just upstream of its outlet to White Lake. Four sampling sites were established on Pierson Drain, three of which correspond to locations that were previously sampled by the MCD (Figure 2).

Figure 1. Aerial photograph showing the location of Mason Drain's surface flow (blue line) and sampling locations (n=2, yellow dots) located on the White Lake Golf Club grounds and at the outlet from Mason Drain to White Lake.

Figure 2. Aerial photograph showing sampling locations on Pierson Drain. All sampling locations shown were sampled by the Muskegon Conservation District during a previous study (MCD 2013a, b), with the exception of site 1a. Sampling locations for the current study are indicated by a red circle with a black dot.

Sampling and analysis

Water quality samples were collected approximately monthly during baseflow conditions from July through December, 2014. This resulted in 5 baseflow sampling events for Mason Drain and 4 baseflow sampling events for Pierson Drain, due to a later start date for the Pierson Drain portion of the project. Storm events, defined as > ¼ inch of rain preceded by at least 72 hours of dry weather, also were sampled at both of the drains. Four storms were sampled at Mason Drain and 3 storms were sampled at Pierson Drain.

During each sampling event, grab samples were collected from each site for analysis of total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate (NO_3^-), ammonia (NH_3), total Kjeldahl nitrogen (TKN), sulfate (SO_4^{2-}), chloride (Cl^-), and suspended sediment concentration (SSC). At the Pierson Drain sites, water samples also were collected in sterile containers for analysis of *E. coli*. General water quality measurements were measured with a YSI 6600 sonde, including dissolved oxygen (DO), temperature, pH, specific conductance, turbidity, total dissolved solids (TDS), redox potential (ORP), chlorophyll *a*, and cyanobacteria (phycocyanin pigment). All water samples were placed in a cooler on ice until received by the AWRI lab.

Water for SRP, NO_3^-, SO_4^{2-}, and Cl^- analysis was syringe-filtered through 0.45-µm membrane filters into scintillation vials and frozen until analysis. NH_3 and TKN were acidified with sulfuric acid and kept at 4°C until analysis. SRP, TP, NH_3, and TKN were analyzed on a SEAL AQ2 discrete automated analyzer (U.S. EPA 1993). NO_3^-, SO_4^{2-}, and Cl^- were analyzed on a Dionex ICS 2100 ion chromatograph (APHA 1992). *E. coli* (colony forming units [cfu]/100 mL) was analyzed using the enzyme substrate method IDEXX Colilert-18 (APHA 1992). Any values below detection were calculated as ½ the detection limit.

General water quality parameters, nutrients, and *E. coli* (Pierson Drain only) were statistically tested to explore 1) differences among sites within each drain during (a) baseflow and (b) storm flow; and 2) differences between baseflow and storm flow within each site. Differences between Mason Drain sites (n=2) were tested (separately for baseflow and storms) using either a two-tailed t-test (normally-distributed data with equal variance) or Mann-Whitney rank sum test (non-normally distributed data and/or unequal variance). Differences among Pierson Drain sites (n=4) were tested (separately for baseflow and storms) using a one-way analysis of variance (ANOVA; normally-distributed data with equal variance) or Kruskal-Wallis one-way ANOVA on ranks (non-normally distributed data and/or unequal variance). Significance between pairwise contrasts was determined using either Holm-Sidak (ANOVA) or Tukey (ANOVA on ranks) multiple comparison tests. At each sampling site, baseflow vs. storm flow differences were tested using either a two-tailed t-test or Mann-Whitney rank sum test (as explained above), with the exception of temperature data, which were analyzed differently to account for seasonal variability. Temperature was analyzed using a paired t-test, with pairs consisting of each storm and the closest-in-time baseflow measurement (3 to 23 days); paired t-tests were performed for each sampling site individually and for all sites pooled within each drain. Normality was tested using the Shapiro-Wilk test and equal variance was tested using the Brown-Forsythe test. Statistical significance was indicated by p-values < 0.05. All statistical tests were performed using SigmaPlot 13.0.

Results and Discussion

Mason Drain

Baseflow. Although most water quality parameters were within the acceptable range, dissolved oxygen and phosphorus concentrations were indicative of an impaired waterbody. Average dissolved oxygen (DO) concentration was < 5 mg/L at the surface site during baseflow, but was significantly higher at the outlet to White Lake (Table 1; $p < 0.05$), where flow turbulence or backwash from White Lake may have accounted for reaeration. DO concentrations < 5 mg/L can be harmful to aquatic life but any impairment would be restricted to the biota inhabiting the golf course pond, as opposed to biota in White Lake.

Specific conductance was well below the 600 µS/cm level that reflects human impacts (Table 1). Turbidity was also low with average values < 1 NTU during baseflow (Table 1). Average chloride concentrations ranged from 25-30 mg/L, which is below the State of Michigan's 50 mg/L water quality standard for the Great Lakes and connecting water bodies (Table 2) (MDEQ 2006). Sulfate concentrations were within the typical range for surface water at both sites (Table 2). Average nitrate and ammonia concentrations were low at both sites in Mason Drain, but were significantly higher at the outlet than at the surface site during baseflow ($p < 0.05$) (Table 2; Figure 3A).

Both SRP and TP concentrations were high at the two Mason Drain sites (Table 2; Figure 3B). On average, SRP accounted for 18% of TP at the surface site and 57% of TP at the outlet. SRP is the bioavailable form of phosphorus, so the low percentage in the surface pond may be due to biotic uptake by algae and aquatic plants. The SRP concentration of ~20 µg/L measured at both sites is relatively high, and of potential concern (Table 2). Surface SRP concentrations in White Lake have been measured at <10 µg/L (Steinman et al. 2009), so these elevated Drain concentrations could stimulate algal growth in the zone of discharge at the outlet. TP was very high at the surface site, with average values well into the hypereutrophic range (i.e., > 100 µg/L), although concentrations were significantly lower at the outlet than at the surface site ($p < 0.05$). Despite these high SRP and TP concentrations, it is unlikely that the Drain is contributing a substantial P *load* to White Lake, given the relatively small flow out of the discharge pipe. Suspended sediment concentration was significantly higher at the surface site than at the outlet ($p < 0.05$), but was fairly low regardless of site (Table 2).

Storm flow. Most of the surface vs. outlet patterns observed during baseflow also were evident during storm events (Tables 1 and 2). For example, DO concentrations were significantly greater at the outlet than the surface site, in contrast to turbidity, TKN, SRP, TP, and SSC, all of which were much lower, some significantly so, at the outlet than the surface site (Tables 1 and 2). A storm event in August had especially high TP concentration (> 600 µg/L) at the surface site (Figure 3B).

Baseflow vs. storm flow. The only statistically significant difference in parameters measured during baseflow vs. storms was found for the surface site, where nitrate was greater during storms than during baseflow ($p < 0.05$) (Table 2; Figure 3A). Despite the ~4 × increase in average nitrate concentrations during storms, concentrations were still within the naturally-occurring range (i.e., < 1 mg/L) (Table 2). Although differences in temperature were not statistically significant, water temperature was elevated by 5 to 8 °C during the August (surface site only) and September storm events when compared to the closest-in-time baseflow measurements (Figure 3C). This type of thermal pollution can negatively impact biota (Caissie 2006), and may deserve additional attention.

Pierson Drain

Baseflow. Water quality monitoring results from Pierson Drain reflect degraded conditions in this sub-basin, particularly in the upper reaches. Baseflow dissolved oxygen concentrations were < 2 mg/L at Site 4 during all but the December monitoring event, indicative of an impaired condition. Average turbidity values were elevated (≥ 18 NTU) at all sites (Table 1). Chloride concentrations were significantly higher at Site 6 than at Site 1a during baseflow ($p < 0.01$), but were well below water quality standards (Table 2). Sulfate was significantly higher at Sites 3 and 6 than the other sites during baseflow ($p < 0.01$) (Table 2); average sulfate concentrations at these sites were higher than typical freshwater concentrations (~20 mg/L, WHO 2004). Nitrate was significantly higher at Sites 3 and 6 than the other sites, with concentrations ranging from 1.2 to 3.4 mg/L ($p < 0.05$) (Figure 4A). Ammonia concentrations were generally low in Pierson Drain (Table 2), but high ammonia concentrations were measured at Site 4 during the October baseflow event. TKN was significantly higher at Site 4 than at Site 1a ($p < 0.05$) (Table 2).

Total phosphorus concentrations were high in Pierson Drain throughout the monitoring period, particularly at Site 4, where all samples were > 100 µg/L TP (Figure 4B). Water collected from Site 4 in October contained 520 µg/L TP, which is 5 × the hypereutrophic threshold (Figure 4B). Despite the often high TP concentrations measured at the upstream sites, TP was low (≤ 30 µg/L) at Site 1a during every sampling event except the December baseflow event, when TP was 210 µg/L (Figure 4B). SRP concentrations were generally low to moderate, but very high concentrations (> 100 µg/L) were measured at Site 4 during October and December (Table 2). Suspended sediment concentration was fairly low at all sites in Pierson Drain (Table 2).

E. coli was highly variable during baseflow and exceeded Michigan's water quality standard for total body contact (130 cfu/100 mL, MDEQ 2006) during at least one event at all 4 sites (Figure 4C). Although not statistically significant, Site 4 had the highest average *E. coli* concentration, driven by two very high measurements in October and December. *E. coli* in the December sample exceeded the 1,000 cfu/100 mL standard for partial body contact (MDEQ 2006) (Figure 4C).

Storm flow. Dissolved oxygen concentrations were < 2 mg/L at Sites 4 and 6 during at least one storm (Table 1). Similar to baseflow, nitrate and sulfate were both significantly higher at Sites 3 and 6 than the other sites ($p < 0.001$) (Figure 4A). Site 4 was particularly anomalous with respect to nutrients, with elevated concentrations of ammonia, TKN, and TP relative to other Pierson Drain sites (Table 2); this appears to be driven largely by concentrations in the November storm event (Figure 4B). TP concentrations during the November event were just below 400 µg/L TP, which is ~4 × the hypereutrophic threshold (Figure 4B). Similar to most of the TP measurements made during baseflow, TP was low (≤ 30 µg/L) at Site 1a during every sampling event, perhaps reflecting biotic uptake in the Pierson swamp located immediately upstream of this sampling site. SRP was significantly higher at Site 3 than at Sites 1a and 4 during storms ($p < 0.05$) (Table 2). Suspended sediment concentration was fairly low in Pierson Drain, even during storm events (Table 2), which was unexpected given the previously established relationship between stream sediment and storm events in agricultural land uses (Sharpley et al. 2008a,b).

Similar to baseflow, *E. coli* was highly variable during storm events and exceeded Michigan's water quality standard for total body contact (130 cfu/100 mL, MDEQ 2006) during at least one storm event at all 4 sites (Figure 4). All sites except for site 1a had *E. coli* concentrations > 400 cfu/100 mL during at least one monitored storm (Figure 4C).

Baseflow vs. storm flow. When all sites were included in the analysis, water temperature was significantly higher during storms than baseflow in Pierson Drain ($p < 0.05$) (Table 1; Figure 4D). Similar to Mason Drain, the August and September storms elicited temperature increases of 4 to 8 °C at all sites (Figure 4D). The November storm had lower water temperatures than the closest-in-time baseflow event, which was in October and likely had naturally higher water temperatures due to seasonal variation. The potential impact of this thermal pollution may warrant additional attention. There were no other statistically significant differences in parameters measured during baseflow vs. storms in Pierson Drain.

Table 1. Average and standard deviation of general water quality parameters recorded at each of the monitoring stations during baseflow (Mason: n=5, Pierson: n=4) and storm conditions (Mason: n=4, Pierson: n=3).

			Temp, C		**DO, mg/L**		**pH**		**SpCond, µS/cm**		**Turb, NTU**		**TDS, g/L**		**ORP, mV**		**Chl *a* , µg/L**		**BGA, cells/mL**	
Drain	**Flow**	**Site**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Mason	Base	Surface	11.84	7.83	3.94	2.73	6.6	0.3	330	79	0.7	1.3	0.215	0.051	395	31	12.5	6.8	3736	2387
		Outlet	12.74	7.08	9.60	1.58	7.1	0.5	330	37	0.0	0.1	0.214	0.025	408	25	10.4	2.3	3042	1660
	Storm	Surface	16.66	6.45	3.07	1.62	6.6	0.4	336	70	10.5	14.6	0.218	0.046	384	47	21.1	5.0	4076	776
		Outlet	15.97	4.91	8.44	0.75	7.2	0.7	337	66	1.9	1.3	0.220	0.043	403	26	12.9	4.6	3062	487
Pierson	Base	1a	9.66	6.56	12.29	2.57	7.6	0.6	337	64	18.4	36.3	0.219	0.042	382	33	4.9	1.5	2430	1048
		3	8.65	6.67	10.79	1.84	7.5	0.2	404	79	22.5	24.0	0.263	0.052	394	20	7.0	0.8	2220	721
		4	8.15	6.75	4.05	5.97	6.9	0.2	302	72	56.0	49.2	0.196	0.046	398	18	13.6	5.9	3984	1103
		6	9.71	6.81	9.22	2.07	7.3	0.3	417	103	18.1	8.1	0.271	0.067	390	25	6.6	0.8	2107	322
	Storm	1a	15.28	7.59	8.31	1.09	7.4	0.3	355	19	0.0	0.0	0.231	0.012	394	35	3.5	1.2	1919	183
		3	15.59	6.47	8.09	1.87	7.5	0.3	456	13	16.4	5.2	0.198	0.170	394	18	7.9	5.6	2593	627
		4	14.43	6.61	5.69	3.30	7.1	0.2	354	63	21.4	10.9	0.230	0.041	364	27	63.8	54.1	10464	7749
		6	15.55	6.04	5.61	4.17	7.1	0.5	405	91	24.3	20.2	0.188	0.137	326	113	8.2	2.6	2505	123

Table 2. Average and standard deviation of nutrient concentrations, suspended sediment, and *E.coli* measured at each of the monitoring stations during baseflow (Mason: n=5, Pierson: n=4) and storm conditions (Mason: n=4, Pierson: n=3). "–" indicates not measured.

			Cl, mg/L		**SO_4, mg/L**		**NO_3, mg/L**		**NH_3, mg/L**		**TKN, mg/L**		**SRP, µg/L**		**TP, µg/L**		**SSC, mg/L**		***E. coli* , cfu/100 mL**	
Drain	**Flow**	**Site**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Mason	Base	Surface	25	5	5	3	0.14	0.24	0.02	0.01	1.76	0.77	21	9	114	81	17	13	--	--
		Outlet	28	4	10	3	0.71	0.40	0.07	0.05	0.95	0.04	24	9	42	7	2	1	--	--
	Storm	Surface	25	9	6	2	0.51	0.17	0.02	0.01	2.06	0.67	30	13	231	266	51	42	--	--
		Outlet	30	8	10	6	0.48	0.16	0.05	0.04	0.93	0.64	20	19	49	20	4	2	--	--
Pierson	Base	1a	18	2	15	2	0.77	0.44	0.01	0.01	0.56	0.20	21	33	73	91	14	13	161	224
		3	23	4	34	12	1.76	0.41	0.05	0.02	0.79	0.21	30	21	87	69	14	7	160	108
		4	21	4	4	3	0.41	0.31	0.16	0.20	2.29	2.15	66	72	278	179	25	15	479	557
		6	27	2	42	4	1.98	1.07	0.04	0.02	0.85	0.28	14	4	83	48	26	17	149	123
	Storm	1a	15	5	16	1	0.40	0.23	0.02	0.01	0.32	0.00	3	1	20	8	2	1	75	79
		3	24	4	38	8	1.67	0.30	0.03	0.01	0.71	0.17	34	15	104	86	13	3	436	538
		4	20	3	3	2	0.33	0.28	0.11	0.11	2.11	1.36	6	6	204	149	21	9	328	454
		6	23	4	43	6	1.32	0.29	0.05	0.02	1.05	0.61	18	11	151	113	58	54	290	321

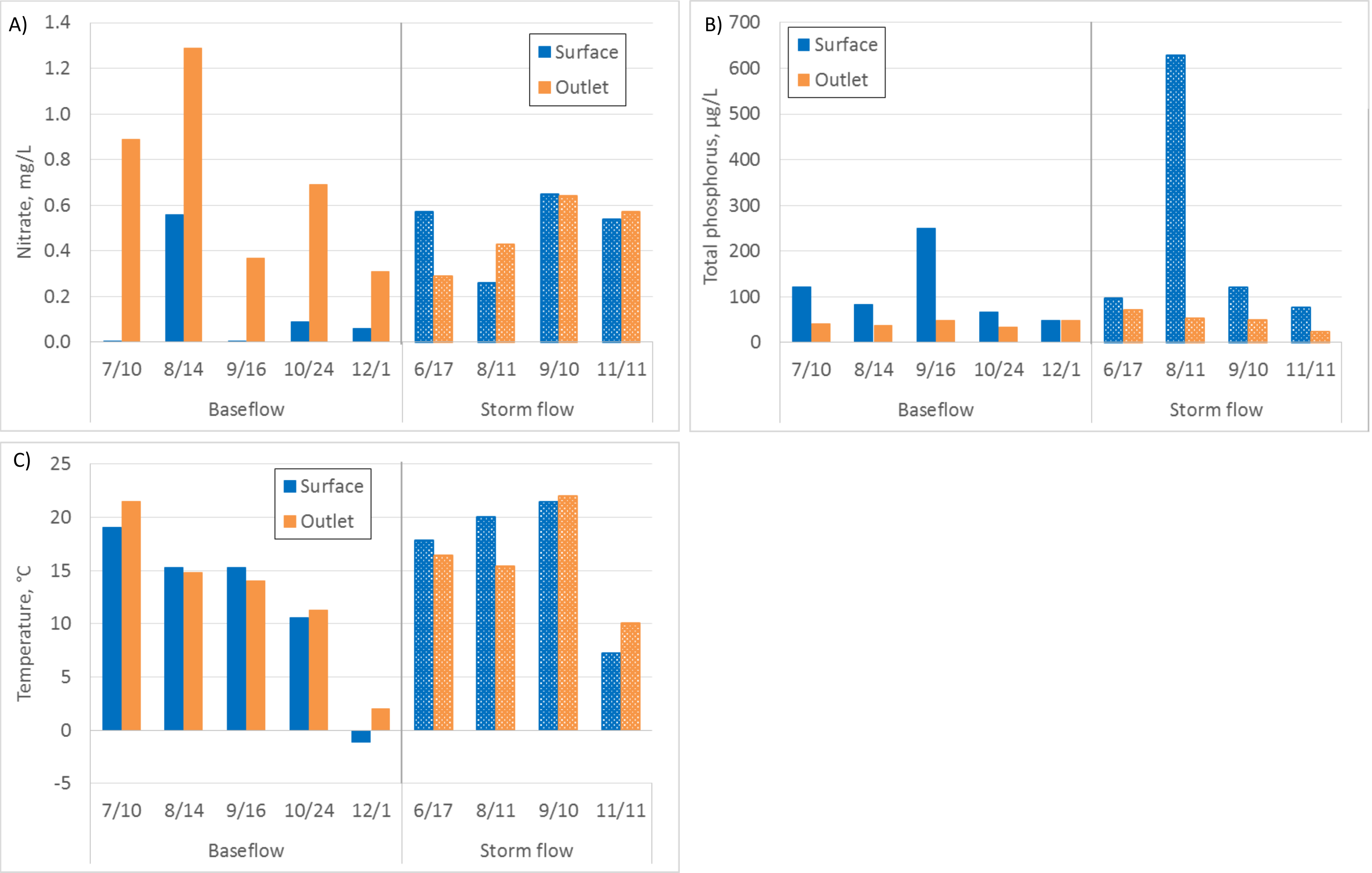

Figure 3. Select water quality parameters measured at two locations in Mason Drain in 2014 during baseflow and storm conditions: (A) nitrate (B) total phosphorus, and (C) temperature. Solid bars represent baseflow conditions; stippled bars represent storm conditions.

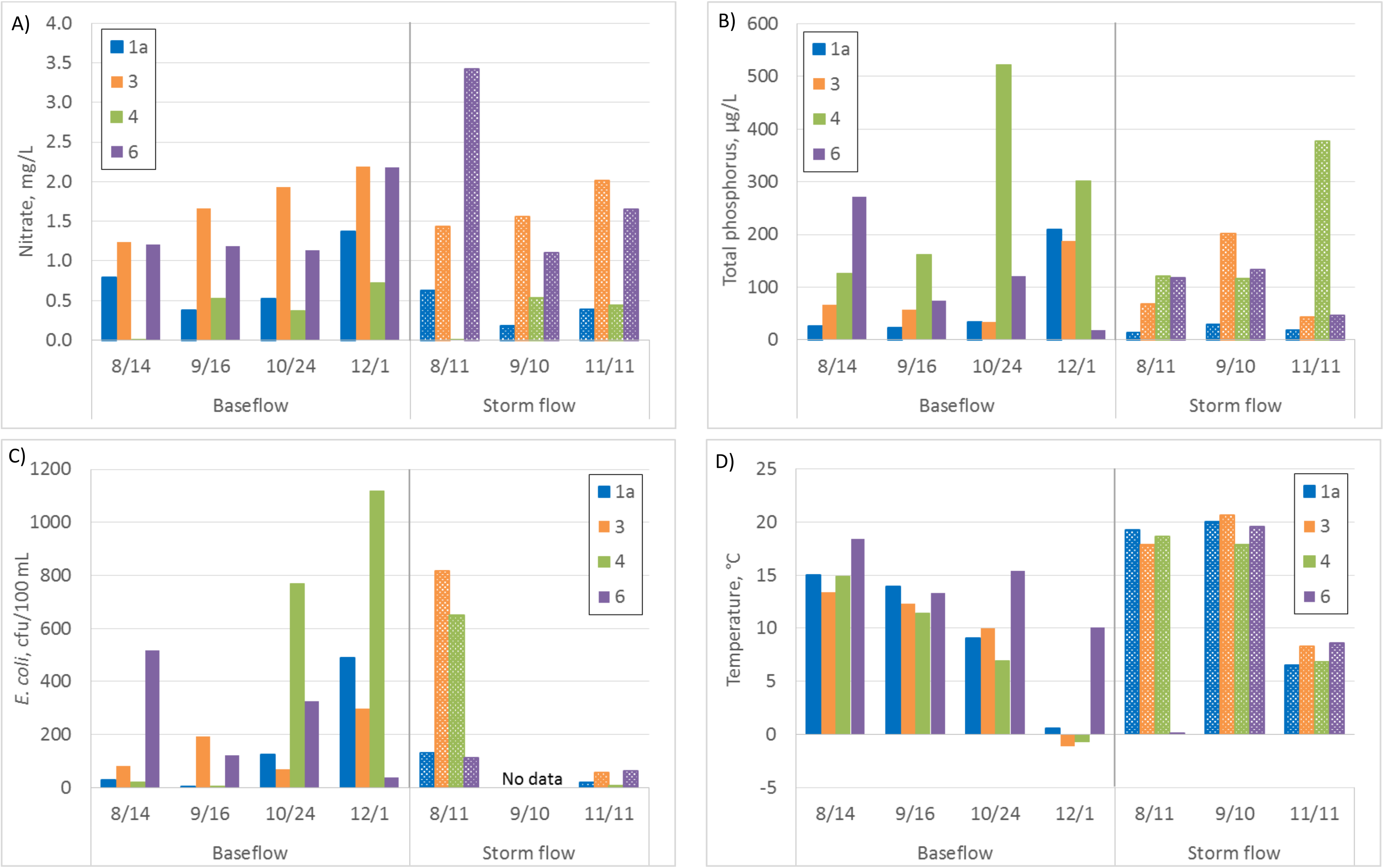

Figure 4. Select water quality parameters measured at four locations in Pierson Drain in 2014 during baseflow and storm conditions: (A) nitrate, (B) total phosphorus, (C) *E. coli,* and (D) water temperature. Solid bars represent baseflow conditions; stippled bars represent storm conditions.

Summary

Our monthly sampling regime provides a relatively coarse level analysis of water quality dynamics in Mason and Pierson Drains. For example, it is possible that we may have missed impacts associated with fertilizer application if we sampled just prior to application. Nonetheless, these data allow us to make some general assessments of water quality conditions in both drain systems.

As currently structured, upstream sites in both Mason and Pierson Drains contained very high concentrations of total phosphorus, well into the hypereutrophic range. Pierson Drain also had high concentrations of nitrate in its upper reaches, as well as periodic high *E. coli* concentrations throughout the monitored reaches. Elevated water temperature during storms suggested thermal pollution may be an issue in both drains. The water quality monitoring results from Pierson Drain presumably reflect the agricultural influence in its subwatershed and align with the MCD's prior study (MCD 2013a, b). Site 4 in Pierson Drain appears to be particularly problematic. Nonetheless, water quality was acceptable for the most part at the downstream-most monitoring sites in both drains, suggesting that these pollutants and stressors are being mitigated to some degree as they move through the sub-basin. Consequently, it is unlikely that they are having a negative impact on White Lake as a whole, although there may be some localized impacts.

Reengineering the hydrology of both drains may very well alter the fate and transport of pollutants in both systems. For example, improving flow through the drains to alleviate flooding would likely reduce transit time and reduce the opportunity for nutrients and other pollutants to be absorbed or adsorbed (Groffman et al. 2003). Hence, any redesigns of the drains for hydrologic purposes should also take into account potential impacts to water quality.

Based on these results, we do not see the need for continued baseline monitoring of these drains. Rather, we recommend the implementation of Best Management Practices (BMPs) to reduce N, P, and *E. coli* concentrations and thermal pollution during storms in the upper portions of the Mason and Pierson Drain sub-basins. At that point, we recommend monitoring to document the efficacy of these BMPs, which will provide important information on which ones will provide the greatest water quality benefit in other drainage districts in the County and beyond.

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