

To: Mr. Fred Farkas, Lake Manitou Association **Date:** 12/31/2018
From: Josh Kieser, K&A
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RE: Findings for 2018 Water Quality Monitoring of Lake Manitou and Drains

This memorandum presents 2018 results compiled by Kieser & Associates, LLC (K&A) related to water quality monitoring efforts at Lake Manitou, Shiawassee County, Michigan. K&A conducted water quality monitoring support services between May and October of 2018, at the request of the Lake Manitou Association. Sampling efforts included two in-lake water and sediment sampling events and six drain monitoring events: two dry-weather baseflow events and four wet-weather events. Drain sampling efforts for Lake Manitou included the installation and monitoring of four staff gauges. Additional staff gauge readings and samples from the Hardy-Jennings Drain were collected by Fred Farkas, Lake Manitou Association, throughout the monitoring period. The purpose of the monitoring program is to better understand critical needs and relevant influences on current water quality issues in Lake Manitou, building on the 2017 Kieser & Associates Phase I analyses (K&A, 2017)

2018 Sampling Events and Precipitation

Hourly, monthly, and annual precipitation data were collected from the MSUE Enviro-weather [MAWN HAS](#) station located near Haslett, MI, approximately 12 miles southwest of Lake Manitou. These data were cross-correlated with precipitation data from USGS Precipitation Station [425255083590401](#) at Three Mile Creek near Durand, MI, approximately 12 miles southeast of Lake Manitou. Table 1 shows that the region received slightly less-than-average total rainfall between April and October 2018, compared to the same months from 2015-17.

Table 1. Lake Manitou regional total rainfall data¹.

Year	Rainfall Total (in.)	Hours with Rainfall
2018	21.51	333
2017	22.94	316
2016	23.12	279
2015	22.12	283

¹MSUE Enviro-weather, Haslett Station: <<https://mawn.geo.msu.edu/station.asp?id=has&rt=60>>

Tables 2 and 3 outline the GPS coordinates and description for drain sampling stations as well as weather data and descriptions for sampling events and event types. Table 4 outlines GPS coordinates and water depths for in-lake sampling stations.

Figure 1 depicts all of these 2018 Lake Manitou sampling station locations. Figure 2 shows 2018 sampling events conducted by K&A graphed against hourly precipitation. Results from these events, as well as additional sampling and staff gauge readings conducted by Fred Farkas, are fully discussed in the monitoring results sections and presented in Attachments 2 and 3.

Table 2. 2018 Lake Manitou drains sampling station locations and details.

Sampling Station	Station Description	GPS Coordinates
Hardy-Jennings Up (HJ-Up)	Hardy-Jennings Drain along S Morrice Rd, 1,120-ft south of W Garrison Rd, upstream E. Branch of HJ Drain, downstream side of driveway culvert.	N42° 55.148' W84° 11.000'
Hardy-Jennings Down (HJ-Down)	Hardy-Jennings Drain crossing at W Garrison Rd, 460-ft west of S Morrice Rd, downstream of E. Branch of HJ Drain, downstream side of road bridge.	N42° 55.332' W84° 11.098'
Hardy-Jennings Inlet (HJ-In)	Hardy-Jennings Drain at Waugh Rd, inlet to Lake Manitou, 860-ft north of W Garrison Rd, upstream side of culverts.	N42° 55.451' W84° 11.884'
Forest Lake Inlet (FL-In)	Forest Lake crossing at W Garrison Rd, inlet to Lake Manitou, weir structure on upstream side of culvert.	N42° 55.303' W84° 12.277'
Mirror Lake Inlet (ML-In)	Mirror Lake crossing at W Garrison Rd, inlet to Lake Manitou, upstream side of culvert.	N42° 55.301' W84° 12.492'
Lake Out	Lake Manitou outlet structure, upstream side of structure.	N42° 55.669' W84° 12.275'

Table 3. Lake Manitou drains sampling dates and details.

Date	Event Type	Ambient Weather Data ¹			
		Description	Wind Direction, Speed (mph)	Air Temp. (°F)	Avg. Precip, past 24-hrs (in)
10-May-18	Dry	Partly cloudy, overcast	W, 3-5	65	0.27
17-May-18	Dry	Sunny, calm	NNE, 3-7	68	0.00
31-May-18	Wet	Partly cloudy	SE, 3-10	74	0.32
6-Aug-18	Wet	Light rain, cloudy	SE, 1-5	78	0.32
1-Oct-18	Wet	Heavy to light rain, overcast	NE, 1-5	50	1.5
31-Oct-18	Wet	Light to heavy rain, overcast	NW	40	0.33

¹MSUE Enviro-weather, Haslett Station: <<https://mawn.geo.msu.edu/station.asp?id=has&rt=60>>

Table 4. 2018 Lake Manitou in-lake sampling station locations and details.

Sampling Station	Sampling Date	GPS Coordinates	Water Depth (ft)
Mid (S3)	10-May-18	N42° 55.416' W84° 12.326'	12.5
	29-Aug-18	N42° 55.421' W84° 12.307'	12.2
	1-Oct-18 ¹	N42° 55.420' W84° 12.317'	12.2
Deep (S10)	10-May-18	N42° 55.669' W84° 12.133'	19.0
	29-Aug-18	N42° 55.671' W84° 12.141'	17.9
	1-Oct-18 ¹	N42° 55.670' W84° 12.139'	17.8

¹In-lake sampling on 1 October 2018 for sediments only.

Figure 1. Lake Manitou 2018 drain sampling and in-lake sampling station locations.

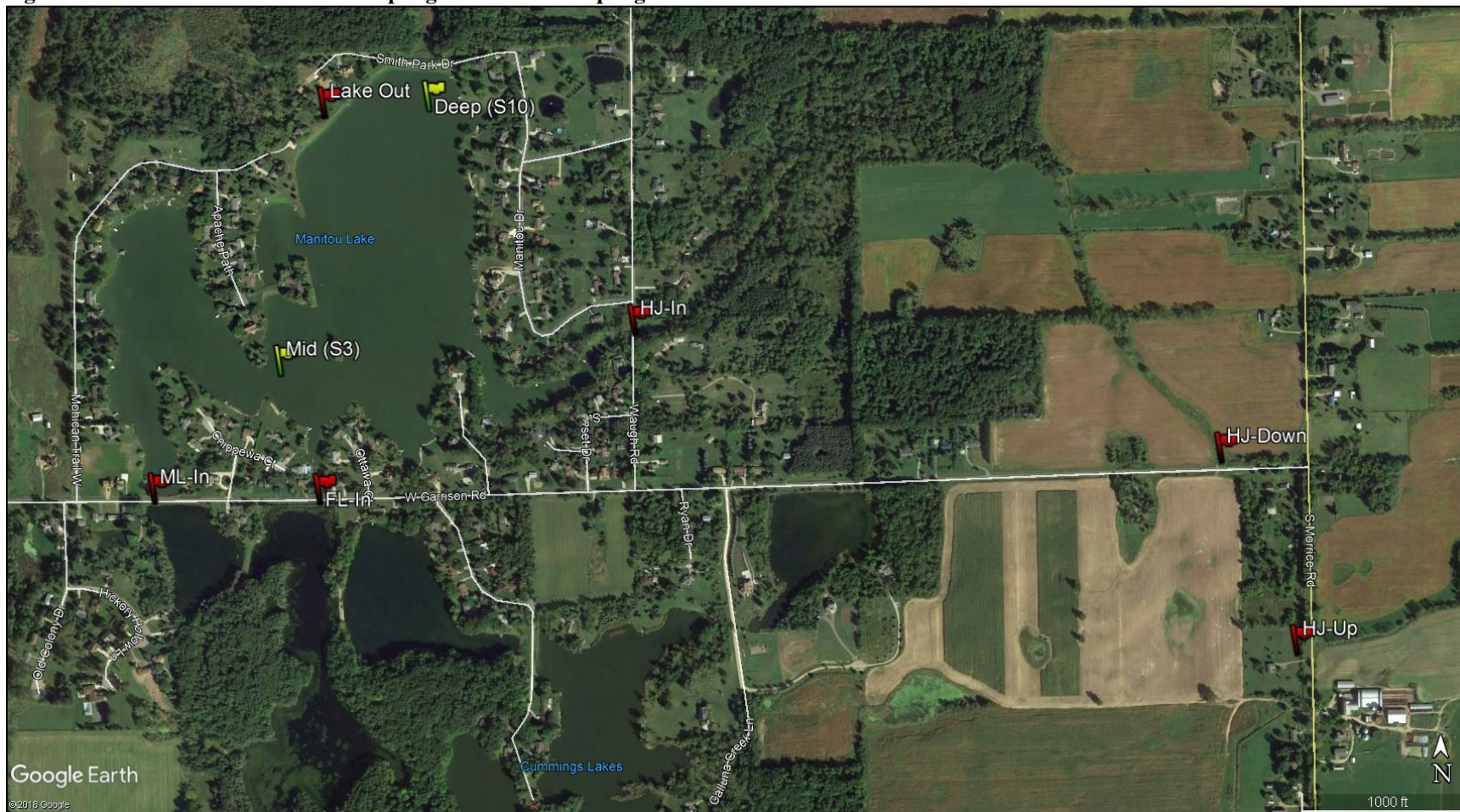
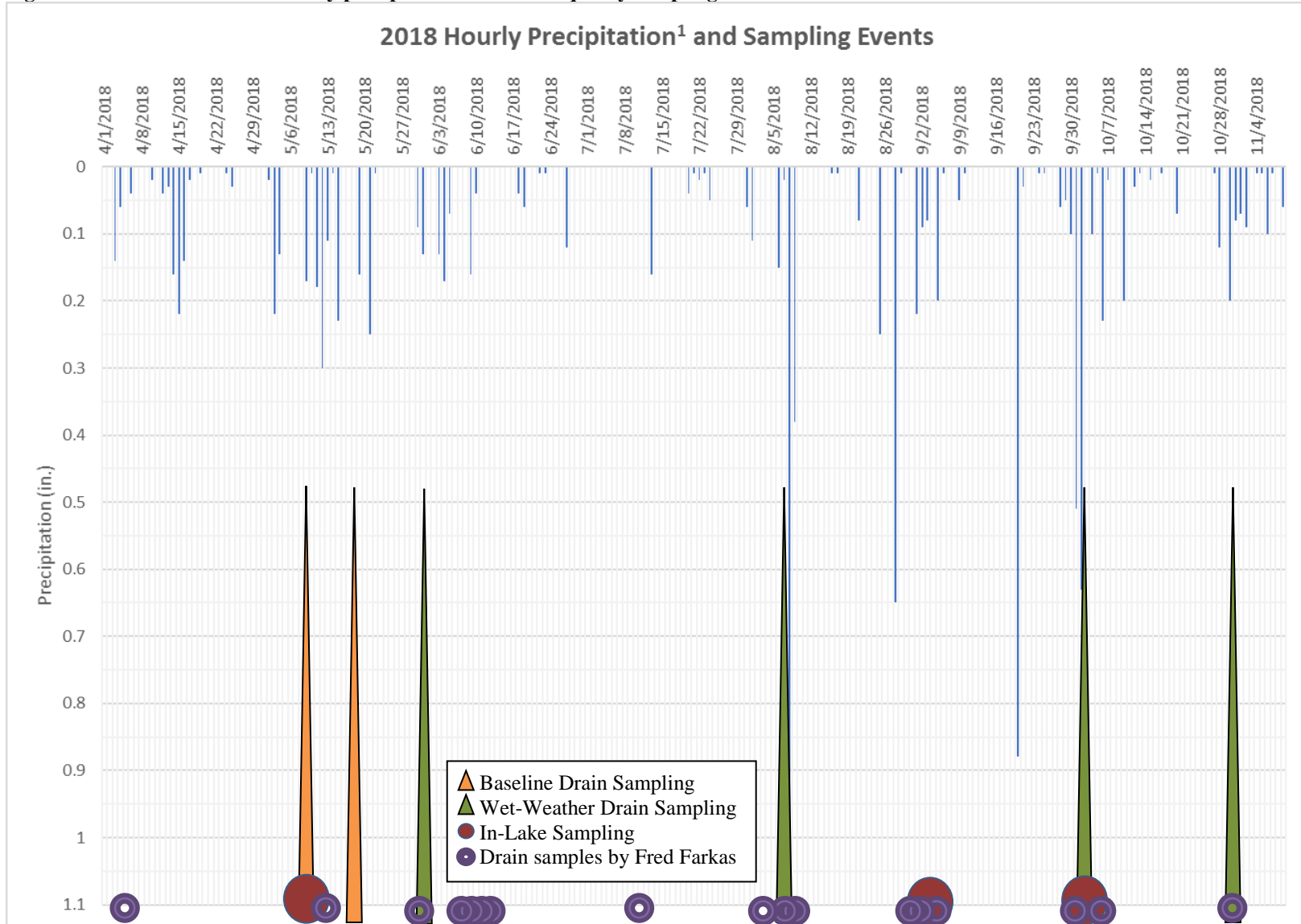


Figure 2. Lake Manitou 2018 hourly precipitation and water quality sampling events.



¹MSUE Enviro-weather, Haslett Station: <<https://mawn.geo.msu.edu/station.asp?id=has&rt=60>>

2018 Lake Manitou Drains Sampling Results

Drain samples were collected by K&A field staff throughout the 2018 monitoring period following the Quality Assurance/Quality Control (QA/QC) procedures outlined in Attachment 1. Drain sampling efforts for Lake Manitou included the installation and monitoring of four staff gauges. Additional staff gauge readings and water quality samples for select parameters were collected by Fred Farkas throughout the monitoring period.

Stage-discharge relationships were established to calculate instantaneous flows, based on the static dimensions of each Lake Manitou inlet and the outlet, and on staff gauge readings and in-stream measurements collected during the monitoring period. The corresponding processed analytical data, discussed in the following section, are compiled in Attachment 2. Tables showing raw field data, laboratory analytical results, and staff gauge readings (including data collected by Fred Farkas), are found in Attachment 3. Copies of the full analytical laboratory reports are included as Attachment 4.

Stage-Discharge Relationships

The following equations were used to calculate flows for the Lake Manitou drains:

FL-In and Lake Out:

Flows are calculated by the Francis rectangular weir calculation:

$$Q = 3.33H^{1.5}(W - 0.2H)$$

Where:

- Q = Flow (cfs)
- H = Water height over weir (ft)
- W = Width of weir (ft)

HJ-In and ML-In:

Flows are calculated using an equation fitting to measured flow (measured velocity * calculated area) to gauge height. Equations for the area of water inside a pipe are shown below. For HJ-In, fitting equations were calculated for both the left and right culverts and then added together.

Area of Water in Pipe Calculation:

If water height (d) is less than the pipe radius (r):

$$A = \frac{r^2\theta\sin(\theta)}{2} \quad \text{where } \theta = 2\cos^{-1}\left(\frac{r-d}{r}\right)$$

If $d > r$:

$$A = \pi r^2 - \frac{r^2\theta\sin(\theta)}{2} \quad \text{where } \theta = 2\cos^{-1}\left(\frac{d-r}{r}\right)$$

Best fit equations:

$$\text{HJ-In: } Q = 3.362x^2 + 11.193x - 7.949 \quad \text{where } x = \text{gauge height.}$$

$$\text{ML-In: } Q = 0.341x - 0.218 \quad \text{where } x = \text{gauge height and } x > 0.655$$

Instantaneous flows were applied to pollutant concentrations with a unit conversion to calculate instantaneous pollutant loads at each site, for each sample event. Though loads are typically expressed as monthly or annual in water quality assessments, the limited scope of this K&A study and data analysis (which precluded continuous flow and water quality monitoring as

recommended in the Phase I Report), leaves these computations as instantaneous loads. These data and results can, however, be used in future, detailed watershed loading assessments. The equation used to calculate instantaneous pollutant loads is:

$$W = Q * C * 28.32$$

Where:

- W represents the instantaneous pollutant load (mg/s)
- Q represents the instantaneous flow (cfs)
- C represents the pollutant concentration (mg/L)
- 28.32 liters per ft³ is used to convert the imperial units to metric.

Flows and pollutant loads for each drain are compiled as Attachment 2.

As expected, flows were highest during the spring months and tapered off significantly during the summer, with overall increases during a relatively wet fall. During dry periods in July and August, Forest Lake and Mirror Lake produced no flows into Lake Manitou. Between July and October of 2018, flows out of Lake Manitou were observed to occur on only five separate instances during monitoring events. These observations coincide with lower total rainfall during the 2018 monitoring season.

Flows at the Hardy-Jennings Drain inlet to Lake Manitou averaged 1.29 cfs from May to June, 0.59 cfs from July-August, and 0.69 cfs from September-October of 2018 based on all events where staff gauge measurements were collected. On two occasions, the mornings of August 6 and October 2, both prior to rain events, staff gauge readings at HJ-In corresponded to calculated negative flows. This suggests that during the driest periods, surface water may slightly backflow out of Lake Manitou into the lower sections of the Hardy-Jennings Drain. Higher pollutant loads at the Hardy-Jennings Drain correlate with higher flows throughout the year. As would be expected, pollutant loads at HJ-In were higher during the spring months, even during the baseline sampling events.

Discussion of Drain Sampling Results

Temperature, Dissolved Oxygen (D.O.), Conductivity, and pH

Water temperature, D.O., conductivity, and pH were recorded at all Lake Manitou drain sampling locations during each sampling event. These data show that in-lake water temperatures at the Lake Manitou outlet were typically similar to water temperatures at the Forest Lake and Mirror Lake inlets to Lake Manitou. While water temperatures were comparable between each Hardy-Jennings Drain sampling station, temperatures were consistently 3-5°C lower in the HJ Drain than at the other sampling stations. Similarly, field data showed the range of conductivity throughout the HJ Drain (490-700 µS/cm) to be nearly two times higher than at the other drain sampling stations (310-440 µS/cm). Conductivity levels above 500 µS/cm in freshwater streams indicate high ion concentrations detrimental to supporting diverse aquatic life and possibly suggesting a source of contamination (MDEQ, 2006).

Dissolved Oxygen (D.O.) concentrations in surface waters will vary depending on the season, water depth, and location. D.O. concentrations below 5 mg/L can be detrimental to aquatic life (MDEQ, 2006). In the Hardy-Jennings Drain, D.O. concentrations ranged from 6.0 to 13.8 mg/L

throughout the 2018 sampling season. D.O. concentrations were consistently lowest at the HJ-Down station, intermediate at the HJ-In station, and highest at the HJ-Up station.

At the Forest Lake inlet, D.O. concentrations ranged widely from 5.67 mg/L in mid-summer to 14.6 mg/L in fall. Similarly, D.O. concentrations at the Mirror Lake inlet ranged from 6.76 mg/L during a wet-weather event in spring to 12.33 mg/L during a baseline dry-weather event in spring. Surface water D.O. concentrations at the Manitou Lake Outlet were consistent with in-lake sampling results. Field data showed pH ranging between 7.25 and 9.02 at all stations.

Total Suspended Solids (TSS)

Total suspended solids (TSS) samples have not historically been collected in Lake Manitou nor its inlets or outlet, though evidence suggests that TSS loading is contributing to water quality problems in Lake Manitou. TSS include all particles suspended in water which will not pass through a filter. Suspended solids can result from soil erosion, decaying plants and animal matter. Suspended solids in a lake or stream absorb heat from sunlight, which increases water temperature and thus causes decreased levels of dissolved oxygen. Photosynthesis also decreases with higher TSS, since less light can penetrate the water. TSS can also destroy fish habitat and smother the eggs of fish and aquatic insects. Suspended solids can also harm fish directly by clogging gills, reducing growth rates, and lowering resistance to disease. The State of Michigan does not have an established water quality standard for TSS, though most people consider water with a TSS concentration less than 20 mg/l to be clear (MDEQ, 2006).

In general, TSS concentrations were higher at all Lake Manitou Drain stations in the spring months than in the fall months. TSS loading at the Lake Manitou outlet was dramatically higher during and after wet weather events, with the highest outflows occurring in spring. TSS monitoring results reflect the need for future upstream conservation practices and are relevant to costly past and potential future needs for dredging efforts in the Hardy-Jennings drain. See Attachments 2 and 3 for all 2018 concentration and pollutant load data.

Phosphorus

Total phosphorus (TP) loading into Lake Manitou generally reflects inputs of fertilizers, eroded farmland soils and manure applied on agricultural fields. Nutrients also originate from urban runoff, onsite septic systems, wildlife, and atmospheric emissions. Excess nutrient loading can cause nuisance and harmful algal blooms (HABs), and oxygen-depleted conditions. TP is often linked to TSS. The US EPA suggests 0.03125 mg/L TP as a reference water quality standard (WQS) concentration for surface waters.

The 2018 sampling results showed elevated TP concentrations during wet weather and spring sampling events. TP concentrations at the Lake Manitou outlet remained below the reference WQS during all events except for the wet-weather event on October 1, 2018. Samples from the Mirror Lake and Forest Lake inlets averaged concentrations of less than 0.03 mg/L TP throughout the year, with the highest concentrations of TP occurring during the August 6, 2018 wet-weather event.

TP concentrations in the Hardy-Jennings Drain were relatively uniform, at about 0.17 mg/L TP, at the HJ-In and HJ-Down sampling stations. Instantaneous load calculations show much higher

TP loads entering Lake Manitou from the Hardy-Jennings inlet than other drains. The average TP load at HJ-In during spring months was noted to be nearly four times higher than the average TP load occurring in fall months. The highest TP load at HJ-In occurred during the May 5, 2018 baseline event.

In the Hardy-Jennings Drain, TP concentrations at HJ-Down were, on average, slightly higher than concentrations at HJ-Up, suggesting contributions of TP loads originating in the Hardy-Jennings East Branch. Variability in this trend, however, is also consistent with findings for TSS loading in the Hardy-Jennings Drain, which suggest multiple sources of sediment and nutrient loading exist throughout the drain.

Nitrates

Nitrate sample concentrations in the Lake Manitou drains ranged from below the laboratory reporting limit (<0.5 mg/L) to 2 mg/L during the 2018 sampling period. In the Hardy-Jennings Drain, nitrate concentrations averaged 1.1 mg/L throughout the sampling period, with nitrate loads ranging from 10.47 mg/s (October 31, 2018) to 57.04 mg/s (May 10, 2018). This suggests greater nitrate loading occurs during high baseflow and wet-weather periods in the spring. Nitrate concentrations varied between the HJ-Up and HJ-Down stations, averaging approximately 1.1 mg/L. Concentrations tended to be higher at HJ-Up than HJ-Down in spring, but this trend reversed in mid-summer and fall. K&A's Lake Manitou Phase I report showed historic nitrate average concentrations at 1.561 mg/L, consistent with 2018 data.

Samples collected at the Mirror Lake and Forest Lake Inlets were consistently reported as below the laboratory reporting limit (<0.5 mg/L). This is consistent with historic sample results between 1993 and 2002, which showed an average nitrate concentration of 0.035 mg/L at these locations. The 2018 data are consistent with historic findings that the Hardy-Jennings Drain, and not the Cummings Lakes, is the primary source of nitrate loads entering Lake Manitou, which experiences periodic elevated nitrate levels.

Escherichia coli

During the 2018 sampling period, Fred Farkas voluntarily collected 13 *Escherichia coli* (*E. coli*) samples. MDEQ has established exposure limits for *E. coli* for partial body contact recreation (year-round) at a daily maximum of 1,000 *E. coli* per 100 ml water. Sample results are shown in the "Water Quality Samples Collected by Fred Farkas" table in Attachment 3.

E. coli samples collected from the HJ-In, HJ-Down, and a sample collected from the East Fork of the Hardy Jennings Drain, showed levels of >1,000,000 *E. coli* per 100 ml water on October 2, 2018, one day after a significant rain event. These excessively high *E. coli* concentrations support the assertion that historic dairy operations and/or manure spread on fields have been a significant source of bacteria and pathogen concentration inputs into Lake Manitou. At HJ-Up, upstream of an existing dairy operation, concentrations on October 2, 2018 were found at less than 100 times that downstream of the dairy input.

This assertion is also supported by previous *E. coli* concentrations found in the downstream Hardy-Jennings Drain, which were as high as 61,000 *E. coli* per 100 ml water in October 2017 and 70,000 *E. coli* per 100 ml water in July 2017. 2018 *E. coli* concentrations in samples

collected outside of the Hardy-Jennings Drain ranged from 10-40 *E. coli* per 100 ml water. The significantly elevated 2018 *E. coli* results from the Hardy-Jennings Drain may correspond to the dairy operation on the Hardy-Jennings East Branch in 2018, discussed briefly in the next section.

Dairy Operation on the Hardy-Jennings Drain

The Hardy-Jennings Drain has historically received stormwater runoff and tile drain discharges from a commercial dairy operation located on South Morrice Road. This property sits on the southeast corner of two branches of the Hardy-Jennings Drain, which form a confluence immediately downstream on the west side of S Morrice Rd. Manure generated at this operation has also historically been field-applied to agricultural properties within the Lake Manitou watershed (Fred Farkas, personal communication, 2018). This dairy operation is likely still active as of 2018, though their current level of production is unknown (Fred Farkas, personal communication, 2018).

Continued monitoring of pollutant loads and bacteria concentrations should continue in order to assess loading changes over time. Continued monitoring of the Hardy-Jennings Drain will help to pinpoint other pollutant sources to inform future management decisions as well especially if cropped acreage remains active through purchase or leasing to other farm operators.

2018 Lake Manitou In-Lake Sampling Results

In-Lake sampling was conducted by K&A field staff throughout the 2018 monitoring period following the Quality Assurance/Quality Control (QA/QC) procedures outlined in Attachment 1. Tables showing all raw field data and analytical results are included as Attachment 3. Copies of laboratory reports are included as Attachment 4. In-lake sampling stations were based on historic station locations previously named Station 3, herein represented by the Sample ID “Mid (S3)” and Station 10, herein represented by the Sample ID “Deep (S10).”

Discussion of In-Lake Sampling Results

The 2017 Phase I report authored by K&A fully detailed and analyzed the extent and relevance of historic monitoring and sampling trends and suggested where data is lacking. The following discussion of results builds on these analyses for each analyte monitored during the 2018 season. For a detailed discussion of the importance of each analyte to water quality in Lake Manitou, refer to the Phase I report.

Temperature and Dissolved Oxygen (D.O.)

Continued monitoring of depth profiles for temperature and dissolved oxygen can help assess the risk for anoxic conditions and determine if alternative management efforts would be beneficial for fisheries and for inhibiting internal nutrient loading from the sediments. Historic profiles of temperature and D.O. show that Lake Manitou thermally stratifies during the summer months in the deeper sections of the lake with a thermocline periodically forming at depths of 10 ft or deeper by early summer. D.O. data show that Lake Manitou bottom waters experience routine oxygen depletion. Figures 3 and 4 graphically illustrate 2018 temperature and D.O. profiles collected at the Deep (S10) and Mid (S3) stations.

Figure 3. Lake Manitou Deep (S10) station temperature, D.O., and pH profiles.

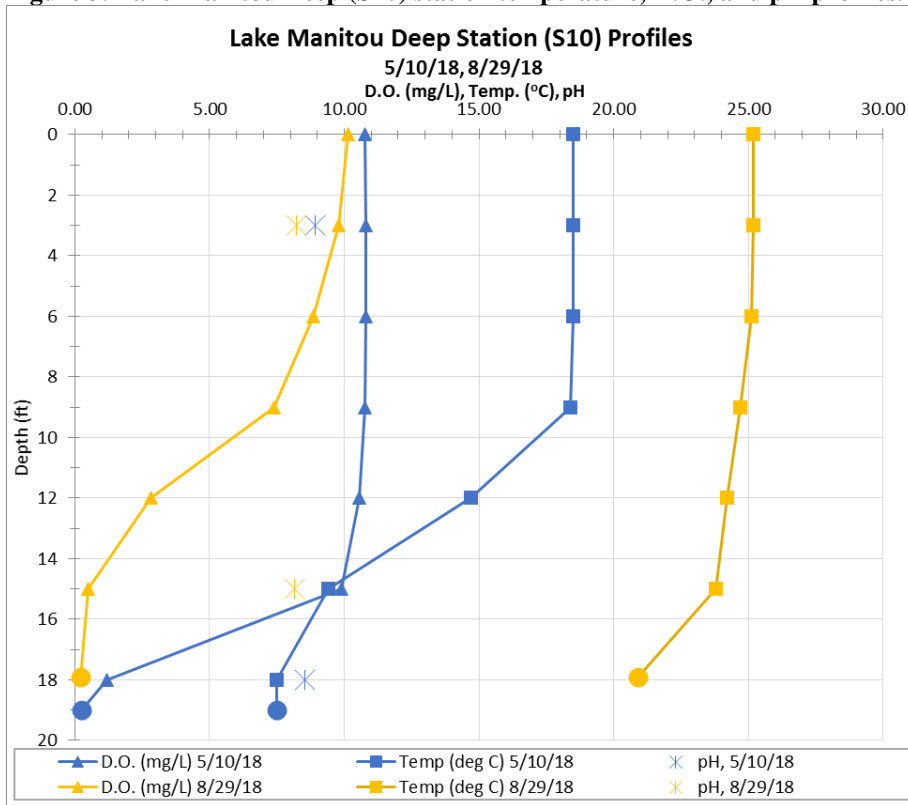
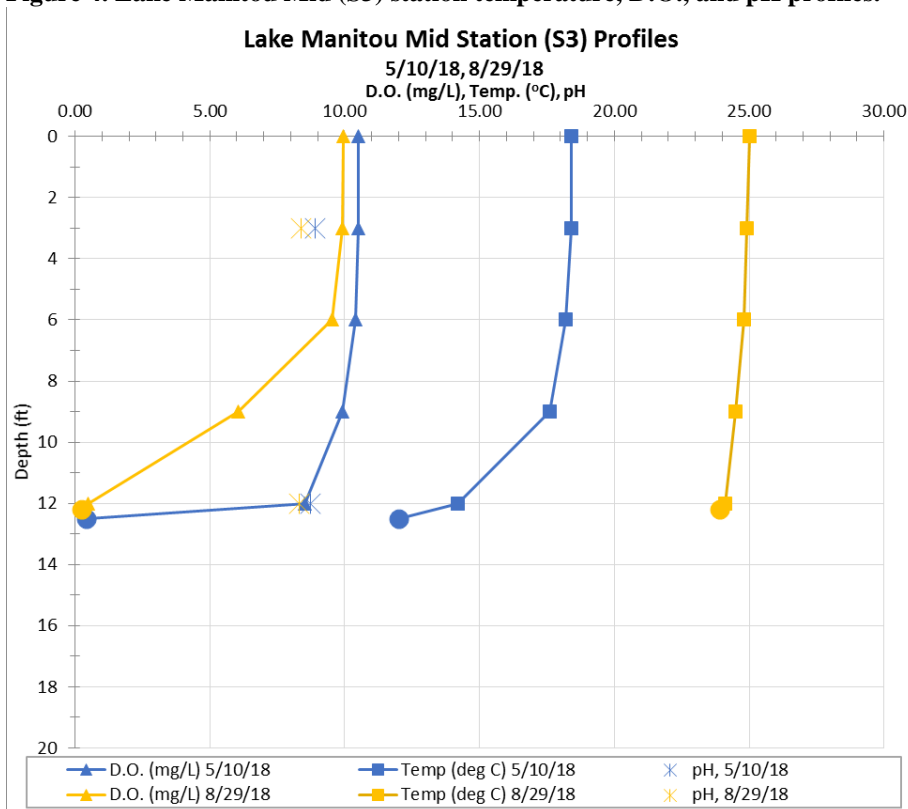


Figure 4. Lake Manitou Mid (S3) station temperature, D.O., and pH profiles.



Early summer sampling (10 May 2018) showed thermal stratification at the Mid (S3) station (12-13 ft total depth) began to occur at depths greater than 9 ft, with anoxic conditions occurring below 12 ft. At the Deep (S10) station (18-19 ft total depth), early summer sampling also showed thermal stratification began to occur at depths greater than 9 ft, with anoxic conditions occurring between 15-18 ft depths. Late summer sampling (29 August 2018) showed thermally-mixed conditions at the Mid (S3) station (12-13 ft total depth), with anoxic conditions occurring below 9 ft. At the Deep (S10) station (18-19 ft total depth), late summer sampling also showed thermally mixed conditions, with anoxic conditions occurring between 9-12 ft depths.

The 2018 monitoring data are consistent with the temperature and D.O. patterns highlighted in the Phase I report. The Phase I report suggests that Lake Manitou experienced anoxic (oxygen-depleted) conditions as shallow as 13 feet. If anoxia occurred as shallow as 13 feet, 21.4% of Lake Manitou's bottom waters could be at risk for anoxia. Data suggest that this was likely the case during the 2018 monitoring season.

pH

Figures 3 and 4 also show field records for pH, which was measured during each sampling event at approximately 3 ft from the surface and 1 ft from the bottom at the Mid (S3) and Deep (S10) stations. At both in-lake stations in 2018, surface pH ranged from 8.22-8.93, while bottom pH ranged from 8.16 to 8.52.

These measures are in line with historic Lake Manitou pH measures, as indicated in the Phase I report, which ranged from 7.3-9.7 with an average of 8.4 based on 1993-2002 WQI data sets. Lake Manitou experiences slightly alkaline conditions compared to the average inland lake in Michigan. Higher pH can reflect conditions of high plant and algal productivity, consistent with observations of Lake Manitou.

Conductivity

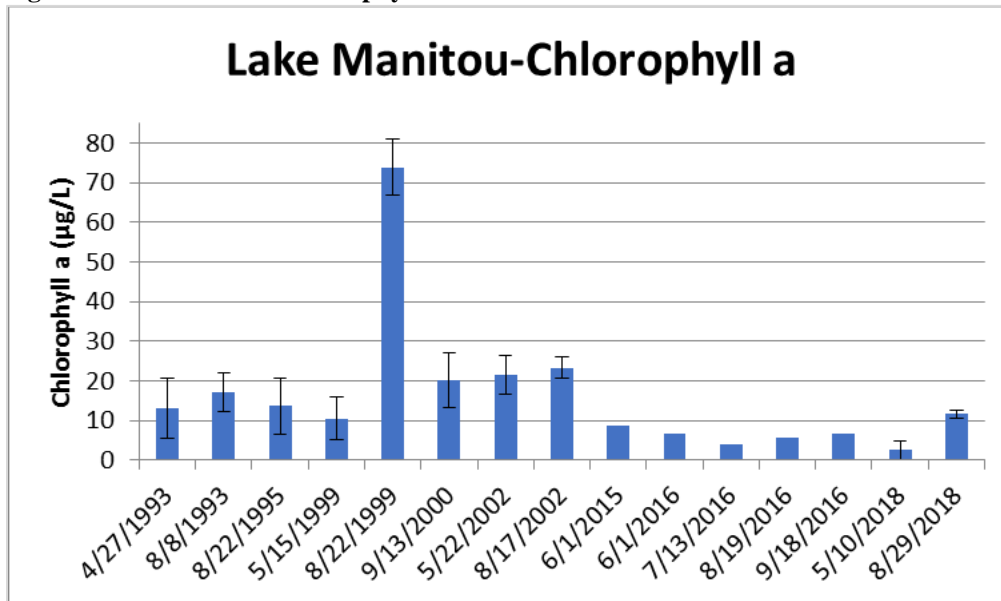
Conductivity can serve as an indicator of septic system or road salt inputs. Conductivity measurements combined with other monitoring parameters (e.g., *E. coli*) can potentially help locate pollutant sources. Historical sampling of Lake Manitou from 1993-2002 (WQI) show conductivity concentrations ranging from 220-520 $\mu\text{S}/\text{cm}$. All 2018 in-lake conductivity profile measurements fell within this range, from 387-428 $\mu\text{S}/\text{cm}$ in May and 364-394 $\mu\text{S}/\text{cm}$ in August. Lake sediment conductivity averaged 429 $\mu\text{S}/\text{cm}$ in May and 495 $\mu\text{S}/\text{cm}$ in August.

Chlorophyll a

A main concern for Lake Manitou water quality has been warm-season algae blooms, including the presence of harmful algal blooms (HABs) consisting of toxin-producing cyanobacteria. Chlorophyll *a* has been used as a limited proxy to estimate algal density. The Lake Manitou Phase I report details the limitations of chlorophyll *a* as a proxy for algal density and specifies the current scientific discussions of microcystin and harmful algal blooms. Generally, HABs are more likely to occur during blue-green algae blooms in waters with chlorophyll *a* concentrations of greater than 30 $\mu\text{g}/\text{L}$. Other conditions considered favorable for cyanobacteria growth include high phosphorus and nitrogen concentrations, slow moving/stagnant water with a long hydraulic retention time, and high temperatures. These conditions have been observed in Lake Manitou.

Figure 6 plots average chlorophyll *a* concentration for each sample event in 2018, along with standard deviation.

Figure 6. Lake Manitou Chlorophyll *a* concentration data.



Average chlorophyll *a* concentrations from 2018 were significantly higher in August, at 11.7 µg/L, than in May, at 2.5 µg/L. The WQI chlorophyll *a* data from 1993 to 2002 showed average concentrations in Lake Manitou ranging widely from 10.5 µg/L (May 1999) to 73.9 µg/L (August 1999). The Cooperative Lakes Monitoring Program (CLMP) chlorophyll *a* data, collected annually since 2015, showed a chlorophyll *a* range of 1.9 µg/L to 15 µg/L. The notable difference between more recent and past concentrations may be a result of different sampling techniques including different sampling depths or sample preservation methods.

Alkalinity

Alkalinity measurements and pH are influenced by soil types and watershed inputs. Alkalinity is an important parameter to help guide the selection and application of aquatic herbicides and algaecides. Historic samples performed by WQI from 1993-2002 show alkalinity in Lake Manitou ranging from 82-225 mg/L. 2018 sample results for alkalinity averaged 172 mg/L and ranged from 144-195 mg/L, well within the historic range. Alkalinity concentrations tended to be slightly lower in surface samples than bottom samples and higher, on average, during the May 10, 2018 sampling event than the August 29, 2018 sampling event.

Total Nitrogen

The Phase I Lake Manitou report discusses historic sampling for nitrates in Lake Manitou. Total nitrogen (TN) was measured at each in-lake station during the 2018 sampling events. Total nitrogen is expressed as the sum of multiple nitrogen concentrations, including Nitrate-N, Nitrite-N, and Total Kjeldahl Nitrogen. Total nitrogen concentrations were consistently highest in the bottom water samples of the Deep (S10) station, at 0.73 and 1.20 mg/L during spring and late-summer, respectively. Bottom water concentrations at the Mid (S3) station were 0.37 and

0.7 mg/L during spring and late-summer, respectively. Average surface water TN concentrations for both events at both stations were 0.49 mg/L.

Lake Manitou Sediments

The Lake Manitou Phase I Report discussed modeled water flows and phosphorus loads in and out of Lake Manitou in the Water Balance and Phosphorus Mass Balance Assessment section (pages 29-31). Modeling efforts found that an estimated 80% of the annual phosphorus load into Lake Manitou is retained in lake sediments. Anoxic conditions in deep bottom waters can increase the release and recirculation of accumulated phosphorus from sediments, serving as an “internal” source of total phosphorus. This internal loading further contributes to poor water quality conditions, including nuisance plant and algal growth which in turn exacerbates problems of low oxygen through plant decay and release of phosphorus into the water column. Internal loading can be a significant source of phosphorus loading long after “external” loading issues have been addressed.

Results of the 2018 in-lake sediment sampling are shown in Table 5, while inferences for internal phosphorus loading are shown in Table 6.

Table 5. 2018 Lake Manitou in-lake sediment sampling results.

Date	Sample ID	TP (mg/kg)	Fe (mg/kg)	%Solids	Lab
5/10/2018	Lake Deep (S10)	1,090	28,800	16.8	Pace
5/10/2018	Lake Mid (S3)	592	21,500	20.2	Pace
10/1/2018	Lake Deep (S10)	569	19,700	21.0	Merit
10/1/2018	Lake Mid (S3)	454	20,000	29.0	Merit

Table 6. Internal phosphorus loading potential based on 2018 sediment sampling Iron to TP ratios.

Date	Sample ID	Fe:TP
5/10/2018	Lake Deep (S10)	26.42
5/10/2018	Lake Mid (S3)	36.32
10/1/2018	Lake Deep (S10)	34.62
10/1/2018	Lake Mid (S3)	44.05

At ratios of Fe:TP of 15 or greater sediments are considered to have TP retention capacity. Lower concentrations of TP and Fe in October compared to May suggest release from sediments is occurring during the summer months. Note that instantaneous TP load calculations showed significantly higher surface water TP loads entering Lake Manitou in spring months than during fall months. Additionally, average flows leaving Lake Manitou at its only outlet were also found to be significantly higher in 2018 from spring to mid-summer (1.98 cfs) than from mid-summer to fall (0.14 cfs). (Refer to the K&A Phase I Report for a discussion of implications regarding internal phosphorus loading in Lake Manitou.)

Conclusions and Recommendations

Results from the 2018 water quality monitoring support services, which represent a limited portion of the Phase II tasks recommended in K&A's Phase I Lake Manitou report, offer greater insight of current water quality conditions in Lake Manitou and its inlets and outlet. Of particular importance is the recording of flows entering Lake Manitou through each of its inlets, which was absent in the historic datasets. Additionally, a significant lapse in water quality data occurred between 2002 and 2016. Continuity of sampling locations and techniques, including flow monitoring, is critical for future analyses to long-term trends and watershed best management practices to address water quality problems throughout the Lake Manitou drainage areas.

The 2018 monitoring study shows that as would be expected, higher nutrient and suspended sediment loading occurs during spring months, when flows are highest due to snowmelt and more frequent rain events. Flow monitoring reveals that low to no flows leave the Lake Manitou outlet from mid-summer to fall in a less-than-average rainfall year. The monitoring study confirms the watershed modeling conclusions in the Phase I report which suggest a retention time of 174 days, with approximately 80% of phosphorus reaching Lake Manitou remaining in the lake. The 2018 in-lake sediment monitoring further suggests that internal phosphorus loading is occurring during the summer months.

Water quality and flow monitoring in the Lake Manitou drains affirms that the majority of sediment and nutrient loading into Lake Manitou occurs at the Hardy-Jennings Drain. Pollutant loads measured at the Hardy-Jennings inlet to Lake Manitou were several orders of magnitude higher than pollutant loads entering Lake Manitou from the Cummings Lakes. Monitoring of two upstream stations in the main branch of the HJ Drain confirm that the East Branch of the HJ Drain contributes significant nutrient inputs. This is also true of bacteria concentrations, as shown by the high *E. coli* concentrations collected in the East Branch and at HJ-Down and HJ-In compared to HJ-Up. Monitoring results also show, however, that sediment and nutrient inputs occur throughout the HJ Drain during wet weather events. This includes sediment and nutrient loads and some bacteria concentrations occurring on the HJ-Drain's main branch, upstream of the East Branch.

Sediment basins have been historically used at the Hardy-Jennings Drain inlet to Lake Manitou to facilitate sediment cleanout by the Shiawassee County Drain Commission, though this has not occurred for approximately six years. Sediment cleanouts at the HJ-In location are a costly measure and the question of who must pay for this service has prevented its regular occurrence (Fred Farkas, personal communication, 2018). Accumulated sediments in the final stretch of the HJ Drain, which are now mounding within the channel, will continue to be a source of sediment loading into Lake Manitou. As such, investing again in the process of sediment cleanout at the HJ Drain may be a necessary short-term solution until upstream sources of sediment loading are fully identified and addressed. The 2018 monitoring study supports the conclusions of K&A's Phase I report in this regard.

Although the dairy operation, likely a significant contributor of nutrients and bacteria to the HJ East Branch, may have reduced its production in 2018, pollutant loading still occurs throughout the drainage area. A visual survey of the upstream and downstream portions of the HJ Drain would be necessary to detect pollutant sources, which may include erosion sites, tile drain inputs,

and other potential point source discharges or nonpoint source pollutant inputs. Only then would identifying and prioritizing management solutions be best discerned to address pollutant issues at their source, eventually preventing the need for expensive clean-outs at the Hardy-Jennings inlet.

Close coordination with the Shiawassee County Conservation District and other state agencies to begin implementing conservation solutions is still highly recommended once pollutant areas are identified. Results of the 2018 monitoring should help leverage interests in pursuing conservation projects in the Hardy-Jennings Drain. Continued monitoring will further confirm the need to implement future pollutant management strategies in the watershed. Staff gauges installed for the 2018 monitoring efforts remain at each drain inlet and the lake outlet, and should be maintained in these locations, so that pollutant loads can be derived from future water quality samples collected in these locations.

Although Lake Manitou experienced only a few algal blooms in 2018, potentially due in part to lower overall precipitation, the development of a long-term vision for addressing watershed pollutant loading is still necessary to minimize frequency and duration of future harmful algal blooms. This must include identifying and prioritizing management practices to address pollutant loading in the upstream areas of the watershed, with a focus on the Hardy-Jennings drainage area. Additional recommendations for future efforts put forward by the Phase I report, including a suite of recommended future efforts for algal monitoring and analysis of opportunities to reduce hydraulic retention times still apply.

Works Cited

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