Lake Heney Water Quality Sampling and Analysis, 2018
Final Report

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EXECUTIVE SUMMARY

This report describes the methods and results associated with the 2018 sampling of water quality of Lake Heney, lac Desormeaux, lac a la Barbue, lac Vert, and lac Noir. Sampling was conducted during three periods, early spring, late summer and late fall. The early spring sampling captured spring turnover of Lake Heney, when lake water temperatures are near 4°C from top to bottom and when the lake is potentially fully mixed. The fall sampling period captured fall turnover in Lake Heney. The late summer sampling period captured worst-case conditions when the lake is most stratified, and when dissolved oxygen levels are expected to be at their lowest in the deep strata of the lake.

All of the lakes (including Heney) experienced oxygen sag during the late summer sampling period, reflecting relatively high concentrations of phosphorus.

Concentrations of total phosphorus in Lake Heney were lower in 2018 including during spring (11.7 µg/L) and fall (8 µg/L) sampling periods than reported during the pre-treatment period (1999 to November 2007).

The watershed-area lakes have had variable whole-lake total phosphorus concentrations over the last three years, generally exceeding whole-lake levels in Lake Heney. The watershed lakes therefore contribute to the phosphorus loadings of Lake Heney.

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List of Acronyms and Abbreviations

°C – degrees Celsius
CCME – Canadian Council of Ministers of the Environment
CO_2 – Carbon Dioxide
DO – Dissolved Oxygen
KAL – Kilgour & Associates Ltd.
Kg – Kilograms
m – meters
mg/L – milligrams per litre
MOB – meter off bottom
QA/QC – Quality Assurance / Quality Control
RPD – Relative Percent Difference
TP – Total Phosphorus
µg/L – micrograms per litre

1.0 INTRODUCTION

Lake Heney, situated near Gracefield, Québec, is relatively large (12.32 km2) and deep (32.5 m). The Lake Heney watershed contains > 800 buildings, > 500 cottages, and > 300 shoreline dwellings (Carignan, 2015). The lake has had a history of challenges related to water quality, relative to other large lakes in the area. Excessive loading of nutrients in waterbodies, such as nitrogen and phosphorus, can lead to eutrophication. Eutrophication is the process whereby nutrient enrichment promotes algal blooms which can have negative effects on the health of a waterbody. Phosphorus is regarded as the most limiting nutrient for the growth of phytoplankton and is therefore the leading cause of algal blooms (Schindler et al. 2008; Márquez-Pacheco et al. 2013; Søndergaard et al. 2013).

The effects of phosphorus loading in Lake Heney were exacerbated from 1994 to 1999 when a fish farm (Truiticulture S.L.) was in operation and releasing effluent into a tributary to the lake (Carignan 2003; 2015). The Québec Ministry of the Environment and Wildlife reported that the nutrient-rich wastewater from the fish farm contributed 450 out of a total 1143 kg (about 40 %) of annual external contributions of phosphorus to Lake Heney (Bird and Mesnage 1996). According to Bird and Mesnage (1996), other external contributions to phosphorus inputs included inputs from tributaries (312 kg), cottage septic systems (195 kg), and atmospheric fallout (186 kg). Bird and Mesnage (1996) estimated the flushing of phosphorus from Lake Heney at approximately 231 kg, such that a little over 900 kg of phosphorus was retained in the lake each year (Bird and Mesnage 1996; Prairie 2005). Kilgour & Associates (2019) provides a re-evaluation of the mass balance of TP into Lake Heney, concluding that estimates from precipitation and tributaries were reasonable but absolute values may depend on the year and total precipitation.

The Québec government and the Association for the Protection of Lac Heney forced the closure of the fish farm in 1999. Phosphorus levels, however, continued to be elevated almost a decade afterwards, showing little to no sign of reduction (Carignan 2014).

Iron (Fe) binds with phosphorus (Prairie et al. 2001; Prairie 2005; Carignan 2003), resulting in the precipitation of phosphorus to the lake bottom. Iron concentrations in Lake Heney were examined, with the conclusion that levels were generally low relative to what is present in other similar lakes, and also inadequate to bind with all of the phosphorus entering the lake (Prairie 2005). In November of 2007, the Heney Lake Foundation added reactive iron chloride ($FeCl_3$) solution, which has a high phosphorus adsorption capacity, into the water with the aim to remove excess phosphorus from the lake (Prairie 2005; Carignan 2014).

Regular water quality monitoring has taken place in Lake Heney since early 2007 (eight months before the iron treatment in November 2007) in order to characterize variations over time. Sampling has generally focused on the main basin of Lake Heney. In 2015, the lake association commenced sampling the quality of water of the Lake Heney watershed lakes (major lakes in the major drainages to Lake Heney). Sampling was completed by Dr. Carignan (Université de Montréal) from 2007 until March 2014 (Carignan 2014), by Golder Associates Ltd. (Ottawa) from May 2014 until the end of 2015 (Golder 2015; 2016), and by Kilgour & Associates Ltd. (KAL, Ottawa) in 2016 (KAL 2017), and 2017 (KAL 2018).

This technical report provides the detailed methodologies and data summaries associated with the 2018 sampling of Lake Heney and the watershed lakes. Kilgour & Associates Ltd. was also retained by the lake association to complete a mass balance of total phosphorus for Lake Heney. That exercise started in June of 2018, and will be completed by the end of May 2019, and will be subsequently reported.

2.0 MATERIALS AND METHODS

2.1 Sample Locations

Sample locations for the lake-based water quality program are listed in Table 1 below and illustrated in Figure 1 also below.

Table 1 Summary of sampling dates in 2017

Lake	Coordinates (UTM)	Sampling Location Maximum Depth (m)
Lake Heney	427975 E; 5097005 N	34
Lac à la Barbue	430145 E; 5101105 N	10
Lac Désormeaux	426814 E; 5098529 N	15
Lac Noir	426622 E; 5095372 N	8.4
Lac Vert	427112 E; 5094653 N	13

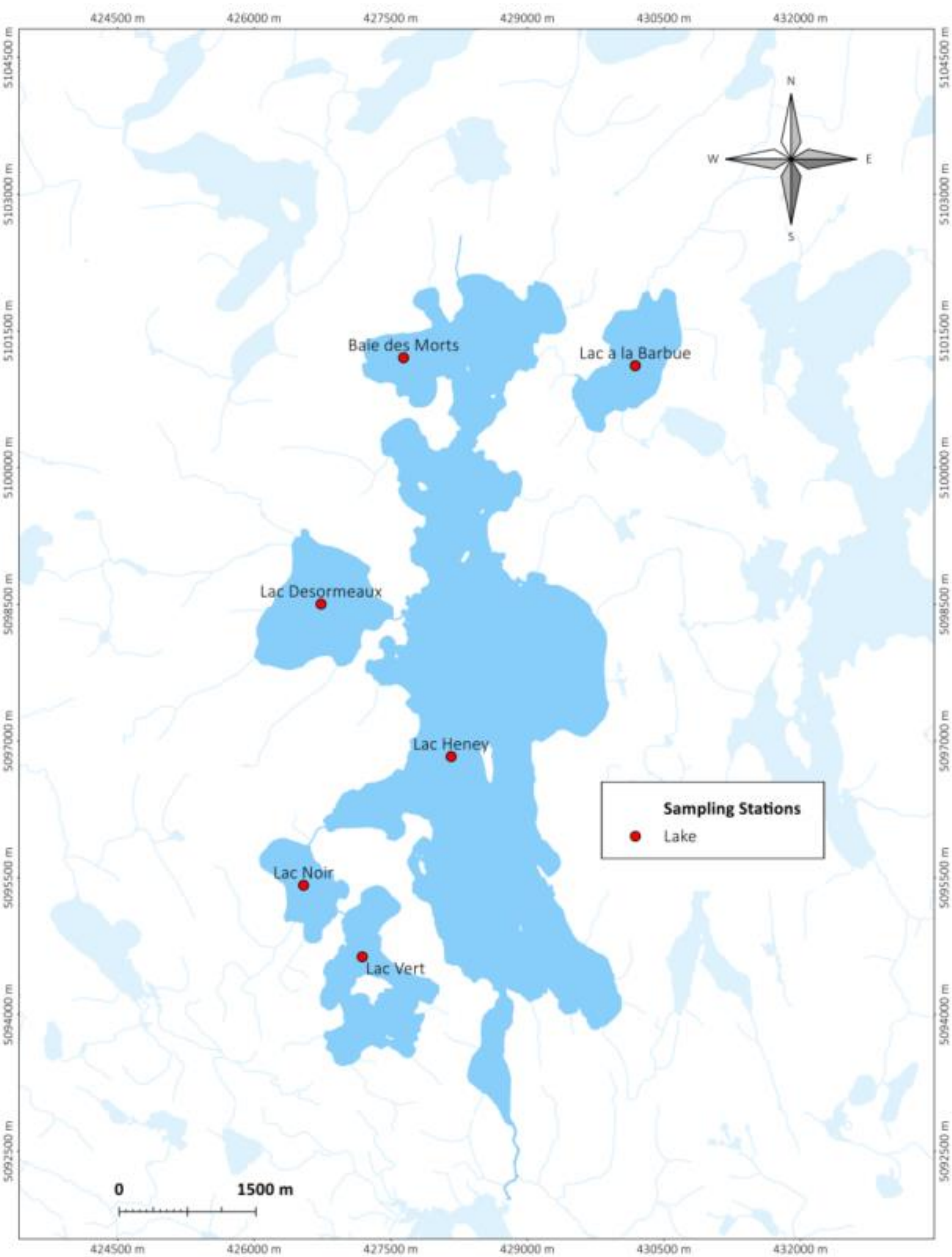


Figure 1 Lake Heney 2018 sampling locations

2.2 Sample Dates

Sampling was completed on the following dates:

- Mid May (May 15 and 16, 2018) to capture spring turnover;
- Mid September (September 9, 2018) to capture late summer lake stratification; and,
- Late November (November 20, 2018) to capture fall turnover for Lake Heney.

All five lakes were sampled during the spring turnover and late summer stratification sampling periods. Only Lake Heney and Lac Vert were sampled during fall turnover. The other three lakes had frozen over by the time water temperatures in Lake Heney had dropped to 4°C.

2.2.1 Rationale for reducing the number of sample periods

The sampling dates were specifically chosen to be informative as to the trophic status of Lake Heney. Spring and fall turnover refer to the condition of a lake water temperature being 4°C. Water that is 4°C is denser than water that is both warmer or colder. Water at the bottom of a deep lake (like Heney) is therefore generally 4°C. In winter, water near the surface is of course near zero °C, and increases in temperature until it reaches 4°C. As the lake warms up in the spring it will eventually be 4°C from top to bottom. At that time, the water in the lake is able to vertically fully mix, a condition referred to as 'turnover'. In summer, warm water rises to the top. Deep lakes may stratify such that temperatures may be very warm near surface, may decrease gradually with depth to about 6 to 10 m (depending on lake size and wind), at which point (i.e., the 'thermocline') temperatures decrease rapidly to 4°C. The thermocline prevents mixing of the surface epilimnetic waters with the deeper, colder hypolimnetic waters. The water in the hypolimnion in the summer may experience oxygen depression in lakes that are nutrient enriched, such as occurs in Lake Heney. In the fall when a stratified lake cools, the lake will have 'turnover' potential again when water temperatures reach 4°C. It is the spring and fall turnover periods that are considered optimum for estimating the concentrations of various chemicals, because that is the time when the lake is fully mixed. So, the spring and fall turnover periods were selected in order to estimate total phosphorus concentrations in Lake Heney (as well as the watershed lakes), while reducing the costs associated with sampling at other times.

The late summer period is the time when stratified lakes have experienced peak oxygen depression associated with the hypolimnion being isolated from mixing and aeration with surface waters. The late summer sampling period therefore provides an indication as to the quality of water in the hypolimnion of Lake Heney.

Prior sampling programs by University of Québec researchers and Golder had collected samples on roughly a monthly interval. Those data were completely adequate for estimating temporal (annual) variations in total phosphorus. The reduced sampling conducted in 2018 was proposed as a means of reducing costs associated with sampling, while not impairing the ability of the association to understand if there were trends across years in concentrations of total phosphorus.

2.3 Water Quality Samples

During each of the three visits to each lake, water samples were collected with a 2-L Van Dorn sampler for laboratory analysis of the following variables:

- total phosphorus;
- nitrogen variables (total nitrogen; total Kjeldahl nitrogen, nitrate, nitrite, and ammonia).

In Lake Heney, samples were collected from depths of 1 and 3 m below the surface, and then at 3 m intervals to 30 m (i.e., 1, 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30 m). During the May sampling event, as the water depth of Lake Heney was recorded as 34 m, a water sample was also taken at 33 m.

In the watershed lakes and Baie des Morts, samples were collected at 1 m, the thermocline (i.e., the depth with the largest temperature difference as determined by the water quality profiles), and 1 m off bottom (MOB). In the event that there was no apparent thermocline (i.e., in the fall turnover), the watershed lake's samples were collected at 1 m, mid-depth, and 1 MOB.

Once collected, samples were stored in coolers with ice (i.e., at roughly 4°C) and delivered within 24 hrs to the Maxxam Analytics (Maxxam) sample distribution centre in Ottawa, Ontario.

2.3.1 Quality Assurance / Quality Control

Duplicate water samples were collected from random depths from each of the five lakes during each sampling visit. Field blanks (i.e., sample bottles filled in the field with laboratory-provided distilled water), and trip blanks (sample bottles filled in the laboratory with laboratory-provided distilled water) were also analyzed for the variables listed above. Field blanks provide a measure of potential contamination from field procedures, whereas trip blanks provide a measure of contamination from laboratory procedures.

2.4 In-Situ Water Quality Variables

The following water quality variables were measured *in-situ* using a YSI Professional Plus electronic meter:

- Temperature;
- dissolved oxygen;
- pH; and,
- specific conductivity.

These variables were measured at 1 m intervals from the surface down to 1 m off the bottom (MOB) in Lake Heney, including the four watershed lakes.

Secchi disc depths were recorded for each lake as a measure of transparency.

2.5 Data Handling

2.5.1 Treatment of 'non-detect' Values

Laboratory results that were recorded by Maxxam as non-detect or less than the detection limits were recorded as half the detection limit (unless in graph format when they were recorded as the detection limit in order to improve clarity).

2.5.2 Duplicates

When a duplicate was taken of an original sample, the original value was used in subsequent analyses.

Duplicates were used to compute Relative Percent Difference (*RPD*), where:

$$RPD = \frac{|sample\ result - duplicate\ result|}{(sample\ result + duplicate\ result)/2} \times 100\%.$$

RPD values are typically considered acceptable if they fall between 0 and 20% (CCME, 2016).

2.6 Calculation of Mean Whole Lake Total Phosphorus

Mean whole lake total phosphorus concentration was estimated for each sampling period in 2018. Mean concentrations of whole lake total phosphorus (**C**av) for Lake Heney were calculated according to Carignan (2014), using the equation:

$$Cav = \frac{\sum_{0\,m}^{32\,m} CzVz}{Vtot}$$

where **C**z represents the interpolated concentration of each depth at 0.5 m intervals, **V**z is the volume of water in each 0.5 m interval, and **V**tot is the total volume of Lake Heney[1].

The mean whole lake total phosphorus was also calculated for the four watershed lakes using the same equation. Values of **C**z and **V**z were calculated for every 1 m for Lac à la Barbue and Lac Noir, and every 2 m for Lac Désormeaux and Lac Vert using the bathymetric data from Carignan presented in Golder (2016).

2.7 Calculation of Potential Habitat for Lake Trout

Lake Trout can survive temperatures of up to 23°C (Gibson and Fry 1954) but prefer (seek out) and optimally grow at temperatures of between about 8 and 12°C (Christie and Regier 1988). Lake Trout normally reside in the deeper, colder waters of deep lakes like Heney. Dissolved oxygen concentrations, however, generally need to be in excess of 6.5 mg/L in order to be suitable Lake Trout (Sellers et al., 1998; CCME 1999; Evans, 2007).

[1]These estimates assume that phosphorus taken at a certain depth will be consistent throughout the lake at that depth, which is seldom the case. To accurately measure the mean lake total phosphorus would be virtually impossible as measurements of phosphorus concentrations are required throughout the lake.

The worst-case conditions for Lake Trout are during late summer/early fall when the surface waters are warmest (confining suitable temperatures to deeper waters) and when anoxia in the deeper waters results in insufficient dissolved oxygen levels in shallower waters, leaving the fish nowhere to thrive. The lake would be considered unsuitable when preferred temperatures of 8 to 12°C have < 6.5 mg/L dissolved oxygen. Here, we determined the depths at which the waters of Lake Heney were 'suitable' during late summer, in terms of both water temperature and dissolved oxygen for the post-treatment period between 2008 and 2018.

3.0 RESULTS AND DISCUSSION

All of the 2018 water quality data are provided to the Heney Lake Foundation with this report in digital form.

3.1 QA/QC

Quality Assurance and Quality Control data are presented in Table 2 below. Trip blanks were 'clean' containing < 0.001 mg/L (i.e. < 1 µg/L) total phosphorus, while 2 of 3 field blanks were also 'clean', while the field blank from the November trip produced 0.0035 mg/L (3.5 µg/L) phosphorus. Field duplicates on average had an RPD of 17%, which is less than the recommended guideline of 20% (CCME, 2016). Laboratory duplicates produced an RPD of ~ 9%. The QA/QC data suggest an acceptable level of cleanliness, and precision.

QA/QC data were only obtained for total phosphorus because it is the critical analyte for this program.

Table 2 Quality Assurance / Quality Control data for total phosphorus, Lake Heney and associated tributary lakes, plus trip and field blanks, 2018

Sample Date	Sample	Units	DL	Total Phosphorus	Trip blank	Field blank	Field dupl.	Field dupl. RPD %	Lab. Dupl.	Lab dupl. RPD %
2018-05-15	Heney, 3m	mg/L	0.001	0.012					0.013	8
	Heney, 6m	mg/L	0.001	0.013			0.015	14		
	Desormeaux, mid	mg/L	0.001	0.029			0.026	11		
	Noir, bottom	mg/L	0.001	0.025			0.026	4		
	Trip blank	mg/L	0.001	<0.0010	<0.001					
	Field blank	mg/L	0.001	<0.0010		<0.001				
2018-09-06	Heney, 6m	mg/L	0.001	0.0032					0.0038	17
	Heney, 12m	mg/L	0.001	0.0048			0.0053	10		
	Desormeaux, mid	mg/L	0.001	0.016			0.0091	55		
	Vert, surface	mg/L	0.001	0.0025			0.0022	13		
	Trip blank	mg/L	0.001	<0.001	<0.001					
	Field blank	mg/L	0.001	<0.001		<0.001				
2018-11-20	Heney, 6m	mg/L	0.001	0.0093					0.0093	0
	Heney, 27m	mg/L	0.001	0.007			0.0092	27		
	Vert, surface	mg/L	0.001	0.008			0.0084	5		
	Trip blank	mg/L	0.001	<0.001	<0.001					
	Field Blank	mg/L	0.001	0.0035		0.0035				
Average					<0.001	0.0018	0.011	17	0.009	8.4

3.2 Water Quality Depth Profiles

Depth profiles for key water quality variables (temperature, dissolved oxygen, total phosphorus) are presented here.

3.2.1 Lake Heney

In Lake Heney, the spring and fall sample dates reasonably captured the spring and fall turnover periods, with water temperatures relatively consistent from surface to lake bottom. In the spring sample, surface water temperatures had increased above 4°C to about 7°C, such that the lake was beginning to stratify. The late September sample period shows the lake highly stratified with temperatures of about 23°C down to about 8 m, with the thermocline at between 8 and 12 m where water temperatures decreased to between 5 and 8°C. Phosphorus concentrations were relatively homogenous during the spring and fall turnover samples, ranging between about 10 and 15 µg/L in spring and between about 5 and 10 µg/L in fall. The late summer profiles indicate total phosphorus concentrations increasing with depth, upwards to almost 30 µg/L. An increase in phosphorus with depth during stratification (summer) is a classic observation for lakes that are modestly enriched. The increase with depth is caused by phosphorus being resuspended from the sediments during periods of anoxia (note that dissolved oxygen levels near the sediment water interface were near zero at that time).

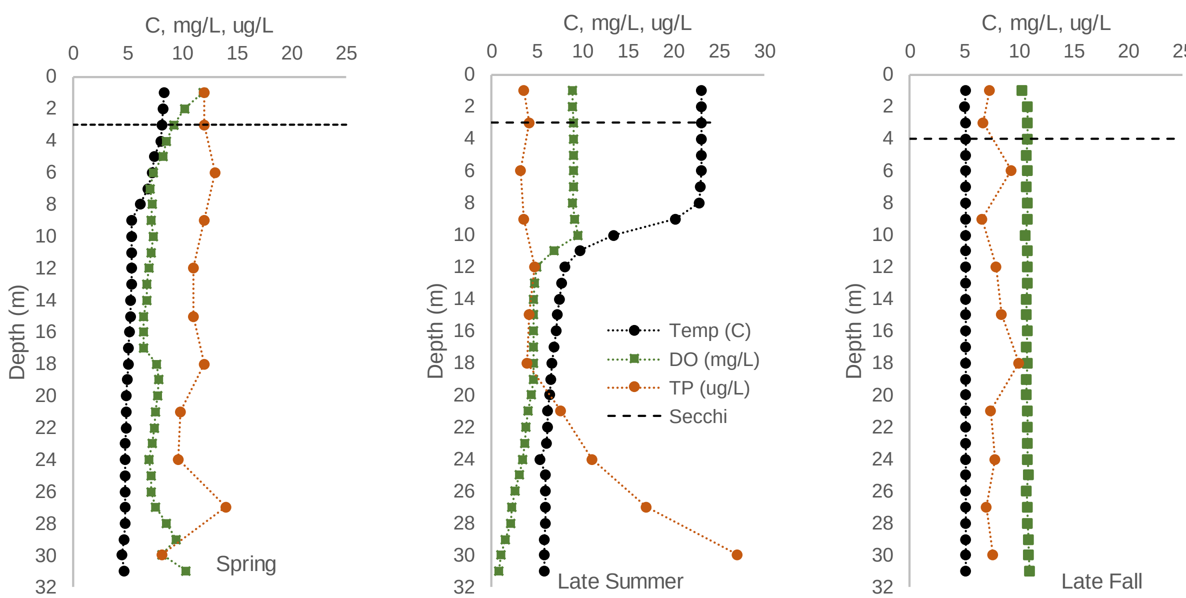


Figure 2 Depth profiles of water temperature, dissolved oxygen (DO), and total phosphorus (TP) in Lake Heney in spring, summer and fall of 2018

Figure Note: Secchi disc depth (in m) is also indicated.

3.2.2 Lac à la Barbue

In lac à la Barbue, the spring sampling program missed the spring turnover event, with surface water temperatures of >10°C. Lac à la Barbue is clearly a eutrophied lake, with dissolved oxygen levels in the deeper depths (10m) being nearly anoxic in the spring, and anoxic in the later summer. The anoxic conditions reflect relatively high total phosphorus concentrations in the spring (>20 µg/L).

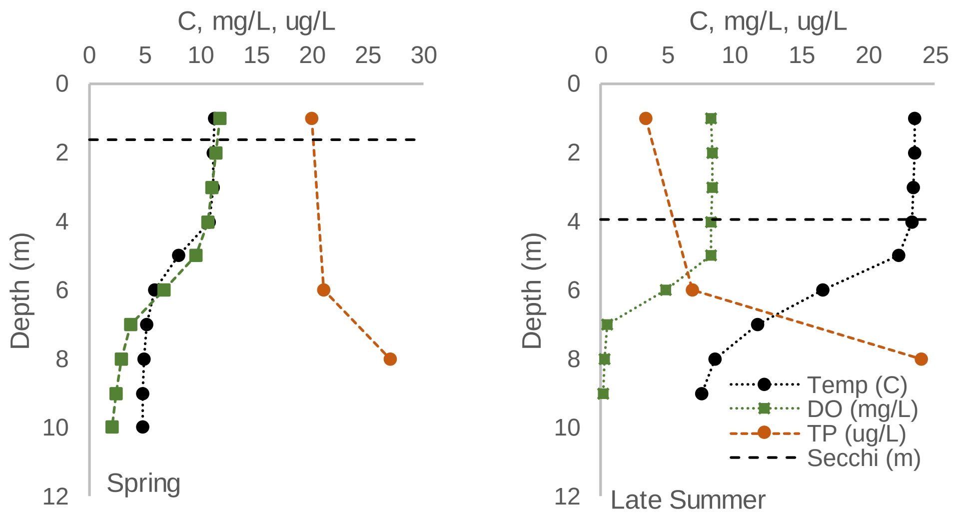


Figure 3 Depth profiles of water temperature, dissolved oxygen (DO), and total phosphorus (TP) in lac à la Barbue in spring and summer of 2018

Figure Note: Secchi disc depth (in m) is also indicated.

3.2.3 Lac Desormeaux

Spring turnover was also missed in lac Desormeaux, with surface water temperatures at the time of the May sample being > 10°C. Like lac à la Barbue, lac Desormeaux is eutrophic, with low concentrations of dissolved oxygen in the spring sample in deeper water (i.e., 10 to 14 m), and with anoxia during the late summer sample. Total phosphorus concentrations were > 25 µg/L in the spring, and up to 100 µg/L in the deepest sample in the late summer sample. That sample from 14 m may reflect that the sample was collected too close to the sediment-water interface, or potentially because of resuspension of sediments associated with deployment of sampling apparati.

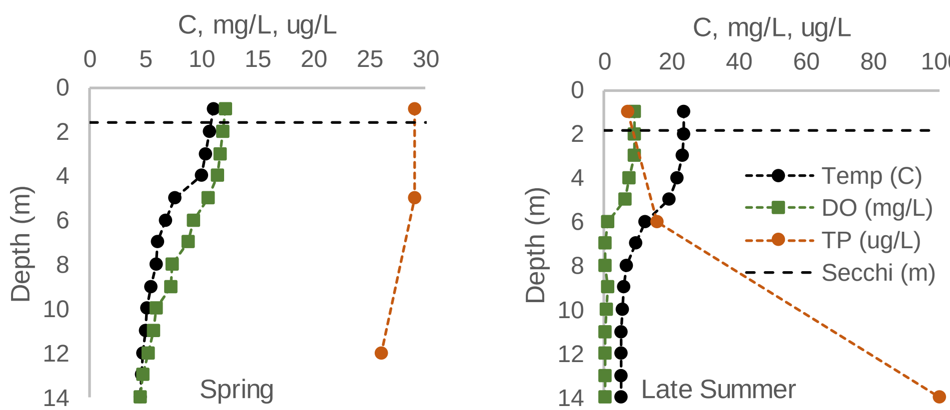


Figure 4 Depth profiles of water temperature, dissolved oxygen (DO), and total phosphorus (TP) in lac Desormeaux in spring and summer of 2018

Figure Note: Secchi disc depth (in m) is also indicated.

3.2.4 Lac Vert

Spring turnover was also missed in lac Vert, with surface water temperatures at the time of the May sample being > 10°C. Unlike lac à la Barbue, and Lac Desormeaux, lac Vert is not eutrophic, reflected by the deeper strata in this lake not going anoxic during summer. This lake is somewhat unusual with what is termed a 'hypolimnetic oxygen maximum' at 8 to 10 m depth. Note in the figure below that during the summer sampling period, the dissolved oxygen levels were higher at 8 to 10 m than in shallower or deeper water. It is unusual for that to happen in lakes. It is related to algae falling to the thermocline where they are highly active, converting CO_2 to biomass, with oxygen as a by-product. Concentrations of total phosphorus in this lake were higher with increasing depth in all three sampling periods, reflecting resuspension of phosphorus from sediments near the anoxic sediment-water interface. The observation of 100 µg/L at 12 m in the fall sample is probably erroneous and likely reflecting that the sample contained sediment (similar to the fall sample from lac Desormeaux.

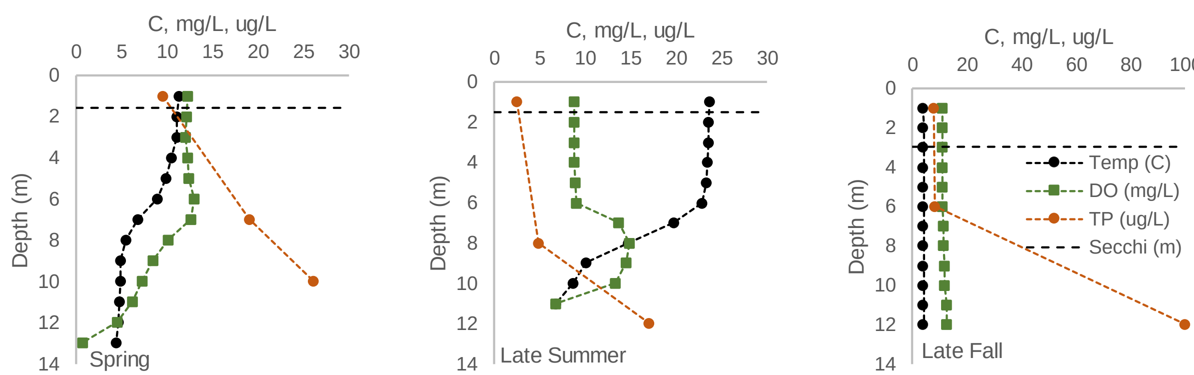


Figure 5 Depth profiles of water temperature, dissolved oxygen (DO), and total phosphorus (TP) in lac Vert in spring, summer and fall of 2018

Figure Note: Secchi disc depth (in m) is also indicated.

3.2.5 Lac Noir

Spring turnover was missed in lac Noir, with surface temperatures > 10°C. This lake experiences near anoxia in deeper strata (6 to 7 m) during the late summer sampling period, reflecting a eutrophic nature. Concentrations of total phosphorus also increased with depth, reflecting resuspension of phosphorus from sediments related to anoxia at the sediment – water interface.

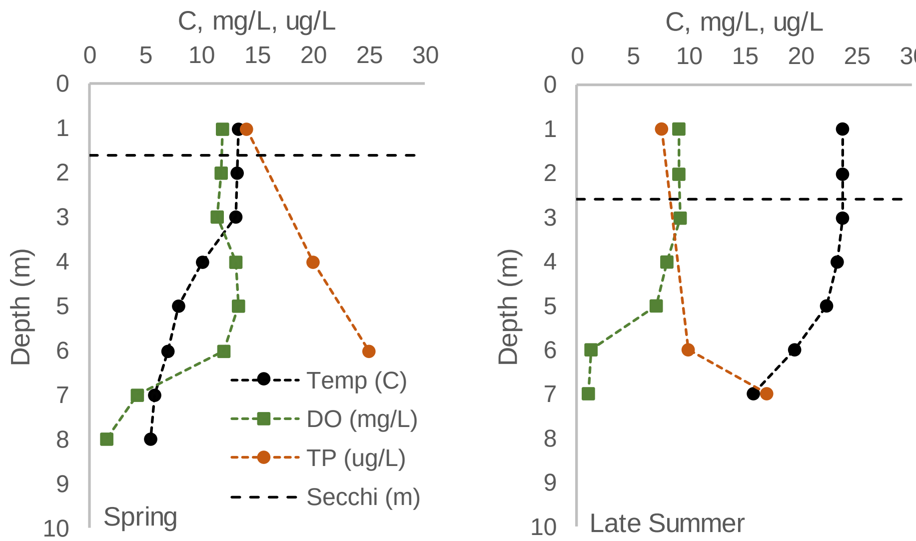


Figure 6 Depth profiles of water temperature, dissolved oxygen (DO), and total phosphorus (TP) in lac Noir spring and summer of 2018

Figure Note: Secchi disc depth (in m) is also indicated.

3.3 Potential Habitat for Sensitive Cold-Water Fish Species

The figure below illustrates variations in dissolved oxygen and temperatures in Lake Heney from 2008 to 2018. The graph is intended to illustrate whether the quality of Lake Heney is limiting to Lake Trout. The grey shading in the figure illustrates the depths and times when dissolved oxygen levels are < 6.5 mg/L, or unsuitable for Lake Trout. There are times each year when the deeper (>12 m or so) hypolimnetic waters of the lake are unsuitable. Oxygen depression in the deeper waters of Lake Heney are well documented and are suspected as being a stress on Lake Trout and may have contributed to the losses of Deepwater Sculpin (*Myoxecephalus thompsonii*) from Lake Heney (Deepwater Sculpin is a species that is listed as Special Concern under the Federal Species at Risk Act, *SARA*).

The red shading indicates depths and times when temperatures would be lethal to Lake Trout, that is temperatures that exceed about 24°C. There have only been four documented occurrences of surficial waters having temperatures in excess of 24°C. High surface water temperatures are not uncommon nor unexpected; and Lake Trout normally do not swim near the surface of lakes during the peak of summer anyways. Blue shading indicates depths and times when the water was cooler than the optimum for Lake Trout (<8°C), while green shading indicates depths and times at which temperatures were optimal (i.e., 8 to 12°C), and yellow shading indicates depths and times when temperatures exceeded the optima.

There were more observations of temperatures and oxygen levels made across the summer period in 2008 through 2014, and fewer made from 2015 through 2018 (simply a part of an effort to reduce costs of the monitoring program). There was only one observation in fall of 2018 that was targeted to identify the worst-case condition (i.e., the late fall sampling period). In all years, except perhaps for 2015 (when there was no late summer / early fall observation), there has been at least a brief period when the whole lake is technically unsuitable habitat for Lake Trout either because depth strata had oxygen levels that were too low (in deeper water), or depth strata had water temperatures that exceeded the thermal optima for the species (i.e., shallower water). The duration of these less suitable periods in Lake Heney have not been fully documented, but from review of the available data from earlier years (i.e., 2008 through 2014), it would appear that these less suitable periods occur from about September through to October, but generally for a brief time, perhaps of a few weeks in duration. It is unclear if that duration of time is sufficient to cause loss of a species like Lake Trout. During periods like that, juvenile Lake Trout would be at greater risk of being predated; that is they would be 'forced' from the deeper oxygen depleted waters into shallower waters where they would be more visible, with potential for being predated on by Northern Pike

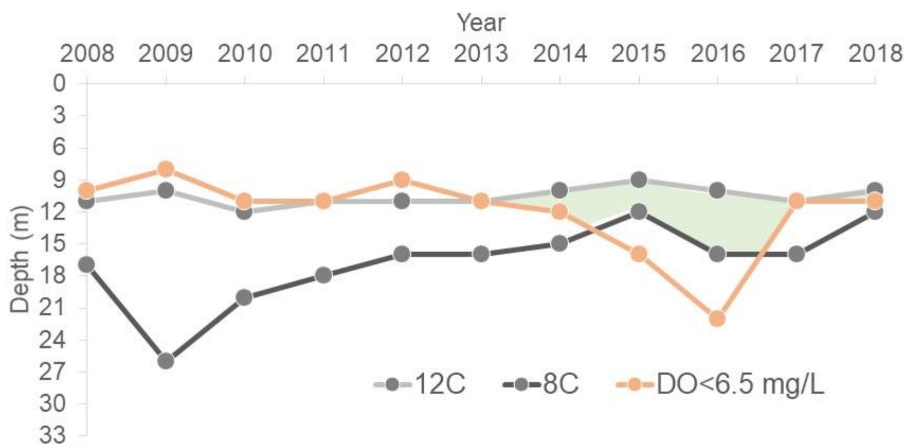


Figure 7 Depths of temperature and dissolved oxygen requirements of Lake Trout

Green shading indicates times and depths that were highly suitable for Lake Trout given temperature and dissolved oxygen.

3.4 Whole Lake Average Phosphorus Concentrations

Figure 8 and Figure 9 illustrate variations over time in whole lake total phosphorus concentrations. Figure 8 Figure 8 shows all sample dates, regardless of seasonality; whereas Figure 9 shows fall (top) and spring (bottom) data. Figure 8 illustrates variations in whole lake average concentrations in Lake Heney relative to surficial concentrations in the watershed lakes. Surface waters in the watershed lakes will be conveyed downstream to Heney. It is therefore the surficial concentrations in the watershed lakes that are relevant to Heney. Whole lake concentrations for the watershed lakes are provided in digital files (Appendix A).

Figure 9 may be more interesting for looking at trends over time in whole lake concentrations because the spring and fall periods should approximate the spring and fall turnover events, which as discussed above are the conventional periods for estimating whole lake concentrations. The spring and fall data indicate, like the whole-lake averages, that concentrations of phosphorus in Lake Heney have decreased in the last few years.

Somewhat regardless of which graphs are used, the data reflect a considerable reduction in whole lake total phosphorus concentrations after treatment in November 2007, while there are indications that concentrations have decreased since 2014. Whole lake concentrations of total phosphorus have been less than the “target” level of 15 µg/L since 2015. Fall 2018 data in particular was the lowest on record with a concentration of 8.0 µg/L. The 2018 spring turnover lake average was 11.7 µg/L. Both spring and fall values were therefore below the recovery target.

There are no data however to suggest what the baseline concentration of phosphorus was historically for Lake Heney. A modeling exercise by Kilgour & Associates Ltd. (2019) using Ontario’s Lakeshore Capacity Model suggests that the historical baseline was potentially ~ 5 µg/L, while the long-term forecast considering shoreline development may be ~ 7 µg/L. Concentrations in Lake Heney can therefore be expected to continue to decline from the current levels. The lake has a flushing rate of about seven years. Flushing in lakes is generally imperfect when lakes are stratified, and it can therefore take longer than the flushing rate to reach a new equilibrium. The chemistry of Lake Heney therefore appears to be on a reasonable trajectory to an anticipated equilibrium of potentially ~ 7 µg/L.

One of the concerns that has been regularly raised by Foundation committee members is for the potential for changes in analytical laboratories to have caused the change (reduction) in total whole-lake phosphorus levels. The Foundation began using consultants (Golder) in spring 2014 and changed consultants to Kilgour & Associates in 2016. Both Golder and Kilgour used a commercial analytical laboratory (Maxxam) for the analysis of water samples (see Figures 8 and 9). In addition to the QA/QC data that are reported above, Maxxam also conducts routine calibration and recovery checks. The original data sheets provided by Maxxam to Kilgour for 2018 are provided in digital form for review by committee members. The data provided by Maxxam for 2016 through 2018 can be considered to be of high quality. There is no way for Kilgour & Associates at this time to verify the veracity of the measurements by the various universities that have been previously involved, however it can be expected that the methods used by the universities would also have involved (minimally) the use of calibrations. There should be reasonable comfort in concluding that whole lake phosphorus concentrations in Lake Heney have declined since the treatment in 2007, and secondarily since about 2014. The monitoring data minimally do not indicate that concentrations are increasing.

Kilgour & Associates (2019) has completed a full year (July 2018 to June 2019) inventory of phosphorus in tributaries in support of a mass-balance exercise to quantify inputs and exports of phosphorus into and out of Lake Heney. That mass balance exercise has been designed to quantify the phosphorus load to Lake Heney, relative to historical estimates. The loading estimates support and validate modeling of the long-term prospectus for the quality of water in Lake Heney.

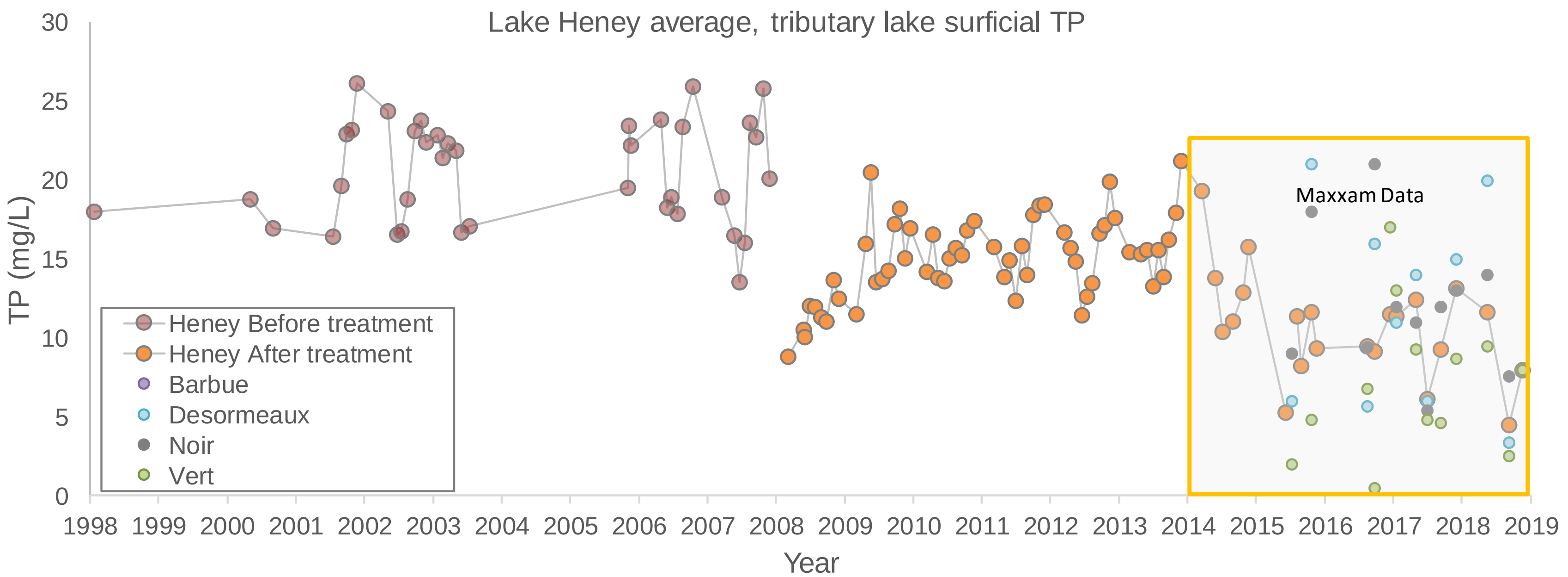
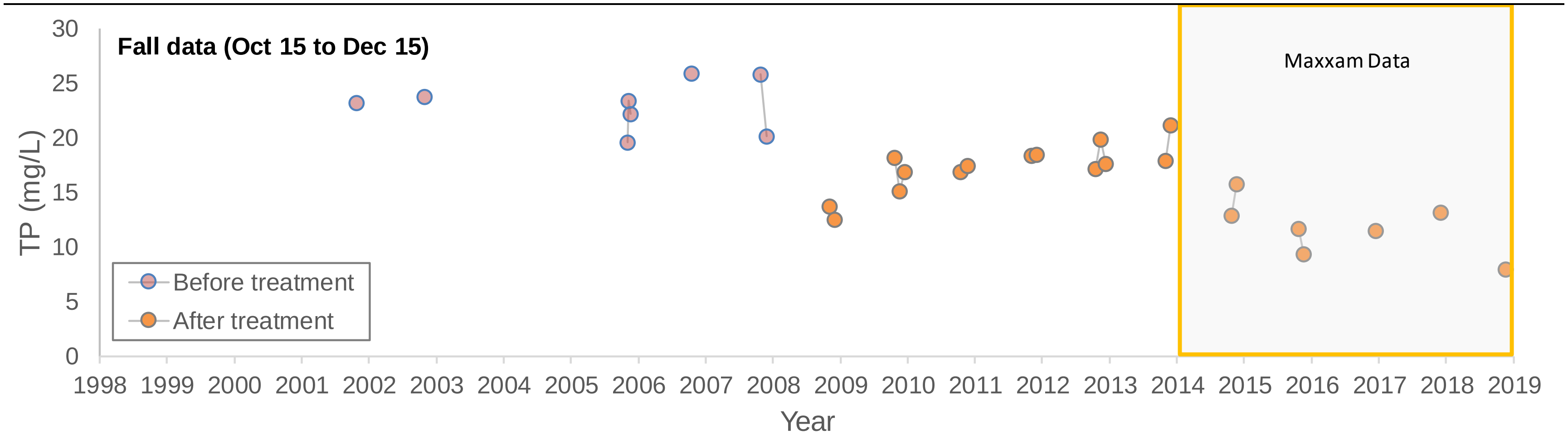


Figure 8 Variations in mean whole lake total phosphorus concentrations in Lake Heney and surface water total phosphorus concentrations in the tributary lakes, 1998 to 2018



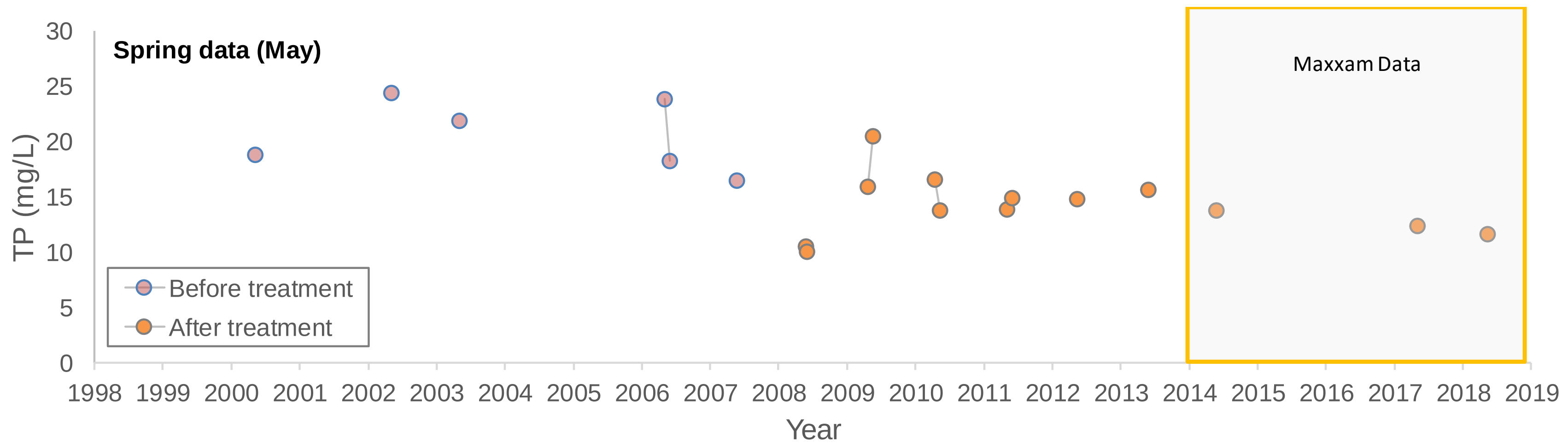


Figure 9 Variations in whole lake total phosphorus concentrations considering only fall data (top graph) or spring data (bottom graph), for Lake Heney from 1998 to 2018

4.0 RECOMMENDATIONS

The monitoring data suggest that phosphorus levels in Lake Heney are stable and/or decreasing. Stable or improving conditions can be used to justify a reduction in monitoring. From 2016 to 2018, we have regularly identified ways of making the ongoing monitoring program streamlined and efficient. Below, we provide a basic monitoring program that will characterize the water quality of Lake Heney.

As in 2018, we recommend a sampling program for Lake Heney that includes the following:

- Sampling water during spring turnover, late summer, fall turnover;
- Collecting dissolved oxygen, and temperature at 1 m intervals;
- Collecting Total Phosphorus samples at 3 m intervals;
- Collecting total nitrogen at 2, 15 and 27 m in order to confirm that Lake Heney is phosphorus limited; and,
- Collecting Secchi disc depth measurements.

Sampling of phosphorus in Lake Heney has focused on the lake mid point. Monitoring of total phosphorus in inland lakes frequently relies on samples from the mid point of the lake under the assumption (and general observation) that horizontal mixing process are rapid and efficient such that the mid point of the lake provides a good representation of the lake average. There can be, however, instances when a lake is not well mixed horizontally such that there may be concentration gradients from the lake middle to shallower bays (e.g., MacIntyre and Melack, 1995). This is a concern that has been raised by the Heney Lake Foundation. So use of the lake middle as a sampling point is conventional, but should be confirmed as being representative. In part to address this, sampling is proposed to be extended to Baie des Morts and to the bay that received the tributary flows from Lac Noir.

The Heney Lake ownership is encouraged to collect Secchi disc depth and dissolved oxygen data through the summer as well as spatially through the lake. Additional dissolved oxygen data could greatly improve the characterization of lake area that is suitable for Lake Trout.

5.0 CLOSURE

This report was prepared for exclusive use by the Heney Lake Foundation and may be distributed only by the Foundation. Questions relating to the data and interpretation can be addressed to the undersigned.

Respectfully submitted,

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Appendix A Raw Data

Raw data from 2018 are provided as an attachment in digital form