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OUTAOUAIS

SYNTHESIS OF STUDIES PERFORMED ON LAKE HENEY, MUNICIPALITIES OF LAC-STE-MARIE AND GRACEFIELD

PRESENTED TO
LA FONDATION DU LAC HENEY

PREPARED FOR :
LA FONDATION DU LAC HENEY

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Lake Heney is located within the Regional Municipality of Gatineau. This lake overlaps the municipalities of Gracefield to the north and Lac Ste-Marie to the south. It extends over two Townships, those of Northfield and Lac Ste-Marie. It is situated between longitudes 75° 57' and 75 ° 54' and latitudes 45 ° 59' and 46 ° 40'.
Lake Heney is primarily a residential and recreational area. More than 300 shoreline owners currently live around Lake Heney. Monfortian Fathers who built a recreational area in the sector also reside along its shores, as well as the Brothers of the Sacred Heart. A few commercial activities take place around the lake, including five (5) outfitters and a sawmill which is now closed.

The recent exploitation of a commercial fish farm, from 1994 to 1999, seems to have contributed to the significant increase of the phosphorus (P) load in Lake Heney's waters. Since the fish farm's closure, the average total P concentration has remained near 25 µg/L and the lake has not shown signs of recovery up until 2004. Nonetheless, the latest available information seems to indicate a possible recovery, with an average P concentration of 19.3 µg/L for the summer of 2005 (Prairie, 2005b). It appears that the phosphorus associated with organic matter, which breaks up at the bottom of the lake, is not retained by sediments, but instead suspended in the water column. Lake Heney's low sediment retention properties, as far as phosphorus is concerned, indicate a reactive iron deficiency. Such a deficiency could have natural causes, such as a low geochemical iron concentration found naturally in the lake's rocks and surficial materials of the watershed (Carignan and Langlais, 2002) or even the presence of important headwater lakes acting as traps for the iron that is exported from the watershed (Carignan, 2003).

Lake Heney was naturally low in iron and the additional phosphorus content created by the fish farm's activities seems to have worsened the situation. In addition, preliminary tests performed on the lake's water, sampled in the fall of 2004, have shown that the addition of approximately 1.3 mg/L of reactive iron caused a significant drop in phosphorus levels. These results suggest that the addition of approximately 230 tons of reactive iron to the entire lake would restore it to its **oligotrophic** state. Such an intervention should take place rapidly during the fall turnover, while the majority of phosphorus is present in the form of PO_4 (phosphate ion) within the main basin, such a few weeks prior to ice formation, when the surface temperature reaches approximately 6 °C.

In order to ensure the effectiveness of the treatment, the application of an iron compound in the lake should also be done in the most homogeneous way possible. While other compounds could be considered, such as **aluminum sulfates**, the use of neoformed ferric oxyhydroxyde (added in the form of $FeCl_3$ or $FeCl_2$) would have the advantage of countering the lake's iron deficiency, while presenting no demonstrated risk of toxicity.

1

1 INTRODUCTION

La Fondation du Lac Heney has mandated Fondex Outaouais to produce a synthesis of previous studies performed on Lake Heney to this day, including a description of the foreseen rehabilitation work.

This synthesis is not a meant as a popularization media, but simply relates to Lake Heney's water quality problem as well as to studies performed to this day, in order to understand this problematic issue.

Summarized index cards of all carried out studies are presented in appendix 2. The investigations and their outcomes are presented in chronological sequence in order to have a better understanding of the factors impacting Lake Heney's water quality deterioration, as well as to establish the best treatment for its restoration.

To help the unfamiliar reader with certain scientific terms in limnology, a glossary is available in chapter five (5). A simplified explanation of the action of elements such as phosphorus and iron in a lake, as well as of the importance of the sediments in the chemical reactions of a lake is presented in appendix 1.

1.1 Lake Heney

Lake Heney is located within the Regional Municipality of Gatineau. This lake overlaps the municipalities of Gracefield to the north and Lac Ste-Marie to the south. It extends over two Townships, those of Northfield and Lac Ste-Marie. It is located between longitudes 75° 57' and 75 ° 54' and latitudes 45 ° 59' and 46 ° 40'. Lake Heney is primarily a residential and recreational area.

More than 300 shoreline owners currently live around Lake Heney. Monfortian Fathers who built a recreational area in the sector also reside along its shores. A few commercial activities take place around the lake, including five (5) outfitters and a sawmill, which is now closed.

Lake Heney has an altitude of 144 meters. This lake covers a total surface of 12,32 km2 and has a water volume of 172 300 000 m3. Its water residence time is 6.4 years. Its average depth is 14 meters while its maximum depth is 32.5 meters. The lake's 64,8 km^2 watershed is 95% covered, by a forest mainly comprised of leafy species. The forest has experienced some tree-cutting varying from 30 to 90 years ago (Carignan, 2002). The lake also includes 0,576 km^2 of wetlands.

Aside from Lake Heney, the watershed is comprised of lakes Vert, Noir, Long, Désormeaux, Ruglis, à la Barbue, du Chat sauvage and des Perdrix, whose surfaces add up to 5,4 km^2 (Carignan, 2003). These surrounding lakes do not possess properties that would make it possible to formulate comparisons with Lake Heney which is long and narrow, with a north-south orientation, like most lakes of glacial origin. The lake is protected relatively well form western winds. It is rather large and deep (30-33 m maximum), with only one trough.

1.2 The problematic issue

The recent exploitation of a commercial fish farm, from 1994 to 1999, seems to have contributed to the significant increase of the phosphorus (P) load in Lake Heney's waters. Since the fish farm's closure, the average total P concentration has remained near 25 µg/L and the lake did not show signs of recovery until 2005. It appears that the phosphorus associated with organic matter, which breaks up at the bottom of the lake, is not retained by sediments, but instead suspended in the water column. The release of phosphorus by sediments, which occurs primarily in the presence of oxygen, is attributed to low iron content in the sediments. Lake Heney's iron deficiency could have natural causes, which may have been aggravated by fish farm operations.

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2 SYNTHESIS OF STUDIES CARRIED OUT BETWEEN 1995 AND 2005

2.1 Follow up on Lake Heney's water quality

The first data concerning the water quality in Lake Heney were analyzed in 1995 by Bird and Mesnage (1996). They then find an average P concentration of 21 µg in the entire water column. I-1.

Such a phosphorus concentration indentifies the lake between an **oligotrophic** state and a clearly **eutrophic** state. The state of this lake is thus called "**mesotrophic**". In other words, this is a continuum where Lake Heney has lost its **oligotrophic** properties, without having yet reached a **eutrophic** threshold, according to the OECD's Eutrophication Program 1980. (see table below).

Table I. Classification of trophic state and three water fertility measurements: results from the study of approximately 100 lakes worldwide (OECD's Eutrophication Program 1980): Averages and fiducial limits, which include two thirds of the lakes in this class (in brackets).

Trophic classification	Total Phosphorus $\mu g. l^{-1}$	Chlorophylle $\mu g. l^{-1}$	Transparency m
Oligotrophic	8 (5 to 13)	1.7 (0.8 to 3.4)	9.9 (5 to 16.5)
Mesotrophic	27 (8 to 91)	4.7 (3 to 7.4)	4.2 (2.4 to 7.4)
Eutrophic	84.4 (17 to 424)	14.3 (6.7 to 31)	2.5 (1.5 to 4)

(Bird and Mesnage, 1996)

According to Bird and Mesnage (1996), the annual P output in 1995 was 1 143 kg, 450 kg of which came from the fish farm's discharges, 195 kg from the surrounding septic systems discharges, 312 kg from tributaries and 186 kg which can be attributed to an atmospheric contribution. Of all these sources, 231 kg of P exits the lake annually, through its only outlet. According to this assessment, 912 kg of P is added to the lake each year. The hydrous assessment suggests that the « water renewal time » for this lake is 7 years (Bird and Mesnage, 1996).

P increases in the **hypolimnion** from 27 $\mu g. l^{-1}$ in June, to 85 $\mu g. l^{-1}$ in July and then to 122 $\mu g. l^{-1}$ in September. This increase in phosphorus in the hypolimnion, is explained, according to Bird and Mesnage (1996), by a great concentration of phosphorus in sediments. P concentration in lake waters is 20 $\mu g. l^{-1}$ while it can reach levels as high as 2 500 $\mu g. l^{-1}$ in sediments.

In 1995, the scientific community believed that the phosphorus concentration in Lake Heney was controlled by; 1) the external charge; 2) the internal charge and 3) the lakes P retention (according to the sedimentation rate, water renewal time and chemical state of sediments) (Bird and Mesnage, 1996).

Two years later, results form May 7th 1997 demonstrated that the water column was thouroughly mixed with a homogenous total phosphorus concentration of 23 µg/l. Following the spring turnover and subsequent to the establishment of thermal stratification, P content is reduced 10 µg/l in the epilimnion. However, a P peak up to 30 µg/l is noticed in the **thermocline** (Prairie, 1998).

This noticeable difference in profiles and concentrations indicates a rapid P sedimentation in the period following the spring turnover. P in the epilimnion accumulates mainly at the thermocline level, while hypolimnion P is deposited at the bottom. (Prairie, 1998).

During the summer of 1998, Carignan analysed the average total P concentration, which had risen to 18,3 µg/l. Such a concentration is considered abnormally elevated compared to those observed in other southwestern Quebec lakes located within the Canadian Shield.

Furthermore, the average phosphorus content in Lake Heney for 2001 was 20,6 µg/l, an increase in comparison with 2000, when its content averaged approximately 18 µg/l (Prairie, 2001).

In order to get a better understanding of the oxygen cycle in the lake, following the establishment of thermal stratification, Prairie (2001) analysed the oxygen which is diluted in the hypolimnion. In early May, deeper layers were isolated from the rest of the lake and diluted oxygen levels began to lessen, following the decomposition of the organic matter which consumes oxygen. On average, 66 µg/l of diluted oxygen is lost daily. By the end of the summer, the entire hypolimnion is considered as anoxic. This situation is similar to that of previous years and shows no sign of improvement.

During the summer of 2004, Lake Heney showed no sign of recuperation. In fact, it continued to deteriorate, in comparison with previous years. The total P concentration increased slightly to 23 μg/l while the hypolimnetic oxygen consumption level was relatively high (105 μg. l^{-1} d^{-1}) (Prairie, 2005).

2.1.1 The phosphorus cycle and sediments

According to Carignan's study (2002), the seasonal evolution of P masses present in the lake demonstrates a massive P loss (1 300 kg) in the superior portion of the lake between the months of May and June. According to this author, such a loss can only be a result of accelerated diatoms algae sedimentation and/or of the absorption of P on calcite micro crystals (originating from rocks containing calcium carbonate) that form and precipitate in early summer. Also, the observed gain in the superior portion of the lake can only be attributed to tributary inflow.

Carignan's study results (2002) show that part of the augmentation in P concentration that began in August is due to a release of shallow sediments, whose surface is constantly exposed to an oxygen concentration that's superior to 3,5 mg/l.

Moreover, an important P release (approximately 1000 kg) by deeper sediments during the summer (from the end of June) was noticed. Results show that approximately 95% of P is released in a dissolved form, probably as orthophosphate (Carignan, 2002).

Thorough examination of the oxygen and pH profiles measured on the same dates indicates that this release begins once oxygen concentrations in the water column are situated between 2 to 4 mg/l, and ends once these concentrations drop below 1 or 2 mg/l (Carignan, 2002).

Contrary to what had been previously stated (that P release by sediments only happens in anoxic conditions), the release of P by hypolimnetic sediments occurs mostly in the presence of oxygen. Furthermore, hypolimnetic anoxia only occurs in the summer and is most probably a result of springtime algae decomposition. In the summer as well as during winter, TP (total phosphorus) release by sediments begins long before the onset of anoxic conditions.

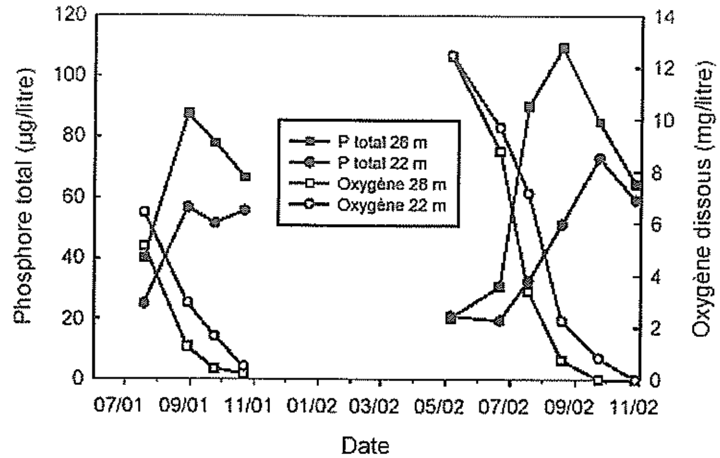

Figure 1. Evolution of diluted oxygen and total phosphorus concentrations at fixed depths of 22 and 28 metres, in Lake Heney, in 2001 and 2002. Note that P concentration augmentation rates reach maximum values when oxygen concentrations are between 8 and 2 ppm. Carignan, 2003.

This figure also shows that the TP concentration starts to lessen once the oxygen concentration drops below 2 mg/l. (Carignan, 2003)

The vertical profile of P concentration during the summer of 2004 clearly indicates that thef P release from the sediments reaches more 100 µg/l, at least 5 times the average for the remainder of the water column. Furthermore, this release was already apparent in the third week of June; almost a full month before the deepest water layers becomes anoxic. This suggests that the process involved in P salting out is not directly linked to anoxia (Prairie, 2005).

The average phosphorus concentration in the water column was 19,3 µg/L during the summer of 2005. The data compiled in the figure presented below shows a continued increase since 1999, which is, ironically, when the fish farm ceased its activities. However, the data acquired in 2005 may be an indication of the end of these increases (Prairie, 2005b).

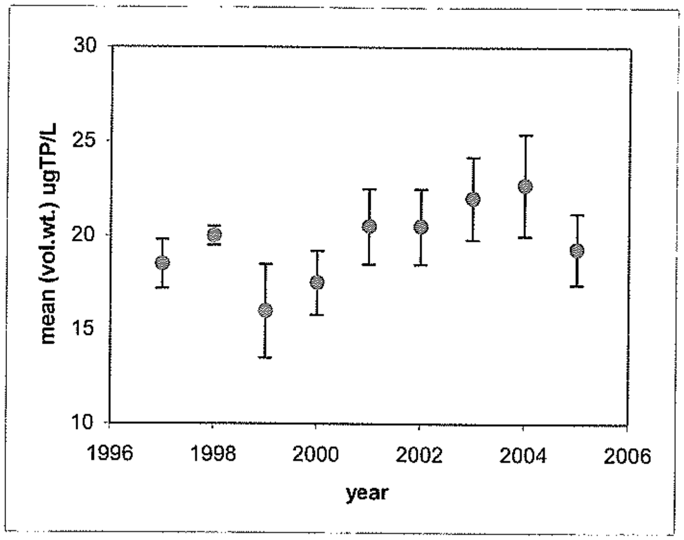

Figure 2 : Temporal template of average TP concentrations in the summertime since 1997

Furthermore, we noticed a seasonal cycle during which the P concentration is generally elevated, immediately after the spring turnover (22 µg/L), followed by a rapid descent and a gradual increase, past July's mid point. Such a cycle had previsouly been documented by Prairie (2001), Carignan (2003) and Prairie (2005b).

The phosphorus concentration's vertical profile, as show in the figure below, clearly indicates that P is released from sediments with a concentration as high as 60 µg/L, approximately three times the average concentration in the water column. This **salting out** was already obvious within the first week of June, more than a month before the deeper layers of the lake became anoxic (Prairie, 2005b).

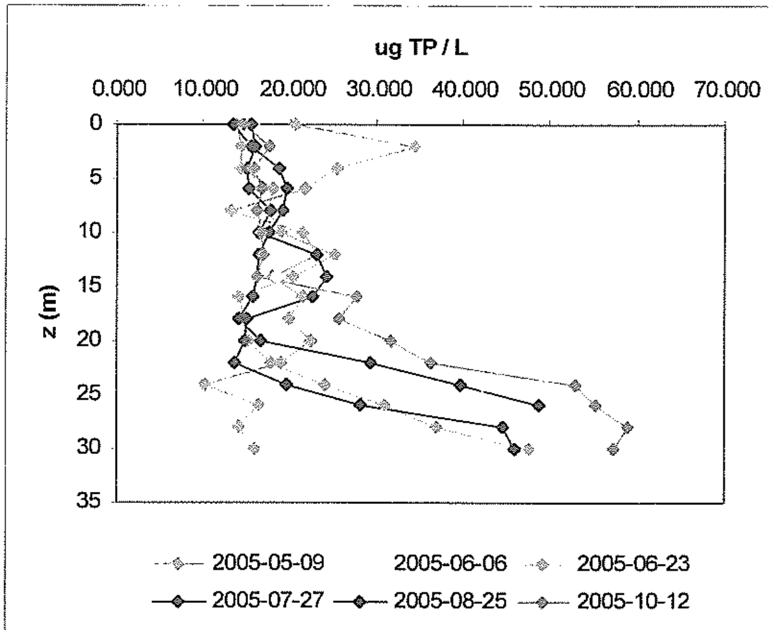

Figure 3 : Lake Heney's vertical profile during the summer of 2005

Between the months of May and October, the net phosphorus accumulation in the hypolimnion corresponds to a net average release of approximately 0,5 mg TP m^{-2} d^{-1} above the sediments surface. Assuming that this rate remains constant for about 5 months of thermal stratification, the total phosphorus released would add up to approximately 500 kg (Prairie, 2005b).

2.1.2 Iron's impacts

According to Carignan (2003), the evolution of the total P mass in Lake Heney since 1995 showed no clear cut tendencies between 1995 and 2003, except maybe for a slight decrease while the fish farm was in operation from 1995 to 1999, followed by a paradoxical increase after its closure. The absence of an increase in phosphorus concentration between 1995 and 1999, as well as the absence of an obvious decrease after 1999 suggests that a biological, geochemical or physical manipulation of the phosphorus mass (or concentration) occurred in this lake.

The lack of substantial amounts of iron in the hypolimnion towards the end of the stratification period signifies that no ferric hydroxide, capable of bringing P to the bottom of the lake thru sedimentation during and after the fall turnover, will be produced.
Such a deficiency could have natural causes, such as low geochemical iron abundance in rocks and surficial materials of the watershed (Carignan and Langlais, 2002) or even the presence of important headwater lakes acting as traps for the iron that is exported from the watershed (Carignan, 2003).

These considerations suggest that the addition of a substantial quantity of Fe (a few tens of tons), in order to precipitate phosphorus in the fall and then retain it on the sediments' surface could be envisaged as a partial solution to the excess P problem in Lake Heney (Carignan, 2003).

Iron plays an important role in numerous chemical reactions within lake waters. The average total iron concentration was 22 µg Fe/l, placing it amongst the lowest in Quebec's lakes. The initial concentration, just before the snowmelt, reaches 26 µg/l then drops to approximately 14 µg Fe/l within 2 weeks (Prairie, 2005).

As the summer progressed, the total iron concentration gradually increases in the hypolimnion. From May to October, this accumulation corresponds to an average release rate of approximately 2 mg Fe m^{-2} d^{-1}, which is an extremely low value in comparison with other lakes. For example, the average rate observed in 10 southern Quebec lakes was 75 mg Fe m^{-2} d^{-1} (Prairie, 2005b).

The slope of correlation representing the relationship between P and Fe suggests that for each gram of iron carried in solution, approximately 0,2 g of phosphorus is released. The generalized interpretation is that iron release is much too weak to justify the observed phosphorus release (Prairie, 2005b).

Moreover, the proper correlation representing the relationship between iron and phosphorus in the hypolimnion suggests a close link between P and Fe. This correlation can be regarded as proof that redox control releases the link between iron and phosphorus (Prairie, 2005b).

The following conclusions were suggested to Lake Heney's administrators;

- P release, from the lakes sediments, begins prior to the hypolimnetic anoxia;
- Iron concentration is low in comparison with comparable lakes;
- Iron is released from sediments, but not in a sufficient quantity to allow a concomitant phosphorus release (Prairie, 2005b).

2.2 Fish farm impacts

Two water quality indicators; transparency and dissolved oxygen levels clearly show that during the period from 1979 to 1987, Lake Heney was already subjected to certain issues pertaining to a surplus of phosphorus content. These indicators also show that Lake Heney's condition worsened after the fish farm began its operations (Carignan, 2002).

Between 1995 and 1999, while the fish farm was operating, quantities of P rejected as a result of those operations reached 600 to 700 kg/year. Nonetheless, the lake's condition does not appear to have worsened after 1995 and shows no obvious sign of recovering since the fish farm's closure in June of 1999 (Carignan, 2002).

Carignan (2003) has established the situation for Lake Heney and its watershed in relation with that of other comparable lakes in the area, as well as other lakes present in the watershed, in order to clarify past and present repercussions from the fish farm's operations. Furthermore, in 2002, Carignan and Langlais had characterized Lake Heney's watershed and its geology.

The main lakes present in Lake Heney's watershed, as well as Lake Saint-Laurent, which neighbours Lake Heney, show higher phosphorus concentrations than those measured in Lake Heney, from 20 to 50 µg/l in the spring and fall (Carignan, 2002). Aside from Lake Heney, the watershed is comprised of lakes Vert, Noir, Long, Désormeaux, Ruglis, à la Barbue and du Chat sauvage.

Their results suggest that within Lake Heney's watershed, the dissolution of carbonated rocks and marbles could represent an important natural source of P in underground and surface waters. Because of the elevated pH level in surface waters, as well as the surficial materials generated by these rocks, the Fe :P ratio (22 :4) does not encourage a substantial P retention by the iron oxides generated by the alteration of these rocks (Langlais et Carignan, 2002).

Four regional lakes comparable to Lake Heney, located within another watershed, display oligo-mesotrophic properties and P concentrations slightly higher than 10 µg/l in the spring, and close to 6 µg/l in the summertime. However, the six neighboring lakes, including a comparable lake (Lake Saint-Laurent), show P concentrations comparable to those of Lake Heney or higher, even though some of these lakes are not subjected to any important human disturbance.

The presence of these mesotrophic lakes in Lake Heney's immediate proximity, supports historical transparency and oxygen level data, establishing that Lake Heney already displayed mesotrophic properties prior to the fish farm's operations.

The methods explored by the authors in order to accurately evaluate Lake Heney 's situation prior to the fish farm's operations indicate that this lake was already in a mesotrophic state and that its average P concentration was probably not inferior to 15 µg/l. This value could serve as a lower limit within the framework of the lake's rehabilitation. Any action aimed at lowering the average concentration below 15 µg/l should be geared towards the significant external inflow in this lake.

2.3 Feasibility study in Petite baie des Prêtres Bay

In order to evaluate and study the ecological and chemical impacts of phosphorus precipitation through the addition of iron chloride to Lake Heney as a whole, Carignan (2005b) performed a feasibility study in Petite Baie des Prêtres Bay, north of Lake Heney.

With a surface covering 0,087 km^2, Petite Baie des Prêtres Bay drains a 0,83 km^2 watershed. Its average depth is 5,2 m and its water volume is 455 000 m^3. According to the average regional flow, the average water residence time of the bay waters is approximately 1,78 years. In November of 2004, submerged aquatic plants were abundant above the 2.5 m isobath, covering 35% of the bay's entire surface.

The Bay was closed in Novermber of 2004 and treated with the anticipated dosing of reactive iron, in order to determine, *in situ*; the chemical efficiency of the treatment, the sedimentation rate of neoformed ferric oxyhydroxyde as well as to estimate the biological repercussions of applying a reactive iron treatment to Lake Heney.

A tarp was set at the entrance of Petite Baie des Prêtres Bay on November 15th 2004 and lowered to the bottom of the lake on November 22nd 2004.

Approximately 5 000 kg of ferric chloride solution was distributed throughout Petite Baie des Prêtres Bay on November 22nd and 23rd 2004, using a 21 foot boat, equipped with a 135 H.P engine, a tank and a 12 Volt DC Flojet diaphragm pump, model number 4300-142. To ensure immediate dispersion in the water, the solution was pumped directly in front of the engine's propeller, at a speed of about 5 km/h. The solution was applied in a homogenous manner to the entire Bay.
The figure below illustrates the evolution on the total Fe concentration (average calculated at 4 depths) before and after the addition of $FeCl_3$ in Petite Baie des Prêtres Bay. On November 2005, two days after the $FeCl_3$ treatment, only 30% of a total 1,3 g/m^3 (1 300 µg/L) of Fe remained in the water column.

However, there are limitations; it is rather improbable that $Fe(OH)_3$ sedimentation within the large turbulent basins of lake Heney would occur as quickly as it did in Petite Baie des Prêtres Bay.

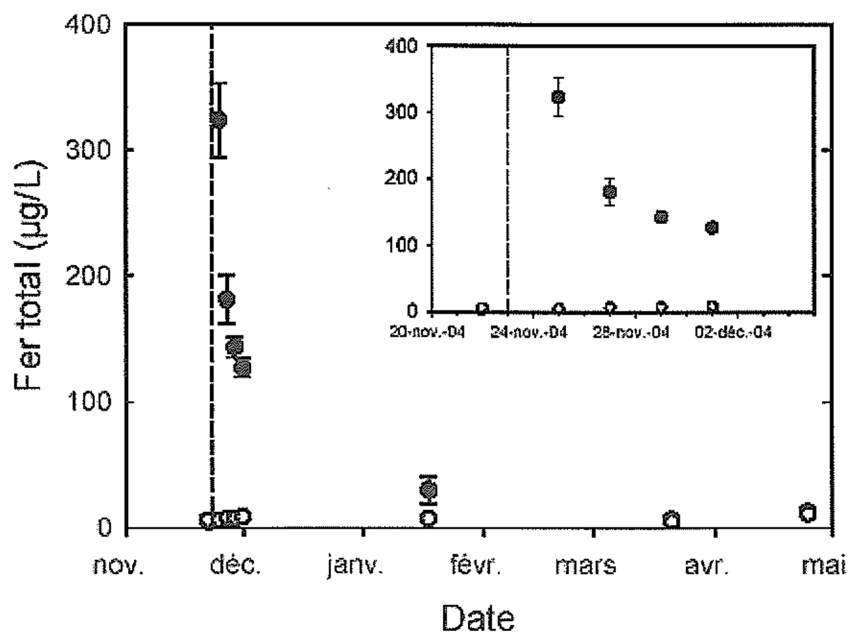

Figure 4. Evolution of the Fe concentration inside (white circles) and outside (black circles) of Petite Baie des Prêtres Bay. The dotted line indicates the date at which the $FeCl_3$ treatment was applied to the Bay. The frame shows in detail, the evolution of the concentrations in the few days following the application. Excerpt from R. Carignan, 2005b.

The addition of $FeCl_3$ to Petite Baie des Prêtres Bay was a success as shown by the significant decrease in total phosphorus levels (5 µg/L) and total dissolved phosphorus levels (10 µg/L), which occurred after the ice formation took place. However, the drop in P levels was independent from the Fe sedimentation, which occured much faster. The lag between the P decrease and that of Fe strongly suggests that P is only present in the form of PO_4-P reacts to $Fe(OH)_3$.

The results of this experiment show that the addition of 1,3 g/m^3 of Fe in the form of $FeCl_3$ to Lake Heney would not cause a dramatic drop in pH levels and would not significantly change the transparency of the water column in the short run.
Furthermore, the addition of 1,3 g/m^3 of Fe in the form of $FeCl_3$ to Petite Baie des Prêtres Bay has engendered a significant 60% decrease in plankton chlorophyll in April of 2005 and was not significantly toxic to benthos and fish.

2.4 The treatment to Lake Heney

These results show that artificial hypolimnion oxygenation; carried out in order to reduce the release of P by the sediments is ineffective, as the latter occurs mostly in the presence of oxygen (between 2 and 8 mg/l) (Carignan, 2003).

The springtime data suggests that the assimilation of DP (dissolved phosphorus) by the algae could begin before the ice melts. Consequently, measures taken in order to isolate P using chemical additives such as alum, $Fecl_2$ or FeOOH will be most efficient during the fall turnover, two or three weeks prior to ice formation, when the surface temperature reaches approximately 6°C (Carignan, 2003).

Carignan (2003) suggests the following solutions;

- Draining of certain wetlands;
- Reduction of P originating from dwellings;
- Reduction of the inflow from pastures and forage land;
- Reduction of the inflow originating form the sawmill;

Furthermore:

- The addition of approximately 72 tons of reactive iron should, in theory, be sufficient to stabilize the desired P quantity. Therefore, about 200 tons of a commercial iron solution would be required to treat the whole lake.

Judging by the experiment conducted in Petite Baie des Prêtres Bay, $Fe(OH)_3$ only reacts to P's free form (PO_4-P). These results have an important impact on any foreseen $FeCl_3$ treatment of the lake. Firstly, it would be useless to start treatment prior to the beginning of the autumnal P mineralization in the water column. Secondly, we can only hope for the removal of about 10-12 µg/L of P (approximately 40% of TP) from the lake's waters, as this represents the maximum quantity of PO_4-P formed in the lake during the fall and therefore react to $Fe(OH)_3$ (Carignan, 2005b).

In conclusion, $Fe(OH)_3$ only appears to have an impact on algae during the following spring, by limiting the amount of PO_4-P available. Moreover, treating the entire lake should eventually cause a decrease in littoral benthos populations and an increase in deeper species, which should no longer be subjected to seasonal anoxia.

During the treatment and modification of trophic levels within Petite Baie des prêtres Bay, no dead specimens were encountered.

3

3 PROPOSED TREATMENT OPTIONS

Carignan (2005c) estimated the feasibility of such a $FeCl_2$ or $FeCl_3$ addition to the entire lake, by submitting an Fe addition plan, designed to maximize its efficiency, while minimizing costs and the number of treatment locations.

The injection of $FeCl_n$ from fixed points has numerous important disadvantages, namely the elevated cost of required infrastructures. $FeCl_n$ will have to be delivered to injection sites using 40-ton tanker trucks. Therefore, it will be necessary that each site possesses a loading platform for these trucks as well as foresee the installation of six 40-ton cisterns which are to be laid on concrete footings, in order to stock at least the equivalent of one $FeCl_n$ delivery. This will ensure the continuous distribution of the product.

The current $FeCl_n$ distribution system is conceptual and will require onsite testing and trials.

According to observed mixing speeds, it would be possible to add 2000 tons of iron solution, in a 20 day period, during the fall, from six (6) fixed points, without causing a notable acidification of the area. However, it is highly unlikely that a sufficient number of owners accept the installation of the infrastructures required for such a treatment for the lake.

Alternatively, according to the experiment carried out in Petite Baie des Prêtres Bay in 2004 (Carignan, 2005c), it would be possible to apply 2 000 tons of product to the entire lake by mobilizing about 20 « pontoon » type boats, at least 20 feet (6.1 m) in length, equipped with $1m^3$ tanks and serviced at Whitefish Outfitters, for approximately 20 days. With such a scenario, all boats and their crew would be gathered in one single location and serviced by a tanker truck.

Such a process requires:

- Localizing 20 pontoons, at least 20 feet in length, equipped with 20-60 H.P. engines and conveying them to Lake Heney;
- Mobilizing 20 pilots and 20 assistants who are willing to work for about 20 days in Lake Heney;
- Finding lodging and food accommodations for 45 people as well as storage space sufficient for 20 boats;
- Finally, before making a purchase for 20 $FeCl_n$, systems, the 2004 system should be tested onsite for at least 20 days, in order to avoid any mechanical complication during the lake's treatment.

The feasibility and cost of an application using 20 pontoon boats will have to be evaluated as soon as possible if treatment of the whole lake were to be considered for the fall of 2006.

4

4 CONCLUSION

A few important facts emerged from all of the studies concerning the evolution of Lake Heney's water quality, since 1995.

Lake Heney and a few of its neighbouring lakes were already in a mesotrophic state, showing phosphorus concentrations around 15 µg/l, prior to 1995, when the fish farms began its operations in Lake Heney.
The suggested hypothesis is that rocks within the watershed, combined with pH levels of nearby waters and neutrality all contribute to the phosphorus content in this lake.

The fish farm operations that took place from 1995 to 1999 did significantly increase the phosphorus inflow in the lake. Surprisingly, the lake shows few signs of recuperation since the fish farm's closure.

A significant portion of the phosphorus inflow originates in the sediments, which have a phosphorus concentration that is 5 to 20 times higher than that of water. The phosphorus release mechanism, as opposed to other large surface lakes, occurs when sediments are oxygenated, thus starting in June and lasting until mid July. Once all of the oxygen has been consumed in deeper layers, conditions become anoxic and sediments then release less phosphorus. Another important fact that emerged from these studies is that the average total iron concentration of 22 ug Fe/l in Lake Heney in 2004, was amongst the lowest in all of Québec's lakes (Prairie, 2005a). Iron is a very important element for the absorption and precipitation of phosphorus to the bottom of the lake. Following a successful experiment in a by located north of the lake, the authors of these studies suggest an inflow of 1,3 mg/l of reactive Fe in order to reduce the phosphorus levels in the lake, thus restoring it to the state it was in, prior to the fish farm's operations.

5

5 PERSONNEL

This synthesis was prepared by Mrs. Christine Galipeau, biologist with Fondex Outaouais and reviewed by Mr. Ghislain Ladouceur, biologist with Fondex Outaouais.

FONDEX Outaouais

pour

Christine Galipeau, biol.

Ghislain Ladouceur, biol.

CG/GL/cg/ac

6

6 GLOSSARY

To adsorb: To hold a mineral particle within a liquid interface

Advection: The process of transfer by horizontal motion in the atmosphere

Aluminum phosphate : $AlPO_4$

Anoxia: Condition of extremely weak oxygen availability, where certain microorganisms use forms of nitrogen, sulfur or carbon to ensure cellular breathing.

Bathymetry: Probe measurement of the depth of seas, lakes.

Benthic: Designates an aquatic bottom-dwelling.

Benthos: Sedentary, bottom-dwelling marine plant and animal organisms.

Biochemistry: The chemistry of living organisms and of the chemical, molecular, and physical changes occurring therein.

Biogeochemistry: Study of the chemical, physical, geological, and biological processes and reactions that govern the composition of the natural environment.

Calcite: CaCO3. Calcium carbonate. Lozenge shaped crystals. Generally white, it can also be colorless or of various colors such as grey, pink, blue or brown. White stripes. Vitreous and pearly appearance, mat when massive. Mostly translucent, sometimes transparent. Fragile. Hydrochloric Acid soluble.

Calcium carbonate: CaCO3. Is found in two crystal forms: aragonite and calcite. Basic component of chalk, limestone and marble. Constitutes the shell of many aquatic animals.

Carbonated rock: Sedimentary rock formed of at least 50 % carbonates (calcite, dolomite). Two main groups exist, limestones and intermediate dolomites.

Catalyst: An agent that provokes or speeds significant change or action.

Colloid: Very small sized (a few microns) particles that remain in suspension in water.

Coriolis force: An apparent force that as a result of the earth's rotation deflects moving objects (as projectiles or air currents) to the right in the northern hemisphere and to the left in the southern hemisphere. It is stronger at both poles yet inexistent in the equator area.

Dissolved phosphorus: $(H_2PO_4)^-$ et $(HPO_4)^{2-}$ quantity of Phosphorus in a solution

Dissolved oxygen: DO, quantity of oxygen, dissolved in water at a given temperature.

Ferric chloride: $FeCl_3$

Ferrous chloride: $FeCl_2$

Epilimnion: The water layer overlying the thermocline of a lake. Zone where gas exchanges between water and the atmosphere are possible.

Eutrophic: Lake where nutrients are numerous and productivity is very high.

Eutrophication: The process by which a body of water becomes enriched in dissolved nutrients (as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen

Fe(II): Ferrous chloride : $FeCl_2$

Fe(III): Ferric chloride : $FeCl_3$

Hypolimnetic oxygen demand (HOD): Is calculated by estimating the amount of oxygen consumed during the summer stratification, within the water volume comprised between the 12 meter isobath and maximum depth.

Hydrology: Science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere

Iron hydroxydes: Fe (OH) :

Iron phosphate: $FePO_4$

Hypolimnion: The part of a lake below the thermocline, made up of water that is stagnant and of essentially uniform temperature except during the period of overturn.

Littoral: Of, relating to, or situated or growing on or near a shore especially of the sea.

Marble: Metamorphic sedimentary rock (limestone and metamorphized dolomite) white, grey, pink or rusty brown in color. Grains are average to coarse sized, of a crystalline texture, with a massive or flaky structure. It is essentially composed of calcite and/or re crystallized dolomite and can contain a wide variety of minerals (graphite, phlogopite, diopside, etc.)

Mesotrophic: Lake within which the biomass fertility and productivity is moderate

Metalimnion: Intermediate layer of a thermal stratification lake. This layer is located between the epilimnion and hypolimnion and is characterized by the thermocline.

Morphometry: Geological study of sand grain sizes.

Oligotrophic : Body of water which is deficient in plant nutrients and has abundant dissolved oxygen .

Organophosphorus : Relating to, or being a phosphorus-containing organic compound and especially a pesticide that acts by inhibiting cholinesterase.

Orthophosphate: H_3PO_4. Also called phosphoric acid. Used as a food additive.

Outlet: Stream that evacuates waters from another water surface.

Oxydation : Chemical reaction through which an element is transformed, completely or not, into oxyde.

Oxyde : A binary compound of oxygen with a more electropositive element or group.

Iron oxyhydroxides: FeO (OH).

Pelagic: Relating to, or living or occurring in the open sea.

PH : A measure of acidity and alkalinity of a solution that is a number on a scale from 1 to 14, on which a value of 7 represents neutrality while lower numbers indicate increasing acidity and higher numbers increasing alkalinity.

Phytoplankton: Group of microscopic plant life organisms, living in suspension in the water (animal: zooplankton).

Reduction : Reaction during which a reductive body yields electrons to an oxidant body.

Salting out: The separation of serum or plasma protein fractions in the serum or plasma by precipitation in increasing concentrations of neutral salts.

Sediment Accumulation of detrital, chemical or organic deposit following the precipitation of the suspended matter or dissolved in water.

Seiche: An oscillation of the surface of a landlocked body of water (as a lake) that varies in period from a few minutes to several hours.

Suboxique: Situated between aerobic and anoxic states.

Subsidence: A slow descent of a mass of air, over a wide area, generally accompanied by horizontal divergence in the lower layers.

Thermal stratification: Water stratificatio, which occurs in mild tempature lakes, during the warmest period of the year. Three (3) distinctive layers are present : epilimnion, la metalimnion and hypolimnion.

Thermocline: Region in a thermaly stratified body of water, which separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth.

Total phosphorus: Group of mineral and organic phosphoric molecules present within a lacustrine habitat.

Water flea: Water flea, small crustaccan borer Puce d'eau, petit crustacé d'eau douce. Fréquemment utilisée lors d'études toxicologiques

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