Water quality trends in the last decade for ten watersheds dominated by diffuse pollution in Québec (Canada)

M. Patoine, S. Hébert and F. D’Auteuil-Potvin

ABSTRACT

The aim of this work is to evaluate and discuss river water quality trends over the last decade in ten watersheds where diffuse pollution represents more than half of the annual load of phosphorus (P) and nitrogen (N). Trend analyses taking into account flow data indicate a significant reduction of total P in eight rivers, of ammonia N in five rivers, of nitrate + nitrite in four rivers, of total filtered N in three rivers and of suspended solids in two rivers. An increase of turbidity was observed in four rivers and, for fecal coliforms, no trends. P decrease can be explained by reduced mineral P inputs on cropped lands related to means such as agro-environmental fertilization plans and addition of phytase in pig and poultry feed. However, for seven of them, median P concentrations remain at least two times greater than the Québec water quality guideline for protection of rivers against eutrophication. Concentrations of other parameters remain problematic in some rivers too. These results indicate the need to continue the efforts for further diffuse pollution reduction. Future work should better quantify actions taken at the watershed scale to reduce diffuse pollution.

Key words | agriculture, diffuse pollution, water quality trend

INTRODUCTION

In the province of Québec, efforts have been made over the past 30 years to reduce river pollution. Legislation and water pollution abatement programs initially targeted municipal point source pollution, both domestic and industrial, and manure storage improvement but were only partially successful in correcting water quality problems (Gangbazo & Painchaud 1999). For many watersheds, diffuse pollution sources, mainly from agriculture, have been identified as the main source of phosphorus (P) and nitrogen (N) in many rivers exceeding water quality guidelines (Gangbazo & Babin 2000; Gangbazo et al. 2005).

Over the last decade, new regulations on agricultural pollution, supported by financial programs (Boutin 2004; Prime-Vert Program 2009), have focused on diffuse P control. The Regulation respecting the reduction of pollution from agricultural sources (GOQ 1997) introduced the obligation of agro-environmental fertilization plans (AEFP) and spreading registers for the majority of farms. It also prohibited manure and mineral fertilizers spreading outside the period of 1 April to 30 September. The AEFP, based on a balance between crop requirements and nutrients supplied from all sources, must take into account the P richness of soils and identify reduction measures when soils are too rich. The modernization of the 1997 regulation in 2002 has permitted intensification of its control. Additional measures were introduced, like restriction of animal access to watercourses in 2005 (MDDEP 2010a).

At the province of Québec scale, these measures have contributed to reduce the P budget (difference between nutrients supplied from all sources and crop uptake) from 14.4 kg P/ha in 1998 to 8.3 kg P/ha in 2007. In spite of a 6% increase in animal units (AU), improvements in animal feeding (generalized use of phytase) and a 32% decrease in the application of mineral P fertilizer have helped to improve the P budget. The N budget and mineral N fertilizer sales in Québec, however, remained relatively stable over this period. Manure spreading after fall harvest also decreased, passing from 46 to 34% of manure volume for annual crops and from 69 to 24% of manure volume for grasslands. Some point source improvements like the increase from 66 to 74% of total AU with watertight manure storage and a decrease in dairies untreated wastewater volume from 58 to 33% of total cow AU also occurred (BPR 2008).

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The aim of this work is to evaluate water quality trends over the last decade for total P, suspended solids (SS), turbidity, filtered N forms and fecal coliforms (FC) in ten watersheds where diffuse pollution is dominant and to discuss the results of corrective actions taken over the same period.

**METHODS**

**Studied watersheds**

Ten watersheds located in the St. Lawrence Lowlands and the Appalachians, with drainage area ranging from 20 to 550 km², were selected (Figure 1). Five of them were not affected by any municipal point source pollution. The other five received effluent from wastewater treatment plants but these facilities did not undergo any treatment upgrade in the last decade. One watershed (number 8) also received untreated municipal wastewater. The population in the watersheds did not change significantly over the period. Diffuse sources in these watersheds represent more than half of the annual P and N loads. The nearest gauging stations operated by the Centre d’expertise hydrique du Québec were used to evaluate the flow-concentration relationship and to flow-adjust the water quality data.

**Water sampling and analysis**

Water quality data from MDDEP (2010b) database were used. Grab samples were taken monthly or bi-monthly and were analyzed with standard methods (CEAEQ 2010) by the Centre d’expertise en analyse environnementale du Québec. For watersheds 2 to 5, 9 and 10, samples were filtered on a 0.45 μm filter for N forms (methods MA. 303 – N tot 1.0, MA. 303 – N 1.0, MA. 303 – NO₃ 1.0) and suspended solids (MA. 104 – S.S. 1.1) and total P was analyzed after a persulfate digestion (MA. 303 – P 5.0). For watersheds 1, 6, 7 and 8, a filter of 1.2 μm was used and total P was obtained by the sum of separately analyzed particulate and dissolved forms (MA. 303 – P 5.0). Turbidity and fecal coliforms were analyzed in all watersheds using the same methods (MA. 103 – Tur. 1.0 and MA. 700 – Fec.Ec 1.0).

**Statistical methods**

Trends in water quality variables over the period of 1999–2008 were analyzed using SAS 9.1 (SAS Institute 2003).
Correlation between log transformed water quality data and mean flows at the day of sampling were examined with the Pearson parametric test using all water quality data. Water quality data were flow-adjusted, except in the absence of significant correlation with flow ($p \geq 0.1$). First data of each month were used for flow-adjustment and trend tests. Depending on site and parameter, between 77 and 120 data were available for trend analysis. The null hypothesis $H_0$ is that there is no significant trend in the series ($p \geq 0.05$). The alternate hypothesis ($H_1$) is the presence of a monotone trend.

Non-parametric approaches with the SAS LOESS procedure for flow-adjustment were used when less than 5% of the water quality data were censored. Non-parametric approaches were also used when water quality data were not correlated with flow. The Mann–Kendall test was selected when both seasonality and autocorrelation were not detected. The seasonal Mann–Kendall test was used when data showed seasonality without autocorrelation (Gilbert 1987; Helsel & Hirsch 2002). In presence of autocorrelation, Lettenmaier–Spearman’s approach (Lettenmaier 1976) was used if there was no seasonality. With seasonality, Hirsch & Slack (1984)’s approach was used and missing data were filled in by the monthly median value calculated over the whole period. However, the presence of these filled in data can impair the detection of existing trends.

Parametric approaches were used when water quality data were correlated with flow and 5% or more of data were censored. In this case, a SAS Tobit regression model with time, season and flow was used, except for total P obtained from the sum of particulate and dissolved forms. In the latter case, the SAS LIFEREG procedure which supports this kind of partially censored data was used. Water quality and flow data were log transformed for normality. The statistical approach used for each trend test analysis on physicochemical parameters is presented in Table 1.

### RESULTS AND DISCUSSION

Trend analyses results of water quality data taking into account flow data are presented in Table 2. A significant reduction was observed for total P in eight rivers, for ammonia N in five rivers, for nitrate + nitrite in four rivers, for total N in three rivers and for SS in two rivers. However, results show that a significant increase of turbidity occurred in four rivers. Trend analyses for FC (not presented) indicate no change for the ten stations.

#### Phosphorus

The total P decrease in eight rivers over the last decade suggests that efforts to reduce P pollution were efficient. Moreover, trend results for P forms (not presented) indicate that the total P trends occurred essentially on dissolved P, except for watershed 8 where a significant decreasing trend was also observed on particulate P. These results reinforce the idea that a decrease in feed and fertilizer mineral P used in the watersheds was responsible for the P decrease in rivers. In watershed 8, measures to control erosion, not documented in our study, might have played an important role too.

<table>
<thead>
<tr>
<th>Station number</th>
<th>Total phosphorus</th>
<th>Suspended solids</th>
<th>Turbidity</th>
<th>Ammonia</th>
<th>Nitrate + nitrite</th>
<th>Total nitrogen</th>
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Non-parametric approach: SMK, Seasonal Mann–Kendall; MK, Mann–Kendall; LMS, Lettenmaier–Spearman; HS, Hirsch & Slack (1984). For HS test, values in italics indicate percent of blanks filled in by the monthly median value calculated over the whole period. Parametric approach: Tobit, Tobit regression; LP, SAS LIFEREG procedure. Trend tests followed by ‘na’ were applied on data not adjusted for flow; ‘No test’ indicates that no test was used because the trend slope was zero.
The restrictions on P spreading imposed by the regulation since 1997 encouraged an optimum use of mineral P in animal feed and cropped fields. At the provincial scale, the use of phytase to reduce P in feed increased significantly over the period 1998–2003 period, passing from 27 to 90% of animal units in pig sector and from 3 to 54% for poultry sector, and remained stable thereafter (BPR 2008). A 32% decrease in the use of mineral P fertilizer was also observed over the last decade (data from the Association des fabricants d’engrais du Québec (AFEQ) for years 1999 and 2008). These large-scale improvements in P management have yet to be confirmed at the individual watershed scale.

Assuming a 20% P decrease in manure of farms where phytase replaced mineral P in feed, we estimated, for each of the ten watersheds, the P input reduction resulting from the use of phytase. Livestock and poultry data came from the 2001 and 2006 Census of Agriculture (Statistics Canada 2002, 2006) and P excretion data from CPAQ (1998) for pig and from CRAAQ (2001) for poultry. We also estimated the change in chemical P fertilizer applied in each watershed using the ratio of fertilizers and lime expenditures in each of these watersheds to the whole of Québec’s expenditures (Statistics Canada 2002, 2006) multiplied by Québec’s fertilizer P sales from the AFEQ for years 2001 and 2006 respectively. Data from Statistics Canada being available only at the municipal scale, watershed scale data were calculated on a pro rata basis by using the proportion of the municipality area located within the boundaries of the watershed. Figure 2 shows that the estimated decrease in P inputs associated with phytase use in the studied watersheds is correlated with rivers total P decrease. The combined effect of measures from all inputs (phytase in feed and chemical fertilizers reduction) shows the efficiency of mineral P optimal use on rivers total P reduction.

Other improvements like watertight manure storage, livestock watercourse access restriction and fall spreading decrease, reported at a regional scale (BPR 2008), but not at our studied watershed scale, may have contributed to the river total P decrease.

Our results are partially coherent with the results of short-term paired watershed studies on best management practices (BMPs) in Québec. Baril et al. (1998) did not find any significant change in stream P concentration after implementation of fertilization plans. Enright et al. (1999) did not observe stream P improvement after reducing P applications on treatment watershed, but P applied on control watershed was not inventoried. In more recent studies, Michaud et al. (2009) measured a stream P decrease in two of their three paired watershed studies. One occurred in a control watershed with a P budget reduction. The other was noticed in a watershed with no change in P budget, but with an important increase of surface area with no-till. Finally, AAC (2010) found a decrease of P runoff for two of the three study years with BMPs to control N losses from hog slurry application on corn and forage fields. One possible explanation for the lack of a generalized decreasing trend like the ones observed in our study is the shorter monitoring period of the paired watershed studies. As explained by Meals & Dressing (2010), the lag time in water quality response to BMPs could be an important limiting factor.

In spite of the encouraging P decrease in most of the rivers studied, for seven of them, median concentrations

### Table 2 | River water quality trends at the ten monitoring stations. Symbols indicate decrease (▼) or increase (▲) or no statistically significant trend at 5% level (▬) of the parameters median values over the last decade

<table>
<thead>
<tr>
<th>Station number</th>
<th>Total phosphorus</th>
<th>Suspended solids</th>
<th>Turbidity</th>
<th>Ammonia</th>
<th>Nitrate + nitrite</th>
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Note: Concentrations with significant correlation with flow (p < 0.1) are flow-adjusted for trend analysis.
remain at least two times greater than Québec’s water quality guideline (0.030 mg/l P) for preventing eutrophication (MDDEP 2009). These results indicate the need to continue efforts to further reduce P pollution.

Nitrogen

Decreasing trends over the last decade were observed in five watersheds for ammonia, in four watersheds for nitrate + nitrite and in three for total filtered N. These results suggest that the efforts to reduce diffuse pollution over the last decade, mainly oriented on P sources, have had a positive effect on nitrogen pollution too, in one third to half of the studied watersheds.

The introduction of AEFP in the 1997 regulation might have encouraged a balanced nitrogen fertilization and a better spreading synchronization with crop requirements. Indeed these factors could explain improvements in some watersheds for all N forms. Fall manure spreading reduction could explain ammonia improvements. Gangbazo et al. (1997) observed that an increase of N losses in runoff and drainage water was related to N applied to crops for all N forms, but in the case of ammonia, to fall manure spreading only. When it becomes available, information on N budget and fall manure spreading changes over the last decade at the watershed scale should confirm our assumptions.

In a paired watershed study, Baril et al. (1998) measured a nitrate + nitrite reduction in a stream draining lands where mineral N fertilizer use decreased by less than 10%. In another study where fertilization plans were implemented, Enright et al. (1999) measured an improvement for stream ammonia and total N. Michaud et al. (2009) also measured a decrease of stream nitrate in three watersheds and of ammonia in one. Factors explaining the N decrease for nitrate involve a N budget improvement or hydrologic factors. In the case of ammonia, a better synchronized spreading could explain the decrease. Finally, AAC (2010) found a decrease in nitrate runoff for two of the three study years with BMPs to control N losses from hog slurry application on corn and forage fields.

In spite of the encouraging ammonia reduction in half of the rivers, median concentrations remain greater than the Quebec water quality guideline for raw water disinfection efficiency (0.20 mg/l N) (MDDEP 2009) in one of them (watershed 7). Median concentration of nitrate + nitrite remains greater than the Quebec water quality guideline for aquatic life protection (chronic effect: 2.9 mg/l N) (MDDEP 2009) in one of the studied rivers (watershed 3).

For total filtered N, there is no Quebec water quality guideline yet. However, the median concentration of each river exceeds the 0.99 mg/l N target proposed by Chambers et al. (2008) to protect small agricultural watersheds from...
eutrophication and the 0.7 mg/l N guideline proposed by Smith & Tran (2010) for large rivers.

**Suspended solids and turbidity**

Turbidity increase in four rivers, SS decrease in two and the absence of change in the others suggest that measures to reduce diffuse pollution, mainly oriented on fertilization, had mixed effects on these two parameters.

Soil conservation practices such as no-till, which increased from 9 to 25% of annual crop area over the 2001–2006 period (Statistics Canada 2002, 2006) in watershed 5, may explain the SS decrease. In watershed 3, the SS decrease is not explained by no-till which remained stable to about 5% during the period. Turbidity increase in four watersheds is not well understood, but absence of SS trend suggests a phenomenon related to very fine particles (<1.2 μm). Even if some soil conservation actions such as no-till may have contributed to reduce the SS concentrations in some rivers, other factors, such as the increasing proportion of annual crop, might have had the reverse effect on SS and turbidity. Unfortunately, the lack of information about the extent of soil conservation actions at the watershed scale level did not allow us to make a more complete analysis.

In a paired watershed study with mineral fertilizers reduction as BMPs, Enright et al. (1999) did not show any significant change in stream SS. However, Michaud et al. (2009) measured significant SS stream decrease in two watersheds where no-till went from less than 10% to about 50% of annual crops area. In one of them, many hydro-agricultural installations were also added.

The results indicate that more has to be done to reduce this type of pollution and stress the need of reporting the extent of BMPs at the watershed scale.

**Fecal coliforms**

Absence of significant trends for FC concentrations in the ten rivers suggests that the measures to reduce diffuse pollution, mainly oriented on P pollution, were not efficient to reduce microbial pollution.

Controlled access of cattle to watercourses, which rose from 49 to 81% of the AU in Québec in the last decade, and manure treatment, adopted for 2% of AU (BPR 2008), are examples of measures that should be implemented at a larger scale.

In Québec, the only paired watershed study which measured the FC (Baril et al. 1998) did not find any significant change after implementation of fertilization plans.

Depending on rivers, between 5 and 60% of samples still show FC concentrations exceeding the Québec water quality guideline of 1,000 CFU/100 ml for protection of indirect contact recreational activities such as boating, canoeing or fishing (MDDEP 2009). These results indicate the need to continue efforts to further reduce FC pollution.

**CONCLUSIONS**

Water quality trends in ten Québec watersheds where diffuse pollution is dominant were evaluated taking into account flow data. Results suggest that the measures to reduce diffuse pollution, mainly oriented on P sources, improved water quality in most studied rivers for P and, in some rivers, for N and SS. However, water quality median values remain higher than the Québec guideline in most rivers for P and in some for N forms and FC, indicating the need to continue pollution abatement efforts. The increasing trend in turbidity measurements for some rivers command additional efforts to understand implicated factors. Future work should take into account more complete information on BMPs at the watershed scale when they become available.

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**REFERENCES**


CRAAQ (Centre de référence en agriculture et agroalimentaire du Québec) 2001 Estimation des rejets d’azote et de phosphore par les animaux d’élevage – productions avicoles (Estimation of N and P excreted by poultry), Comité ad hoc sur l’agroenvironnement, Québec, Canada.


Gazette officielle du Québec (GOQ) 1997 Regulation respecting the reduction of pollution from agricultural sources. Gazette officielle du Québec 129 (24), Part 2, 2607–2632.


MDDEP (Ministère du Développement durable, de l’Environnement et des Parcs, Québec) 2010b Banque de données sur la qualité du milieu aquatique (Aquatic environment database), Direction du suivi de l’état de l’environnement, Québec.


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