TOXIC POTENTIAL ASSESSMENT OF MUNICIPAL WASTEWATER TREATMENT PLANT EFFLUENTS IN QUEBEC

FINAL REPORT

Prepared by:

- Ministère de l’Environnement du Québec
- Environment Canada

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PRODUCTION TEAM

Writing:

Hélène Dufour	
Isabelle Giroux	
Isabelle Guay	of the Ministère de l’Environnement du Québec
Carole Lachapelle	
Robert Tétreault	
Manon Bombardier	
Manon Harwood	of Environment Canada
Marc Villeneuve	
Benoit Pigeon	of B. P. Conseiller

Collaboration:

Jean-Pierre Blouin	
Guy Fortin	of the Ministère de l’Environnement du Québec
Paule Tremblay	
Sylvie Roberge	of Environment Canada

Sampling Work:

Centre d’épuration Rive-Sud
Communauté urbaine de Montréal
Environnement E.S.A.
Roche
Sodexen

Laboratory Work:

B.A.R. Environmental
St. Lawrence Centre
Centre d’expertise en analyse environnementale du Québec
CRÉALAB
Envirolab
Laboratoires Bodycote Technitrol
Laboratoire de Génie Sanitaire
Laboratoire de l’environnement LCQ

Translation:

Ann Faler
Benoit Boulay
Patricia Potvin (editing)

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ABSTRACT

BACKGROUND OF THE STUDY

Major financial and technical resources have been marshalled over the last 20 years to recover use of Quebec's watercourses. Some $7 billion has been spent within the framework of two water cleanup programs: the *Programme d'Assainissement des Eaux du Québec* (PAEQ) and the *Programme d'Assainissement des Eaux Municipales du Québec* (PADEM). By virtue of these programs, 98% of the Quebec population with existing sewer services were connected up to wastewater treatment plants. Observed trends and changes in contaminant loads over time suggest that the water cleanup initiatives begun in 1979 have had positive effects on the water quality of Quebec rivers. Time series analyses of nitrite-nitrates, ammonia nitrogen, total phosphorus, turbidity and fecal coliforms reveal a preponderant downward trend. Loads of biochemical oxygen demand (BOD_5) and suspended matter (SM) in municipal effluents are also diminishing.

Despite the improved quality of effluents released to watercourses in the wake of the PAEQ and PADEM programs, however, it is possible that certain municipal effluents are potentially toxic to some aquatic species. Municipal effluents may also contain persistent and bioaccumulable substances that can degrade the quality of the flesh of organisms exposed to them.

Studies and toxicity tests conducted throughout North America have revealed the toxicity of many municipal treatment plant effluents. Some effluents were highly toxic, causing the death of organisms within a short time (acute lethal toxicity), while others had more long-term effects (chronic toxicity). These studies established that chlorine disinfection and the presence of ammonia nitrogen at elevated concentrations were major, generalized causes of the toxicity measured. In the case of ammonia nitrogen, toxicity was especially evident in winter, when nitrification is reduced. Hydrogen sulfide was identified as an additional cause of toxicity in unaerated lagoons. Other substances, such as metals, surfactants and some organic compounds, may also contribute to the toxicity of municipal effluents. The problem of effluent toxicity in Quebec was less well understood as few toxicity tests had yet been conducted.

In light of this information, and given the progress of the water cleanup programs, the Quebec Environment Ministry (MENV) decided in 1993 to strike a committee mandated to determine the means by which to assess the toxic potential of effluents generated by municipal wastewater treatment plants in Quebec. The committee first concluded that very few effluents could be toxic due to chlorine disinfection since only two treatment plants in the province continued to employ this process at the time (both plants have since replaced this method with ultraviolet disinfection). The committee also concluded that several plants, primarily aerated lagoons in winter, could present an elevated risk of toxicity due to the presence of high concentrations of ammonia nitrogen.

The committee recommended that the effluents of 15 municipal treatment plants be characterized. These 15 plants were selected for their representativeness in terms of treatment processes employed in Quebec, and for their different operating conditions (i.e. with/without chemical dephosphatization; with/without major industrial inputs). The committee also recommended that this campaign be undertaken over two different periods, in winter and summer operating conditions.

Implementation of the characterization campaign and production of the present study were made possible under the aegis of a Quebec-Canada harmonization agreement: the *St. Lawrence Vision 2000* Program (SLV 2000).

OBJECTIVES AND INTERPRETATIVE LIMITATIONS OF THE STUDY

The objective of the study was to obtain a comprehensive and representative snapshot of the toxic potential of municipal treatment plant discharges that is, to assess the toxicity of undiluted effluents without taking account of the particularities of receiving environments or loads discharged. The approach adopted for this study made it possible to compare the municipal effluents on a common basis in order to:

- assess end-of-pipe toxicity (acute or chronic) of treated wastewater discharges of municipal treatment plants;
- point up the substances that are the likely sources of the measured toxicity;
- identify the common causes of toxicity and the effect of certain factors that might influence effluent toxicity.

This approach, however, does not allow for a cause-and-effect link to be made between measured toxicity and potential effects on the environment. The toxicity of various contaminants may be modified due to certain environmental characteristics of receiving environments, such as water hardness, pH, temperature, the presence of other substances, degradation of parent products into more or less toxic by-products, the health of populations present, etc. Concentrations alone are inadequate to assess the apprehended impact of an effluent on its receiving environment; consideration must also be given to loads discharged, physical (flow, hydrodynamics, deposition zones) and chemical characteristics of the specific receiving environment.

This study looked only at the toxicity of effluents without taking account of other possible impacts of municipal wastewater discharges on a body of water. The physical impacts of effluents and sewer overflows (volumes of excess water released untreated during episodes of heavy rainfall or spring snowmelt) on habitats, as well as the thermal, aesthetic and microbiological impacts were not assessed. The aspect of the toxicity of overflow water was not addressed, either.

Lastly, due to the low sampling rate, we were unable to process the results statistically or to characterize the recognized variability of municipal wastewaters.

EXPERIMENTAL APPROACH AND TOOLS FOR ASSESSING TOXIC POTENTIAL

The 15 municipal wastewater treatment plants selected are representative of the main treatment processes used in Quebec (see Table 1). Seven of these plants are associated with a major industrial-source load; four use chemical dephosphatization (phosphorus removal) year-round, six do so only in summer, and five plants do no phosphorus removal whatsoever. All the plants were characterized over a period stretching from 1996 to 1999, mostly over two seasons, winter and summer. During these sampling campaigns, all plants functioned normally and, overall, respected the discharge requirements (BOD_5, SM and P_T) for which they were designed.

TABLE 1: CHARACTERISTICS OF SELECTED MUNICIPAL TREATMENT PLANTS

Process	**Number of treatment plants**			
	Low industrial inputs		**High industrial inputs**	
	With dephosphatization	**Without dephosphatization**	**With dephosphatization**	**Without dephosphatization**
Activated sludge	1	1	2	1
Aerated lagoon	1	1	2	1
Biofiltration	1	1	-	-
Physico-chemical	1	-	1	-
Unaerated lagoon	1	-	-	-

Sampling was carried out over three inconsecutive days for each season. In all, seven toxicity tests were performed and up to 26 conventional physico-chemical parameters, 19 metals and eight families of chlorinated and unchlorinated organic substances were analysed in the samples drawn (see tables 2 and 3). While the comparison of results for certain substances may be biased due to changes in the analytical profile over the course of the project, our experimental protocol produces a representative snapshot of the quality and potential toxicity of municipal wastewaters under normal plant operating conditions.

Toxic potential is assessed using a complementary, three-pronged approach: studying the amplitude of exceedances of water quality criteria for the chemicals analysed, studying the amplitude of exceedances of overall toxicity criteria for toxicity tests, and studying the compilation of so-called “toxic prints”, which are toxicity measuring components of the Potential Ecotoxic Effects Probe (PEEP) Index. With this approach, the substances proper to municipal wastewater treatment plants can be identified, as can the toxicity of the effluents and the substances likely to be responsible. The importance of treatment process type, effect of industrial source loading, presence of a chemical dephosphatization process or effectiveness of treatment by season of the year can also be determined.

TABLE 2: TOXICITY TESTS USED AND DESCRIPTIVE CHARACTERISTICS

Organism	**Species**	**Trophic level**	**Toxicity level**	**Variable of effect**
Marine bacteria	*Vibrio fischeri* (Microtox™)	Decomposer	Acute sublethality	Inhibition of luminescence
Bacteria	*Escherichia coli* PQ37 (SOS Chromotest)	Decomposer	Chronic sublethality	Genotoxicity and cell viability
Algae	*Selenastrum capricornutum*	Primary producer	Chronic sublethality	Inhibition of cell division
Cladocerans (crustaceans)	*Ceriodaphnia dubia*	Primary consumer	Chronic lethality and sublethality	Mortality and reproductive inhibition
Cladocerans (crustaceans)	*Daphnia magna*	Primary consumer	Acute lethality	Mortality
Fish larvae	*Pimephales promelas* (Fathead minnow)	Secondary consumer	Chronic lethality and sublethality	Mortality and growth inhibition
Fish	*Oncorhynchus mykiss* (Rainbow trout)	Secondary consumer	Acute lethality	Mortality

TABLE 3: LIST OF PARAMETERS ANALYSED AT TREATMENT PLANTS

Physical/chemical parameters (PCP)	**Metals**	**Organic substances**
• Conventional parameters: pH, dissolved oxygen (DO) and temperature Conductivity Total hardness (in $CaCO_3$) Total organic carbon (TOC) Biochemical oxygen demand (BOD_5) Carbonated BOD ($CBOD_5$) Chemical oxygen demand(COD) Suspended matter (SM) Total solids (TS) • Nutrients: Ammonia nitrogen ($N\text{-}NH_3\text{-}NH_4^+$) Total Kjeldahl nitrogen (N-TKN) Nitrites (NO_2) Nitrites-nitrates ($NO_2\text{-}NO_3$) Total phosphorus (P_T) • Major ions: Chlorides (Cl^-) Total residual chlorine (TRC) Cyanates (CNO^-) Total cyanides (CN^-) Total fluorides (F^-) Sulfates (SO_4^{2-}) Dissolved sulfides (S^{2-} dis.) Total sulfides (S^{2-} tot.) • Oils and greases: Total hydrocarbons Freon extractibles	• Aluminum (Al) • Antimony (Sb) • Arsenic (As) • Barium (Ba) • Beryllium (Be) • Boron (B) • Cadmium (Cd) • Chromium (Cr) • Cobalt (Co) • Copper (Cu) • Iron (Fe) • Lead (Pb) • Mercury (Hg) • Molybdenum (Mo) • Nickel (Ni) • Selenium (Se) • Silver (Ag) • Vanadium (V) • Zinc (Zn)	• Phenolic substances • Semi-volatile organic substances (SVOCs): Scan of over 50 organic substances • Volatile organic substances (VOCs): Scan of over 40 organic substances • Nonionic and anionic surfactants • Polychlorinated biphenyls (PCBs): 43 specific congeners Homologues • Polycyclic aromatic hydrocarbons (PAHs): 22 specific PAHs • Chlorinated dioxins and furans: 17 specific congeners Homologues • Pesticides: 32 organophosphorus and other pesticides 14 phenoxyacid herbicides

RESULTS OF PHYSICO-CHEMICAL ANALYSES AND TOXIC POTENTIAL BASED ON THE AMPLITUDE OF EXCEEDANCES OF WATER QUALITY CRITERIA FOR SUBSTANCES ANALYSED

The variable quality of municipal effluents was recognized upon examining the analytical results. The toxic responses and measured concentrations of several substances differed significantly from one sampling day to the next. Seasonal variations were also observed for some substances, including those that depend upon biological activity during wastewater treatment, such as ammonia nitrogen and hydrogen sulfide, or where their use is seasonal, like the chlorides used in road de-icing agents.

The substances most frequently detected in samples drawn at the 15 plants are shown in Table 4. Since they were detected in more than 85% of samples analysed, the results suggest that these substances are likely to be found in the wastewaters of a number of plants in Quebec.

TABLE 4: SUBSTANCES DETECTED IN MORE THAN 85% OF SAMPLES ANALYSED

Nutrients	**Major ions**	**Metals**	**Organic substances**
Ammonia nitrogen Nitrites and nitrates Phosphorus	Chlorides Fluorides Sulfates	Aluminum Arsenic Barium Boron Chromium Copper Iron Mercury (1)	PCBs Chlorinated dioxins and furans Herbicides (2) PAHs Anionic surfactants

(1): Frequency exceeds 85% in samples drawn in 1998–99 due solely to the use of a method with a better detection limit.

(2): Pesticides (herbicides and insecticides) were analysed in 42 samples drawn from two plants alone. Only the herbicides 2,4-D and mecoprop were detected in more than 85% of samples.

Although these substances are practically ubiquitous in the wastewaters of all 15 plants, they are not necessarily found in effluent at concentrations deemed toxic or harmful. Many did not exceed water quality criteria (sulfates, barium, boron, and herbicides) or showed a few specific low-range exceedances (chlorides, fluorides, iron, and PAHs).

Of those pesticides used in urban applications, seven were detected in effluents of the two treatment plants where these analyses were performed. These were herbicides 2,4-D, mecoprop and dicamba, all of which are contained in commercial lawn treatment mixtures, as well as the insecticides diazinon, carbaryl, malathion and chlorpyrifos. Other pesticides applied on field crops were also detected: in municipal effluents; their presence is probably attributable to atmospheric transport from the farmbelts surrounding urban areas. In summer, concentrations of pesticides, and most especially herbicides, appear to swell during rainfall events due to urban runoff. These results have been corroborated by other studies conducted in Ontario and the U.S.

An examination of the amplitude of exceedances of the quality criteria for the protection of aquatic life shows that there are frequent exceedances for certain substances, with some attaining high amplitudes (> 10). This is true for ammonia nitrogen, phosphorus, hydrogen sulfide, aluminum, silver, chromium, copper, two insecticides (diazinon and chlorpyrifos) and, most especially, surfactants. Indeed, wherever nonionic and anionic surfactants were detected, they exceeded the water quality criteria, and the exceedances are substantial in the majority of cases. The presence of these substances at such concentrations suggests that municipal wastewater presents a toxic potential that is harmful to aquatic life in the long term, particularly in watercourses with only a moderate assimilative capacity.

Other substances known to be toxic and highly bioaccumulable appear to be ubiquitous, and were detected at significant concentrations relative to the quality criteria for the prevention of contamination of aquatic organisms. This is the case for PCBs and chlorinated dioxins and furans, and, to a lesser extent, mercury. These substances can contaminate the flesh or tissue of fish, molluscs and crustaceans, making them unfit for unrestricted consumption. These substances can be even more harmful to fish-eating land animals, as the quantity of fish they consume is greater than that consumed by humans and because they eat the entire organism, including those tissues where bioaccumulation is greater than in flesh.

The sources of these bioaccumulable substances in municipal wastewaters, especially PCBs and chlorinated dioxins and furans, are many and complex. Other than industrial discharges, these substances may come from relatively distant atmospheric sources and contaminate urban runoff waters as well as the aquatic receiving environments from which municipalities draw their water supply. Only mass balance studies of the municipal network would enable us to determine the inputs of various sources being channelled to municipal treatment plants.

TOXIC POTENTIAL FOR AQUATIC LIFE BASED ON TOXICITY TESTS OF THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT

With acute toxicity tests, there are few exceedances of the overall toxicity criteria of 1 acute toxic unit (TUa) and they are of low amplitude, in the majority of cases. More than half of the treatment plants studied (53%) had no result above 1 TUa. Twenty-two percent of samples were toxic to rainbow trout, with 11% being toxic to *Daphnia magna*. For purposes of comparison, a similar study in Ontario in 1992 shows corresponding percentages of 56% and 27%, respectively. These differences mainly have to do with the fact that, unlike many plants in Ontario, Quebec treatment plants use no chlorine treatment to disinfect their wastewater.

Ammonia nitrogen, at concentrations greater than 10 mg/L, appears to be mainly responsible for the acute toxicity measured. Surfactants may be the second most generalized contaminant while nitrites are suspected at one plant. The presence of pesticides in summer could be another cause of toxicity.

Chronic toxicity effects were measured in the undiluted effluents of almost all the plants, but, overall, exceedances of the overall toxicity criteria of 1 TUc are of low amplitude (responses of 1 to 2 TUc), which suggests that there will be few or no effects on the environment once the effluent mixes into the watercourse. All seasons combined, a little over one-third of the plants obtained results above 10 TUc, thereby making these effluents potentially harmful to aquatic life in watercourses with a weak assimilative capacity. One plant obtained results above 30 TUc.

Almost all the samples stimulated algal growth. This positive response in the algae *Selenastrum capricornutum* was not quantified in terms of toxic units, but it does nonetheless indicate the potential harm of the eutrophication process for aquatic life.

Those substances most likely to have contributed to the chronic toxicity measured are ammonia nitrogen, a few metals (mainly copper, chromium and aluminum), surfactants and, probably, certain pesticides including diazinon and chlorpyrifos. In some specific cases, nitrites, cyanides or hydrogen sulfide might have played a role. In all these cases, though, the expression of chronic effects coincides with the simultaneous presence of several substances at concentrations greater than safe limits.

Toxicity identification evaluations (TIEs) are the only way to determine, on a case-by-case basis, which substances are responsible for chronic and acute toxicity.

TOXIC POTENTIAL BASED ON TOXIC PRINTS OF THE PEEP INDEX

No threshold or criterion has yet been established to indicate a worrisome or harmful level relative to toxic prints of the Potential Ecotoxic Effects Probe (PEEP) Index. Although it is impossible to reach any conclusions about the toxic potential of municipal effluents in terms of toxic prints, this tool does allow us to better define wastewater quality, and has proven useful to interpreting the results.

The genotoxicity test was particularly sensitive to municipal wastewater, with toxic responses observed at more than two out of three plants. These results suggest that undiluted municipal effluents may contain substances at concentrations capable of altering bacterial DNA.

INFLUENCE OF SEASON, TREATMENT TYPE, INDUSTRIAL LOADING AND DEPHOSPHATIZATION ON TOXIC POTENTIAL

The results of the study indicate that the toxic potential of municipal effluents in Quebec varies from one plant to another. Effluents of aerated lagoons that were characterized during winter operating conditions are often acutely toxic for rainbow trout because of the elevated concentrations of ammonia nitrogen. Treatment processes that don’t include aeration equipment (unaerated lagoons and physico-chemical processes) may present a higher toxic potential at certain times of the year (during spring emptying of unaerated lagoons and in summer for physico-chemical treatment) due to the biological production of hydrogen sulfide under anaerobic conditions.

Plant effluents that are subject to major industrial loading were, overall, more toxic than those of plants with low industrial inputs. Our results show that industrial inputs appear to be a determining factor in the toxic potential of municipal effluents, even though effluents may be toxic where there is little or no industrial input.

In addition to removing phosphorus, chemical dephosphatization had a beneficial effect on the removal of metals. In contrast, though, it does seem to lead to an increase in the concentration of metal serving as a coagulant. Although chemical phosphorus removal also appears to have a beneficial effect on the potential toxicity of municipal effluents, it is impossible to say so with any certainty, since the toxicity test results obtained in this study are much more influenced overall by treatment type, season of the year and industrial load than by dephosphatization.

CONCLUSION ON ANALYTICAL METHODS AND SAMPLES USED

The use of the best analytical techniques made it possible to lower detection limits and thus obtain a better snapshot of the quality of municipal wastewater, in addition to producing results that are comparable to defined safety limits (water quality criteria) for several substances and metals. Our use of these best techniques also allowed us to point up the presence of substances rarely quantified in this type of effluent (e.g. PCBs and chlorinated dioxins and furans).

Unlike studies conducted elsewhere, this study targeted pesticides that are likely to be found in the urban environment. This proved useful to the task of selecting the appropriate analytical methods to point up the presence of these pesticides in municipal wastewaters.

In the case of municipal effluents, scanning analytical methods for semi-volatile and volatile organic substances were found to be lacking in specificity and resolution. It might be better to target a small number of substances, e.g. the 20-odd VOCs used in laboratory accreditation processes.

The present study confirmed yet again the importance of using a number of different toxicity tests to adequately assess effluent toxicity because of the variability of contaminants present in samples, which can cause a reaction in one species and not in an other.

GENERAL CONCLUSIONS

The municipal cleanup initiatives begun in Quebec in 1979 have had positive effects on the quality of watercourses. Treatment plants built in the context of these cleanup programs were specifically designed to reduce the main contaminants contained in municipal wastewaters; that is, conventional parameters (BOD_5, SM, phosphorus and fecal coliforms). Although these plants can attain a certain yield for the removal of other contaminants potentially contained in municipal wastewaters, they cannot eliminate them completely.

This study characterized the effluents of 15 different municipal treatment plants. The toxicity test results show that although the treated wastewaters of almost all the plants studied are toxic, they expressed, with only a few exceptions, low amplitude toxicity to the test species.

The main substance responsible for the toxicity measured appears to be ammonia nitrogen, at concentrations above 10 mg/L. During winter, when the nitrification process is reduced, concentrations of ammonia nitrogen are higher, especially in aerated lagoons. Anionic surfactants are next, followed, to a lesser extent, by nonionic surfactants. Surfactants are organic molecules that enter into the composition of hundreds of products used, among other things, as cleaning agents for both domestic and industrial purposes. Finally, other substances, like certain pesticides and metals, could also be responsible for the toxicity measured.

This study points up the ubiquitousness of a number of substances in the municipal wastewaters of 15 treatment plants, including certain organic substances rarely quantified in other studies and found at concentrations that could impair use of the water. These are, namely, surfactants, PCBs and chlorinated dioxins and furans. Certain pesticides may be added to the list in summer during rainfall events. However, to assess the actual impact of these substances, discharge loads must be considered and, in each case, sound information held on the biophysical and chemical characteristics of the respective receiving environments.

The significance of industrial inputs to treatment plants appears to be a determining factor in the toxic potential of municipal effluents, even though effluents may be toxic where there is little or no industrial input.

RECOMMENDATIONS

Those municipal treatment plants that do respect their discharge requirements may have a difficult time further reducing the toxicity of their effluents. Adding equipment to this end may be costly and relatively ineffective given the significance of the discharges and the dilution of contaminants. *The focus would be better directed toward at-source reduction* where intervention may be much cheaper and more effective, particularly with regard to industrial-source contaminants. In this way, public-education initiatives should also be envisaged to reduce the use of certain contaminants that are widely employed for domestic purposes, especially pesticides and surfactants.

Nonetheless, *other solutions must be found to problems inherent to certain treatment types in order to reduce effluent toxicity*. This is the case, for example, for aerated lagoons having concentrations of ammonia nitrogen that exceed 10 mg/L in winter. Although the selection criteria in this study rejected plants with elevated concentrations of ammonia nitrogen, we were nonetheless able to establish a link between this parameter and effluent toxicity. Several Quebec treatment plants show elevated concentrations of ammonia nitrogen. Based on all the data collected since 1995, 16 municipal treatment plants have obtained at least one result above 50 mg/L of ammonia nitrogen, and 27 plants (or 5% of plants in Quebec) obtained a general average greater than 10 mg/L. The highest concentrations are generally due to the presence of industrial plants, especially the agri-food sector, for which at-source reductions remain the best solution.

Just as in previous studies, the present study demonstrates that municipal treatment plants can be a source of contaminants at levels that are sometimes toxic or harmful to use of the water. We are not in a position to make any determinations on the impact of these effluents on their respective receiving environments. To do so, *the sampling frequency of a complete characterization of the effluents must be higher in order to consider variability, and the results should be analysed against environmental discharge objectives (EDO)*. EDOs are based on the quality criteria applicable to different uses of the water, and they take account of specifics of the effluent (especially flow rate) and characteristics of receiving environments.

The establishment of EDOs for the substances present in effluents and for overall toxicity, as measured by toxicity tests, is proving to be essential to determining the problems apprehended in a specific environment and to identifying the substances responsible, on a case-by-case basis. However, *municipal effluents are not the sole source of contamination of receiving environments. Inputs should be assessed as a function of other sources* such as sewer overflows of untreated wastewater, urban runoff, agricultural pollution, industries not connected up to municipal sewer systems, atmospheric deposition, upwellings of water on contaminated land, and sanitary landfill sites.

Lastly, *basic data on the water quality of receiving environments is also vital to this process.* Where it exists at all, real data on the majority of toxic substances in most water bodies is incomplete. *The MENV should continue to seek more such information and target problem substances on a priority basis.*

RÉSUMÉ

CONTEXTE DE L'ÉTUDE

D'importants moyens financiers et techniques ont été mis en œuvre depuis plus de 20 ans afin de récupérer les usages des cours d'eau du Québec. Environ sept milliards de dollars ont été dépensés dans le cadre du *Programme d'assainissement des eaux du Québec* (PAEQ) et du *Programme d'assainissement des eaux municipales* (PADEM). Ces programmes ont permis de raccorder à une station d'épuration 98 % de la population desservie par un réseau d'égouts. Les tendances observées dans les cours d'eau et l'évolution temporelle des charges suggèrent que les interventions d'assainissement des eaux réalisées depuis 1979 ont eu des effets positifs sur la qualité de l'eau des rivières du Québec. L'analyse des séries chronologiques des nitrites-nitrates, de l'azote ammoniacal, du phosphore total, de la turbidité et des coliformes fécaux révèle une prépondérance de tendances à la baisse. Les charges en demande biochimique en oxygène (DBO_5) et en matières en suspension (MES) provenant des eaux usées municipales sont également en baisse.

Malgré l'amélioration de la qualité des eaux rejetées dans les cours d'eau suite à la réalisation du PAEQ et du PADEM, il est possible que certains effluents municipaux présentent un potentiel toxique pour certaines espèces aquatiques. Les effluents municipaux peuvent aussi contenir des substances persistantes et bioaccumulables pouvant dégrader la qualité des tissus des organismes aquatiques qui y sont exposés.

Des études et des tests de toxicité effectués sur les effluents de stations d'épuration municipales un peu partout en Amérique du Nord ont révélé que plusieurs étaient toxiques. Certains effluents étaient fortement toxiques, causant la mort d'organismes en peu de temps (toxicité létale aiguë). D'autres avaient des effets à plus long terme (toxicité chronique). Ces études ont établi que la désinfection au chlore et la présence d'azote ammoniacal à des concentrations élevées étaient des causes généralisées importantes de la toxicité mesurée. Dans le cas de l'azote ammoniacal, la toxicité se produisait surtout l'hiver lorsque la nitrification est réduite. Le sulfure d'hydrogène a été identifié comme une cause additionnelle de la toxicité dans les étangs non aérés. D'autres substances comme les métaux, les surfactants et certains composés organiques pouvaient également contribuer à la toxicité des effluents municipaux. Au Québec, la problématique de la toxicité des effluents municipaux était moins bien connue puisque peu de tests de toxicité avaient été réalisés.

À la lumière de ces informations, et compte tenu de l'état d'avancement des programmes d'assainissement au Québec, le ministère de l'Environnement du Québec décidait en 1993 de former un comité dont le mandat était de déterminer les moyens à utiliser pour évaluer le potentiel toxique des effluents des stations d'épuration municipales du Québec. Le comité a d'abord conclu que bien peu de stations au Québec pouvaient présenter une toxicité due à la désinfection au chlore puisque seules deux stations utilisaient encore la chloration à cette époque,

méthode remplacée depuis par une désinfection aux ultraviolets. Le comité a également conclu que plusieurs stations, principalement des étangs aérés en hiver, pouvaient présenter des risques de toxicité dus à la présence de fortes concentrations d'azote ammoniacal.

Les recommandations du Comité étaient de procéder à la caractérisation des effluents de 15 stations d'épuration municipales, sélectionnées pour être représentatives non seulement de l'ensemble des principaux procédés de traitement existants au Québec, mais aussi des différentes conditions d'opération (i.e. avec et sans déphosphatation chimique; avec et sans apport industriel important). Il recommandait aussi que cette campagne soit réalisée à deux périodes différentes, soit en conditions d'opération hivernales et estivales.

La mise en œuvre de la campagne de caractérisation et la production de la présente étude ont été réalisées par le biais de l'entente d'harmonisation Québec-Canada : le programme *Saint-Laurent Vision 2000* (SLV 2000).

OBJECTIFS ET LIMITES D'INTERPRÉTATION DE L'ÉTUDE

L'objectif de l'étude était d'obtenir un portrait global et représentatif du potentiel toxique des rejets des stations d'épuration municipales, c'est-à-dire évaluer la toxicité des effluents non dilués sans tenir compte des particularités des milieux récepteurs ou de la charge rejetée. L'approche utilisée permet de comparer les effluents municipaux sur une base commune de façon à :

- évaluer la toxicité (aiguë et chronique) des rejets d'eaux usées traitées des stations d'épuration municipales à l'effluent (en bout de tuyau);
- mettre en évidence les substances susceptibles d'être à l'origine de la toxicité mesurée;
- identifier les causes communes de la toxicité et l'effet de certains facteurs pouvant influencer la toxicité à l'effluent.

Cette approche ne permet toutefois pas de faire un lien de cause à effet entre la toxicité mesurée et les effets potentiels sur le milieu. En effet, la toxicité de divers contaminants peut être modifiée en raison de certaines caractéristiques environnementales du milieu récepteur telles que la dureté, le pH, la température, la présence d'autres substances, la dégradation de produits parents en produits plus ou moins toxiques, la santé des populations présentes, etc. Pour évaluer l'impact appréhendé d'un effluent sur son milieu récepteur, il faut considérer, en plus des concentrations, les charges rejetées ainsi que les caractéristiques physiques (débit, hydrodynamisme, zones de déposition) et chimiques du milieu récepteur spécifique.

L'étude s'est limitée à l'aspect toxicité des effluents sans tenir compte des autres impacts possibles occasionnés par le rejet d'eaux usées municipales dans un cours d'eau. Les impacts physiques des effluents et des eaux de débordement (volumes d'eaux usées excédentaires rejetés sans traitement lors d'épisodes de pluies ou de fonte printanière) sur les habitats ainsi que les impacts thermiques, esthétiques et microbiologiques n'ont pas été évalués. L'aspect toxique des eaux de débordement n'a pas non plus été abordé.

Finalement, le faible échantillonnage ne permet pas de faire un traitement statistique des résultats et de caractériser la variabilité reconnue des eaux usées municipales.

APPROCHE EXPÉRIMENTALE ET OUTILS D'ÉVALUATION DU POTENTIEL TOXIQUE

Les quinze stations d'épuration municipales sélectionnées sont représentatives des principaux procédés de traitement utilisés au Québec (voir tableau 1). Sept d'entre elles sont associées à une charge industrielle importante. Quatre stations procèdent à la déphosphatation chimique toute l'année, six la font de façon saisonnière en période estivale et cinq stations ne font aucune déphosphatation. Elles ont été caractérisées sur une période s'échelonnant de 1996 à 1999, au cours de deux saisons pour la plupart, soit en hiver et en été. Durant les échantillonnages, toutes les stations ont fonctionné normalement et ont dans l'ensemble respecté les exigences de rejet (DBO_5, MES et P_t) pour lesquelles elles ont été conçues.

TABLEAU 1 : CARACTÉRISTIQUES DES STATIONS D'ÉPURATION MUNICIPALES SÉLECTIONNÉES

Procédé	**Nombre de stations d'épuration**			
	Faible apport industriel		**Fort apport industriel**	
	Avec déphosphatation	**Sans déphosphatation**	**Avec déphosphatation**	**Sans déphosphatation**
Boues activées	1	1	2	1
Étangs aérés	1	1	2	1
Biofiltration	1	1	-	-
Physico-chimique	1	-	1	-
Étangs non aérés	1	-	-	-

L'échantillonnage s'est déroulé sur trois jours non consécutifs à chaque saison. En tout, sept tests de toxicité ont été réalisés et jusqu'à 26 paramètres physico-chimiques génériques, 19 métaux et 8 familles de substances organiques chlorées et non chlorées ont été analysés dans les échantillons recueillis (voir tableaux 2 et 3). Bien qu'il puisse y avoir un biais dans la comparaison des résultats pour certaines substances en raison des modifications qui ont été apportées au profil analytique au cours du projet, le protocole expérimental utilisé permet d'obtenir un portrait représentatif de la qualité et de la toxicité potentielle des eaux usées municipales et ce, en conditions normales d'opération des stations.

TABLEAU 2 : TESTS DE TOXICITÉ UTILISÉS ET CARACTÉRISTIQUES DESCRIPTIVES

Organisme	Espèce	Échelon trophique	Niveau de toxicité	Variable d'effet
Bactéries marines	*Vibrio fischeri* (Microtox™)	Décomposeur	Sublétalité aiguë	Inhibition de la luminescence
Bactéries	*Escherichia coli* PQ37 (SOS Chromotest)	Décomposeur	Sublétalité chronique	Génotoxicité et viabilité cellulaire
Algues	*Selenastrum capricornutum*	Producteur primaire	Sublétalité chronique	Inhibition de la division cellulaire
Cladocères (crustacés)	*Ceriodaphnia dubia*	Consommateur primaire	Létalité et sublétalité chronique	Mortalité et inhibition de la reproduction
Cladocères (crustacés)	*Daphnia magna*	Consommateur primaire	Létalité aiguë	Mortalité
Larves de poisson	*Pimephales promelas* (Tête-de-boule)	Consommateur secondaire	Létalité et sublétalité chronique	Mortalité et inhibition de la croissance
Poissons	*Oncorhynchus mykiss* (Truite arc-en-ciel)	Consommateur secondaire	Létalité aiguë	Mortalité

TABLEAU 3 : LISTE DES PARAMÈTRES ANALYSÉS AUX STATIONS D'ÉPURATION

Paramètres physico-chimiques (PPC)	Métaux	Substances organiques
• Paramètres conventionnels : pH, oxygène dissous (OD) et température Conductivité Dureté totale (en $CaCO_3$) Carbone organique total (COT) Demande biochimique en oxygène (DBO_5) DBO carbonée (DBO_5C) Demande chimique en oxygène (DCO) Matières en suspension (MES) Solides totaux (ST) • Éléments nutritifs : Azote ammoniacal ($N\text{-}NH_3\text{-}NH_4^+$) Azote total Kjeldahl (N-NKT) Nitrites (NO_2) Nitrites-nitrates ($NO_2\text{-}NO_3$) Phosphore total (P tot.) • Ions majeurs : Chlorures (Cl^-) Chlore résiduel total (CRT) Cyanates (CNO^-) Cyanures totaux (CN^-) Fluorures totaux (F^-) Sulfates (SO_4^{2-}) Sulfures dissous (S^{2-} dis.) Sulfures totaux (S^{2-} tot.) • Huiles et graisses : Hydrocarbures totaux Matières extractibles au fréon	• Aluminium (Al) • Antimoine (Sb) • Argent (Ag) • Arsenic (As) • Baryum (Ba) • Béryllium (Be) • Bore (B) • Cadmium (Cd) • Chrome (Cr) • Cobalt (Co) • Cuivre (Cu) • Fer (Fe) • Mercure (Hg) • Molybdène (Mo) • Nickel (Ni) • Plomb (Pb) • Sélénium (Se) • Vanadium (V) • Zinc (Zn)	• Substances phénoliques • Substances organiques semi-volatiles (SOBN) : Balayage de plus de 50 substances organiques • Substances organiques volatiles (SOV) : Balayage de plus de 40 substances organiques • Surfactants non ioniques et anioniques • Biphényles polychlorés (BPC) : 43 congénères spécifiques Groupes homologues • Hydrocarbures aromatiques polycycliques (HAP) : 22 HAP spécifiques • Dioxines et furanes chlorés : 17 congénères spécifiques Groupes homologues • Pesticides : 32 pesticides organophosphorés et autres 14 herbicides phénoxyacides

L'approche d'évaluation du potentiel toxique adoptée comporte trois outils d'évaluation complémentaires : l'étude de l'amplitude des dépassements des critères de qualité de l'eau pour les substances chimiques analysées; l'étude de l'amplitude des dépassements des critères de toxicité globale pour les tests de toxicité; puis l'étude de la compilation des toximesures, l'une des composantes de l'indice BEEP. Cette approche permet de faire ressortir les substances propres aux eaux usées des stations d'épuration municipales ainsi que la toxicité des effluents et les substances susceptibles d'en être responsables. Elle permet aussi de juger de l'importance du type de procédé de traitement, de l'effet de la charge industrielle, de la présence d'un procédé de déphosphatation chimique ou de l'efficacité des traitements en fonction des saisons.

RÉSULTATS DES ANALYSES PHYSICO-CHIMIQUES ET POTENTIEL TOXIQUE SELON L'AMPLITUDE DES DÉPASSEMENTS DES CRITÈRES DE QUALITÉ DE L'EAU POUR LES SUBSTANCES ANALYSÉES

L'un des premiers constats qui s'impose à l'examen des résultats analytiques est la variabilité de la qualité des eaux usées municipales. Les réponses toxiques et les concentrations mesurées pour plusieurs substances varient significativement d'une journée d'échantillonnage à l'autre. Une variation saisonnière a également été observée pour certaines substances, dont celles qui dépendent de l'activité biologique lors du traitement des eaux usées, tels l'azote ammoniacal et le sulfure d'hydrogène, ou dont l'utilisation est saisonnière, tels les chlorures utilisés dans les fondants pour le déglaçage des routes.

Les substances les plus fréquemment détectées dans les échantillons prélevés aux 15 stations sont présentées au tableau 4. Comme elles ont été détectées dans plus de 85 % des échantillons analysés, ces résultats suggèrent que ces substances sont susceptibles de se retrouver dans les eaux usées de plusieurs stations au Québec.

TABLEAU 4 : SUBSTANCES AYANT ÉTÉ DÉTECTÉES DANS PLUS DE 85 % DES ÉCHANTILLONS ANALYSÉS

Éléments nutritifs	Ions majeurs	Métaux	Substances organiques
Azote ammoniacal Nitrites et nitrates Phosphore	Chlorures Fluorures Sulfates	Aluminium Arsenic Baryum Bore Chrome Cuivre Fer Mercure (1)	BPC Dioxines et furanes chlorés Herbicides (2) HAP Surfactants anioniques

(1) : Fréquence supérieure à 85 % avec les échantillons prélevés en 98-99 uniquement en raison de l'utilisation d'une méthode ayant une meilleure limite de détection.

(2) : Les pesticides (herbicides et insecticides) ont été analysés dans 42 échantillons prélevés à deux stations seulement. Seuls les herbicides 2,4-D et mécoprop ont été détectés dans plus de 85 % des échantillons.

Bien que ces substances soient pratiquement omniprésentes dans les eaux usées des 15 stations, elles ne se retrouvent pas nécessairement dans l'effluent en concentrations jugées toxiques ou nuisibles. Plusieurs ne présentent aucun dépassement des critères de qualité de l'eau (sulfates, baryum, bore et herbicides) ou présentent quelques dépassements ponctuels de faible amplitude (chlorures, fluorures, fer et HAP).

Parmi les pesticides recherchés pour leur utilisation en milieu urbain, sept ont été détectés à l'effluent des deux stations d'épuration où ces analyses ont été effectuées. Ce sont les herbicides 2,4-D, mécoprop et dicamba, trois herbicides présents dans les mélanges commerciaux utilisés pour le traitement des pelouses, ainsi que les insecticides diazinon, carbaryl, malathion et chlorpyrifos. D'autres pesticides utilisés en grande culture ont également été détectés. La détection de ces derniers dans les effluents municipaux est probablement attribuable au transport atmosphérique depuis la zone agricole ceinturant la région urbaine. En été, les concentrations de pesticides, et plus particulièrement celles d'herbicides, semblent augmenter lors d'événements pluvieux en raison du ruissellement urbain. Ces résultats sont corroborés par d'autres études effectuées en Ontario et aux États-Unis.

L'étude de l'amplitude des dépassements des critères de qualité pour la protection de la vie aquatique montre qu'il y a pour quelques substances des dépassements fréquents des critères de qualité dont certains atteignent de fortes amplitudes (> 10). C'est le cas notamment pour l'azote ammoniacal, le phosphore, le sulfure d'hydrogène, l'aluminium, l'argent, le chrome, le cuivre, deux insecticides (le diazinon et le chlorpyrifos) et plus particulièrement pour les surfactants. Dans ce dernier cas, partout où les surfactants non ioniques et anioniques ont été détectés, ils dépassaient les critères de qualité de l'eau, et les dépassements sont importants dans la majorité des cas. La présence de ces substances à de telles concentrations suggère que les eaux usées municipales présentent un potentiel toxique nuisible à long terme pour la vie aquatique et ce, plus particulièrement dans les cours d'eau qui n'auraient pas une grande capacité assimilatrice.

D'autres substances, reconnues pour être toxiques et hautement bioaccumulables, semblent être omniprésentes et ont été détectées à des concentrations significatives par rapport aux critères de qualité pour la prévention de la contamination des organismes aquatiques. C'est le cas pour les BPC et les dioxines et furanes chlorés, et dans une moindre mesure, pour le mercure. Ces substances peuvent contaminer la chair ou les tissus des poissons, mollusques et crustacés, les rendant impropres à une consommation sans restriction. Pour la faune terrestre piscivore, ces substances peuvent être plus dommageables puisque la quantité de poissons consommée par cette faune est plus élevée que celle consommée par les humains et qu'elle consomme les organismes en entier, incluant les tissus où la bioaccumulation est plus élevée que dans la chair.

Les sources de ces substances bioaccumulables dans les eaux usées municipales, BPC et dioxines et furanes chlorés plus particulièrement, sont multiples et complexes. Outre les rejets industriels, ces substances peuvent provenir de sources atmosphériques plus ou moins éloignées et contaminer les eaux de ruissellement urbain de même que les milieux aquatiques récepteurs desquels les municipalités puisent leur eau d'approvisionnement. Seules des études de bilan massique sur le réseau municipal permettraient de déterminer l'apport des différentes sources acheminées aux stations d'épuration.

POTENTIEL TOXIQUE POUR LA VIE AQUATIQUE SELON LES TESTS DE TOXICITÉ DE L'APPROCHE DE PROTECTION DU MILIEU AQUATIQUE DU MENV

Avec les tests de toxicité aiguë, il y a peu de dépassements du critère de toxicité globale de 1 UTa et ceux-ci sont de très faibles amplitudes dans la majorité des cas. Plus de la moitié des stations (53 %) n'ont obtenu aucun résultat supérieur à 1 UTa. 22 % des échantillons ont été toxiques pour la Truite arc-en-ciel et 11 % l'ont été pour *Daphnia magna*. À titre de comparaison, une étude ontarienne similaire réalisée en 1992 montre des pourcentages de 56 % et 27 % respectivement. Ces différences sont principalement liées au fait que les stations d'épuration du Québec n'appliquent pas un traitement au chlore pour désinfecter leurs eaux usées, contrairement à plusieurs stations en Ontario.

L'azote ammoniacal, à des concentrations supérieures à 10 mg/L, semble être le principal responsable de la toxicité aiguë mesurée. Les surfactants pourraient être le deuxième contaminant le plus généralisé alors que les nitrites sont à suspecter à une station. La présence de pesticides en été peut être une autre cause de toxicité.

Des effets de toxicité chronique ont été mesurés sur les effluents non dilués de presque toutes les stations, mais dans l'ensemble les dépassements du critère de toxicité globale de 1 UTc sont de faible amplitude (réponses de 1 à 2 UTc), ce qui suggère qu'il n'y aura pas ou peu d'effets sur le milieu une fois l'effluent mélangé dans le cours d'eau. Toutes saisons confondues, un peu plus du tiers des stations ont obtenu des résultats au-dessus de 10 UTc, ce qui confère à ces effluents le potentiel de nuire à la vie aquatique là où les cours d'eau ont une faible capacité assimilatrice. Une seule station a obtenu des résultats supérieurs à 30 UTc.

Presque tous les échantillons ont provoqué une stimulation de la croissance algale. Cette réponse positive chez l'algue *S. capricornutum* n'est pas quantifiée en terme d'unité toxique, mais indique tout de même un potentiel de nuisance pour la vie aquatique par le processus d'eutrophisation.

Les substances les plus susceptibles d'avoir contribué à la toxicité chronique mesurée sont l'azote ammoniacal, quelques métaux (cuivre, chrome et aluminium principalement), les surfactants et, de façon probable, certains pesticides dont le diazinon et le chlorpyrifos. Dans certains cas spécifiques, les nitrites, les cyanures ou le sulfure d'hydrogène ont pu jouer un rôle. Dans tous les cas, l'expression d'effets chroniques coïncide avec la présence simultanée de plusieurs substances à des concentrations supérieures aux seuils sécuritaires.

Seules des études d'identification de la toxicité permettraient de déterminer, au cas par cas, les substances responsables de la toxicité chronique et aiguë.

POTENTIEL TOXIQUE SELON LES TOXIMESURES DE L'INDICE BEEP

Aucun seuil ou critère n'a encore été fixé pour indiquer un niveau de préoccupation ou de nuisance en regard de la toximesure de l'indice BEEP (Barème d'effets écotoxiques potentiels).

Bien qu’il ne soit pas possible de conclure sur le potentiel toxique des effluents municipaux à l’égard des toximesures, cet outil permet de mieux définir la qualité des eaux usées et il s’est avéré utile dans l’interprétation des résultats.

Le test de génotoxicité a été particulièrement sensible aux eaux usées municipales puisque des réponses toxiques ont été observées à plus de deux stations sur trois. Ces résultats suggèrent que les effluents municipaux non dilués peuvent contenir des substances en concentrations capables d’altérer l’ADN bactérien.

INFLUENCE DES SAISONS, DU TYPE DE TRAITEMENT, DE LA CHARGE INDUSTRIELLE ET DE LA DÉPHOSPHATATION SUR LE POTENTIEL TOXIQUE

Les résultats de l’étude indiquent que le potentiel toxique des effluents des stations d’épuration municipales du Québec est variable d’une station à l’autre. Les effluents des étangs aérés caractérisés en conditions d’opération hivernales sont souvent toxiques aigus pour la Truite arc-en-ciel en raison de concentrations élevées d'azote ammoniacal. Les procédés de traitement sans équipement d’aération (étangs non aérés et procédés physico-chimiques) pourraient présenter un potentiel toxique plus élevé certaines périodes de l’année (durant la vidange de printemps pour les étangs non aérés et durant l’été pour le traitement physico-chimique) en raison de la production biologique de sulfure d’hydrogène en conditions anaérobies.

Les effluents des stations ayant une importante charge industrielle ont été, dans l’ensemble, plus toxiques que ceux des stations avec une faible charge industrielle. L’examen des résultats indique que l’apport industriel semble être un facteur déterminant du potentiel toxique des effluents municipaux, même si ceux-ci peuvent être toxiques sans apport industriel important.

En plus de l’enlèvement du phosphore, la déphosphatation chimique aurait un effet bénéfique sur l’enlèvement des métaux. Par contre, elle semble entraîner une augmentation de la concentration du métal utilisé comme coagulant. Bien que la déphosphatation chimique semble également avoir un effet bénéfique sur le potentiel toxique des effluents municipaux, il est impossible de conclure en toute certitude puisque les résultats des tests de toxicité obtenus ici sont dans l’ensemble beaucoup plus influencés par le type de traitement, les saisons et la charge industrielle que par la déphosphatation.

CONCLUSION À L’ÉGARD DES MÉTHODES D’ANALYSE ET D’ÉCHANTILLONNAGE UTILISÉES

L’utilisation de meilleures techniques analytiques a permis d’abaisser les limites de détection et ainsi d'obtenir un meilleur portrait de la qualité des eaux usées municipales, en plus d’obtenir des résultats comparables aux seuils sécuritaires définis (les critères de qualité de l’eau) pour plusieurs substances et métaux. Ces meilleures techniques ont aussi permis de mettre en évidence la présence de substances rarement quantifiées dans ce type d’effluents (par exemple les BPC et les dioxines et furanes chlorés).

Contrairement à d’autres études réalisées ailleurs, le ciblage des pesticides susceptibles de se retrouver en milieu urbain s’est avéré utile ici dans le choix de méthodes analytiques plus appropriées pour mettre en évidence leur présence dans les eaux usées municipales.

Les méthodes d’analyse par balayage des substances organiques semi-volatiles (SOBN) et volatiles (SOV) ont montré que dans le cas des effluents municipaux ces méthodes manquaient de spécificité et de résolution. Il y aurait avantage à cibler un nombre restreint de substances, par exemple uniquement la vingtaine de SOV faisant l’objet d’une accréditation des laboratoires.

Cette étude confirme encore une fois la nécessité d’utiliser plusieurs tests de toxicité afin d’évaluer adéquatement la toxicité d’un effluent en raison de la variabilité des contaminants présents dans les échantillons qui fait parfois réagir une espèce, parfois une autre.

CONCLUSION GÉNÉRALE

Les interventions en assainissement municipal réalisées au Québec depuis 1979 ont eu des effets positifs sur la qualité des cours d’eau. Les stations d’épuration construites dans le cadre de ces programmes d’assainissement ont été conçues de façon à réduire particulièrement les principaux contaminants des eaux usées municipales, soit les paramètres conventionnels (DBO_5, MES, phosphore et coliformes fécaux). Bien que ces stations puissent atteindre un certain rendement à l’égard de l’enlèvement des autres contaminants potentiellement présents dans les eaux usées municipales, elles ne peuvent les éliminer complètement.

Dans le cadre de cette étude, les effluents de 15 stations d’épuration municipales ont été caractérisés. Les résultats des tests de toxicité montrent que même si les eaux usées de presque toutes les stations étudiées présentent une toxicité après traitement, les effluents municipaux sont, à quelques exceptions près, peu toxiques pour les espèces testées.

La principale substance responsable de la toxicité mesurée semble être l’azote ammoniacal, à des concentrations supérieures à 10 mg/L. En saison froide, lorsque le processus de nitrification est réduit, les concentrations d'azote ammoniacal sont plus élevées, particulièrement dans les étangs aérés. Suivraient les surfactant anioniques, puis dans une moindre mesure, les surfactants non ioniques. Les surfactants sont des molécules organiques qui entrent dans la composition de centaines de produits utilisés, entre autres, comme agents nettoyants autant à des fins domestiques qu’industrielles. Enfin, d’autres substances, telles que certains pesticides et métaux, pourraient aussi être responsables de la toxicité mesurée.

Cette étude met en évidence l’omniprésence de plusieurs substances dans les eaux usées municipales de quinze stations d’épuration, dont certaines substances organiques rarement quantifiées dans d’autres études et se retrouvant à des concentrations pouvant détériorer des usages de l’eau. Il s’agit des surfactants, des BPC et des dioxines et furanes chlorés. Il en est de même pour certains pesticides en saison estivale lors d’événements de pluie. Toutefois, pour évaluer leur impact réel, il faudrait considérer les charges rejetées et détenir dans chacun des cas de bonnes connaissances des caractéristiques biophysiques et chimiques des milieux récepteurs respectifs.

L’importance de l’apport industriel aux stations d’épuration semble être un facteur déterminant du potentiel toxique des effluents municipaux, même si ceux-ci peuvent être toxiques sans apport industriel important.

RECOMMANDATIONS

Les stations d’épuration municipales qui respectent leurs exigences de rejet pourraient difficilement réduire davantage la toxicité de leurs effluents. L’ajout d’équipements pour accomplir cette tâche risque d’être coûteux et peu efficace compte tenu de l’importance des débits et de la dilution des contaminants. *Les efforts devraient plutôt être orientés vers la réduction à la source* où les interventions risquent d’être beaucoup plus économiques et efficaces, particulièrement en ce qui a trait aux contaminants de source industrielle. Dans cette optique, des efforts de sensibilisation adressés aux citoyens devraient également être envisagés pour réduire l’usage de certains contaminants utilisés dans une large mesure à des fins domestiques (pesticides et surfactants notamment).

Toutefois, *certains problèmes inhérents au type de traitement devront trouver d’autres avenues de solution afin de réduire la toxicité des effluents*. C’est le cas, par exemple, pour les étangs aérés avec des concentrations d'azote ammoniacal supérieures à 10 mg/L en hiver. Les critères de sélection des stations retenues ici excluaient celles ayant des concentrations élevées d'azote ammoniacal. Malgré cela, l’étude a pu établir un lien entre ce paramètre et la toxicité des effluents municipaux. Au Québec, plusieurs stations obtiennent des concentrations élevées d'azote ammoniacal. Sur l’ensemble des résultats compilés depuis 1995, 16 stations d’épuration municipales ont obtenu au moins un résultat supérieur à 50 mg/L d'azote ammoniacal et 27 stations ont obtenu une moyenne générale supérieure à 10 mg/L, ce qui représente 5 % des stations au Québec. Les concentrations les plus élevées sont généralement dues à la présence d’industries, surtout du secteur agroalimentaire. Dans ce dernier cas, la réduction à la source demeure une solution à privilégier.

Comme d’autres études l’ont fait auparavant, l’étude démontre que les stations d’épuration municipales peuvent être une source de contaminants à des seuils parfois toxiques ou nuisibles aux usages de l’eau. La présente étude ne permet cependant pas de juger de l’impact des effluents sur leur milieu récepteur respectif. Pour ce faire, *la fréquence d’échantillonnage d’une caractérisation complète des effluents doit être plus élevée pour en apprécier la variabilité et les résultats devraient être analysés à la lumière d’objectifs environnementaux de rejet (OER)*. Les OER sont basés sur les critères de qualité pour les différents usages de l’eau et ils tiennent compte de la spécificité de l’effluent (le débit notamment) et des caractéristiques des milieux récepteurs.

L’établissement d’OER pour l’ensemble des substances présentes à l’effluent et pour la toxicité globale mesurée à l’aide des tests de toxicité s’avère donc essentiel pour préciser au cas par cas les problèmes appréhendés dans un milieu précis et pour identifier les substances qui en sont responsables. Toutefois, *les effluents municipaux ne sont pas les seules sources de contamination des milieux récepteurs. Leur apport devrait être évalué en fonction des autres sources* telles que les débordements d'eaux usées non traitées via les ouvrages de surverses, les eaux de ruissellement urbain, la pollution d'origine agricole, les industries hors réseau d'égouts municipal, les retombées atmosphériques, les eaux de résurgence des terrains contaminés et des lieux d'enfouissement sanitaire.

Enfin, *des données de base sur la qualité de l'eau des milieux récepteurs sont aussi nécessaires dans cette démarche*. Pour la majorité des substances toxiques, les données actuelles sont partielles, voire inexistantes, pour la plupart des plans d'eau. *Le MENV devrait continuer à favoriser ce gain d'information et cibler en priorité les substances problématiques*.

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GLOSSARY

Acute toxicity – Toxicity that occurs within a short time period (seconds, minutes, hours or a few days) relative to the life expectancy of the test organism.

Bioaccumulation – The net accumulation of a substance in the tissues of an organism resulting from the exposure to different sources of contamination in the environment.

Biodegradation – Microbiological process (e.g. due to bacterial activity) that alters the chemical structure of a compound. It usually causes decomposition of organic molecules into smaller components. For example, biodegradation of hydrocarbons in aerobic conditions ultimately releases organic carbon (CO_2) and water (H_2O).

Biological characterization – Group of toxicity tests conducted to evaluate the ecotoxic potential of an experimental matrix (e.g. a sample of effluent from a wastewater treatment plant).

Chronic toxicity – Toxicity that occurs during a relatively long exposure period, corresponding to at least 10% of the organism's life cycle.

Composite sample – Reconstituted sample from the mixture of effluent sub-samples or from feed water collected at the sampling point of the treatment plant.

Discharge requirement – Specific limits defined by the MAMM (Quebec Municipal Affairs Ministry) and expressed in concentrations and loads to ensure optimal operation of each municipal wastewater treatment plant. The discharge requirements are defined for one or more of the following parameters: BOD_5, SM, P_T and/or fecal coliforms.

Environmental discharge objectives (EDOs) – Specific limits defined by the MENV, expressed in concentrations and loads. These environmental discharge objectives do not necessarily convert into discharge requirements because they take technological limitations into consideration. The environmental discharge objectives are based on quality criteria for different activities in water bodies. They also take into consideration the specificity of the effluent (flow rate, for one) and the characteristics of the receiving environment.

Ecotoxic effect – Toxic effect for one or many environmental components.

IC_{50} – Median inhibition concentration. The estimated concentration of the effluent (% v/v) that leads to 50% inhibition of a quantitative biological function (e.g. growth), with respect to the control organisms, after a given exposure period.

LC_{50} – Median lethal concentration. The concentration of the effluent (% v/v) that is considered lethal for 50% of the organisms subjected to the test. LC_{50} is derived by statistical analysis of deaths observed at different experimental concentrations after a given exposure period (e.g. 96 hours).

Lethal – That which results in the death of exposed organisms. For example, the death of trout is defined as the moment when signs of movement or activity cease to be observed.

LOEC – Lowest observed effect concentration. The lowest concentration of an experimental matrix that produces harmful effects on organisms exposed thereto. For example, the LOEC is the most reliable concentration to which the growth of algae exposed to the effluent sample differs significantly from the control organisms.

NOEC – No-observed effect concentration. The highest concentration of an experimental sample that produces no observed harmful effect on the organisms exposed thereto. The no-observed effect must also be statistically significant. For example, NOEC is the highest test concentration to which the growth of algae does not differ significantly from the control organisms.

Planar or coplanar PCB – PCB molecule that can adopt a planar configuration.

Quality control – Group of techniques and means to measure and assess the quality of data, and if required, corrective measures to apply when quality standards are not being met.

Sublethal – That which is harmful for the organism subjected to the test, but below the level that leads to death during a test.

TEC – Threshold effect concentration. The geometric mean of NOEC and LOEC.

Toxicity – Capacity specific to a substance or matrix (e.g. a sample of effluent from a wastewater treatment plant) to result in harmful effects to the organism exposed thereto.

Toxicity test – Laboratory test that allows for the determination of the effect of matter or of a matrix (e.g. a sample of effluent from a wastewater treatment plant) on a group of organisms from the same species (e.g. *Vibrio fischeri*), in well-defined conditions. A toxicity test is usually serves either to measure the proportion of organisms affected or to determine the intensity of the observed effect, after exposure to matter or to a given experimental matrix. Generally called a *bioassay* or *biological test*.

Toxic unit – Relative toxicity unit of an experimental sample; for an effluent, calculate as follows:

$$\text{Toxic unit} = \frac{100\,\%}{\text{toxicity result (ex.: IC}_{50} = \text{x \%)}}$$

SYMBOLS AND ABBREVIATIONS

<	result or mean concentration lower than the detection limit
*	result rejected relative to quality control
( )	(result shown in parentheses): result with a high level of uncertainty in relation to quality control; to be considered with caution
	(blank box in results tables): indicates a parameter that was not measured
ß-gal	ß-galactosidase
µg	microgram (10^{-6} g)
µS	microSiemens
% v/v	volume percent
ACAL	acute water quality criterion for the protection of aquatic life
$\mathrm{ATU.bvu}^{-1}$	adjusted toxic unit per bioanalytical volume unit
$\mathrm{ATU.h}^{-1}$	adjusted toxic unit per hour
BOD_5	five-day biochemical oxygen demand
CBOD_5	five-day carbonated biochemical oxygen demand
CCAL	chronic water quality criterion for the protection of aquatic life
CPCO	water quality criterion for the prevention of contamination of aquatic organisms
CPPW	water quality criterion for the protection of piscivorous wildlife
CUM	Communauté urbaine de Montréal (Montreal Urban Community)
CUO	Communauté urbaine de l’Outaouais (Outaouais Urban Community)
CUQ	Communauté urbaine de Québec (Quebec Urban Community)
d	day
Df	dilution factor
DNA	desoxyribonucleic acid
EDO	environmental discharge objective
FAV	final acute value (= 2 x ACAL)
$\mathrm{GU}_{\mathrm{CS}}$	chronic sublethality genotoxic unit
IC_{50}	median inhibition concentration
LC_{50}	median lethal concentration
LD	limit of detection
< LIM	mean concentration lower than the detection limit
LOEC	lowest observed effect concentration
MAMM	ministère des Affaires municipales et de la Métropole du Québec (Quebec Municipal Affairs Ministry)
MENV	ministère de l’Environnement du Québec (Quebec Environment Ministry)
ng	nanogram (10^{-9} g)

nl	non-lethal
nm	nanometre
NOEC	no-observed effect concentration
ns	non-significant
nv	non-valid
PADEM	Programme d'assainissement des eaux municipales (Quebec Municipal Wastewater Abatement Program)
PAEQ	Programme d’assainissement des eaux du Québec (Quebec Wastewater Abatement Program)
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PCP	physico-chemical parameter
PEEP	potential ecotoxic effects probe
pg	picogram (10^{-12} g)
P_T	total phosphorus
S9	microsomal fraction of rat liver
SLAP	St. Lawrence Action Plan
SLV 2000	St. Lawrence Vision 2000
SM	suspended matter
SVOC	semi-volatile organic substance
TEC	threshold effect concentration
TM	total metal
TRC	total residual chlorine
TUa	acute toxic unit
TU_{AS}	acute sublethality toxic unit
TUc	chronic toxic unit
TU_{CS}	chronic sublethality toxic unit
TU_L	lethal toxic unit
TU_S	sublethal toxic unit
VOC	volatile organic substance
Xgal	5-bromo-4-chloro-3-β-D-galactoside (X-gal)

1 INTRODUCTION

1.1 Background

Major financial and technical resources have been marshalled over the last 20 years to recover use of Quebec's watercourses. Some $7 billion was spent within the framework of two water cleanup programs: the *Programme d'Assainissement des Eaux du Québec* (PAEQ) and the *Programme d'Assainissement des Eaux Municipales du Québec* (PADEM). By virtue of these programs, 98% of the Quebec population that have existing sewer services were connected up to wastewater treatment plants. Observed trends and changes in contaminant loads over time suggest that the water cleanup activities[1] carried out between 1979 and 1998 have had positive effects on the water quality of Quebec rivers (Painchaud, 1997; Simard and Painchaud, 2000). Time series analyses of nitrite-nitrates, ammonia nitrogen, total phosphorus, turbidity and fecal coliforms reveal a preponderant downward trend. Improvement in water quality has been more noticeable during the last 10 years (1988-1998) than during the 1979-1994 period (Simard and Painchaud, 2000). Loads of biochemical oxygen demand (BOD_5) and suspended matter (SM) in municipal effluents are also diminishing.

Despite the improved quality of effluents released to watercourses in the wake of the PAEQ and PADEM programs, it is possible that certain municipal effluents are potentially toxic to some aquatic species. Municipal effluents may also contain persistent and bioaccumulable substances that can degrade the quality of body tissue in organisms exposed to them. These substances also increase the exposure sustained by fish-eating animals.

Studies and toxicity tests conducted throughout North America found that many municipal treatment plant effluents were toxic to the organisms observed fish, shellfish and algae (Rutherford *et al*., 1993; Orr *et al*., 1992). Some effluents were highly toxic, causing the death of organisms within a short period of time (acute lethal toxicity), while others had more long-term effects (chronic toxicity).

In light of this information, and given the progress of the water cleanup programs, the Quebec Environment Ministry (MENV) decided, in 1993, to set up a committee mandated to determine the means by which to assess the toxic potential of effluents generated by municipal wastewater treatment plants in Quebec.

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[1] Activities carried out in the municipal, industrial and agricultural sectors.

1.2 Global Issue and Studies Carried Out by the Quebec Environment Ministry Committee

The toxicity of a municipal effluent may have several origins. For example, it may be due to contaminants in the effluent of the wastewater treatment plant not being sufficiently controlled by the treatment; substances, such as chlorine, that are added during treatment; changes in the physico-chemical characteristics of the water, such as the transformation of organic nitrogen into ammonia nitrogen, during treatment, or the combined effect of several contaminants simultaneously present in the effluent.

By virtue of the MISA program (Municipal and Industrial Strategy for Abatement), the Ontario Ministry of the Environment conducted several studies to assess the toxicity of municipal effluents. A sampling of 37 municipal treatment plants at first showed that within the range of contaminants analysed, metals were found most frequently and in significant concentrations relative to water quality criteria (Canviro Consultants, 1989).

In a second report, Beak and Canviro (1990) established that chlorine and ammonia nitrogen were major causes of the toxicity measured. Indeed, chlorine disinfection was identified as a source of toxicity for aquatic life. They also emphasized that primary treatment effluents, even without chlorine disinfection, were generally toxic. This was likely due to the presence of high concentrations of ammonia nitrogen and to insufficient removal of BOD_5. The secondary treatment effluents were sometimes toxic, particularly when concentrations of ammonia nitrogen exceeded 10 mg/L. This occurred mostly during winter, when nitrification is reduced. In the case of unaerated lagoons, hydrogen sulfide was identified as an additional cause of toxicity. According to the authors, other substances, such as metals, surfactants and some organic compounds, may also contribute to the toxicity of municipal effluents.

Following this report, the Ontario Ministry of the Environment conducted toxicity tests on the effluents of 10 municipal treatment plants (Orr *et al*., 1992). Acute toxicity tests established that of the 123 water samples drawn, 56% were toxic (acute lethality) for rainbow trout (*Oncorhynchus mykiss*) and 27% were toxic (acute lethality) for the cladoceran *Daphnia magna*. Chlorine disinfection and high concentrations of ammonia nitrogen were identified as the main causes of this toxicity. Other toxicity tests were conducted on 80 samples selected and treated[2] to measure chronic toxicity: 69% of those samples caused a reduction in the growth of the fathead minnow (*Pimephales promelas*) and 56% of the samples affected the reproduction of the cladoceran *Ceriodaphnia dubia*. Other parameters, such as BOD_5, dissolved organic carbon, SM and metals also appeared to be related to the toxicity of some samples. In addition, hydrogen sulfide seemed to have contributed to the toxicity observed in the samples taken from unaerated lagoons. Finally, as for other studies, the Orr *et al.* study (1992) showed that the sensitivity of organisms to toxic substances found in the samples varies from one species to another, and that is why it is important to use several toxicity tests that are representative of various trophic levels.

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[2] The samples were dechlorinated and the pH was adjusted when high concentrations of chlorine and ammonia nitrogen were measured, in order to reduce toxicity due to those substances.

In the United States, a NPDES permit (National Pollutant Discharge Elimination System) is required to release wastewater into the environment. When renewing the licenses of municipal wastewater treatment plants, monitoring requirements are established and included in the license, such as toxicity tests and contaminant concentration levels to be respected. When toxicity tests demonstrate that an effluent is toxic, identification and toxicity reduction procedures are established (*toxicity identification evaluation* – TIE and *toxicity reduction evaluation* – TRE).

In Canada, all wastewater treatment plant effluents are subject to Section 36(3) of the *Fisheries Act*. This provision prohibits the disposal of harmful substances in any water frequented by fish. Under this law, the Minister of Fisheries and Oceans has the power to authorize exceptions to the general prohibition, by means of regulations. Such power has not been exercised in relation to the discharge of municipal wastewater.

The problem of effluent toxicity in Quebec is not well understood, as few toxicity tests have yet been conducted. However, the situation in Quebec is different from that of Ontario or the United States, due to the fact that chlorine disinfection of wastewater is almost non-existent. The toxicity of chlorine being recognized when Quebec introduced its cleanup program, other systems, such as ultraviolet disinfection, were preferred.

In addition, in Quebec, industrial facilities that are connected to a municipal sewer system must comply with the discharge standards of the municipal by-laws in effect. Most municipalities have adopted such by-laws. However, the prescribed concentrations do not ensure that discharges will be free of toxic substances once treated. The toxicity of the effluent at the end of the treatment process would therefore depend on the composition of the wastewaters going into the treatment plant and on the performance of the treatment system. It must also be said that municipal by-laws do not cover all potential contaminants.

Following an analysis of the situation, the committee created by the MENV produced a report in February 1994 (Tétreault *et al*., 1994). In this report, the committee concluded that very few treatment plants in Quebec generated any toxicity due to chlorine disinfection[3]. On the other hand, of the 160 plants for which data was available in 1991–92, 61 plants (38%) showed at least one downstream sampling result containing more than 20 mg/L of ammonia nitrogen. For the committee, these plants — particularly those with aerated lagoons where the nitrification process is reduced in winter — presented a high toxicity risk. To this list may be added the few unaerated lagoons with continuous winter flow, since they may contain high concentrations of hydrogen sulfide.

The committee recommended a characterization campaign, including physico-chemical analyses and toxicity tests, to assess the toxic potential of municipal effluents. It recommended a campaign covering 15 municipal treatment plants, selected for their representativeness in terms of all treatment processes and various operating conditions (i.e. with/without chemical dephosphatization, with/without major industrial inputs) employed in Quebec. Plants using

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[3] At the time of the report, in 1994, there were two treatment plants in Quebec still using chlorine disinfection and both were planning to convert to an ultraviolet disinfection system. One converted in 1996 while the other did so in 2000.

chlorine disinfection and those with very high concentrations of ammonia nitrogen were excluded. The toxicity of these effluents having been established in Ontario and elsewhere, there was limited use in confirming this recognized fact. For the same reason, continuous discharges from unaerated lagoons in winter were also excluded. The committee finally recommended that the campaign be carried out over two different periods, covering winter and summer operating conditions.

1.3 Objectives of the Study

The primary objective of the study was to assess the toxic potential of Quebec municipal treatment plant discharges and, more specifically:

- assess acute (i.e. short term) and chronic (i.e. long term) end-of-pipe toxicity of effluents for aquatic life;
- assess the toxic potential for humans and wildlife due to the presence of substances that can degrade the quality of body tissue in aquatic organisms.

However, in order to obtain a complete and coherent analysis with regard to our main objective, several underlying objectives were added to target, when applicable, the causes of toxicity in municipal effluents:

- identify the possible relation between measured toxicity and the substances detected in municipal effluents;
- identify the possible relation between measured toxicity and the type of treatment process;
- determine whether the performance of treatment processes in winter and in summer has an effect on the toxic pattern of municipal effluents;
- verify the influence of industrial inputs on measured toxicity;
- assess the impact of chemical dephosphatization on measured toxicity.

1.4 Implementation of the Characterization Campaign and Approach for Assessing Toxic Potential

The project for assessing the toxic potential of municipal effluents was divided into two characterization campaigns: 1) one campaign carried out in 1996–97, and mainly constituted of characterizations of plants under winter operating conditions; 2) then a second one in 1998–99, mainly conducted under summer conditions.

In 1996, the project was incorporated into the programming of the *St. Lawrence Vision 2000* Action Plan (SLV 2000). The *Protection* component had the responsibility of carrying out the first campaign in 1996–97. In June 1998, a new Quebec-Canada harmonization agreement was signed regarding *SLV 2000 Phase III* and the 1998–99 campaign was part of the *Industrial and Urban* component.

The sampling work, along with several physico-chemical analyses and some toxicity tests, was carried out by private firms. The St. Lawrence Centre carried out several toxicity tests and assessed the quality of the results of the physico-chemical analyses and toxicity tests conducted by private labs. Many organic analyses were carried out at the *Centre d'expertise en analyse environnementale du Québec* (CEAEQ) (Quebec Centre of Expertise in Environmental Analysis). The CEAEQ also took on the task of analysing metals and pesticides during the 1998 and 1999 characterization campaigns.

In order to obtain a representative overview of treatment plants in Quebec, the approach advanced to assess the toxic potential of municipal plant effluents is the following:

- The characterization campaign results (toxicity tests and physico-chemical analyses) are first compared with potential effect thresholds represented by the surface water quality criteria (MEF, 1998). This process allows for an assessment of the potential end-of-pipe toxicity of municipal wastewater discharges. However, to evaluate the expected impact of an effluent on its environment, the nature of the discharges and the characteristics of the receiving aquatic environment must be taken into consideration. This approach, which consists of establishing specific limits for each effluent, by taking into consideration water quality criteria and conditions in the receiving aquatic environment (use of the water, concentration of substances upstream from the effluent, dilution of the effluent under critical conditions, etc.), is not presented in this study, however[4]. Only water quality criteria are used as indicators to analyse overall municipal effluents, that is:
    - to assess the potential toxicity of municipal treatment plant effluents without taking into account the sensitivity of the receiving environment;
    - to highlight the substances that are sensitive sources of the measured toxicity;
    - and to identify the common causes of toxicity.

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[4] The method used to calculate these limits, or environmental discharge objectives (EDOs), is described in the MENV document (1991, rev.1996).

- “Toxic prints”, which are a component of the PEEP Index, are also compiled. This tool is used in the SLV 2000 Program to estimate the relative potential ecotoxic effects of effluents.

2 MATERIALS AND METHODS

2.1 Selection of Treatment Plants

The MENV committee report (Tétreault *et al.*, 1994) was the basis for the selection of the treatment plants. The selection criteria proposed in their report served for the purposes of this study. They aimed to identify plants that were representative of:

- all the main treatment processes existing in Quebec;
- plants having major industrial-source loads and others with minor inputs;
- plants that use dephosphatization (phosphate removal by chemical addition) and others that do not.

In addition, the plant selection criteria also had to take into account the following operating parameters in order for the toxicity to be measured under normal plant operating conditions:

- mean flow between 70 and 110% of design flow;
- BOD_5 upstream between 60 and 150% of the design load;
- effluent that meets discharge requirements for BOD_5 and SM;
- industrial fraction of BOD_5 upstream lower than 10% (low industrial input) or higher than 50% (major industrial input) of total BOD_5 [5];
- concentration of ammonia nitrogen upstream lower than 10 mg/L in summer and lower than 20 mg/L in winter;
- normal operation of the plant for several years without recent major modification of equipment or operating conditions;
- no chlorine disinfection.

The 20 mg/L ammonia nitrogen limit in winter may seem high compared to the results of the MISA program, which showed that concentrations greater than 10 mg/L could be toxic (Beak and Canviro, 1990; Orr *et al.*, 1992). This limit was maintained because, in Quebec, concentrations in aerated lagoons are frequently close to 20 mg/L in winter. Plants with aerated lagoons that exceed this limit, however, are considered isolated cases.

Available data at the MAMM and MENV at the time this project was initiated was used to evaluate the characteristics of treatment plants. These include treatment process type, the characteristics of the water at the inlet and at the outlet of the plant, the theoretical industrial input, and the use of chemical dephosphatization. Other aspects such as the size of the plant (number of persons served) or logistical aspects such as proximity to a large city or to sampling

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[5] The size of the input or of the industrial load in this document refers to the industrial load proportion in the total load in BOD_5, in accordance with criteria listed here.

firms were taken into consideration in the final selection of the plants. Table 2.1 presents the final list of plants selected.

TABLE 2.1: TREATMENT PLANTS SELECTED

Process	**Treatment plant**			
	Low industrial inputs		**High industrial inputs**	
	With dephosphatization	**Without dephosphatization**	**With dephosphatization**	**Without dephosphatization**
Activated sludge:				
- conventional	CUO	---	---	---
- prolonged aeration	---	Jonquière	Farnham (1)	La Prairie (located in Sainte-Catherine)
- with filtration	---	---	Magog	---
Aerated lagoon	Sawyerville (1)	Saint-Gédéon (located in Lac Saint-Jean region)	Warwick (1) and Saint-Joseph-de-Beauce (1)	Cookshire
Biofiltration	Châteauguay (1)	CUQ (East plant)	---	---
Physico-chemical	Longueuil (Centre d'épuration Rive-Sud)	---	CUM	---
Unaerated lagoon	Martinville (2)	---	---	---

(1): Dephosphatization in summer only.
(2): Dephosphatization during spring lagoon emptying only.

This list of 15 plants provides a representative overview of the situation in Quebec, even though it does not cover all categories. The four main treatment processes are represented. They are the "activated sludge", "aerated lagoon", "biofiltration" and "physico-chemical" processes. In 1994, those processes represented, respectively, 12.5%, 13.7%, 10.9% and 62.5%, for a total of 99.6%, of the volume of municipal wastewater treated in Quebec. One plant with unaerated lagoons (Martinville) was also selected for sampling during fall and spring emptying. This corresponds respectively, in this project, to summer operating conditions (wastewater collected throughout summer and then emptied in the fall) and also to winter operating conditions (wastewater collected throughout winter and then emptied in the spring). Plants with unaerated lagoons represented 0.2% of the volume of treated municipal wastewater. Other processes, such as rotating biological filters, represented only 0.2% of the volume of municipal wastewater treated in Quebec in 1994.

Despite the selection criterion which eliminated plants with concentrations of ammonia nitrogen greater than 20 mg/L in winter, the Saint-Joseph-de-Beauce plant was added to include at least one case of an effluent with levels exceeding this criterion.

The Magog plant was also chosen because of the addition of chlorine before tertiary filtration occurs, to prevent biological clogging of the filters. It was deemed appropriate to verify the impact of this practice, in spite of the selection criterion concerning chlorine disinfection.

In the "with dephosphatization" category, six of the plants only use chemical dephosphatization during the summer season, as is the case generally in Quebec. Only the CUO, Longueuil (CERS), Magog and CUM plants use this process on a year-round basis, because their effluents are discharged in eutrophication-sensitive environments, such as lakes or reservoirs. This study thus includes four plants using dephosphatization on a year-round basis, six plants using dephosphatization only in the summer (including Martinville during spring emptying), and five plants which do no dephosphatization at all.

Appendix 1 presents some of the design and technical operating data on the treatment plants selected. Some plants do not comply completely with the overall selection criteria, but they still meet the objectives of the project. In the case of the CUM, the proportion of industrial input is unknown and probably does not meet the criterion of industrial $BOD_{5,}$ being greater than 50% of the total BOD_5. However, given the great diversity of industrial plants and the existence of several service companies operating in various fields of activity in CUM territory, it is likely that a very diverse array of chemical substances will be present at the inlet of this treatment plant. Industrial input is thus considered significant, but its proportion cannot be accurately assessed.

2.2 Scheduling the Characterization Campaigns

The characterization campaigns at the municipal treatment plants were implemented based on the approach developed within the St. Lawrence Vision 2000 (SLV 2000) Program as part of its industrial characterization activities. The *Guide général de caractérisation SLV 2000* (general guide for characterization), published in April 1995, was used to draw up the specifications. Sampling firms that had pre-qualified for industrial characterizations were requested to bid according to the requirements contained in the Guide.

The campaigns were carried out over two time periods: 1996–97 and 1998–99. The 1996–97 campaign consisted of two phases, a pre-test in the fall of 1996 and characterization during the winter of 1996–97.

The first phase, the so-called "pre-test", served as a test campaign in preparation for the characterizations which would be conducted in winter 1996–97. This phase provided the means to validate the specifications and adjust them to the context of municipal plants. It was also used to ensure the respect of quality control requirements for field activities and analyses. The pre-test consisted of the characterization of two treatment plants under summer conditions: Sawyerville (September 1996) and Martinville during the fall lagoon emptying process (October 1996).

In the second phase, 14 treatment plants were sampled (all except Martinville) under winter operating conditions between December 1996 and February 1997.

Following the 1996–97 campaign the results were compiled and a status report was published in July 1998 (MENV and Environment Canada, 1998). The partial winter results were examined to adjust and improve the characterization program in preparation for the remainder of the project, by trying certain other analysis methods, and by adding several analyses, particularly for metals and some organic parameters.

The 1998–99 campaign was carried out between September 1998 and July 1999. In all, 12 plants were sampled, two of them twice (CUM and Longueuil). Of these 12 plants, 11 were sampled under summer conditions and one under winter conditions (Martinville in May 1999 during spring lagoon emptying). The three plants not visited were Sawyerville (already characterized in summer conditions during the pre-test phase), Magog and Warwick. These last two plants, which should have been sampled in summer, were eliminated to make room for more advanced analyses at other plants. The CUM and Longueuil plants were characterized twice in summer due to an error which occurred on certain samples drawn in the summer of 1998 during the toxicity test with *P. promelas*. Consequently, a second sampling was conducted in June 1999 to repeat the toxicity test and other analyses.

Table 2.2 presents a summary of the sampling program of the two characterization campaigns and Section 2.4 presents the analytical differences between the 1996–97 and the 1998–99 campaigns.

During the summer of 1999, the presence of certain pesticides in municipal effluents was also tested for. Because of the high cost of pesticide analysis and because of their seasonal and episodic use, it was decided to carry out intensive sampling at only two plants instead of sporadic sampling at all the plants. The two plants thus selected were the CUM and Longueuil plants, because of the size of the urban areas in question, the large proportion of combined sewer systems, and the availability of personnel and equipment to carry out the sampling.

Specialized lawn treatment firms usually apply pesticides in three stages. A first treatment during the summer, in May or June (when weeds first appear), a second herbicide treatment towards the end of July or the beginning of August, sometimes coupled with an insecticide treatment, and a final treatment in the fall, at the end of August, beginning of September. Obviously, treatments are also carried out by individuals who do not call in specialized firms. Sampling was thus performed more specifically to target the two first application stages.

TABLE 2.2: SAMPLING PROGRAM FOR THE CHARACTERIZATION CAMPAIGNS

Treatment plant	Winter operating conditions	Summer operating conditions
Châteauguay	January 21, 23 and 25, 1997	June 15, 17 and 19, 1999
CUM	December 10, 12 and 14, 1996	September 29, October 1 and 3, 1998 and June 8, 10 and 12, 1999
CUO	January 7, 9 and 11, 1997	July 6, 8 and 10, 1999
CUQ (East plant)	January 6, 8 and 10, 1997	July 6, 8 and 10, 1999
Cookshire	February 3, 5 and 7, 1997	July 13, 15 and 17, 1999
Farnham	February 11, 13 and 15, 1997	July 13, 15 and 17, 1999
Jonquière	January 20, 22 and 24, 1997	September 15, 17 and 19, 1998
La Prairie	December 3, 5 and 7, 1996	June 15, 17 and 19, 1999
Longueuil	December 10, 12 and 14, 1996	September 29, October 1 and 3, 1998 and June 8, 10 and 12, 1999
Magog	January 14, 16 and 18, 1997	Not characterized
Martinville	May 31, June 2 and 4, 1999	October 24, 28, 30 and November 1, 1996
Saint-Gédéon	January 20, 22 and 24, 1997	September 15, 17 and 19, 1998
Saint-Joseph-de-Beauce	January 27, 29 and 31, 1997	September 21, 23 and 25, 1998
Sawyerville	February 3, 5 and 7, 1997	September 23, 25 and 27, 1996
Warwick	January 27, 29 and 31, 1997	Not characterized
Number of treatment plants	15 treatment plants	13 treatment plants (CUM and Longueuil twice each)
Number of characterizations	14 characterizations in the winter of 1996–97 1 characterization in spring 1999	2 characterizations in 1996 (pre-test) 5 characterizations in summer 1998 8 characterizations in summer 1999

2.3 Toxicity Tests

The results of the toxicity tests carried out in winter and summer at all 15 municipal treatment plants were the subject of a specific report. Consequently, this section is a summary of previously published information. For further details on test methods, processing of the data or the specific results of each toxicity test, consult one of the 30 scientific and technical biological characterization reports published on the treatment plants by Environment Canada’s St. Lawrence Centre (Bombardier, M.; Harwood, M., 1996 to 1999).

2.3.1 Selection of toxicity tests

A series of seven toxicity tests were retained for the study. The tests were essentially selected to meet the standard of the MENV (MEF, 1998) and to provide for the calculation of the toxic print component of the PEEP Index developed by Environment Canada (Costan *et al.*, 1993). Table 2.3 presents the list of toxicity tests selected and a few descriptive characteristics.

TABLE 2.3: SELECTED TOXICITY TESTS AND DESCRIPTIVE CHARACTERISTICS

Organism	**Species**	**Trophic level**	**Toxicity level**	**Variable of effect**
Marine bacteria	*Vibrio fischeri* (1) (Microtox™)	Decomposer	Acute sublethality	Inhibition of luminescence
Bacteria	*Escherichia coli* PQ37 (SOS Chromotest)	Decomposer	Chronic sublethality	Genotoxicity and cell viability
Algae	*Selenastrum capricornutum*	Primary producer	Chronic sublethality	Inhibition of cell division
Cladocerans (crustaceans)	*Ceriodaphnia dubia*	Primary consumer	Chronic lethality and sublethality	Mortality and reproductive inhibition
Cladocerans (crustaceans)	*Daphnia magna*	Primary consumer	Acute lethality	Mortality
Fish larvae	*Pimephales promelas* (Fathead minnow)	Secondary consumer	Chronic lethality and sublethality	Mortality and growth inhibition
Fish	*Oncorhynchus mykiss* (Rainbow trout)	Secondary consumer	Acute lethality	Mortality

(1): Species previously known as *Photobacterium phosphoreum*.

In Quebec, within the framework of the *Programme de réduction des rejets industriels* (PRRI) (industrial wastewater abatement program) and as part of the process of evaluating and examining the impact of new industrial plants, a series of criteria were established for the selection of toxicity tests aimed at assessing effluent toxicity.

Based on these criteria, the MENV had selected five tests to measure the toxicity of industrial effluents (MENVIQ, 1990, rev. 1992). To measure acute toxicity, lethality tests using rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*) and the cladoceran *Daphnia magna* were retained. To measure chronic toxicity, growth inhibition tests using fathead minnow larvae and the alga *Selenastrum capricornutum* were selected.

These tests, with the exception of the acute lethality test using *P. promelas,* were all chosen for this assessment of municipal effluents. On the other hand, anticipating that the alga chronic toxicity test would not be very sensitive to municipal effluents (Rutherford *et al.*, 1993), the inhibition test on the reproduction and survival of the cladoceran *Ceriodaphnia dubia* was added to evaluate the sublethal toxicity of the effluents.

In addition, in order to complete the tests required to calculate the PEEP Index toxic print component, the inhibition of luminescence test on the bacteria *Vibrio fischeri* (Microtox^{TM}) and the (geno) toxicity test[6] SOS Chromotest on the *Escherichia coli* PQ37 were added.

2.3.2 Sampling methods

Samples were collected and transported to the labs by specialized contracting firms in accordance with the requirements of the SLV 2000 general characterization guide (SLV 2000, 1995).

Samples of mechanical treatment plant effluents (activated sludge, biofiltration and physico-chemical treatments) were collected using portable automatic samplers. These devices collect a given volume of water at fixed intervals, providing for a representative 24-hour sample. In the case of aerated and unaerated lagoons, spot samples of the effluent were drawn. This approach is acceptable for such process types because of the low variation in water quality over time.

For each of these characterizations, toxicity tests were conducted on three samples drawn over three inconsecutive days (days 1, 3 and 5). A total volume of approximately 240 L (divided into four 60-L containers) was collected on each sampling day. All the wastewater samples were delivered the same day to the St. Lawrence Centre lab to be prepared, processed and subdivided.

2.3.3 Preparation and subdivision of samples

As soon as they were received, the samples drawn the same day and contained in the four 60-L containers were mixed together in the lab. A summary physico-chemical characterization of each sample was carried out immediately thereafter (see Section 2.3.4.1). Samples were then subdivided in preparation for the various toxicity tests. In addition, a 30-L portion of each daily sample (days 1, 3 or 5) was set aside to obtain a composite sample of 90 L (combination of samples from all three days). Figures 2.1 and 2.2 respectively illustrate the method generally used to prepare and subdivide the daily samples and the composite sample.

The acute toxicity tests (*D. magna* and *O. mykiss*) were carried out using each daily sample, except for the test with *V. fischeri*, which was carried out with the composite sample. The chronic toxicity tests (*E. coli* PQ 37, *S. capricornutum, C. dubia* and *P. promelas*) were carried out using the composite sample and/or the daily samples. In the latter case, the day 1 sample was used to start the

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[6] Test used to detect the presence of substances that can cause primary lesions to bacterial DNA and reduce cell viability (Quillardet *et al.*, 1982).

testing, while the day 3 and 5 samples allowed for the water to be renewed respectively on the third and fifth day of testing with *C. dubia* and *P. promelas*.

Although there were slight differences between the 1996–97 and 1998–99 campaigns, samples were generally processed and subdivided as follows (Figure 2.1). In the case of daily samples, 2-L and 20-L aliquot portions were extracted from each sample (day 1, 3 and 5) then transferred into opaque white plastic buckets and stored at 4°C until their transport to the contract labs for toxicity testing with *D. magna*, *C. dubia* and *P. promelas.* The residual sampling volume, also placed in opaque white plastic buckets and stored at 4°C, was used to carry out tests with *O. mykiss*.

From the composite sample (Figure 2.2), a volume of 10 L was extracted and stored at 4°C until its delivery to the contract lab for toxicity testing with *C. dubia*. An aliquot portion of 1 L was filtered at 0.2 µm (polycarbonate, Nuclepore^{TM}) and stored at 4^{o}C to be used in the toxicity tests with microorganisms (*V. fischeri*, *E. coli* PQ 37 and *S. capricornutum*). Finally, an aliquot portion of 10 L was aerated, and a 1-L sub-sample was filtered and subjected to the same toxicity tests as the unaerated portion, in order to assess the persistence of or changes in toxicity. The aerating method consists of having a constant air flow through (approximately 5 cm^3 per minute per litre of sample [$\approx$ 5 $mL/(min.L^{-1})$]), at room temperature (20 ± 2°C), for five days. Opaque white plastic buckets served as containers for the tests.

FIGURE 2.1: IN-LAB PREPARATION AND DIVISION OF DAILY SAMPLES (DAYS 1, 3 AND 5)

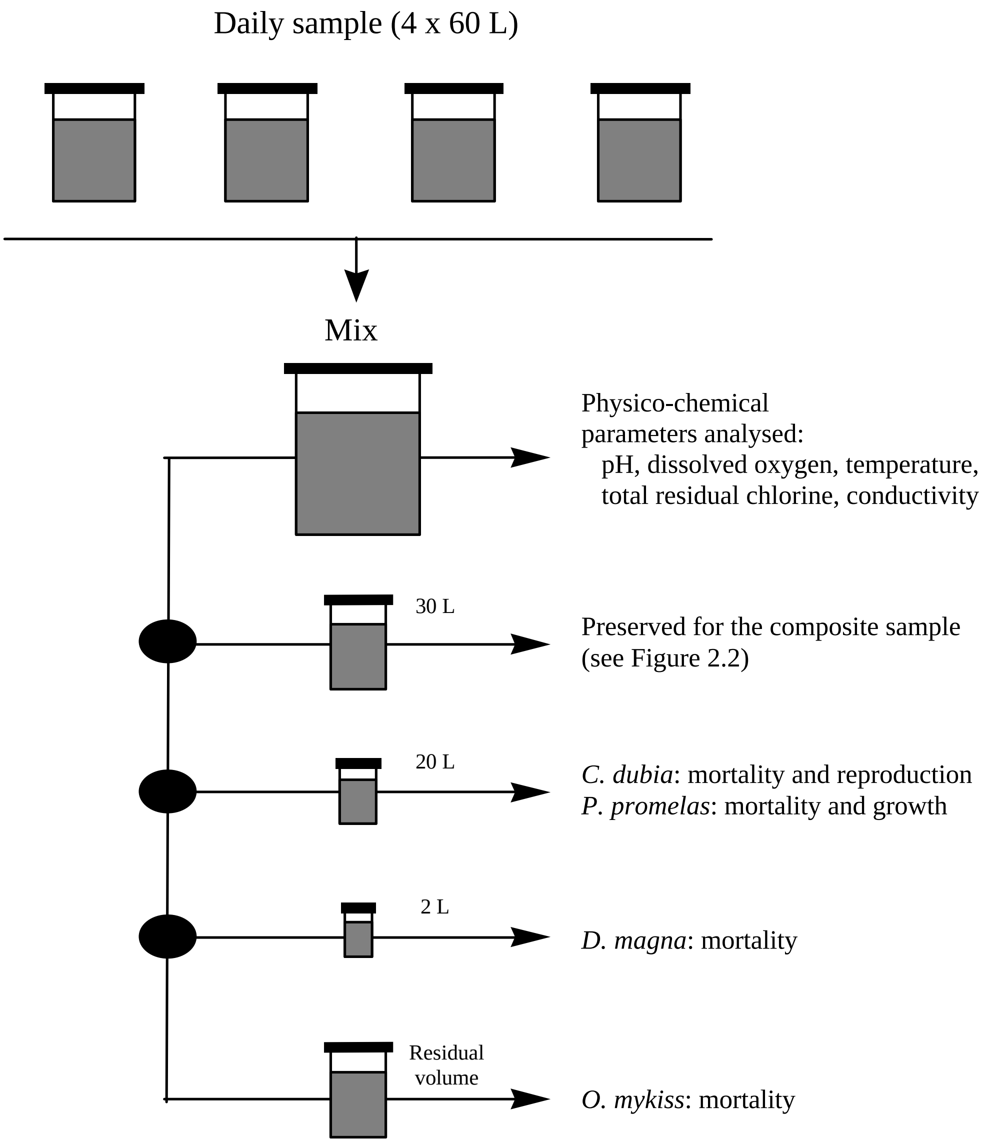
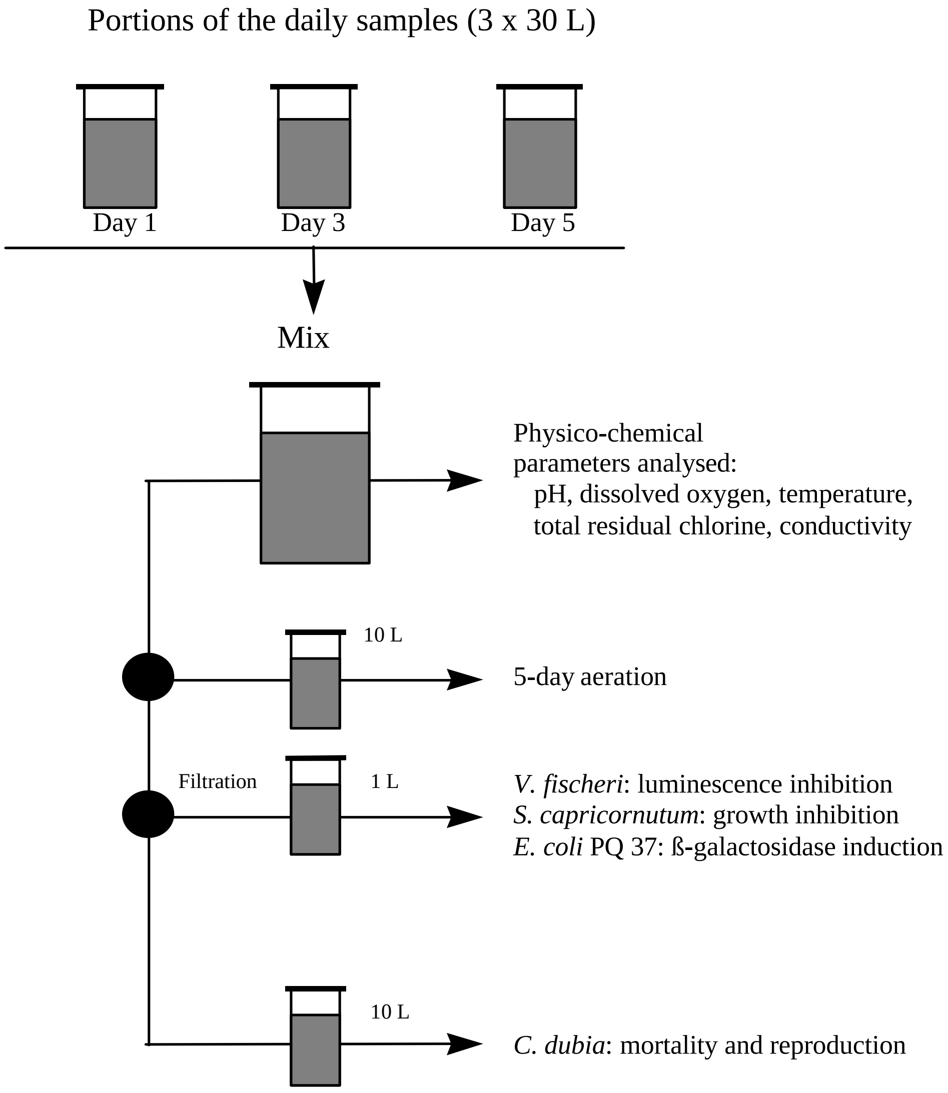


FIGURE 2.2: IN-LAB PREPARATION AND DIVISION OF COMPOSITE SAMPLE



2.3.4 Toxicity test methods

All toxicity tests with microorganisms (*V. fisheri, E. coli* PQ 37, *S. capricornutum*) were carried out at the St. Lawrence Centre lab. The rainbow trout (*O. mykiss*) tests were carried out at the St. Lawrence Centre lab for the samples drawn in 1996–97 and 1998, while the tests on samples drawn during the summer of 1999 were carried out at the *Laboratoire de l'environnement LCQ* (Sainte-Foy, Quebec). Tests on fathead minnow larvae (*P. promelas*) and cladocerans (*D. magna* and *C. dubia*) were performed by various contract labs, namely, B.A.R. Environmental Inc. (Guelph, Ontario), Laboratoires Bodycote Technitrol (Pointe-Claire, Quebec) or *Laboratoire de l'environnement LCQ* (Sainte-Foy, Quebec). The test protocols followed are presented in Table 2.4.

Appendix 4 provides a more detailed description of the toxicity test methods employed.

TABLE 2.4: TOXICITY TEST PROTOCOLS

Toxicity test	**Protocol**	**Reference**
Vibrio fischeri (Microtox^{TM})	Environment Canada standard method (1992a) with few modifications	Environment Canada (1995)
Escherichia coli PQ 37 (SOS Chromotest)	St. Lawrence Centre Laboratory method	Environment Canada (1993)
Selenastrum capricornutum	Environment Canada standard method (96 wells microplate)	Environment Canada (1992b)
Ceriodaphnia dubia	Environment Canada standard method	Environment Canada (1992c)
Daphnia magna	Environment Canada standard method	Environment Canada (1990a; 1990b)
Pimephales promelas (Fathead minnow)	Environment Canada standard method	Environment Canada (1992d)
Oncorhynchus mykiss (Rainbow trout)	Environment Canada standard method	Environment Canada (1990c; 1990d)

2.3.4.1 Physico-chemical parameters supporting the toxicity tests

A series of physico-chemical analyses were usually carried out on the daily and composite samples to ensure sample quality and to obtain complementary information to support the toxicity tests when the results are interpreted.

The temperature, pH (before and after filtration), dissolved oxygen, conductivity and total residual chlorine (TRC) were measured on all samples according to standard methods (APHA, AWWA and WEF, 1995). In the case of the composite sample, pH was measured before and after aeration. In addition, the total organic carbon (TOC) concentration in the unaerated portion of the composite sample was determined at the beginning and at the end of the test using the persulfate oxidation method (APHA, AWWA and WEF, 1995) in order to assess the biodegradability of the effluents.

2.3.5 Quality control

Stringent quality control procedures were applied throughout the toxicity testing, as described in the *Guide de caractérisation des eaux usées industrielles* (Environment Canada, 1996d) (guide for the characterization of industrial wastewater).

2.4 Physico-chemical Analyses

Up to 26 conventional physico-chemical parameters, 19 metals and 8 families of chlorinated and unchlorinated organic parameters were measured in the effluents of the 15 treatment plants selected for this project. The list of parameters analysed is presented in Table 2.5.

2.4.1 Selection of the conventional physico-chemical parameters

During the first campaign in 1996–97, the group of conventional physico-chemical parameters (PCPs) to be analysed, defined in the SLV 2000 general characterization guide (SLV 2000, 1995), were chosen. These include parameters identified as conventional, as well as certain major ions and oils and greases. Only the measurement of carbonated BOD_5 was added at all plants. Since chlorine is added to the treatment process at the Magog plant, total residual chlorine was also analysed at this plant.

For the 1998–99 campaign, adjustments were made to the PCPs characterization profile. Some parameters for which no water quality criteria exist were eliminated (total solids, TOC and cyanates, for example) while others were added, particularly those parameters providing a better interpretation of the results with regard to water quality criteria (conductivity, hardness and dissolved sulfides).

TABLE 2.5: LIST OF PARAMETERS ANALYSED AT MUNICIPAL TREATMENT PLANTS

Parameter			**Campaign**		**Analytical scope (in number of treatment plants)**	
			1996-97	**1998-99**	**Winter**	**Summer**
Physico-chemical parameters (PCPs):					15	13
• *Conventional parameters:*						
pH, dissolved oxygen (DO) and temperature (1)			√	√		
Five-day biochemical oxygen demand (BOD_5)			√	√		
Carbonated BOD ($CBOD_5$)			√	√		
Chemical oxygen demand (COD)			√	√		
Suspended matter (SM)			√	√		
Total organic carbon (TOC)	Total solids (TS)		√			
Conductivity	Total hardness (in $CaCO_3$)			√		
• *Nutrients:*						
Ammonia nitrogen (NH_3- NH_4^+)	Total Kjeldahl nitrogen (N-TKN)		√	√		
Nitrites-nitrates (NO_2-NO_3)	Nitrites (NO_2)		√	√		
Total phosphorus (P_T)			√	√		
• *Major ions:*						
Chlorides (Cl^-)	Total fluorides (F^-)		√	√		
Sulfates (SO_4^{2-})	Total sulfides (S^{2-}_T)		√	√		
Total cyanides (CN^-)			√	√		
Total residual chlorine (TRC)	Cyanates (CNO^-)		√			
Dissolved sulfides (S^{2-}_D)				√		
• *Other parameters:*						
Phenolic substances (2)			√	√		
Total hydrocarbons (mineral oils and greases)			√	√		
Freon extractibles (total oils and greases)			√			
Metals:					15	13
Aluminum (Al)	Copper (Cu)	Lead (Pb)	√	√		
Silver (Ag)	Iron (Fe)	Selenium (Se)	√	√		
Cadmium (Cd)	Mercury (Hg)	Zinc (Zn)	√	√		
Chromium (Cr)	Nickel (Ni)		√	√		
Antimony (Sb)	Beryllium (Be)	Molybdenum (Mo)		√		
Arsenic (As)	Boron (B)	Vanadium (V)		√		
Barium (Ba)	Cobalt (Co)			√		
Semi-volatile organic substances (SVOCs):					2	11
Scan of over 50 organic compounds			√	√		
Volatile organic substances (VOCs):					7	11
Scan of over 40 organic compounds			√	√		
Nonionic and anionic surfactants			√	√	6	12
Polychlorinated biphenyls (PCBs):					7	11
43 specific congeners			√	√		
Homologues (± 200 congeners)			√	√		
Polycyclic aromatic hydrocarbons (PAHs):					6	11
22 specific PAHs (50 PAHs in 1999)			√	√		
Chlorinated dioxins and furans:					4	11
17 specific congeners			√	√		
Homologues			√	√		
Pesticides:						2
32 organophosphorus and other pesticides (triazines, carbamates, etc.)				√		
14 phenoxyacid herbicides				√		

(1): pH, dissolved oxygen and temperature were measured on site during sampling.

(2): Phenolic substances were analysed by scanning methods at 8 plants in 1996–97 and by colorimetry at 11 plants in 1998–99.

Most of the selected parameters constitute the main contaminants of domestic wastewater. Consequently, they also provide the means to evaluate the performance of a municipal treatment plant. In addition, historical data exist for some of these parameters since they are subject to regular monitoring by the operators of the treatment plants (ammonia nitrogen, BOD_5, SM, and phosphorus).

2.4.2 Selection of metals

For the 1996–97 campaign, the SLV 2000 general characterization guide’s (SLV 2000, 1995) list of 11 metals was adopted for purposes of our analysis. These metals are those that are generally cited in the literature and they are present in significant concentrations in municipal effluents relative to water quality criteria (U.S. EPA, 1981; McDonald, 1989; Orr *et al*., 1992; U.S. GAO, 1991; World Wildlife Fund, 1995). However, when the usual analysis methods were used in 1996–97, the detection limits of certain metals (silver, cadmium and mercury) were not sensitive enough to verify compliance with water quality criteria.

During the 1998–99 campaign, the use of different analysis methods (see Section 2.4.5) with better detection limits corrected the situation observed in 1996–97. In addition, the list of metals analysed was increased from 11 to 19, in order to obtain a more complete analysis.

Water quality criteria exist for all metals analysed.

2.4.3 Selection of the families of chlorinated and unchlorinated organic substances

Several organic substances are potentially present in municipal effluents, especially if industrial facilities are connected to the sewer system. The concentrations of these substances are therefore hard to predict, particularly as effluents are mixed into the sewer system and diluted by seepage and catchment water. They also depend on the effectiveness of the treatment applied by the municipal treatment plant and on any pre-treatment carried out by some industrial facilities before discharging wastewater into the sewer system.

In Quebec, no exhaustive characterization of organic substances in municipal effluents had ever been done before. In the absence of data, an exploratory characterization profile was drawn up for the 1996–97 campaign. Seven families of chlorinated and unchlorinated organic compounds were retained for analytical purposes at a few specific plants.

Following an analysis of the results obtained in 1996–97, the organic substance characterization program was reviewed and the analyses were extended to all plants for the 1998–99 campaign. In addition, an eighth family of organic substances, pesticides, was added at two plants for the sampling work performed in the summer of 1999.

Table 2.6 presents the families of organic parameters selected for analysis by treatment plant, while the three following subsections provide further details on the subject.

TABLE 2.6: SELECTION OF ORGANIC ANALYSES BY TREATMENT PLANT

Treatment plant	Phenolic substances (1)	SVOCs	VOCs	Surfactants	PCBs (2)	PAHs (2)	Chlorinated dioxins and furans (2)	Pesticides
Châteauguay	S	S	S	S	S	S	S	
CUM (3)	W+S	S	W+S	W+S	W+S	W+S	S	S
CUO	S	S	S	S	S	S	S	
CUQ (East plant)	W+S	S	W+S	S	W+S	W+S	W+S	
Cookshire	W+S	W+S	W+S	W+S	W+S	S	S	
Farnham	W+S	S	W+S	W+S	W+S	W+S	S	
Jonquière	S	S	S	S	S	S	S	
La Prairie	W+S	S	W+S	S	W+S	W+S	W+S	
Longueuil (3)	W+S	S	W+S	S	W+S	W+S	W+S	S
Magog	W							
Martinville	W	W	W	W	W	W	W	
Saint-Gédéon	S	S	S	S	S	S	S	
St-Joseph-de-Beauce	S	S	S	S	S	S	S	
Sawyerville				S				
Warwick				W				

W (winter): Organic substances were analysed with samples drawn during winter operating conditions.
S (summer): Organic substances were analysed with samples drawn during summer operating conditions.
(1): Phenolic substances were analysed with a scanning analytical method for the samples drawn in winter and by colorimetry for the samples drawn in summer (see text).
(2): PCBs, PAHs and chlorinated dioxins and furans were analysed at all treatment plants with the trace analysis methods, except the CUM plant in the winter of 1996 (for PCBs and PAHs only), where basic and neutral extraction followed by scanning detection methods were used.
(3): For the CUM and Longueuil plants, the table refers to the summer of 1998, when organic analyses were carried out; pesticide analyses were carried out in summer 1999.

2.4.3.1 Phenolic substances, SVOCs, VOCs and surfactants

PHENOLIC SUBSTANCES

Certain studies conducted in the U.S. have shown that phenolic substances may be detected in municipal effluents (U.S.GAO, 1991; U.S. EPA, 1981). In addition, they are likely to be present in plant discharges of various industrial sectors (Malo and Gouin, 1977).

A scan analysis that can measure close to fifty separate phenolic substances was performed at seven plants sampled under winter conditions during the 1996–97 campaign (see Table 2.6). No acceptable result was obtained using this method and it was therefore eliminated for the 1998–99 campaign. However, a colorimetric analysis, which can proportionately combine a large array of phenolic substances into a single analytical result, was used at all plants in 1998–99.

SEMI-VOLATILE (SVOCS) AND VOLATILE (VOCS) ORGANIC SUBSTANCES

The scanning analysis methods used for these two families of compounds cover a wide spectrum of semi-volatile and volatile organic substances. The list of selected substances for these two families of compounds is defined in the SLV 2000 general characterization guide (SLV 2000, 1995).

The group of semi-volatile organic substances obtained by using basic and neutral extraction (SVOCs) covers a large array of organic substances, including certain PCBs (Aroclor), PAHs, chlorinated benzenes and phthalates. The detection limits for this method do not permit the verification of water quality criteria for certain substances, such as PCBs and many PAHs. In addition, in the Ontario study conducted by Orr *et al.* (1992), few substances analysed using this method were detected in municipal effluents and the majority of them were detected in concentrations deemed non-toxic for aquatic life.

That is why this analysis method was selected for exploratory purposes during the 1996–97 campaign (winter conditions) at the Cookshire plant, which receives significant industrial loading, and also at the CUM plant. At Cookshire, PCBs were not included in the analysis as they were already measured using the trace analysis method for organic substances. At the CUM plant, only PCBs and PAHs were analysed in order to compare the results with those obtained by Pham and Proulx (1996) using a more precise method. The results from Cookshire were discarded because they were not up to quality control standards. At the CUM, a few PAHs were detected, but no PCBs, which does not confirm the results obtained by trace analysis (Pham and Proulx, 1996).

During the 1998–99 campaign, to clarify the results and validate the analysis method for SVOCs in municipal effluents, measurements were taken at all plants. PCBs were not analysed with this method, however, because their detection limits are definitely insufficient. The list of SVOCs retained covers over 50 substances.

The analysis method for volatile organic substances (VOCs) can be used to measure over 40 compounds and covers several substance groups, many of which are often detected in municipal discharges (U.S. EPA, 1981; U.S. GAO, 1991; WWF, 1995; McDonald, 1989; Paxéus, 1996). These analyses were performed on the samples of six treatment plants under winter conditions during the 1996–97 campaign that is, four plants where the industrial input is considered significant and two plants where it is considered non-significant. In view of the results obtained, VOCs were analysed at all plants during the 1998–99 campaign.

The list of SVOCs and VOCs analysed, as well as their detection limits, are presented with the complete campaign results in Appendix 8.

SURFACTANTS

Surfactants are organic molecules that include hundreds of different compounds. They are used, among other things, as cleaning agents for domestic as well as industrial purposes. Apart from their cleansing properties, they are also used for their disinfecting and softening properties, and as loosening agents. They are therefore likely to be found in the effluents of various industrial (textiles, cleaners, cosmetic products, pulp and paper) and institutional (hospitals) facilities as well as in domestic effluents.

It was therefore deemed appropriate, for exploratory purposes, to additionally analyse for nonionic and anionic surfactants at five plants during the 1996–97 campaign. As the results were significant, surfactant analyses were carried out at all plants in 1998–99.

2.4.3.2 Trace levels of organic substances: PCBs, PAHs and chlorinated dioxins and furans

PCBs, PAHs and chlorinated dioxins and furans are toxic substances that are generally present in very small concentrations. One analytical approach can be used to detect these substances at much lower thresholds (pg/L) than with traditional scanning methods (g/L). This approach is based on filtration, extraction, purification and measurement of contaminants by gas chromatography/high resolution mass spectrometry (GC-HRMS) or by gas chromatography/tandem mass spectrometry (GC-MS/MS) (Cossa *et al.*, 1998). In addition, when the targeted substances in the sample are found in trace amounts, measurements can be carried out on sample portions of approximately 18 L (commonly known as “large volume”) instead of 1-L volumes, which makes for lower detection limits. However, this large-volume extraction technique does not provide as effective an analysis resolution as do smaller-volume methods.

The results of both the mass balance of chemical contaminants in the St. Lawrence River project (Cossa *et al.*, 1998) and the study of the CUM effluent (Pham and Proulx, 1996) have demonstrated the effectiveness of the method in detecting these substances at very low concentrations. The CUM plant study also showed that concentrations of PCBs and PAHs measured at the inlet (before treatment) and in the effluent (after treatment) were much higher than in St. Lawrence River water (Pham and Proulx, 1996; Pham, 1993).

These trace-level analyses of organic substances were therefore selected for a few plants only in 1996–97 (winter conditions: see Table 2.6), and then for all plants during the 1998–99 campaign.

PCBs

Polychlorinated biphenyls (PCBs) are a family of 209 congeners divided into 10 sub-classes (homologue groups). In North America, all PCBs were produced under the trademark Aroclor (BEST, 1980), corresponding to mixtures of various congeners. Because of their great chemical stability and physical properties, PCBs had many industrial applications.

They were used in long-running applications (closed circuit), such as the dielectric fluids used in transformers and condensers, hydraulic equipment and heat exchanger fluids. They were also used in short-running applications (open circuit) for the fabrication of a number of products, such as lubricants, plastics, paint, waxes, glues, inks, textiles, dust guard agents, cutting oils, etc. (Carrier, 1991).

In the 1970s, concerns voiced over the effects on the environment and on health led to the replacement of PCBs, and, in 1977 in North America, finally resulted in the prohibition on the production, importation and use of these substances in most non-electrical applications (Environment Canada, 1981). In spite of this, they are still pervasive in the environment because of their great stability and persistent and bioaccumulable nature.

Even today, PCBs can be released into the environment due to leaking of heat transport liquids contained in condensers and transformers or when accidental spills occur. They may also be produced unintentionally in the form of impurities or by-products in many chemical processes such as the synthesis of chlorobenzene, chlorinated solvents, chlorinated alkanes or pigments (MEF, 1995). PCBs may also be formed during the thermal degradation of chlorinated organic compounds in municipal incinerators (MENV, 1995).

Several studies attest to the presence of PCBs in municipal effluents and in the aquatic environment in urban areas. The use of tracers (aquatic mosses) has revealed the presence of PCBs in several drainage basins in Quebec and, in particular, downstream of municipal treatment plants (Berryman, 1996a and 1996b; Berryman and Nadeau, 1995, 1996 and 1999). PCBs have also been detected in the water at several sampling sites in the St. Lawrence River (Cossa *et al.*, 1998; Pham and Proulx, 1996) and the Ottawa River, its main tributary (Cossa *et al.*, 1998). In Ontario, PCBs were analysed in the effluents of several municipal treatment plants (Canviro, 1989), whereas practically no analyses had been conducted previously in Quebec, with the exception of those performed on CUM plant effluent (Pham, 1993; Pham and Proulx, 1996). It was therefore appropriate to include these analyses in our study.

As part of this study, 43 specific PCB congeners, in addition to homologue groups, were analysed. During the 1996–97 campaign, nine homologue groups were analysed, which represents 206 possible substituted congeners with two chlorine atoms or more. During the 1998–99 campaign, the dichlorobiphenyls group was not analysed, which represents 194 possible substituted congeners with three chlorine atoms or more. The list of PCBs analysed and complete results are presented in Appendix 10.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) include several organic compounds that contain at least two benzene rings. There are many sources of PAHs. In Quebec, the biggest source of PAHs would probably be atmospheric emissions from aluminum plants using the Söderberg process. Other significant sources of PAH releases are residential wood heating, the burning of wood wastes, forest fires and fossil fuel combustion by various modes of transportation (Lavalin Environment, 1988). Oil spills and refinery effluents also seem to be significant sources of contamination of aquatic environments (CCME, 1999).

As is the case for PCBs, several studies attest to the presence of PAHs in municipal effluents, in the St. Lawrence River and in various other Quebec rivers.

Twenty-two PAHs were analysed at the plants sampled in 1996, 1997 and 1998. That number grew to 50 in 1999 because of additional measurement standards acquired by the lab responsible for the analyses. The list of PAHs analysed and complete results are presented in Appendix 11.

CHLORINATED DIOXINS AND FURANS

Dioxins and furans are not products purposely made for commercial or industrial use. They are formed during combustion activities or as undesirable by-products of certain manufacturing processes of chemical compounds (Dy, 1985). In all cases, they are released into the environment in the form of a complex mixture of various congeners.

Although certain natural combustion phenomena such as forest fires may be sources of dioxins and furans in the environment, human activities generate the highest concentrations. Among the biggest potential anthropogenic sources in Canada are atmospheric releases due to the combustion of municipal, industrial, medical and hazardous wastes of all kinds, and particularly cement kilns and steel works (NACEC, 2000; CCME, 1999). Wood combustion (residential heating, fires, combustion of wood wastes treated with pentachlorophenol) as well as the combustion of fossil fuels (coal, heating oil, automobile exhaust) are also emission sources that may release small quantities into the environment (Carrier, 1991).

Certain industrial processes also generate dioxins and furans. Such is the case for the chlorine bleaching process used by certain pulp and paper plants (Trudel, 1991; MENV, 2000) as well as facilities that use colorants and pigments (Williams *et al.*, 1992; Remmers *et al.*, 1992). Effluents from the textile industry and even domestic wash-water may also contain dioxins and furans originating from clothing fabric dyes (Horstmann and McLachlan, 1994 and 1995). Other sources are the application of products contaminated by dioxins and furans, such as certain pesticides and chlorinated solvents.

There are therefore multiple paths of transmission and the potential for dioxins and furans to be present in municipal wastewater is obvious.

Seventeen specific congeners were measured as part of the study, along with five homologue groups of substituted dioxins and furans having four to eight chlorine atoms each. The list of chlorinated dioxins and furans analysed and the complete results are presented in Appendix 13.

2.4.3.3 Pesticides

Many types of pesticides can be used in urban environments: pesticides used for treating lawns and decorative residential plants (trees, shrubs), parks and golf courses; those used for extermination purposes in residential buildings or in the food industry; and biocides used in air-conditioning systems or for the treatment of industrial fluids (preservation of metallurgical fluids, process water in the pulp and paper industry or industrial water cooling systems). Since biocides and products used in pest extermination are usually not discharged into sewer systems, research was focused on products used in landscape maintenance. These products are likely to get into the sewers and travel to the treatment plant during a rainfall.

Two types of lab analyses were carried out (see Section 2.4.5) to verify the presence of 46 pesticides used in landscape maintenance. Of these, the herbicides 2,4-D, mecocrop and dicamba are particularly targeted because of their use in urban areas, along with the insecticides diazinon, chlorpyrifos, dimethoate, carbaryl and malathion. The list of pesticides analysed and their detection limits are presented in Appendix 14.

2.4.4 Sampling methods

Sampling and sample delivery to the laboratories were carried out in accordance with the requirements of the SLV 2000 general characterization guide (SLV 2000, 1995).

For the majority of the physico-chemical analyses, 24-hour composite samples were drawn from the effluents of the mechanical treatment plants (activated sludge, biofiltration and physico-chemical processes) and spot samples were collected in the effluents of plants with aerated and unaerated lagoons. These sampling practices are consistent with those used in the monitoring programs established by the MENV. The samples were then immediately sent to the contract labs certified by the MENV and to the *Centre d'expertise en analyse environnementale du Québec* (CEAEQ).

In the case of the trace-level analyses of organic substances, the volume of water sampled was approximately 18 L. Water samples were collected in 20-L stainless steel containers treated with organic solvents (Cossa *et al.*, 1996), and protected against atmospheric deposition by a Teflon sheet. Upon reception at the St. Lawrence Centre lab, the samples were prepared and sent to the CEAEQ for analysis.

The personnel of the CUM and Longueuil plants performed the pesticide sampling work in accordance with the procedures described below. In both these cases, the samples were stored in coolers and immediately sent via express mail to the CEAEQ.

At the CUM plant, samples were collected at the settling tank outlets, using the plant's Manning model sampler. The sampler was adequately equipped to measure organic pollutants (Teflon and silicone tubing, glass containers). The sampler was pre-set to collect an 85-mL sample every hour, for a total of two litres per 24-hour period. These composite samples were collected three times a week on Mondays, Tuesdays and Wednesdays, from May 17 through July 28, 1999. Each composite sample was divided into two sub-samples. One was put into a 1-L, previously-acidified (H_2SO_4) glass bottle for the analysis of phenoxyacid pesticides, while the other was placed in a 500-mL container to be scanned for organophosphorus substances (OPS). Thirty composite samples were collected.

At the Longueuil plant, during three heavy rainfall events that occurred between May 19 and September 7, 1999, a total of 12 samples were collected to obtain four composite samples. Water samples were collected at the outlets of the settling tanks using an ISCO 3700-type sampler. The sampler was adequately equipped to measure organic pollutants and included 24 350-mL glass bottles. It was set at the start of each rainfall to collect four series of six 350-mL samples. The six samples were collected in sequence and the four series of samples were spread over the cumulative volume curve of the plant. The six 350-mL samples were mixed together, shaken and transferred into the 1-L bottles, for the phenoxyacid pesticides, and into the 500-mL bottles, for the OPS scan.

2.4.5 Analysis methods

The SLV 2000 general characterization guide (SLV 2000, 1995) served as a reference for sample conservation requirements and for the analysis methods regarding the following parameter groups:

- the conventional physico-chemical parameters (PCP);
- the 11 metals of the 1996–97 characterization campaign;
- the semi-volatile organic substances (SVOCs);
- the volatile organic substances (VOCs);
- the phenols of the 1998–99 campaign (4-AAP colorimetric method).

The 19 metals of the 1998–99 characterization campaign were analysed using the 200-Mét. 1.0 and 200-Hg methods developed at the Centre d'expertise en analyse environnementale du Québec (CEAEQ).

During the 1996–97 campaign, the phenolic substances were analysed using the MENVIQ.92-01/414-Phé 1.1 scanning method.

Total residual chlorine was analysed on site at the Magog plant during the 1996–97 campaign using colorimetric tubes (Hach).

Nonionic surfactants were analysed using the method called *Nonionic Surfactants as CTAS (cobalt thiocyanate active substances)* and anionic surfactants were analysed with the method *Anionic Surfactants as MBAS (methylene blue active substances)*. These two methods are taken from the *Standard Methods for the Examination of Water and Wastewater, 19th Edition* (APHA, AWWA and WEF, 1995).

The preparation and analysis techniques described in Cossa *et al.* (1996), CEAEQ (1997) and Cossa *et al.* (1998) were used for the analysis for trace levels of PCBs, HAPs and chlorinated dioxins and furans.

In the case of pesticides, the analysis of phenoxyacid herbicides (scanning of 14 compounds) was carried out as per the MA 403-P CHLP 2.0 method of the CEAEQ and the OPS analysis (scanning of 32 pesticides, such as triazine, organophosphorous, carbamates and others) was carried out using the MA 403 – Pest 3.0 method of the CEAEQ.

2.4.6 Quality control

Stringent quality control procedures were followed throughout the physico-chemical analyses, as described in the SLV 2000 general characterization guide (SLV 2000, 1995) and in accordance with the *Guide SCA-01* of the CEAEQ certification office.

3 RESULTS

This chapter synthesizes the analytical results. Note that the complete toxicity test results and the results of the physico-chemical analyses are given in the Appendices.

Operating data on the plants studied during both sampling periods are presented first. Toxicity test results are given afterwards, using two different approaches: the protection of the aquatic environment approach used by the MENV and by other environmental protection organizations (Environment Canada, and U.S. EPA), and the PEEP approach used by Environment Canada's St. Lawrence Centre. The results of the physico-chemical analyses are given last.

3.1 Plant Operation during Sampling

Appendix 2 provides a summary of the operating conditions at the treatment plants during sampling. Overall, the treatment plants operated normally throughout the sampling campaign. Flow rate measurement results are relatively reliable, because they were obtained, for the most part, during low infiltration periods. However, a few sewer overflows were observed upstream from some plants (see Appendix 2). In all such cases, however, sampling was conducted on the part of the water that had been through all the treatment steps.

Even if high BOD_5 and SM were observed on some occasions, nothing leads us to believe that the treatment plants sampled do a poor job. Some SM concentrations are also questionable because they do not coincide with the high values of other parameters, such as $P_{T,}$ or with regular monitoring results at the plant.

Those daily results that were found to be higher than periodic concentration discharge requirements are shown in Table 3.1. Note that results may occasionally exceed periodic discharge requirements, because these requirements apply to mean concentrations for the period (semester, month or week, depending on the plant) and not to a point value.

TABLE 3.1: DAILY RESULTS EXCEEDING PERIODIC DISCHARGE REQUIREMENTS AT TREATMENT PLANTS DURING SAMPLING PERIODS

Treatment plant	Date	Parameter	Measured concentration	Discharge requirement	
				Period	Concen-tration
CUM	Dec 13-14/96	SM	(58 mg/L)	Weekly	< 30 mg/L
CUQ	Jan 9-10/97	BOD_5	44 mg/L	Weekly	< 40 mg/L
CUO	Jan 6-7/97	SM	(59 mg/L)	Weekly	< 30 mg/L
CUO	Jan 8-9/97	SM	(167 mg/L)	Weekly	< 30 mg/L
CUO	Jan 10-11/97	SM	(89 mg/L)	Weekly	< 30 mg/L
Cookshire	Jan 7/97	BOD_5	35 mg/L	Winter semester	< 25 mg/L
La Prairie	Dec 6-7/96	SM	112 mg/L	Monthly	< 30 mg/L
Longueuil	Dec 13-14/96	SM	(57 mg/L)	Weekly	< 30 mg/L
Longueuil	Sept 28-29/98	SM	48 mg/L	Weekly	< 30 mg/L
Longueuil	Sept 28-29/98	P_T	1.05 mg/L	Weekly	< 0.75 mg/L
Longueuil	Oct 30-Nov 1/98	P_T	0.85 mg/L	Weekly	< 0.75 mg/L
Warwick	Jan 27/97	BOD_5	22 mg/L	Winter term	< 20 mg/L

( ): Questionable results in parentheses.

Temperature, pH and dissolved oxygen measurement results, carried out on-site during sampling, are given in Appendix 3.

Dissolved oxygen measurements show no irregularity. All plants discharged well-oxygenated effluents during sampling.

Significant fluctuations in levels of pH were detected at the Farnham plant during the 1997 sampling period. Sampling there took place during winter operating conditions. Some reductions in pH were noted, the biggest being a drop from 7.00 to 6.05 pH units, which lasted for a few minutes. On June 14, 1999, a significant decline in pH (7.4 to 6.7) was also recorded in the effluent of the La Prairie plant, this one lasting about two hours. The Saint-Joseph-de-Beauce effluent was particularly acidic during the sampling in summer 1998, pH values being in the 6.0, 6.9, and 5.9 range.

No irregularities were reported in the temperature of effluents. During winter sampling at mechanized plants, the temperature of the effluent decreased progressively as the cold season set in. For aerated lagoons, the temperature of the effluent in winter remained close to the freezing point. During summer sampling, temperatures measured reflect typical summer levels (generally between 15 and 24°C) at all the plants.

The effluent from the Martinville unaerated lagoons differs from the other plants because of periodic emptying. Particularly high pH and dissolved oxygen concentrations were measured during autumnal lagoon emptying (8.0 to 8.8 pH units and 8.7 to 11.2 mg/L, respectively), and relatively high temperatures were observed during the late spring emptying (15 to 16°C).

In the case of the Magog plant, chlorine was indeed added before filtration, according to the current annual analysis. Sampling was therefore carried out under normal operating conditions.

When sampling was performed at the Saint-Joseph-de-Beauce plant in summer 1998, excessive organic loads and a decrease in dissolved oxygen concentrations were observed in the plant's lagoons. Although this situation did not stop the plant from obtaining good BOD_5 (< 10 mg/L) and ammonia nitrogen (< 2 mg/L) results, it was probably not favourable to complete nitrification, as shown by the high nitrite concentrations measured (11 to 25 mg/L).

3.2 Toxicity Tests

3.2.1 MENV approach for the protection of the aquatic environment

The MENV has defined two overall toxicity limits for effluents: one acute toxicity limit, to be respected at all times in the effluent, and a chronic toxicity limit, to be respected on an average basis over a relatively short period of time (e.g. 4 days) in the environment. These two limits were established to ensure that there are no major short-term consequences on aquatic organisms at the discharge point and that concentrations in the environment allow the survival, development, growth and reproduction of aquatic organisms throughout their life cycles. These limits, however, are not translated into discharge requirements for municipal effluents.

An effluent is considered to be acutely toxic to aquatic life when, undiluted, it leads to a 50% or more mortality rate in test organisms in one or more toxicity tests, when the organisms are exposed thereto for a short period of time relative to their life expectancy. The acute lethal effect is considered to decrease rapidly when the effluent mixes with the aquatic environment. Tests carried out on rainbow trout (*O. mykiss*) and daphnias (*D. magna*) correspond to acute toxicity tests, with LC_{50}s (median lethal concentration) being the toxicity thresholds to verify.

In addition, because the quality of effluents varies and the number of tests carried out does not allow this variability to be quantified, all mortality rates between 10 and 50% indicate that an effluent has the potential to exceed the 50% death criterion at some other time.

An effluent is considered to be chronically toxic for aquatic life when it can harm growth, reproduction or survival of organisms subject to one or more toxicity tests for an exposure period equivalent to 10% of their life expectancy. Tests carried out on fathead minnows (*P. promelas*), cladocerans (*C. dubia*) and algae (*S. capricornutum*) correspond to chronic toxicity tests. Although these tests are carried out in the laboratory and over a relatively short period of time, they are designed to represent the sensitivity of a long-term test via the use of sensitive stages of the organisms (*P. promelas*) or the observation of many generations of organisms. (*C. dubia* and *S. capricornutum*) (U.S. EPA, 1994).

The no-observed effect concentration (NOEC) was used as toxicity threshold for the chronic toxicity tests (MENV 1998; Stephan *et al.*, 1985).

To simplify the presentation of results, the acute toxicity criterion is represented by one acute toxicity unit in the effluent (1 TUa), which corresponds to 100/LC_{50} (in % v/v). Likewise, the chronic toxicity limit is represented by one chronic toxicity unit (1 TUc), which corresponds to 100/NOEC (in % v/v). Any result exceeding 1 TUa indicates that the effluent is acutely toxic for aquatic organisms, while any result exceeding 1 TUc indicates the minimum required dilution in the receiving water for the effluent to reach a concentration below the toxic threshold.

3.2.1.1 Acute lethal toxicity

Acute lethality test results on *O. mykiss* and *D. magna* are presented in tables 3.2-W (winter) and 3.2-S (summer). Results are given for each daily sample collected over one week (days 1, 3 and 5) as a percentage of mortality (undiluted effluent) and in acute toxicity units (TUa).

3.2.1.2 Chronic toxicity

The chronic toxicity tests used in the MENV approach for the protection of the aquatic environment were carried out with a two-day water renewal rate (i.e. the day 1 sample starts the testing, while the day 3 and 5 samples are used to renew the water on days 3 and 5, respectively). A single result is thus obtained with the three daily samples. In the case of the algal test, it is conducted using a three-day composite sample.

The chronic toxicity test results for *S. capricornutum*, *P. promelas* and *C. dubia* are shown in tables 3.3-W and 3.3-S in chronic toxicity units (TUc).

TABLE 3.2-W: ACUTE TOXICITY TEST RESULTS CONSIDERED IN THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT (WINTER)

Treatment plant (winter)	**Characteristics**			**Mortality percentage (1) (D1 – D3 – D5)**		**Acute toxicity units (TUa) 100/LC_{50}**	
	Treatment process	**Industrial inputs**	**Dephos-phatization**	***D. magna***	***O. mykiss***	***D. magna***	***O. mykiss***
Farnham	AS	high	without	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
La Prairie	AS	high	without	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
Magog	AS	high	with	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
CUO	AS	low	with	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
Jonquière	AS	low	without	0 - 0 - 0	0 - * - 0	nl - nl - nl	nl - * - nl
Châteauguay	BF	low	without	0 - 0 - 0	* - 0 - 0	nl - nl - nl	* - nl - nl
CUQ (East plant)	BF	low	without	0 - 0 - 0	0 - 22 - 0	nl - nl - nl	nl - <1 - nl
Cookshire	AL	high	without	100 - 100 - 90	100 - * - 100	3.2 - 1.6 - 2	>1 - * - >1
Saint-Joseph-de-Beauce	AL	high	without	0 - 0 - 0	100 - 100 - 100	nl - nl - nl	>1 - >1 - >1
Warwick	AL	high	without	0 - 0 - 0	100 - 100 - *	nl - nl - nl	>1 - >1 - *
Saint-Gédéon	AL	low	without	0 - 0 - 0	63 - 75 - 100	nl - nl - nl	>1 - >1 - >1
Sawyerville	AL	low	without	0 - 0 - 10	29 - 14 - *	nl - nl - <1	<1 - <1 - *
Martinville	UL	low	with	0 - 0 - 0	* - * - *	nl - nl - nl	* - * - *
CUM	PC	high	with	0 - 0 - 0	0 - 0 - ns	nl - nl - nl	nl - nl - ns
Longueuil	PC	low	with	0 - 0 - 0	ns- 0 - ns	nl - nl - nl	ns - nl - ns

Treatment type:

AS:	activated sludge
BF:	biofiltration
AL:	aerated lagoons
UL:	unaerated lagoons
PC:	physico-chemical

Results:

<1:	less than 50% of mortality
>1:	more than 50% of mortality in the undiluted effluent
LC_{50}:	median lethal concentration
nl:	non-lethal (0% of mortality)
*:	result rejected
ns:	non-significant

(1): Mortality percentage measured in 100% effluent (undiluted).

TABLE 3.2-S: ACUTE TOXICITY TEST RESULTS CONSIDERED IN THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT (SUMMER)

Treatment plant (summer)	**Characteristics**			**Mortality percentage [(1)] (D1 – D3 – D5)**		**Acute toxicity units (TUa) 100/LC_{50}**	
	Treatment process	**Industrial inputs**	**Dephos-phatization**	***D. magna***	***O. mykiss***	***D. magna***	***O. mykiss***
Farnham	AS	high	with	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
La Prairie	AS	high	without	0 - 0 - 0	100 - 100 - 100	nl - nl - nl	1.4 - 1.7 - 1.9
Magog	AS	high	with				
CUO	AS	low	with	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
Jonquière	AS	low	without	0 - 0 - 20	0 - 0 - 10	nl - nl - <1	nl - nl - <1
Châteauguay	BF	low	with	5 - 0 - 0	29 - 90 - 29	<1 - nl - nl	<1 - 1.5 - <1
CUQ (East plant)	BF	low	without	0 - 0 - 0	0 - 0 - 0	nl - nl - nl	nl - nl - nl
Cookshire	AL	high	without	30 - 85 - 60	0 - 0 - 0	<1 - 2.9 - 1.4	nl - nl - nl
Saint-Joseph-de-Beauce	AL	high	with	100 -100 - 20	0 - 0 - 0	1.4 - 1.4 - <1	nl - nl - nl
Warwick	AL	high	with				
Saint-Gédéon	AL	low	without	0 - 0 - 10	0 - 0 - 10	nl - nl - <1	nl - nl - <1
Sawyerville	AL	low	with	8 - 0 - 0	* - 0 - 0	<1 - nl - nl	* - nl - nl
Martinville	UL	low	without	0 - 0 - 0 - 0	* - 0 - 0 - 0	nl-nl-nl-nl	*-nl-nl-nl
CUM (1998)	PC	high	with	0 - 0 - 0	0 - 10 - 0	nl - nl - nl	nl - <1 - nl
CUM (1999)	PC	high	with	0 - 0 - 0	0 - 0 - 14	nl - nl - nl	nl - nl - ns
Longueuil (1998)	PC	low	with	100 - 100 - 90	100 - 100 - 100	3 - 1.4 - 1.3	2.8 – 2.8 – 1.4
Longueuil (1999)	PC	low	with	0 - 0 - 0	86 - 43- 43	nl - nl - nl	1.3 - <1 - <1

Treatment type:

AS:	activated sludge
BF:	biofiltration
AL:	aerated lagoons
UL:	unaerated lagoons
PC:	physico-chemical

Results:

<1:	less than 50% of mortality
>1:	more than 50% of mortality in the undiluted effluent
LC_{50}:	median lethal concentration
nl:	non-lethal (0% of mortality)
*:	result rejected
ns:	non-significant

(1): Mortality percentage measured in 100% effluent (undiluted).

TABLE 3.3-W: CHRONIC TOXICITY TEST RESULTS CONSIDERED IN THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT (WINTER)

Treatment plant (winter)	**Characteristics**			**Chronic toxicity units (TUc) 100/NOEC**		
	Treatment process	**Industrial inputs**	**Dephos-phatization**	***S. capricornutum***	***P. promelas***	***C. dubia***
Farnham	AS	high	without	Stimulation	4	2
La Prairie	AS	high	without	Stimulation	5.9	1
Magog	AS	high	with	Stimulation	2	1
CUO	AS	low	with	Stimulation	8	1
Jonquière	AS	low	without	Stimulation	2	1
Châteauguay	BF	low	without	Stimulation (1)	2	1
CUQ (East plant)	BF	low	without	Stimulation	> 17	2
Cookshire	AL	high	without	4.4	8	16
Saint-Joseph-de-Beauce	AL	high	without	Stimulation	17	2
Warwick	AL	high	without	Stimulation	7.7	2
Saint-Gédéon	AL	low	without	Stimulation	2	1
Sawyerville	AL	low	without	2.2	2	1
Martinville	UL	low	with	Stimulation	1	1
CUM	PC	high	with	Stimulation	(> 100)	4
Longueuil	PC	low	with	Stimulation	11	2

Treatment type:
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

( ): Questionable result; to be considered with caution
NOEC: no-observed effect concentration

(1): Growth inhibition at the highest tested concentration (100% v/v), but result is non-significant.

TABLE 3.3-S: CHRONIC TOXICITY TEST RESULTS CONSIDERED IN THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT (SUMMER)

Treatment plant (summer)	**Characteristics**			**Chronic toxicity units (TUc) 100/NOEC**		
	Treatment process	**Industrial inputs**	**Dephos-phatization**	***S. capricornutum***	***P. promelas***	***C. dubia***
Farnham	AS	high	with	Stimulation	1	1
La Prairie	AS	high	without	Stimulation	4	4
Magog	AS	high	with			
CUO	AS	low	with	Stimulation	4	1
Jonquière	AS	low	without	Stimulation	16	16
Châteauguay	BF	low	with	Stimulation	2	2
CUQ (East plant)	BF	low	without	Stimulation	4	1
Cookshire	AL	high	without	Stimulation	17	4
Saint-Joseph-de-Beauce	AL	high	with	Stimulation	1	16
Warwick	AL	high	with			
Saint-Gédéon	AL	low	without	Stimulation	4	16
Sawyerville	AL	low	with	Stimulation	1	2
Martinville	UL	low	without	Stimulation	1	1
CUM (1998)	PC	high	with	Stimulation		4
CUM (1999)	PC	high	with	Stimulation	33	4
Longueuil (1998)	PC	low	with	Stimulation		16
Longueuil (1999)	PC	low	with	Stimulation	2	2

Treatment type:
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

NOEC: no-observed effect concentration

3.2.2 Toxic print component of the PEEP Index

The PEEP Index combines into one value the results of five toxicity tests performed on five organisms at different trophic levels (e.g. decomposers, primary producers, consumers), for a total of six "effect parameters" (e.g. survival, reproduction, growth and genotoxicity). The PEEP concept and the application thereof are described in detail in Costan *et al*. (1993). A brief description is provided below and additional information can be found in Appendix 5.

All results are expressed in toxicity units. This strategy, along with a determination of the persistence of toxicity and the integration of the flow rate measured at the effluent (to evaluate the toxic load), constitutes a first attempt to incorporate various fundamental ecotoxicological concepts into a single discriminating work tool. The following tests are used to determine the PEEP Index: *V. fischeri*, *E. coli* PQ 37 (genotoxicity only), *S. capricornutum* and *C. dubia* (mortality and reproductive inhibition).

PEEP units are calculated from the threshold effect concentration (TEC). This value is the result of the geometric mean of the no-observed effect concentration (NOEC) and the lowest observed effect concentration (LOEC). The PEEP Index provides two types of measurements: the "toxic print" and the "toxic load". The toxic print component represents the relative importance of the scope of the toxic intensity and expresses, in adjusted toxic units per bioanalytical volume unit ($ATU.bvu^{-1}$), the concentration of potentially bioavailable substances. The toxic load component is the product of the toxic print by the flow rate. It is expressed in $ATU.h^{-1}$ and allows for an assessment of the relative contribution of the effluent to the overall toxicity of the discharge considered (Bermingham and Boudreau, 1994).

Within the scope of this study, only the toxic print component of the PEEP Index was used. It is the most appropriate to attain the study's objectives and to compare municipal effluents on a common basis.

Table 3.4 presents the qualitative results of the toxicity tests. Toxic print results are shown in Table 3.5.

TABLE 3.4: QUALITATIVE RESULTS OF THE TOXICITY TEST CONSIDERED IN THE PEEP INDEX (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Winter**										**Summer**									
				V. fischeri		***E. coli* PQ 37**				***S. capricornutum***		***C. dubia***		***V. fischeri***		***E. coli* PQ 37**				***S. capricornutum***		***C. dubia***	
	TT	**II**	**Deph W/S**	**Luminescence**		**Genotox. - S9**		**Genotox. + S9**		**Growth**		**Reproduction**	**Lethality**	**Luminescence**		**Genotox. - S9**		**Genotox. + S9**		**Growth**		**Reproduction**	**Lethality**
				U	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**NA**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**A**	**U**	**NA**
Farnham	AS	high	wo/w	-	-	++	++	++	+	-	-	-	-	-	-	-	-	+++	++	-	-	-	-
La Prairie	AS	high	wo/wo	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	+
Magog	AS	high	w/w	-	-	+	-	-	-	-	-	-	-										
CUO	AS	low	w/w	-	-	+	-	-	-	-	-	-	-	-	-	++	++	-	-	-	-	-	-
Jonquière	AS	low	wo/wo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Châteauguay	BF	low	wo/w	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CUQ (East plant)	BF	low	wo/wo	-	-	++	+	+	-	-	-	-	-	-	-	++	-	-	-	-	-	+	-
Cookshire	AL	high	wo/wo	-	-	++	++	-	++	+	+	+	+	+	-	++	+	++	-	-	-	+	-
Saint-J.-de-Beauce	AL	high	wo/w	-	-	+++	+++	+++	+++	-	-	+	-	-	-	+++	+++	++	++	-	-	++	++
Warwick	AL	high	wo/w	-	-	++	-	-	-	-	-	+	-										
Saint-Gédéon	AL	low	wo/wo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-
Sawyerville	AL	low	wo/w	-	-	+++	+++	+++	+++	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Martinville	UL	low	w/wo	-	-	+++	+++	+++	+++	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CUM (S-98)	PC	high	w/w	+	-	+	+	-	-	+	-	+	-	-	-	-	-	-	-	-	+	+	+
Longueuil (S-98)	PC	low	w/w	-	-	+	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	+	+

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

Legend: - (no toxicity)
\+ (TEC = 1- 6 TU)
++ (TEC = 7-11 TU)
+++ (LOEC > 11 TU)
A: aerated sample
U: unaerated sample
\- S9: without metabolic activation
\+ S9: wtih metabolic activation

TABLE 3.5: PEEP INDEX TOXIC PRINT COMPONENT RESULTS (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**PEEP Index toxic print component (ATU.bvu^{-1}) $^{(1)\,(2)}$ (= n x [Σ TEC / N])**	
	TT	**II**	**Deph W / S**	**Winter**	**Summer**
Farnham	AS	high	wo/w	15.8	6.8
La Prairie	AS	high	wo/wo	0.2	0.6
Magog	AS	high	w/w	0.3	
CUO	AS	low	w/w	0.6	4.5
Jonquière	AS	low	wo/wo	<	0.3
Châteauguay	BF	low	wo/w	<	<
CUQ (East plant)	BF	low	wo/wo	6.8	2.6
Cookshire	AL	high	wo/wo	34.1	17.0
Saint-Joseph-de-Beauce	AL	high	wo/w	91.2	54.3
Warwick	AL	high	wo/w	2.5	
Saint-Gédéon	AL	low	wo/wo	<	1.8
Sawyerville	AL	low	wo/w	81.5	0.3
Martinville	UL	low	w/wo	72.4	<
CUM (S-98)	PC	high	w/w	7.8	3.1
Longueuil (S-98)	PC	low	w/w	1.4	3.4

Treatment type (TT):		II:	industrial inputs	<:	below detection limit
AS:	activated sludge	Deph:	dephosphatization	n:	number of tests exhibiting (geno)toxicity
BF:	biofiltration	w:	with	N:	total number of tests performed
AL:	aerated lagoons	wo:	without	TEC:	threshold effect concentration
UL:	unaerated lagoons	W:	winter		
PC:	physico-chemical	S:	summer		

(1): The toxic print detection limit = 0.1 ATU.bvu^{-1}.
(2): Data were calculated with the results obtained in the unaerated samples.

3.2.3 Physico-chemical analyses used to support toxicity tests

All the samples subject to toxicity testing respected the pH, temperature and dissolved oxygen requirements described in the protocols. The results for total residual chlorine (TRC) almost all showed relatively high concentrations of free and combined chlorine (e.g. chloramines). These values do not explain toxicity differences, however, but because of the nature of the effluents analysed, the results obtained for TRC are probably invalid (see Appendix 7). Appendix 7 gives the results of the physico-chemical analyses conducted in support of the toxicity tests. These analyses were carried out on the daily turnover water samples and on the unaerated part of the composite sample for each effluent studied.

3.2.4 Quality control

The 30 municipal effluent characterizations produced close to 400 biological analyses. Almost all toxicity test results were accepted upon reception because the quality requirements defined in the SLV 2000 general characterization guide (SLV 2000, 1995) were all respected. Results that did not comply with requirements were rejected (identified by asterisks in the tables). More information on the quality assessment of the results may be obtained from any of the 30 scientific and technical biological characterizations of the treatments plants, published by Environment Canada’s St. Lawrence Centre (Bombardier, M.; Harwood, M., 1996 to 1999).

3.3 Physico-chemical Analyses

3.3.1 Conventional physico-chemical parameters and metals

The analytical results of the conventional physico-chemical parameters (PCPs), expressed as mean concentrations for the three sampling days, are presented in tables 3.6-W and 3.6-S (winter and summer respectively). Likewise, the results of the metal analyses for the municipal effluents, expressed as mean concentrations of the total extractable metal, are given in tables 3.7-W and 3.7-S. Complete results and detection limits are detailed in Appendix 8.

TABLE 3.6-W: MEAN CONCENTRATIONS OF CONVENTIONAL PHYSICO-CHEMICAL PARAMETERS (WINTER)

Treatment plant (winter)	**Characteristics**			**Physico-chemical parameters (mg/L)**																		
	TT	**II**	**Deph**	**BOD_5**	**COD**	**SM**	**P_t**	**TKN**	**NH_3-NH_4+**	**NO_2^-**	**NO_3^-**	**NO_2-NO_3**	**Dissolved sulfides**	**Total sulfides**	**Sulfa-tes**	**Min. O&G**	**Phenol . subst.**	**Cl^-**	**CN^-**	**F^-**	**Hard-ness**	**Conduc-tivity**
Farnham	AS	high	wo	*	*	11	*	3.32	1.38	0.197	0.3	0.473		0.05	47	<	<	78	<	0.46		
La Prairie	AS	high	wo	*	*	48	*	5.33	3.87	0.037	1.2	1.203		0.04	(170)	0.10	<	152	<	0.27		
Magog	AS	high	with	*	*	4	*	0.96	0.16	0.057	6.6	6.677		0.07	73	<	<	130	<	0.12		
CUO	AS	low	with	*	*	105	*	13.02	6.17	<	4.9	4.900		0.07	53	<		211	<	0.17		
Jonquière	AS	low	wo	4	28	4	0.31	3.1	2.3			3.5		<	33	0.3		42	<	0.08		
Châteauguay	BF	low	wo	*	*	11	*	8.80	8.32	0.194	2.2	2.413		0.06	73	0.69		242	<	0.74		
CUQ (East plant)	BF	low	wo	30	85	22	1.59	15.00	11.6			0.45		<	49	0.50	<	320	<	0.80		
Cookshire	AL	high	wo	25	168	12	1.5	14.0	10.7			0.6		<	40	(16)	<	368	<	0.07		
St-J.-de-Beauce	AL	high	wo	18	70	19	1.6	26	25			0.6		<	81	0.3		187	<	<		
Warwick	AL	high	wo	17	69	22	2.6	16	13			1.4		<	52	0.4		113	<	<		
Saint-Gédéon	AL	low	wo	6	52	5	1.75	11.70	10.1			1.2		<	27	0.3		95	<	0.12		
Sawyerville	AL	low	wo	6	32	4	1.5	12	10			1.2		<	19	(0.3)		64	<	<		
Martinville	UL	low	with	23	47	18	1.2	5.3	3.7	0.006	<	<	0.12	0.56	20	<	0.006	32	<	0.04	122	437
CUM	PC	high	with	*	*	35	*	9.38	6.60	0.009	0.2	0.220		0.04	68	0.18	<	182	<	0.23		
Longueuil	PC	low	with	*	*	29	*	11.73	9.81			0.164		0.05	171	0.14	<	118	<	0.16		

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

*: result rejected
<: result below detection limit
Blank box: parameter not measured
( ): questionable result quality control; to be considered with caution

TABLE 3.6-S: MEAN CONCENTRATIONS OF CONVENTIONAL PHYSICO-CHEMICAL PARAMETERS (SUMMER)

Treatment plant (summer)	**Characteristics**			**Physico-chemical parameters (mg/L)**																		
	TT	**II**	**Deph**	**BOD_5**	**COD**	**SM**	**P tot.**	**TKN**	**NH_3-NH_4+**	**NO_2^-**	**NO_3^-**	**NO_2-NO_3**	**Dissolved sulfides**	**Total sulfides**	**Sulfa-tes**	**Min. O&G**	**Phenol . subst.**	**Cl^-**	**CN^-**	**F^-**	**Hard-ness**	**Conduc-tivity**
Farnham	AS	high	with	4	37	10	0.2	2.0	0.7	0.018	1.0	1.0	<	0.01	101	<	<	80	<	0.61	179	565
La Prairie	AS	high	wo	5	41	9	0.56	25	24	0.20	0.87	1.07	<	0.02	117	<	<	182	<	0.30	283	1046
Magog	AS	high	with																			
CUO	AS	low	with	<	31	3	0.45	5.5	4.9	0.20	3.07	3.3	<	<	52	<	<	61	<	0.13	96	397
Jonquière	AS	low	wo	<	20	3	0.192	2.3	(1.9)	0.062	1.27	1.36	<	<	32	<	<	35.8	<	(0.12)	93	387
Châteauguay	BF	low	with	9	23	10	0.66	11	9.2	0.15	1.29	1.4	0.01	0.05	77	<	<	79	<	0.91	217	631
CUQ (East plant)	BF	low	wo	11	65	11	1.25	11.6	9.1	0.11	0.16	0.27	<	0.04	57	0.42	<	126	<	0.76	131	622
Cookshire	AL	high	wo	10	90	10	1.10	9.3	6.8	0.59	0.13	0.71	<	0.07	102	0.83	0.010	172	<	0.11	124	858
St-J.-de-Beauce	AL	high	with	6	89	37	0.72	3.2	(1.1)	20	4	22			113	<	<	137	0.13	(0.06)	155	928
Warwick	AL	high	with																			
Saint-Gédéon	AL	low	wo	<	36	<	2.2	9.4	(8.4)	0.57	1.3	1.8			34	<	<	65	0.05	(0.2)	142	632
Sawyerville	AL	low	with	<	23	3.6	0.43	2.9	1.6			2.3		<	29	(<)		42	0.02	0.070		
Martinville	UL	low	wo	18	130	46	0.86	6.5	<			0.32		0.09	9	<		43	<	0.059		
CUM (1998)	PC	high	with	21	104	18	0.57	9.3	4.9	<	0.03	0.03	0.02	0.09	79	0.2	0.005	87	0.02	(0.31)	162	719
CUM (1999)	PC	high	with	41	104	20	0.44	9.4	6.1	0.005	0.01	0.02	0.11	0.20	71	0.41	0.009	97	0.020	0.18	170	719
Longueuil (1998)	PC	low	with	36	140	29	0.85	14	9.5	(0.022)	0.03	0.05	0.14	0.24	106	0.2	0.010	70	<	(0.15)	195	767
Longueuil (1999)	PC	low	with	23	70	17	0.56	14	10	0.004	<	0.01	0.14	0.21	104	0.33	0.010	80	0.004	0.14	201	744

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

*: result rejected
<: result below detection limit
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

TABLE 3.7-W: MEAN CONCENTRATIONS OF TOTAL METALS (WINTER)

Treatment plant (winter)	Characteristics			Total metals (mg/L)																		
	TT	II	Deph	Al	Sb	Ag	As	Ba	Be	B	Cd	Cr	Co	Cu	Fe	Hg	Mo	Ni	Pb	Se	V	Zn
Farnham	AS	high	wo	0.78		<					<	(0.016)		0.048	1.26	<		<	<	<		0.04
La Prairie	AS	high	wo	0.09		<					<	0.028		0.005	<	<		<	<	<		<
Magog	AS	high	with	0.35		<					<	(0.015)		(0.022)	1.17	3 E-4		<	<	<		0.14
CUO	AS	low	with	2.70		0.002					<	(0.012)		0.041	3.27	<		<	(0.0028)	<		0.09
Jonquière	AS	low	wo	0.2		<					<	0.001		0.009	0.07	<		<	0.0016	<		0.02
Châteauguay	BF	low	wo	0.06		<					<	(0.017)		0.040	1.30	<		<	<	<		0.07
CUQ (East plant)	BF	low	wo	0.3		0.008					<	0.005		0.020	0.87	<		<	0.0015	<		0.04
Cookshire	AL	high	wo	0.2		0.005					<	0.012		0.040	0.29	<		<	<	<		0.19
St-J.-de-Beauce	AL	high	wo	<		0.005					<	0.002		0.012	1.23	<		<	<	<		<
Warwick	AL	high	wo	0.2		0.004					<	0.001		0.005	0.35	<		<	<	<		0.02
Saint-Gédéon	AL	low	wo	0.1		0.003					<	0.002		0.017	0.28	<		<	<	<		<
Sawyerville	AL	low	wo	<		0.002					<	<		0.028	0.47	<		<	0.0013	<		0.02
Martinville	UL	low	with	0.253	<	<	0.0018	0.0057	<	0.038	<	0.0010	0.0004	0.003	0.193	2.6 E-5	<	0.002	<	0.0003	0.0006	0.003
CUM	PC	high	with	0.14		<					<	0.026		0.020	1.75	<		<	<	(0.0023)		0.08
Longueuil	PC	low	with	0.93		<					<	0.026		0.012	0.16	<		<	<	<		<

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

*: result rejected
<: result below detection limit
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

Table 3.7-S: Mean Concentrations of Total Metals (Summer)

Treatment plant (summer)	Characteristics			Total metals (mg/L)																		
	TT	II	Deph	Al	Sb	Ag	As	Ba	Be	B	Cd	Cr	Co	Cu	Fe	Hg	Mo	Ni	Pb	Se	V	Zn
Farnham	AS	high	with	0.690	0.0002	<	0.0005	0.069	<	0.038	<	0.0013	0.0026	0.016	0.343	1.0 E-4	0.021	0.007	0.0013	0.0004	0.0008	0.024
La Prairie	AS	high	wo	0.113	0.0006	<	0.0006	0.016	<	0.177	<	0.0011	0.0015	0.009	0.280	1.5 E-5	0.005	0.005	0.0018	0.0006	0.0007	0.026
Magog	AS	high	with																			
CUO	AS	low	with	0.086	0.0002	<	0.0004	0.016	<	0.061	<	0.0010	0.0002	0.005	0.095	3.3 E-5	0.005	0.003	0.0004	0.0003	0.0005	0.013
Jonquière	AS	low	wo	0.125	<	<	<	0.019	<	0.052	<	0.008	<	0.008	0.057	8.0 E-6	<	<	<	<	<	0.020
Châteauguay	BF	low	with	0.587	0.0001	0.0004	0.0005	0.038	<	0.067	<	0.0023	0.0002	0.014	0.250	3.9 E-5	0.002	0.005	0.0004	0.0004	0.0007	0.013
CUQ (East plant)	BF	low	wo	0.148	0.0002	0.0022	0.0006	0.039	<	0.055	<	0.0019	0.0003	0.017	0.780	5.0 E-5	0.007	0.004	0.0014	0.0006	0.0006	0.029
Cookshire	AL	high	wo	0.049	0.0001	<	0.0010	0.017	<	0.042	<	0.020	0.0034	0.028	0.397	1.1 E-4	<	0.046	0.0008	<	0.0003	0.064
St-J.-de-Beauce	AL	high	with	0.057	<	<	0.0002	0.018	<	0.033	<	0.004	0.0009	0.010	0.497	2.2 E-5	<	0.008	0.0004	<	<	<
Warwick	AL	high	with																			
Saint-Gédéon	AL	low	wo	0.063	<	<	<	0.014	<	0.039	<	0.005	<	0.015	0.220	1.1 E-5	<	<	<	<	<	<
Sawyerville	AL	low	with	<		(<)					<	0.0142		0.002	<	<		<	<	<		<
Martinville	UL	low	wo	<		<					<	0.022		<	0.40	<		<	<	<		<
CUM (1998)	PC	high	with	0.963	<	0.0011	4.1 E-4	0.030	<	0.065	1.6 E-4	0.008	<	0.025	0.210	1.3 E-5	<	0.006	0.0016	0.009	<	0.031
CUM (1999)	PC	high	with	0.769	0.0015	0.0007	0.0009	0.030	<	0.076	3.1 E-4	0.0053	0.0004	0.021	0.290	1.7 E-5	0.011	0.005	0.0012	0.0044	0.0006	0.032
Longueuil (1998)	PC	low	with	2.597	<	0.0007	0.0007	0.026	<	0.100	1.0 E-4	0.026	<	0.015	0.267	1.9 E-5	<	0.007	<	<	<	0.016
Longueuil (1999)	PC	low	with	0.940	0.0001	<	0.0006	0.024	<	0.090	2.0 E-4	0.0048	0.0003	0.008	0.273	<	0.004	0.005	0.0008	0.0005	0.0013	0.016

Treatment type (TT):

AS:	activated sludge
BF:	biofiltration
AL:	aerated lagoons
UL:	unaerated lagoons
PC:	physico-chemical

II:	industrial inputs
Deph:	dephosphatization
wo:	without dephosphatization

*:	result rejected
<:	result below detection limit
Blank box:	parameter not measured
( ):	questionable result (quality control); to be considered with caution

Table 3.8: Mean Concentrations of Semi-volatile Organic Substances (SVOCs) Detected (Winter and Summer)

Treatment plant	**Characteristics**			**Winter (SVOCs in μg/L)**				**Summer (SVOCs in μg/L)**			
	TT	**II**	**Deph W/S**	1,4-Dichloro-benzene	Di-n-butyl-phthalate	Diethyl-phthalate	Nitro-benzene	1,4-Dichloro-benzene	Di-n-butyl-phthalate	Diethyl-phthalate	Nitro-benzene
Farnham	AS	high	wo/w					*	<	<	<
La Prairie	AS	high	wo/wo					*	<	1.2	<
Magog	AS	high	w/w								
CUO	AS	low	w/w					*	<	<	<
Jonquière	AS	low	wo/wo					2.1	12.1	<	<
Châteauguay	BF	low	wo/w					<	<	*	<
CUQ (East plant)	BF	low	wo/wo					*	*	*	<
Cookshire	AL	high	wo/wo	<	<	<	<	<	0.5	<	0.7
Saint-J.-de-Beauce	AL	high	wo/w					1.8	*	<	<
Warwick	AL	high	wo/w								
Saint-Gédéon	AL	low	wo/wo					1.6	11.0	<	<
Sawyerville	AL	low	wo/w								
Martinville	UL	low	w/wo	<	<	<	<				
CUM (S-98)	PC	high	w/w					2.6	*	1.2	1.2
Longueuil (S-98)	PC	low	w/w					3.1	*	1.2	<

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

*: result rejected
<: result below detection limit
Blank box: parameter not measured

Table 3.9-W: Mean Concentrations of Volatile Organic Substances (VOCs) (Winter)

Treatment plant (winter)	**Characteristics**			**Volatile organic substances (VOCs in µg/L)**														
	TT	**II**	**Deph**	Bromodichloromethane	tert-Butylbenzene	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	cis-1,2-Dichloroethylene	Ethylic ether	Ethylbenzene	Styrene	Tetrachloroethylene	Toluene	1,2,3-Trimethylbenzene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	Xylenes
Farnham	AS	high	wo	<	<	<	<	<	*	<	<	<	<	*	<	<	<	<
La Prairie	AS	high	wo	<	<	<	<	<	<	1.1	<	<	<	<	<	<	<	<
Magog	AS	high	with															
CUO	AS	low	with															
Jonquière	AS	low	wo															
Châteauguay	BF	low	wo															
CUQ (East plant)	BF	low	wo	<	1.0	<	<	<	<	*	<	<	2.9	28.7	3.4	12.7	4.8	<
Cookshire	AL	high	wo	<	<	<	<	<	<	*	<	<	<	<	<	<	<	<
St-J.-de-Beauce	AL	high	wo															
Warwick	AL	high	wo															
Saint-Gédéon	AL	low	wo															
Sawyerville	AL	low	wo															
Martinville	UL	low	with	<	<	<	<	<	<	<	<	<	<	5.5	<	<	<	<
CUM	PC	high	with	0.7	<	0.7	<	<	0.4	*	2.1	0.6	3.5	10.8	*	1.9	0.5	1.8
Longueuil	PC	low	with	0.8	<	<	<	<	<	*	7.5	0.5	0.8	0.7	*	4.0	1.1	5.6

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

*: result rejected
<: result below detection limit
Blank box: parameter not measured

TABLE 3.9-S: MEAN CONCENTRATIONS OF VOLATILE ORGANIC SUBSTANCES (VOCs) (SUMMER)

Treatment plant (summer)	**Characteristics**			**Volatile organic substances (VOCs in µg/L)**														
	TT	**II**	**Deph**	Bromo-dichloro-methane	tert-Butyl-benzene	1,2-Di-chloro-benzene	1,3-Di-chloro-benzene	1,4-Di-chloro-benzene	cis-1,2-Dichlo-roethy-lene	Ethylic ether	Ethyl-benzene	Styrene	Tetra-chloro-ethylene	Toluene	1,2,3-Tri-methyl-benzene	1,2,4-Tri-methyl-benzene	1,3,5-Tri-methyl-benzene	Xylenes
Farnham	AS	high	with	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<
La Prairie	AS	high	wo	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<
Magog	AS	high	with															
CUO	AS	low	with	<	<	<	<	<	*	<	<	<	<	<	<	<	<	<
Jonquière	AS	low	wo	<	<	<	0.3	*	<	*	<	<	1.2	0.9	<	<	<	*
Châteauguay	BF	low	with	<	<	<	<	<	*	<	<	<	1.2	<	<	<	<	<
CUQ (East plant)	BF	low	wo	<	<	<	*	*	*	<	<	<	<	<	<	<	<	<
Cookshire	AL	high	wo	<	<	<	<	<	<	<	<	<	<	*	<	<	<	<
St-J.-de-Beauce	AL	high	with	<	<	<	0.2	0.5	<	*	<	<	0.7	<	<	<	<	*
Warwick	AL	high	with															
Saint-Gédéon	AL	low	wo	<	<	<	<	*	<	*	<	<	<	<	<	<	<	*
Sawyerville	AL	low	with															
Martinville	UL	low	wo															
CUM (1998)	PC	high	with	<	<	<	<	*	<	*	0.3	0.2	*	*	<	3.2	0.9	1.6
Longueuil (1998)	PC	low	with	<	<	<	<	*	<	*	*	0.2	*	*	*	*	0.1	*

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

*: result rejected
<: result below detection limit
Blank box: parameter not measured

3.3.2 Semi-volatile and volatile organic substances (SVOCs and VOCs)

Table 3.8 presents the results for the semi-volatile organic substances (SVOCs) detected at the treatment plants during winter and summer operating conditions. Tables 3.9-W and 3.9-S give the results for volatile organic substances (VOCs). Complete SVOCs and VOCs results and detection limits are detailed in Appendix 8.

3.3.3 Nonionic and anionic surfactants

Mean concentrations of nonionic and anionic surfactants obtained in winter and summer are given in Table 3.10. Complete results and detection limits for surfactants are detailed in Appendix 9. The detection limit for nonionic surfactants in samples collected in summer at the Cookshire and Farnham plants was 10 times higher (1.0 mg/L instead of the method detection limit of 0.1 mg/L), because of the presence of scum (organic matter) on the samples. This organic matter interfered with the analysis and samples were therefore diluted.

TABLE 3.10: MEAN CONCENTRATIONS OF SURFACTANTS (WINTER AND SUMMER)

Treatment plant	Characteristics			Winter		Summer	
	TT	II	Deph W/S	Nonionic surfactants (mg/L)	Anionic surfactants (mg/L)	Nonionic surfactants (mg/L)	Anionic surfactants (mg/L)
Farnham	AS	high	wo/w	1.4	0.55	< (1)	0.51
La Prairie	AS	high	wo/wo			<	0.24
Magog	AS	high	w/w				
CUO	AS	low	w/w			<	0.12
Jonquière	AS	low	wo/wo			<	0.13
Châteauguay	BF	low	wo/w			0.2	0.91
CUQ (East plant)	BF	low	wo/wo			0.3	1.30
Cookshire	AL	high	wo/wo	4.0	2.10	< (1)	0.42
Saint-J.-de-Beauce	AL	high	wo/w			<	0.28
Warwick	AL	high	wo/w	0.8	0.18		
Saint-Gédéon	AL	low	wo/wo			<	0.45
Sawyerville	AL	low	wo/w			*	<
Martinville	UL	low	w/wo	<	0.17		
CUM (S-98) (S-99)	PC	high	w/w	1.0	2.10	0.9 1.7	2.30 1.80
Longueuil (S-98) (S-99)	PC	low	w/w			4.0 2.0	15.00 3.20

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

*: result rejected
<: result below detection limit
Blank box: parameter not measured

(1): Detection limit is 1.0 mg/L for these samples (instead of 0.1 mg/L).

3.3.4 Trace levels of organic substances

Trace-level analyses of organic substances first require the separation of the dissolved and particulate phases of the samples, followed by each’s extraction and purification. During the 1996–97 sampling period, the purified, dissolved and particulate phases were analysed separately. The concentration results for the two phases were added together to obtain the total concentration, in order that the results might be compared with the quality criteria defined by MENV (MEF, 1998). During the 1998–99 sampling period, purified extracts of the two phases were mixed together and then the total concentration was analysed directly from the composed extract.

3.3.4.1 PCBs

Table 3.11 gives the total mean PCB concentrations determined from the analysis of homologue groups. For the 1996–97 sampling period, the homologues gathered 206 possible PCB congeners substituted using two or more chlorine atoms, and for the 1998–99 sampling period, homologues gathered 194 congeners substituted using three or more chlorine atoms (see Section 2.4.3.2). The results are reported using total concentrations, because, to evaluate and compare the quality of effluents, only PCB total concentrations are considered relative to water quality criteria.

Details on the concentrations for the homologue groups and the 43 congeners specifically analysed, and their detection limits, are given in Appendix 10.

TABLE 3.11: MEAN CONCENTRATIONS OF TOTAL PCBS (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Total PCBs (ng/L)**	
	TT	**II**	**Deph W/S**	**Winter**	**Summer**
Farnham	AS	high	wo/w	7.84	4.09
La Prairie	AS	high	wo/w	7.13	2.44
Magog	AS	high	w/w		
CUO	AS	low	w/w		1.34
Jonquière	AS	low	wo/wo		1.13
Châteauguay	BF	low	wo/w		3.89
CUQ (East plant)	BF	low	wo/wo	8.98	8.72
Cookshire	AL	high	wo/wo	33.54 (1)	(2)
Saint-Joseph-de-Beauce	AL	high	wo/w		1.38
Warwick	AL	high	wo/w		
Saint-Gédéon	AL	low	wo/wo		1.20
Sawyerville	AL	low	wo/w		
Martinville	UL	low	w/w	2.11	
CUM (S-98)	PC	high	w/w		5.99
Longueuil (S-98)	PC	low	w/w	6.84	8.50

Treatment type (TT):				Blank box: parameter not measured
AS:	activated sludge	II:	industrial inputs	
BF:	biofiltration	Deph:	dephosphatization	
AL:	aerated lagoons	w:	with dephosphatization	
UL:	unaerated lagoons	wo:	without dephosphatization	
PC:	physico-chemical	W:	winter	
		S:	summer	

(1): Mean concentration calculated from samples of days 1 and 3 only because day 5 sample was lost.

(2): Cookshire samples were impossible to analyse because they were overloaded with organic matter, which was causing interference with the analytical method.

3.3.4.2 PAHs

PAHs measured at the treatment plants are, for the most part, grouped into two categories, according to carcinogenicity. The first group includes 16 PAHs that show sufficient evidence of carcinogenicity according to the International Agency of Research on Cancer (IARC, 1987). The 28 PAHs of the second group show limited evidence of carcinogenicity, as defined by the IARC. See Appendix 12 for the list of PAHs included in each group.

Twenty-two PAHs were analysed in the effluent samples collected in 1996, 1997 and 1998. Eight PAHs belong to Group 1, 11 to Group 2, and 3 other PAHs. The number of PAHs analysed was increased to 50 at stations where samples were collected in 1999 (Châteauguay, CUO, CUQ, Cookshire, Farnham and La Prairie) that is, 16 PAHs from Group 1, 28 PAHs from Group 2, and 6 other PAHs. This leads to a bias in comparing the results of analyses carried out in 1999 with earlier work. However, these additional PAHs are substances found less frequently in municipal effluents, and do not lead to great variations in the results for Group 1 and total PAHs (only a 0 to 10% increase). Table 3.12 shows the total PAH concentrations. For complete results and detection limits, refer to Appendix 11.

There exists a water quality criterion for the prevention of contamination of aquatic organisms (CPCO) that applies to the total PAH concentration of PAH Group 1. In the case of the second group, there exists a specific quality criterion for seven PAHs. Results obtained at the treatment plants are also presented so as to take this specific quality criterion into consideration. Table 3.13 gives the total PAHs measured included in Group 1, and Table 3.14 gives the mean concentrations of the seven PAHs included in Group 2 for which specific water quality criteria exist.

Table 3.12: Mean Concentrations of Total PAHs (Winter and Summer)

Treatment plant	**Characteristics**			**Total PAHs (1) (ng/L)**	
	TT	**II**	**Deph W/S**	**Winter**	**Summer**
Farnham	AS	high	wo/w	100.6	90.6
La Prairie	AS	high	wo/wo	106.9	124.9
Magog	AS	high	w/w		
CUO	AS	low	w/w		124.3
Jonquière	AS	low	wo /wo		83.8
Châteauguay	BF	low	wo/w		248.1
CUQ (East plant)	BF	low	wo/wo	1 581.7	866.5
Cookshire	AL	high	wo/wo		96.8 (2)
Saint-Joseph-de-Beauce	AL	high	wo/w		93.3
Warwick	AL	high	wo/w		
Saint-Gédéon	AL	low	wo/wo		46.9
Sawyerville	AL	low	wo/w		
Martinville	UL	low	w/wo	174.6	
CUM (S-98)	PC	high	w/w		2 730.8
Longueuil (S-98)	PC	low	w/w	1 819.1	1 707.9

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

Blank box: parameter not measured

(1): Sum of 22 PAHs at all treatment plants, except for summer results at Châteauguay, CUO, CUQ, Cookshire, Farnham and La Prairie plants, and winter result at Martinville plant, where it is the sum of 50 PAHs (see text).

(2): Mean concentration calculated from samples of days 1 and 3 only, because day 5 sample was overloaded with organic matter, which was causing interference with the analytical method.

TABLE 3.13: MEAN CONCENTRATIONS OF GROUP 1 PAHS (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Group 1 PAHs (1) (ng/L)**	
	TT	**II**	**Deph W/S**	**Winter**	**Summer**
Farnham	AS	high	wo/w	23.5	15.9
La Prairie	AS	high	wo/wo	6.6	14.7
Magog	AS	high	w/w		
CUO	AS	low	w/w		5.8
Jonquière	AS	low	wo/wo		10.7
Châteauguay	BF	low	wo/w		27.2
CUQ (East plant)	BF	low	wo/wo	20.0	29.0
Cookshire	AL	high	wo/wo		1.0 (2)
Saint-Joseph-de-Beauce	AL	high	wo/w		2.4
Warwick	AL	high	wo/w		
Saint-Gédéon	AL	low	wo/wo		4.0
Sawyerville	AL	low	wo/w		
Martinville	UL	low	w/wo	<	
CUM (S-98)	PC	high	w/w		53.0
Longueuil (S-98)	PC	low	w/w	9.9	15.5

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization
W: winter
S: summer

<: result below detection limit
Blank box: parameter not measured

(1): Sum of 8 Group 1 PAHs at all treatment plants, except for the summer results at Châteauguay, CUO, CUQ, Cookshire, Farnham and La Prairie, and winter result at Martinville, where it is the sum of 16 Group 1 PAHs (see text).

(2): Mean concentration calculated from samples of days 1 and 3 only because day-5 sample was overloaded with organic matter, which was causing interference with the analytical method.

TABLE 3.14: MEAN CONCENTRATIONS OF GROUP 2 PAHS (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Winter (Group 2 PAHs in ng/L)**							**Summer (Group 2 PAHs in ng/L)**						
	TT	**II**	**Deph W/S**	Acena-phthene	Anthra-cene	Fluoran-thene	Fluo-rene	Naph-thalene	Phenan-threne	Pyrene	Acena-phthene	Anthra-cene	Fluoran-thene	Fluo-rene	Naph-thalene	Phenan-threne	Pyrene
Farnham	AS	high	wo/w	<	<	5.9	2.4	11.4	7.1	17.7	<	<	8.0	3.9	3.7	26.0	10.7
La Prairie	AS	high	wo/wo	2.7	0.2	4.1	6.5	23.9	5.6	7.0	<	<	9.5	7.1	31.1	19.0	15.3
Magog	AS	high	w/w														
CUO	AS	low	w/w								<	1.1	5.2	6.0	38.0	14.0	25.7
Jonquière	AS	low	wo/wo								0.8	<	3.8	2.0	8.2	6.9	8.3
Châteauguay	BF	low	wo/w								5.5	1.0	11.4	14.0	63.7	34.0	13.3
CUQ (East plant)	BF	low	wo/wo	24.7	3.3	14.8	53.9	267.1	87.2	39.3	14.9	3.4	21.0	35.3	158.7	50.7	26.7
Cookshire (1)	AL	high	wo/wo								<	<	6.0	2.4	<	29.0	30.5
St-J.-de-Beauce	AL	high	wo/w								1.1	<	4.0	5.2	5.9	30.7	5.6
Warwick	AL	high	wo/w														
Saint-Gédéon	AL	low	wo/wo								<	<	5.2	3.1	4.9	10.4	4.6
Sawyerville	AL	low	wo/w														
Martinville	UL	low	w/wo	<	<	5.9	2.0	38.3	16.0	2.7							
CUM (S-98)	PC	high	w/w								38.3	16.0	44.0	46.7	543.3	118.7	40.0
Longueuil (S-98)	PC	low	w/w	22.3	3.6	11.9	49.5	308.4	70.5	13.7	14.3	4.5	7.9	18.7	570.0	55.0	10.8

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

<: result below detection limit
Blank box: parameter not measured

(1): Mean concentration calculated from samples of days 1 and 3 only because day 5 sample was too overloaded with organic matter, which was causing interference with the analytical method.

3.3.4.3 Chlorinated dioxins and furans

Usually, compounds analogous to dioxins are found as complex congener mixtures in the environment and have a similar mode of action (Neal, 1985). For this reason, the concept of "toxic equivalence" (TE) was introduced to facilitate their evaluation. The 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is used to estimate the relative toxicity of dioxins and furans. The concentrations presented in Table 3.15 represent the sum of the 17 specific chlorinated dioxin and furan congeners analysed, expressed as toxic equivalents of 2,3,7,8-TCDD. Complete results for the different congeners and homologue groups are given in Appendix 13; the table of toxic equivalents of the 17 congeners is provided in MENV (1998).

TABLE 3.15: MEAN CONCENTRATIONS OF CHLORINATED DIOXINS AND FURANS (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Chlorinated dioxins and furans (pg/L)** (1)	
	TT	**II**	**Deph W/S**	**Winter**	**Summer**
Farnham	AS	high	wo/w		0.147
La Prairie	AS	high	wo/wo	0.012	0.014
Magog	AS	high	w/w		
CUO	AS	low	w/w		0.011
Jonquière	AS	low	wo/wo		0.029
Châteauguay	BF	low	wo/w		0.049
CUQ (East plant)	BF	low	wo/wo	0.038	0.130
Cookshire	AL	high	wo/wo		2.624
Saint-Joseph-de-Beauce	AL	high	wo/w		0.081
Warwick	AL	high	wo/w		
Saint-Gédéon	AL	low	wo/wo		0.469
Sawyerville	AL	low	wo/w		
Martinville	UL	low	w/wo	0.018	
CUM (S-98)	PC	high	w/w		0.268
Longueuil (S-98)	PC	low	w/w	0.038	0.319

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization
W: winter
S: summer

Blank box: parameter not measured

(1): Mean concentrations were calculated from daily values of the sum of 17 specific congeners of chlorinated dioxins and furans expressed as toxic equivalents of 2,3,7,8-TCDD.

3.3.5 Pesticides

Forty-six pesticides were analysed at the two treatment plants studied. Of these pesticides, nine herbicides and six insecticides were detected in at least one sample from both plants. Among those more likely to be found because of their use in urban settings, seven pesticides were detected at the effluent of the two treatment plants. The herbicides 2,4-D, mecoprop and dicamba figure in the commercial mixture for urban lawn treatment (residential lawns, parks, golf courses, etc.) The insecticides diazinon, carbaryl, malathion and chlorpyrifos were also detected. Table 3.16 lists the pesticides detected at the CUM and Longueuil plants and the frequency at which they were detected. The list of all the pesticides analysed may be found in Appendix 14.

TABLE 3.16: DETECTION FREQUENCY OF PESTICIDES IN SAMPLES COLLECTED AT CUM AND LONGUEUIL PLANTS

Pesticide	**Detection frequency (%)**	
	CUM (1)	**Longueuil (2)**
Herbicide		
2,4-D	85.7	91.7
Mecoprop	86.2	91.7
Dicamba	65.5	91.7
Bentazone	3.3	0
MCPB	0	33.3
Atrazine	90.0	66.7
Deethyl-atrazine (DEA)	13.3	8.3
Deisopropyl-atrazine (DIA)	16.6	0
Metolachlor	43.3	66.7
Dimethenamide	3.3	25.0
Diuron	20.0	0
Insecticide		
Diazinon	23.3	66.7
Carbaryl	70.0	16.7
Malathion	13.3	50.0
Chlorpyrifos	36.7	33.3
Dimethoate	0	8.3
Carbofuran	0	8.3

(1): Frequency calculated from 30 composite samples drawn on different days.

(2): Frequency calculated from 12 composite samples drawn on three inconsecutive days at the rate of four samples a day.

3.3.5.1 Pesticides detected in the CUM treatment plant effluent

Twelve pesticides were detected in the CUM treatment plant effluent. The mean concentrations obtained using the results of two or three consecutive sampling days are given in Table 3.17. Complete daily results are included in Appendix 15.

Among the four most frequently detected herbicides (Table 3.16), three are associated with lawn treatment (2,4-D, mecoprop and dicamba). The four other herbicides detected are atrazine, metolachlor, diuron and dimethenamide, including deethyl-atrazine (DEA) and deisopropyl-atrazine (DIA), both atrazine degradation products. These products are used in field crops such as corn. The detection of such products in the CUM's effluent is probably due to atmospheric transport of substances from agricultural areas surrounding the Montreal region. Although 2,4-D, mecoprop and dicamba are also used in agriculture, their detection frequency and the higher mean concentrations measured in this study, compared to low atrazine and metolachlor concentrations, point to their use on urban lawns.

Carbaryl was the insecticide most frequently detected (70% of samples). Its detection in May and June suggests use on residential apple trees and fruit trees. Later in the season, carbaryl may be used to eliminate various insects from gardens or to rid lawns of white grubs (lily beetles). It also figures in cat and dog flea shampoos. Chlorpyrifos and diazinon can be used against various lawn insects (ants, spiders, earwigs, etc.). Malathion is registered for controlling certain insects and mites on ornamental plants (trees, shrubs, and flowers) and in gardens.

Dichlorvos was also detected in 63.3% of the samples, but because it was also detected in the control sample, the results were rejected.

TABLE 3.17: MEAN CONCENTRATIONS OF PESTICIDES DETECTED AT THE CUM PLANT

Pesticide	**Mean pesticide concentrations (1) (µg/L)**										
	May 17-19	**May 25-27**	**June 31-2**	**June 7-9**	**June 14-16**	**June 21-22**	**June 28-29**	**July 5-7**	**July 12-14**	**July 20-22**	**July 26-27**
Herbicide											
2,4-D	0.34	0.26	0.33	0.06	0.22	0.22	0.47	0.24	0.07	<	0.12
Mecoprop	0.41	0.24	0.34	0.21	0.08	0.20	0.53	0.35	0.10	<	0.07
Dicamba	0.05	0.07	0.06	<	0.08	0.23	0.12	0.66	<	<	<
Bentazone	<	<	<	<	<	0.06	<	<	<	<	<
Atrazine	0.86	0.07	0.04	0.09	0.09	<	0.07	0.24	0.04	0.05	0.07
DEA	<	<	<	<	<	<	<	0.46	0.11	<	<
DIA	<	<	<	<	<	<	<	0.04	<	0.33	<
Metolachlor	0.04	0.08	0.02	<	<	<	0.08	0.10	<	<	<
Dimethenamide	<	<	<	<	<	<	<	<	<	<	<
Diuron	<	<	<	<	<	<	0.31	<	<	<	<
Insecticide											
Diazinon	<	0.02	0.02	0.05	<	<	0.03	<	<	0.02	<
Carbaryl	<	0.04	0.09	0.08	0.05	0.05	0.03	<	<	<	<
Malathion	<	<	0.03	<	<	0.02	<	<	<	<	<
Chlorpyrifos	<	0.03	0.02	<	<	<	<	0.02	<	<	<
Dichlorvos	*	*	*	*	*	*	*	*	*	*	*

(1): Mean concentrations calculated from results of samples drawn on 2 or 3 consecutive days, as applicable.
*: Result rejected.
<: Result below detection limit.

3.3.5.2 Pesticides detected at the Longueuil treatment plant effluent

Thirteen pesticides were detected in the effluent of the Longueuil treatment plant. The mean concentrations obtained from the results of four compound samples collected the same day during a heavy rainfall are shown in Table 3.18. Complete results are given in Appendix 15.

Pesticide concentrations detected at the Longueuil plant are generally higher than at the CUM plant. This could be due to the fact that the samples were collected during a rainfall rather than during regular intervals, or to the characteristics of the urban environment (e.g. proportion of residential lawns in the area, parks, and golf courses).

TABLE 3.18: MEAN CONCENTRATIONS OF PESTICIDES DETECTED AT THE LONGUEUIL PLANT

Pesticide	**Mean pesticide concentrations (1) (µg/L)**		
	May 19	**June 28**	**September 7**
Herbicide			
2,4-D	3.10	0.42	0.41
Mecoprop	3.10	0.36	0.46
Dicamba	0.32	0.05	0.03
MCPB	<	<	0.06
Atrazine	0.16	0.10	<
Deethyl-atrazine (DEA)	<	<	<
Metolachlor	0.11	0.11	<
Dimethenamide	<	<	<
Insecticide			
Diazinon	0.11	0.04	<
Carbaryl	0.04	<	<
Malathion	0.10	<	<
Chlorpyrifos	0.04	0.07	<
Dimethoate	0.04	<	<
Carbofuran	<	<	<

(1): Mean concentrations calculated from results of 4 composite samples drawn on a single day during 3 different rainfall events.

<: Result below detection limit.

Those products most frequently detected were the herbicides 2,4-D, mecoprop and dicamba. Just as with the CUM treatment plant, the presence of herbicides associated with field crops was also reported in the Longueuil plant effluent.

Many insecticides were also detected: diazinon, carbaryl, malathion, chlorpyrifos, dimethoate and carbofuran. The potential uses for the first four insecticides have already been mentioned. Dimethoate and carbofuran can be used in a number of agricultural and urban applications. However, in this case, it is difficult to pinpoint the source because they were detected only once.

3.3.5.3 Relation between measured pesticide concentrations and flow rate

An analysis of the results shows a correlation between measured pesticide concentrations and the flow rate recorded at the treatment plants. As mentioned in Section 2.4.1.3, such a correlation was expected and corroborates the conclusions of other studies carried out in Canada and the U.S.

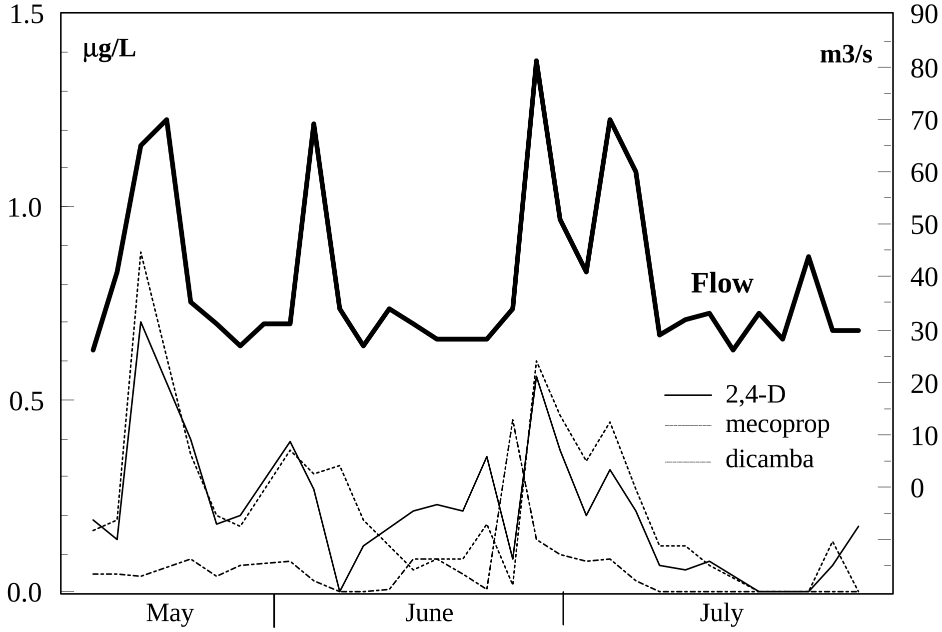
Figure 3.1 shows the relationship between maximum flow rates recorded and the concentration of six pesticides measured in the 30 samples collected at the CUM plant in 1999. Figure 3.2 shows this same information for the four samples collected May 19, 1999 at the Longueuil plant. Concentrations of the various pesticides tend to be higher during rainfall events, when flow rates are greater at the plant. The correlation, however, seems more obvious for herbicides than for insecticides. During the same rainfall, insecticide concentrations do not always follow the flow rate curve (Figure 3.1 at the CUM and June 28, 1999, at Longueuil [results not shown]).

The type of pesticide present and the increase in concentration during a rainfall coincide with the observations of Struger and Ripley (Government of Canada, 2000), and Struger *et al*. (1994), with regard to the presence of urban-origin pesticides in watercourses and runoff water retention lagoons in the cities of Toronto, Hamilton and Guelph, Ontario.

In the United States, two studies conducted by the United States Geological Survey deal with watercourses draining urban areas: Dallas, Texas and Denver, Colorado These studies report the presence of carbaryl (Land *et al.*, 1998; Kimbrough and Litke, 1993), chlorpyrifos and diazinon (Land *et al.*, 1998). The authors indicated that concentrations increase as the flow rate does.

FIGURE 3.1: RELATION BETWEEN MAXIMUM FLOW RATES AND CONCENTRATIONS OF CERTAIN PESTICIDES AT THE CUM PLANT IN 1999

HERBICIDES



INSECTICIDES

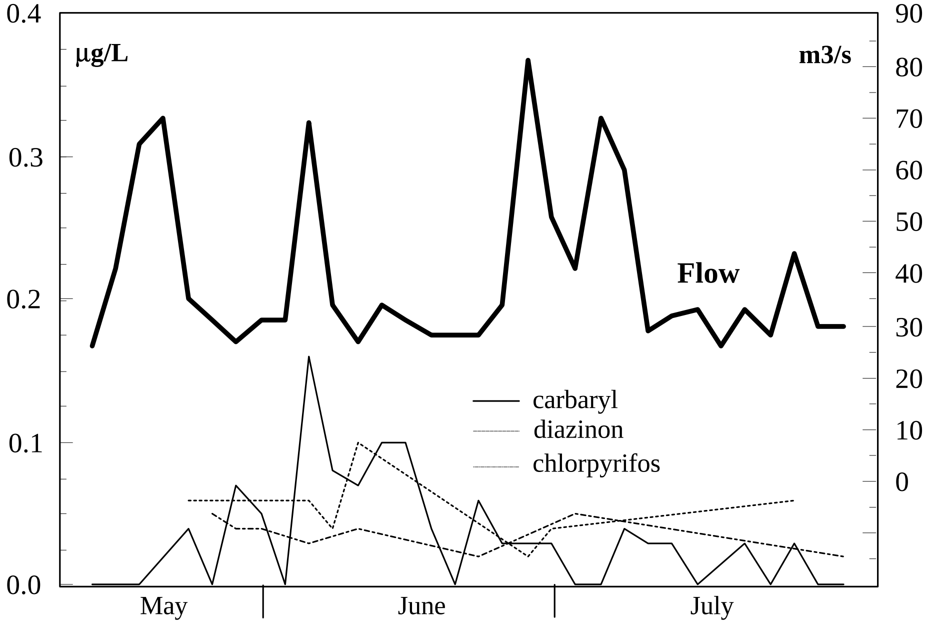
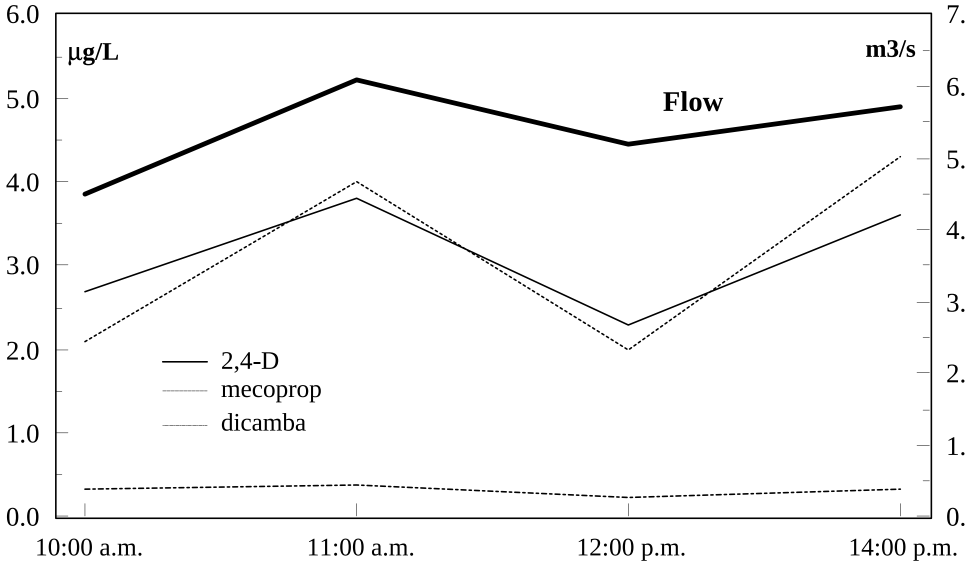
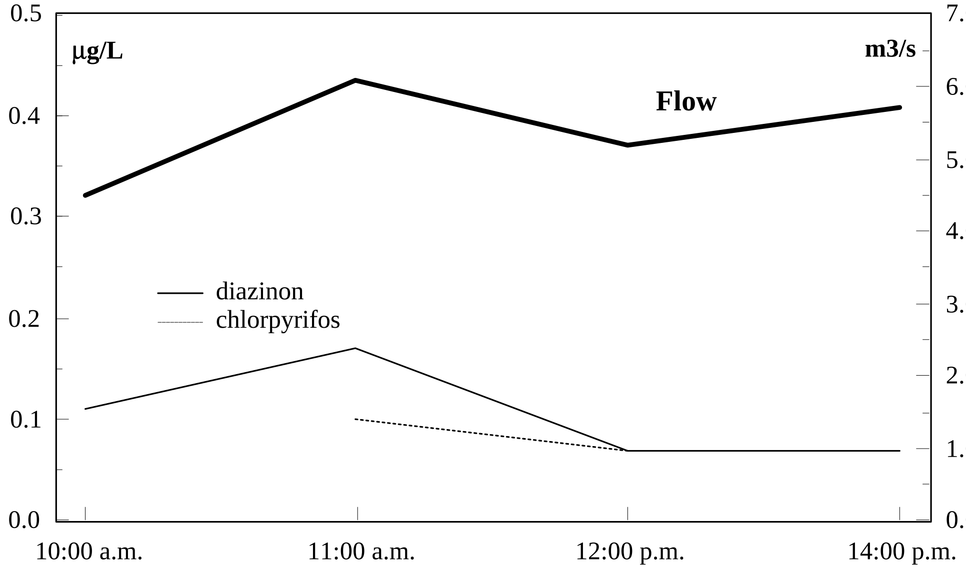


FIGURE 3.2: RELATION BETWEEN FLOW RATES AND CONCENTRATIONS OF CERTAIN PESTICIDES AT THE LONGUEUIL PLANT MAY 19, 1999

HERBICIDES



INSECTICIDES



3.3.6 Quality control

The 30 municipal effluent characterizations produced more than 10 000 physico-chemical analyses. All the analyses were carried out in compliance with the quality requirements of the program contained in the SLV 2000 general characterization guide (SLV 2000, 1995) and the SCA-01 guide of the CEAEQ certification service. They were performed by different private and government laboratories, all certified by the MENV.

The results obtained by the private laboratories who performed the analyses of conventional physico-chemical parameters (PCPs) and metals for the 1996–97 sampling period, along with VOCs and SVOCs, were the subject of specific quality-assessment reports (one report per treatment plant per season of the year). For further details on the subject, consult one of the 30 scientific and technical reports published by Environment Canada’s St. Lawrence Centre (Roberge, S, 1996 to 1999).

For the other analyses conferred to the CEAEQ: metals during the 1998–99 sampling period, trace levels of organic substances (PCBs, PAHs, chlorinated dioxins and furans), surfactants and pesticides, the results were all accepted, with the exception of the dichlorvos pesticide results at the CUM plant and the nonionic surfactants at the Sawyerville plant in winter. When they were deemed doubtful, these analyses were repeated until the results complied with requirements.

All results that did not comply with the quality standards were rejected (identified by asterisks in the results tables or by a note of caution).

4 INTERPRETATION OF THE RESULTS

Two complementary tools are usually used to assess the quality of wastewater discharged to the aquatic environment: the overall toxicity criteria for toxicity tests, and the quality criteria for surface water defined for physico-chemical substances.

Toxicity tests offer certain advantages to the quality assessment of effluents. Among other things, they take account of contaminant bioavailability , chemical interactions among contaminants, and the toxicity of substances that are not analysed or not suspected.

The water quality criteria defined for the protection of aquatic life are based on numerous (eco)toxicological studies and cover a wider variety of "effect parameters" and aquatic species. In addition, quality criteria are defined not only for aquatic life, but also to prevent the contamination of aquatic organisms consumed by humans and terrestrial fauna.

Each of these two tools has its own interpretative limits, but their combined use provides for a more complete assessment of the potential effects of effluent wastewaters discharged to an aquatic environment (MENV, 1998).

The results of the toxicity tests and the physico-chemical analyses presented in the preceding chapter are interpreted in this section so as to evaluate the toxic potential of effluents before they are diluted in the aquatic environment. To this end, the results of the toxicity tests are first compared to the overall toxicity criteria, expressed in toxicity units (TU), after which the results of the physico-chemical analyses are compared to the water quality criteria, expressed in concentration units of chemical substances.

Finally, an analysis is carried out to determine whether one or more substances may be responsible for the toxicity measured and to evaluate the effects of season, treatment process type, the presence of industry and chemical phosphorus removal on the toxicity of effluents.

4.1 Comparison of Toxicity Test Results with Overall Toxicity Criteria

4.1.1 The toxicity tests of the approach for the protection of the aquatic environment

The toxicity tests employed in the MENV approach for the protection of the aquatic environment evaluate the toxic potential of an effluent for aquatic life using the overall toxicity criteria presented in the document, *Critères de qualité de l'eau de surface au Québec (*quality criteria for runoff water in Quebec*)* (MENV, 1998); that is:

- 1 TUa for acute toxicity (*O. mykiss* and *D. magna*)
- 1 TUc for chronic toxicity (*P. promelas*, *C. dubia* and *S. capricornutum*).

Toxicity tests are good indicators of the probable effects of an effluent on the environment (U.S. EPA, 1991). Any toxicity test result exceeding the value of 1 TUa indicates that the effluent can severely, and in a short time, harm aquatic organisms exposed thereto. In addition, when an effluent exceeds the value of 1 TUc, it is an indication of its toxic potential for aquatic organisms were it to be found at such a concentration in the environment. This exercise thus provides a theoretical appreciation of the potential toxicity of an effluent for the receiving environment.

Table 4.1 presents the number and percentage of treatment plants and samples having obtained at least one result that exceeds the overall toxicity criteria of 1 TUa and 1 TUc. Since the criteria are composed of a single unit, the tables are simply a compilation of the toxicity test results that are greater than 1 TU (tables 3.2-W, 3.2-S, 3.3-W, 3.3-S).

4.1.1.1 Acute toxicity

RAINBOW TROUT (*O. mykiss*)

Of the valid results obtained with the samples drawn under winter operating conditions, four treatment plants out of 14 (29%) exhibited acute toxicity (> 50% mortality) for rainbow trout in at least one of the three daily samples (Cookshire, Saint-Gédéon, Saint-Joseph-de-Beauce and Warwick) (tables 3.2-W and 4.1). Among the ten other treatment plants, eight presented no sign of acute toxicity, while two showed mortality percentages below 50% (Sawyerville and CUQ).

In summer, the effluents of three plants out of 13 (23%) exhibited acute toxicity (Châteauguay, La Prairie and Longueuil [1998 and 1999]) and three plants had at least one mortality percentage below 50% (CUM [1998 and 1999], Jonquière and Saint-Gédéon) (tables 3.2-S and 4.1). The other seven plants showed no signs of acute toxicity.

CLADOCERAN (*D. magna*)

Only the Cookshire treatment plant exhibited acute toxicity (over 50% mortality) to *D. magna* in winter. As for the samples drawn in summer, 23% of the plants (3 plants out of 13) exhibited toxicity (Cookshire, Longueuil [1998] and Saint-Joseph-de-Beauce).

TABLE 4.1: NUMBER AND PERCENTAGE OF TREATMENT PLANTS AND SAMPLES EXCEEDING THE OVERALL TOXICITY CRITERIA FOR THE TOXICITY TESTS USED IN THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT (WINTER AND SUMMER)

Toxicity test	**Treatment plants exceeding the overall toxicity criteria (1)**						**Samples exceeding the overall toxicity criteria (2)**					
	Winter		**Summer**		**Total**		**Winter**		**Summer**		**Total**	
	Number	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Acute toxicity (exceedance of the 1 TUa overall toxicity criterion)												
1. Rainbow trout (*O. mykiss*)	4/14	29	3/13	23	7/15	47	10/37	27	8/44	18	18/81	22
2. *Daphnia magna*	1/15	7	3/13	23	3/15	20	3/45	7	7/46	15	10/91	11
Total (1 and 2 combined)	4/15	27	5/13	38	7/15	47	13/82	16	15/90	17	28/172	16
Chronic toxicity (exceedance of the 1 TUc overall toxicity criterion)												
1. *Selenastrum capricornutum*	2/15	13	0/13	0	2/15	13	2/15	13	0/15	0	2/30	7
2. Fathead minnow (*P. promelas*)	14/15	93	9/13	69	14/15	93	14/15	93	9/13	69	23/28	82
3. *Ceriodaphnia dubia*	7/15	47	9/13	69	12/15	80	7/15	47	11/15	73	18/30	60
Total (1 to 3 combined):> 1 TUc	14/15	93	11/13	85	14/15	93	23/45	51	20/43	47	43/88	49
> 10 TUc	5/15	33	6/13	46	7/15	47	5/45	11	7/43	16	12/88	14
> 30 TUc	1/15	7	1/13	8	1/15	7	1/45	2	1/43	2	2/88	2

(1): A plant is included in the total when at least one result exceeds the overall toxicity criterion. A plant is not included in the total when all samples tested for a species are rejected at that plant.

(2): A sample is not included in the total when its result is rejected.

To summarize, seven of 15 stations (or 47%) obtained at least one acute toxicity result with more than 50% mortality in one or another undiluted whole effluent sample analysed at each plant (all seasons and species included). Under winter operating conditions, only four plants out of 15 (27%) did not meet the acute criterion for overall toxicity of 1 TUa for at least one of the two toxicity tests (*D. magna* and *O. mykiss*). In summer, five of 13 plants (38%) obtained results exceeding 1 TUa. As a percentage of the number of samples, 22% were toxic to rainbow trout and 11% were toxic to *Daphnia magna*.

These results, together with the low amplitude of exceedances of the 1 TUa quality criterion, seem to indicate that the municipal treatment plants in Quebec exhibit a low acute lethal toxicity to aquatic organisms. Only two plants Cookshire (winter and summer) and Longueuil (summer) exhibit values well above 1 TUa, which may indicate potential toxicity for organisms living immediately downstream of the plant outfalls.

For purposes of comparison, 56% of the samples examined in assessing the toxicity of ten municipal effluents in Ontario (Orr *et al.*, 1992) were toxic to rainbow trout, and 27% were toxic to *Daphnia magna;* the present study shows percentages of 22% and 11%, respectively. These differences are mainly due to the fact that treatment plants in Quebec do not employ chlorine treatment to disinfect wastewaters, while such was the case in Ontario in 1992.

4.1.1.2 Chronic toxicity

S. capricornutum ALGAE

Of the 30 characterizations (winter and summer), only two treatment plants monitored under winter conditions exhibited chronic toxicity to algae (Cookshire and Sawyerville). All other effluent samples had a stimulating effect on algal growth, probably due to the abundant presence of nutrients in the municipal effluents (see tables 3.3-W, 3.3-S and 4.1). A recent study carried out on the effluents of 18 municipal treatment plants in Australia showed similar results, with an absence of toxicity to the algae *S. capricornutum* (Bailey *et al*., 1999).

However, the stimulated algal growth observed in the winter samples is amplified in comparison with what might actually be observed in an aquatic environment, since the temperature of the test water was 24ºC, while the temperature of the watercourse in winter is ≥ 4°C.

An increase in algal growth is not necessarily a positive effect on an aquatic environment. For example, excessive proliferation of algae and aquatic plants may lead to a dramatic decrease in dissolved oxygen at night (plant respiration) and thereby be detrimental to aquatic life.

FATHEAD MINNOW (*P. promelas*)

In winter, 93% of all plant effluents (14 of 15 plants) presented significant chronic toxicity in the fathead minnow tests (> 1 TUc). For the tests carried out on samples drawn in summer, the effluent of 9 plants out of 13 (or 69%) had an effect on the survival or growth of *P. promelas* larvae. Martinville is the only treatment plant where samples recorded no toxicity, whether they were drawn in winter or in summer. Except for the CUM plant in winter, which exhibited a questionable result above 100 TUc, six plants showed results > 10 TUc: CUQ, Longueuil and Saint-Joseph-de-Beauce in winter, as well as Cookshire, CUM and Jonquière during the summer characterization campaign. The CUM winter result is considered unreliable because of the great variation in the results obtained from one sample to another.

CLADOCERAN (*C. dubia*)

The effluents of 7 of 15 plants (47%) in winter and 9 of 13 (69%) in summer had significant chronic effects on *C. dubia*. The CUO and Martinville plants are the only plants for which the effluent had no effect in winter or summer. The highest responses (> 10 TUc) were recorded at Cookshire in winter, followed by Jonquière, Longueuil (1998), Saint-Gédéon and Saint-Joseph-de-Beauce in summer.

In summary, with the exception of a single plant   that of Martinville   the effluents of all treatment plants exceeded the TUc chronic toxicity criterion in at least one of the three tests. All the effluents characterized in winter as well as in summer had one or more effects on the survival, growth or reproduction of *S. capricornutum, P. promelas* and *C. dubia*. However, the exceedances are small in the majority of cases, since only 14% of the samples (12 out of 88) showed a result above 10 TUc.

In terms of numbers, this corresponds to seven plants out of 15 (47%) having obtained at least one result above 10 TUc (all seasons and tests combined). These plant effluents would be potentially harmful if the receiving environment had a weak streamflow compared to that of the effluent. Only one of the effluents presented a result above 30 TUc.

Almost all samples had a stimulating effect on algal growth. This positive response in the *S. capricornutum* was not quantified in terms of toxic units, but it is nonetheless indicative of the potential harm for aquatic life, as discussed above.

For comparison purposes, the toxicity monitoring of 39 municipal effluent samples since 1987 in Maryland showed that 54% of the effluents exhibited chronic toxicity before dilution. When taking into account the dilution factor allocated to each discharge, only six effluents still exhibited a potential chronic toxicity, and only because these effluents were discharged into very small or intermittent watercourses (Fisher *et al.*, 1998).

Another study, Orr *et al.* (1992), indicates that, of the 80 samples of effluents drawn from ten municipal treatment plants in Ontario, 69% were chronically toxic to fathead minnow and 56% to *C. dubia*, compared to 82% and 60%, respectively, in the present study. However, the samples in the Ontario study were treated to reduce their toxicity due to chlorine and ammonia nitrogen.

4.1.2 The toxic print of the PEEP Index

No threshold or criterion has yet been established to indicate a worrisome or harmful level relative to toxic prints of the PEEP Index.

However, the results indicate that the effluents of Saint-Joseph-de-Beauce (in winter and in summer), Sawyerville (in winter) and Martinville (in winter) stand apart from the rest due to their high toxic prints (see Table 3.5). The latter exceed the detection limit (i.e. 0.1 ATU.bvu^{-1}) by a factor of approximately 550 to 900. The effluents of the Cookshire plant (winter and summer) are next, followed by Farnham's (winter), with respective toxic prints of 34.1, 17.0 and 15.8 ATU.bvu^{-1}, or approximately 340 to 160 times the detection limit. As for the remaining treatment plants, the exceedances range from 1 (i.e. undetectable toxicity) to 80.

The toxic prints of Sawyerville and Martinville in winter are surprising, considering the very low industrial inputs at these treatment plants. The results of the toxicity tests performed at both these sites indicate that only genotoxicity to *E. coli* contributed to the toxic print.

The genotoxic responses in *E. coli* also contributed to high toxic prints at several other plants, particularly at Saint-Joseph-de-Beauce, Cookshire and Farnham (winter and summer in all cases). In addition, the test with *E. coli* seems to have been the most sensitive to municipal effluents since positive responses were recorded at 11 of the 15 plants sampled under winter conditions and at 6 of the 13 plants in summer (Table 3.4). All the positive samples contained direct-acting genotoxic agents; that is, contaminants that require no metabolic activation to produce their effects, except at Farnham in summer. Many of these plants also showed effects following a five-day aeration of the sample, which may suggest that the agents capable of altering bacterial DNA are persistent, at least in the short term, in municipal wastewaters.

The test with *C. dubia* was the most sensitive of all, particularly in summer, with more than half of the effluents having caused significant reproductive inhibition. Five samples, those from Cookshire in winter as well as La Prairie, Saint-Joseph-de-Beauce, CUM and Longueuil in summer, were lethal to this cladoceran.

Only a few samples of the two remaining tests showed phytotoxic responses with the growth test of the algae *S. capricornutum* or bioluminescence inhibition responses in *V. fischeri*. Rather, as discussed in Section 4.1.1.2, tests on *S. capricornutum*, and to a lesser extent *V. fischeri*, indicated significant stimulation throughout the test samples, suggesting the presence of nutrients in the municipal wastewaters.

Positive responses were yielded by the samples drawn at Cookshire throughout testing, with the exception of the test with *V. fischeri* in winter and *S. capricornutum* in summer. The responses suggest a genotoxic potential ranging from marginal to moderate. These results indicate that wastewater at this plant can affect more than one trophic level in the food chain that is, the decomposers, and both the primary producers and consumers.

4.2 Comparison of Results of Physico-chemical Analyses with Water Quality Criteria

This section compares the results of the physico-chemical analyses with the MENV water quality criteria (1998).

Water quality criteria integrate all the information available on potentially toxic concentrations for various uses of water. There may be several quality criteria for a single substance and each of these criteria is defined for the purpose of protecting a specific use of water (MENV, 1998).

In light of the objectives of this study, three uses were selected to interpret the analytical results: aquatic life, the consumption of fish, shellfish and crustaceans by humans, and by piscivorous wildlife. These three uses are present or potentially present in all watercourses in Quebec. They are respectively represented by the chronic water quality criterion for the protection of aquatic life (CCAL), the water quality criterion for the prevention of contamination of aquatic organisms (CPCO), and the water quality criterion for the protection of piscivorous wildlife (CPPW)

The exceedances of quality criteria for all substances analysed are presented in sections 4.2.1 and 4.2.2 below. The ratio *mean concentration:toxicity criterion (CCAL, CPCO* and *CPPW)* was calculated for every substance at every plant and for every season. Only ratios ≥ 1 are presented in the tables.

The ratio value obtained for a given substance indicates the extent to which the concentration measured in the undiluted effluent exceeds the quality criteria. A ratio greater than 1 provides a theoretical appreciation of the toxic potential of the effluent were that concentration to be found as such in the environment. However, since the effluent is diluted in the receiving water, the exceedance value for quality criteria will be lower in the natural environment, or even nil, depending on the case, in relation to the specific characteristics of each receiving environment. Consequently, any amplitude of exceedance of the quality criteria below 10 indicates, as a general rule, a lower degree of concern.

4.2.1 Protection of aquatic life

Chronic water quality criteria for the protection of aquatic life (CCAL) are defined to ensure the long-term protection of all aquatic organisms. They represent the highest permissible concentration of a substance that will not be detrimental to aquatic organisms (and their offspring) exposed to it on a daily basis throughout their lifetimes. The exceedance of a CCAL at the effluent gives an indication of the minimal dilution required for the effluent/aquatic environment mixture to reach a concentration below the threshold of potential effect.

There are CCALs for a number of substances, most of which are related to the most sensitive uses of the water.

4.2.1.1 Conventional physico-chemical parameters

Tables 4.2-W and 4.2-S show the amplitudes of exceedance of CCALs obtained at the various treatment plants for conventional physico-chemical parameters (PCP).

The first three parameters (BOD_5, SM and P_T) are among the main contaminants present in domestic and agri-food industry wastewater, and are used in the design of municipal treatment plants. They are present in large quantities in municipal wastewaters and their removal varies in relation to the treatment process in place. It is therefore possible to observe frequent CCAL exceedances for these substances, although they have no direct toxic effects on the receiving environment.

<u>BOD_5</u>

The results obtained in winter at seven plants were rejected due to a sample contamination problem. Those exceedances that could be calculated for this parameter are generally of low amplitude (1.3 to 14), and by and large indicate a good performance on the part of the treatment plants. Both values > 10 were obtained in summer at plants where wastewater undergoes physico-chemical treatment; the absence of biological treatment explains these results. In the case of the aerated lagoons, exceedances are greater in winter than in summer, particularly at the three plants with heavy industrial inputs (Cookshire, Saint-Joseph-de-Beauce and Warwick). These results are representative of the efficiency expected of aerated lagoons, which is known to be better in summer. The lower exceedances are obtained at the activated sludge plants.

TABLE 4.2-W: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR CONVENTIONAL PHYSICO-CHEMICAL PARAMETERS (WINTER)

Treatment plant (winter)	**Characteristics**			**Exceedances of CCAL for conventional physico-chemical parameters**										
	TT	**II**	**Deph**	**BOD_5**	**SM**	**P_T**	**NH_3 - NH_4^+ (1)**	**NO_2^- (2)**	**NO_3^-**	**H_2S (3)**	**Cl^-**	**CN^-**	**F^-**	**Phenolic subst.**
Farnham	AS	high	wo	*	1.1	*	1.6	—	—		—	LD	2.3	—
La Prairie	AS	high	wo	*	4.8	*	4.5	—	—		—	LD	1.4	—
Magog	AS	high	with	*	—	*	—	—	—		—	LD	—	—
CUO	AS	low	with	*	11	*	7.2	—	—		—	LD	—	
Jonquière	AS	low	wo	1.3	—	10	2.7				—	LD	—	
Châteauguay	BF	low	wo	*	1.1	*	9.7	—	—		1.1	LD	3.7	
CUQ (East plant)	BF	low	wo	10	2.2	53	14				1.4	LD	4.0	—
Cookshire	AL	high	wo	8.3	1.2	50	12				1.6	LD	—	—
Saint-J.-de-Beauce	AL	high	wo	6.0	1.9	53	29				—	LD	—	
Warwick	AL	high	wo	5.7	2.2	87	15				—	LD	—	
Saint-Gédéon	AL	low	wo	2.0	—	58	12				—	LD	—	
Sawyerville	AL	low	wo	2.0	—	50	12				—	LD	—	
Martinville	UL	low	with	7.7	1.8	40	4.3	—	—	20	—	—	—	1.2
CUM	PC	high	with	*	3.5	*	7.7	—	—		—	LD	1.2	—
Longueuil	PC	low	with	*	2.9	*	11				—	LD	—	—

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): Water quality criterion for NH_3-NH_4^+ is determined at each treatment plant from the mean temperature and pH values measured during the chronic toxicity tests.
(2): Water quality criterion for NO_2^- is determined at each treatment plant from the mean chloride concentration measured in the effluent.
(3): Non-ionized H_2S concentration is calculated from the mean concentration of dissolved sulfides measured in the effluent (see text).

TABLE 4.2-S: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR CONVENTIONAL PHYSICO-CHEMICAL PARAMETERS (SUMMER)

Treatment plant (summer)	**Characteristics**			**Exceedances of CCAL for conventional physico-chemical parameters**										
	TT	**II**	**Deph**	**BOD_5**	**SM**	**P_T**	**NH_3 - NH_4^{+} (1)**	**NO_2^{-} (2)**	**NO_3^{-}**	**H_2S (3)**	**Cl^{-}**	**CN^{-}**	**F^{-}**	**Phenolic subst.**
Farnham	AS	high	with	1.3	1.0	6.7	—	—	—	LD	—	—	3.1	—
La Prairie	AS	high	wo	1.7	—	19	28	1.0	—	LD	—	—	1.5	—
Magog	AS	high	with											
CUO	AS	low	with	—	—	15	5.7	1.0	—	LD	—	—	—	—
Jonquière	AS	low	wo	—	—	6.4	(2.2)	—	—	LD	—	LD	(—)	—
Châteauguay	BF	low	with	3.0	1.0	22	11	—	—	2.1	—	—	4.6	—
CUQ (East plant)	BF	low	wo	3.7	1.1	42	11	—	—	LD	—	—	3.8	—
Cookshire	AL	high	wo	3.3	1.0	37	7.9	3.0	—	LD	—	—	—	2.0
Saint-J.-de-Beauce	AL	high	with	2.0	3.7	24	(1.3)	100	—		—	26	(—)	—
Warwick	AL	high	with											
Saint-Gédéon	AL	low	wo	—	—	73	(9.5)	2.9	—		—	10	(1.0)	—
Sawyerville	AL	low	with	LD	—	14	2.1		—		—	4.0	—	
Martinville	UL	low	wo	6.0	4.6	29	LD		—		—	LD	—	
CUM (1998)	PC	high	with	7.0	1.8	19	5.7	—	—	4.3	—	4.0	(1.6)	1.0
CUM (1999)	PC	high	with	14	2.0	15	7.1	—	—	30	—	4.0	—	1.8
Longueuil (1998)	PC	low	with	12	2.9	28	11	(—)	—	26	—	LD	(—)	2.0
Longueuil (1999)	PC	low	with	7.7	1.7	19	12	—	—	39	—	—	—	2.0

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): Water quality criterion for NH_3-NH_4^{+} is determined at each treatment plant from the mean temperature and pH values measured during the chronic toxicity tests.
(2): Water quality criterion for NO_2^{-} is determined at each treatment plant from the mean chloride concentration measured in the effluent.
(3): Non-ionized H_2S concentration is calculated from the mean concentration of dissolved sulfides measured in the effluent (see text).

SM

SM exceedances were of low amplitude (1.1 to 11) and again indicate the good treatment performance of the plant. The highest value was obtained in winter at the CUO (activated sludge process), but these results are unreliable (see Appendix 2). The 4.8 exceedance obtained in winter at the La Prairie plant (activated sludge) was due to a particularly high single-day result (112 mg/L), probably caused by a loss of sludge. A similar exceedance was obtained in summer at Martinville and can be attributed to the discharge method used during the emptying process, which may draw out algae and sometimes sludge. In the case of aerated lagoons, the only exceedances observed were at the three plants receiving large industrial loads.

TOTAL PHOSPHORUS

The total phosphorus results were rejected at seven plants in winter because the analysis control requirements were not met. Exceedances for this parameter ranged from 6.4 to 87. Exceedances were highest (> 40) at plants that do no chemical dephosphatization, either in winter or year-round. Exceedances at plants that carry out chemical dephosphatization half of the year are lower during the season in which the process is executed, except in the Martinville unaerated lagoons. In this case, the exceedance was greater during spring lagoon emptying (winter conditions) with dephosphatization than during fall emptying without dephosphatization (summer conditions). These results are due to phosphorus, which accumulates yearly in the sludge. Indeed, an effluent characterization with dephosphatization (May 1999) was carried out more than two and a half years after the characterization without dephosphatization (October 1996). In addition, for the first time in 1999, the Martinville plant had to add alum to its unaerated lagoons because its total phosphorus discharge requirements were no longer being respected.

Chemical dephosphatization is required at plants where the receiving environment is sensitive to enrichment (eutrophication). This requirement applies in summer (May 15 to October 15/November 15) or year-round when the discharge is upstream from an area of significant sediment accumulation, such as a lake or a reservoir.

NITROGEN

The CCAL for ammonia nitrogen (NH_3-NH_4^+) varies with temperature and level of pH. To obtain the ratio of mean concentration to CCAL, a quality criterion was calculated for each effluent in relation to temperature maintained during the chronic toxicity tests with replacement water (25ºC) and the mean pH measured during the test (Appendix 7).

The greatest exceedances were obtained at the Saint-Joseph-de-Beauce (29) and Warwick (15) aerated lagoons in winter, as well as at the La Prairie activated sludge treatment plant in summer (28). In all three cases, the large organic loads probably come from agri-food plants. At treatment plants with aerated lagoons, the exceedances are all greater in winter, which confirms that nitrification (conversion of ammonia nitrogen into nitrites and then into nitrates by nitrifying bacteria) improves in summer in aerated lagoons.

Nitrites (NO_2^-) and nitrates (NO_3^-) were analysed at seven plants only in winter. For NO_2^-, CCAL varies with chloride concentration. To obtain the ratio of mean concentration to criterion, the CCAL was selected based on the mean chloride concentration measured at each effluent. There were no exceedances of NO_2^- in winter and none of NO_3^- in either season. Only two minor NO_2^- exceedances in summer and one major exceedance were recorded at the Saint-Joseph-de-Beauce plant (100). The latter result can be explained by the incomplete nitrification of ammonia nitrogen due to an increase in the organic load flowing to the lagoons.

HYDROGEN SULFIDE

Non-ionized hydrogen sulfide (H_2S) cannot be measured directly but can be calculated based on the concentration of dissolved sulfides, pH, conductivity and temperature. However, dissolved sulfides were only measured during the 1998–99 campaign. In addition, the method's limit of detection (LD) does not make it possible to verify that the criterion is being met at many plants.

The few exceedances obtained ranged from 2.1 to 39. The highest values were recorded in summer at the CUM and Longueuil plants, which use a physico-chemical treatment, and in winter at the unaerated lagoons of Martinville. These two treatment processes do not include aeration equipment and, without oxygen (anaerobic conditions), hydrogen sulfide is produced.

CHLORIDES

No exceedance of CCAL was recorded for chlorides in summer and cases of exceedances obtained in winter were exceptional and of very low amplitude (1.1 to 1.6). However, it is interesting to note that the concentrations measured in winter seem significantly higher than those measured in summer at the majority of the plants (tables 3.6-W and 3.6-S). This seasonal variation will be discussed further in Section 4.4.1.

CYANIDES

During the 1996–97 campaign (mainly winter results), the mean cyanide concentrations obtained were almost all below the analytical detection limit, which is higher than the quality criterion (CCAL = 0.005 mg/L). During the 1998–99 campaign, the detection limit of the selected analysis method was lower for the majority of plants and only five exceedances were recorded. The greatest CCAL exceedances were obtained at the Saint-Joseph-de-Beauce (26) and Saint-Gédéon (10) plants.

FLUORIDES

There were a few low amplitude exceedances of CCAL for fluorides. At the Farnham, Châteauguay and CUQ plants, the concentrations measured could be explained in part by fluoridation of the drinking water, which is carried out in the municipalities of these three plants.

PHENOLIC SUBSTANCES

During the 1996–97 campaign, a series of phenolic substances were analysed by scanning at seven municipal treatment plants under winter conditions. Several results had to be rejected because of analysis quality control problems, and no other phenolic substance was detected using this method. During the 1998–99 campaign, a colorimetric method was used and only five very low CCAL exceedances (1.2 to 2.0) were recorded (Martinville in winter and Cookshire, CUM [1999] and Longueuil [1998 and 1999] in summer).

TOTAL RESIDUAL CHLORINE

There were no exceedances of the CCAL for total residual chlorine (TRC) at the Magog plant. This parameter does not appear in tables 4.2-W and 4.2-S, since it was only analysed at the Magog plant, and only in winter. TRC concentrations measured at the effluent of this plant were all below the method detection limit of 0.10 mg/L (Appendix 3).

MINERAL OILS AND GREASES

Mineral oils and greases do not appear in tables 4.2-W and 4.2-S because there is no specific quality criterion for these substances. Nevertheless, they can help better define the quality of an effluent.

Mineral oils and greases were detected at the majority of plants (see tables 3.6-W and 3.6-S), but the mean concentrations were all lower than 1.0 mg/L, except at Cookshire in winter, where the mean concentration is much higher (16 mg/L). This result must be considered with some caution, however, because of the lack of quality control in the analytical results.

OTHER PARAMETERS

There are no CCALs for the other conventional physico-chemical parameters analysed (BOD_5, sulfates, hardness, etc.). These parameters do not, therefore, appear in tables 4.2-W and 4.2-S.

4.2.1.2 Metals

CCALs for certain metals (barium, beryllium, cadmium, copper, nickel, lead and zinc) increase with water hardness. The mean hardness measured in the effluent of each plant during the 1998–99 campaign was used to calculate CCALs for these metals. In the case of the three plants that were not sampled in 1998–99, a mean rate of hardness measured in the summer of 2000 was used for the Magog plant (152 mg/L obtained with four samples) and a default value of 100 mg/L served for the other two plants (Sawyerville and Warwick). It is possible that, in the second case, the exceedances of quality criteria for these metals were overestimated because actual hardness is probably greater.

The amplitudes of metal CCAL exceedances are presented in tables 4.3-W and 4.3-S.

TABLE 4.3-W: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR METALS (WINTER)

Treatment plant (winter)	**Characteristics**			**Exceedances of CCAL for metals** (1)																		
	TT	**II**	**Deph**	**Al**	**Sb**	**Ag**	**As**	**Ba**	**Be**	**B**	**Cd**	**Cr**	**Co**	**Cu**	**Fe**	**Hg**	**Mo**	**Ni**	**Pb**	**Se**	**V**	**Zn**
Farnham	AS	high	wo	9.0		LD					—	(8.0)		12	4.2	—		—	—	—		—
La Prairie	AS	high	wo	1.0		LD					—	14		1.2	—	—		—	—	—		—
Magog	AS	high	with	4.0		LD					—	(7.5)		(6.5)	3.9	—		—	—	—		—
CUO	AS	low	with	31		20					—	(6.0)		18	11	—		—	(1.1)	—		—
Jonquière	AS	low	wo	2.3		LD					—	—		4.0	—	—		—	—	—		—
Châteauguay	BF	low	wo	—		LD					—	(8.5)		8.7	4.3	—		—	—	—		—
CUQ (East plant)	BF	low	wo	3.4		80					—	2.5		6.7	2.9	—		—	—	—		—
Cookshire	AL	high	wo	2.3		50					—	6.0		14	—	—		—	—	—		1.5
Saint-J.-de-Beauce	AL	high	wo	—		50					—	1.0		3.5	4.1	—		—	—	—		—
Warwick	AL	high	wo	2.3		40					—	—		2.1	1.2	—		—	—	—		—
Saint-Gédéon	AL	low	wo	1.1		30					—	1.0		5.3	—	—		—	—	—		—
Sawyerville	AL	low	wo	—		20					—	—		12	1.6	—		—	—	—		—
Martinville	UL	low	with	2.9	—	—	—	—	—	—	—	—	—	1.1	—	—	—	—	—	—	—	—
CUM	PC	high	with	1.6		LD					—	13		5.6	5.8	—		—	—	(—)		—
Longueuil	PC	low	with	11		LD					—	13		2.9	—	—		—	—	—		—

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): CCALs for Ba, Be, Cd, Cu, Ni, Pb and Zn were calculated using the mean hardness measured at each plant.

TABLE 4.3-S: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR METALS (SUMMER)

Treatment plant	**Characteristics**			**Exceedances of CCAL for metals $^{(1)}$**																		
(summer)	**TT**	**II**	**Deph**	**Al**	**Sb**	**Ag**	**As**	**Ba**	**Be**	**B**	**Cd**	**Cr**	**Co**	**Cu**	**Fe**	**Hg**	**Mo**	**Ni**	**Pb**	**Se**	**V**	**Zn**
Farnham	AS	high	with	7.9	—	—	—	—	—	—	—	—	—	4.1	1.1	—	—	—	—	—	—	—
La Prairie	AS	high	wo	1.3	—	—	—	—	—	—	—	—	—	1.6	—	—	—	—	—	—	—	—
Magog	AS	high	with																			
CUO	AS	low	with	—	—	—	—	—	—	—	—	—	—	2.2	—	—	—	—	—	—	—	—
Jonquière	AS	low	wo	1.4	—	—	—	—	—	—	—	4.0	—	3.6	—	—	—	—	—	—	—	—
Châteauguay	BF	low	with	6.7	—	4.0	—	—	—	—	—	1.2	—	3.1	—	—	—	—	—	—	—	—
CUQ (East plant)	BF	low	wo	1.7	—	22	—	—	—	—	—	—	—	5.7	2.6	—	—	—	—	—	—	—
Cookshire	AL	high	wo	—	—	—	—	—	—	—	—	10	—	9.9	1.3	—	—	—	—	—	—	—
Saint-J.-de-Beauce	AL	high	with	—	—	—	—	—	—	—	—	2.0	—	2.9	1.7	—	—	—	—	—	—	—
Warwick	AL	high	with																			
Saint-Gédéon	AL	low	wo	—	—	—	—	—	—	—	—	2.5	—	4.7	—	—	—	—	—	—	—	—
Sawyerville	AL	low	with	—		(LD)					—	7.1		—	—	—		—	—	—		—
Martinville	UL	low	wo	—		LD					—	11		—	1.3	—		—	—	—		—
CUM (1998)	PC	high	with	11	—	11	—	—	—	—	—	4.0	—	7.0	—	—	—	—	—	1.8	—	—
CUM (1999)	PC	high	with	8.8	—	7.0	—	—	—	—	—	2.7	—	5.6	—	—	—	—	—	—	—	—
Longueuil (1998)	PC	low	with	30	—	7.0	—	—	—	—	—	13	—	3.6	—	—	—	—	—	—	—	—
Longueuil (1999)	PC	low	with	11	—	—	—	—	—	—	—	2.4	—	1.9	—	—	—	—	—	—	—	—

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): CCALs for Ba, Be, Cd, Cu, Ni, Pb and Zn were calculated using the mean hardness measured at each plant.

Of the 11 metals analysed during the 1996–97 campaign, no CCAL exceedances were observed for three cadmium (Cd), mercury (Hg) and nickel (Ni) both in winter and summer. Also, no CCAL exceedance was observed for the eight metals added to the characterization program of the 1998–99 campaign: antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cobalt (Co), molybdenum (Mo) and vanadium (V). The eight metals for which there were exceedances are presented below.

ALUMINUM

Exceedances of the CCAL for aluminum (Al) were recorded at a majority of plants and for all treatment processes. Among the ten exceedances with the highest amplitudes (ranging from 4.0 to 31), eight were observed at plants that were using aluminum sulfate (alum) for dephosphatization during our sampling. These results suggest a link between aluminum concentrations measured in the effluents and dephosphatization by alum. However, no CCAL exceedances were recorded at the two plants where alum dephosphatization was used in summer: Saint-Joseph-de-Beauce and Sawyerville. Further analysis of the effects of chemical dephosphatization is provided in Section 4.4.3.

For the other plants that do no dephosphatization by alum, it is not possible to confirm whether or not a relationship exists between the aluminum concentrations measured and industrial loading or treatment process.

SILVER

During the 1996–97 campaign, the method detection limit for silver (Ag) was not sensitive enough to verify the CCAL. This means that as soon as a concentration is measured, it exceeds the quality criteria. This is the case with seven plants under winter operating conditions, and the exceedances are significant. However, we have doubts concerning the five results with the highest amplitudes CUQ (80), Cookshire (50), Saint-Gédéon (30), Saint-Joseph-de-Beauce (50) and Warwick (40) as they all come from the same laboratory, no source of silver contamination could be identified at the plants, and these results were not confirmed by those obtained in summer using a different, more sensitive analysis method. In addition, no comparison could be made with other studies on municipal treatment plants, since: i) either the metal was not analysed for; ii) the detection limit was clearly higher than the criterion; iii) or the presence of this metal was observed without being quantified (U.S. EPA, 1981; Orr *et al.*, 1992; Burgess *et al.*, 1995).

No link can be established between the silver concentrations measured and industrial loads since the greatest exceedances are found at both plants with heavy industrial inputs and those low inputs.

CHROMIUM

For chromium (Cr), CCAL exceedances were observed for all treatment types whatever the industrial load. Indeed, the most significant exceedances were observed at plants with heavy industrial inputs that is, La Prairie (14) and CUM (13) in winter as well as at plants with low industrial input, Longueuil in winter (13) and Martinville in summer (11).

COPPER

As with chromium, exceedances of the quality criteria for copper (Cu) are frequent, with only the Martinville and Sawyerville plants, in summer, recording none. No difference was found between plants with heavy industrial inputs and those with low inputs.

IRON

Iron (Fe) concentrations exceed the criterion in all circumstances (treatment type - industrial load). The two plants that added a product containing iron for dephosphatization the CUO plant in winter and summer (ferric sulfate) and the CUM plant in winter (ferric chloride) present the greatest exceedances in winter, with 11 and 5.8, respectively. However, no exceedance was observed in summer at the CUO plant. Exceedances similar to those found at the CUM plant were observed under winter conditions at plants (Farnham, Magog, Châteauguay and Saint-Joseph-de-Beauce) that do not use these products.

LEAD

Only one exceedance of CCAL was recorded for lead (Pb), at the CUO plant. It was of very low amplitude (1.1) and the result is considered questionable because of poor analytical quality control.

SELENIUM

As was the case for lead, there was only a single small exceedance of CCAL (1.8) for selenium (Se) recorded at the CUM plant in the summer of 1998.

ZINC

Here also, a single exceedance of CCAL of very low amplitude (1.5) was observed in winter at the Cookshire plant.

4.2.1.3 Organic Substances

Tables 4.4-W and 4.4-S present the amplitudes of CCAL exceedances for the organic substances analysed (except for pesticides, which are presented in the following section) and for which there is a quality criterion. In the case of SVOCs and VOCs, only the substances that exhibited values ≥ 1 are shown in the tables.

TABLE 4.4-W: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR ORGANIC SUBSTANCES (WINTER)

Treatment plant (winter)	**Characteristics**			**Exceedances of CCAL for organic substances**								
				SVOCs - VOCs			**Surfactants**		**PAHs**			
	TT	**II**	**Deph**	**Toluene**	**1,2-Dichlo robenzene**	**Nitro-benzene**	**Nonionic**	**Anionic**	**Acenaphthene**	**Fluoranthene**	**Naphthalene**	**Phenanthrene**
Farnham	AS	high	wo	*	—		67	14	—	—	—	—
La Prairie	AS	high	wo	—	—				—	—	—	—
Magog	AS	high	with									
CUO	AS	low	with									
Jonquière	AS	low	wo									
Châteauguay	BF	low	wo									
CUQ (East plant)	BF	low	wo	15	LD				—	—	—	—
Cookshire	AL	high	wo	—	LD	—	190	53				
Saint-J.-de-Beauce	AL	high	wo									
Warwick	AL	high	wo				38	4.5				
Saint-Gédéon	AL	low	wo									
Sawyerville	AL	low	wo				*	LD				
Martinville	UL	low	with	2.8	LD	—	LD	4.3	—	—	—	—
CUM	PC	high	with	5.4	1.0		48	53				
Longueuil	PC	low	with	—	—				—	—	—	—

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

TABLE 4.4-S: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR ORGANIC SUBSTANCES (SUMMER)

Treatment plant (summer)	Characteristics			Exceedances of CCAL for organic substances								
				SVOCs - VOCs			Surfactants		PAHs			
	TT	II	Deph	Toluene	1,2-Dichlorobenzene	Nitro-benzene	Nonionic	Anionic	Acenaphthene	Fluoranthene	Naphthalene	Phenanthrene
Farnham	AS	high	with	—	LD	—	LD	13	—	—	—	—
La Prairie	AS	high	wo	—	LD	—	LD	5.9	—	—	—	—
Magog	AS	high	with									
CUO	AS	low	with	—	LD	—	LD	2.9	—	—	—	—
Jonquière	AS	low	wo	—	—	—	LD	3.2	—	—	—	—
Châteauguay	BF	low	with	—	LD	—	11	23	—	—	—	—
CUQ (East plant)	BF	low	wo	—	LD	—	13	33	—	—	—	—
Cookshire	AL	high	wo	*	LD	—	LD	11	—	—	—	—
Saint-J.-de-Beauce	AL	high	with	—	—	—	LD	7.0	—	—	—	—
Warwick	AL	high	with									
Saint-Gédéon	AL	low	wo	—	—	—	LD	11	—	—	—	—
Sawyerville	AL	low	with									
Martinville	UL	low	wo									
CUM (1998)	PC	high	with	*	—	1.2	44	57	—	—	—	—
CUM (1999)	PC	high	with				81	44				
Longueuil (1998)	PC	low	with	*	—	—	189	383	—	—	—	—
Longueuil (1999)	PC	low	with				95	79				

<u>Treatment type (TT):</u>
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

SEMI-VOLATILE (SVOCS) AND VOLATILE (VOCS) ORGANIC SUBSTANCES

SVOCs were analysed in the samples of two plants in winter and 11 plants in summer, while VOCs were analysed at seven plants in winter and 11 in summer. For both these families of organic substances, close to 100 parameters were analysed and several substances were detected. However, the majority of the results were rejected because they did not meet analytical quality control requirements. Only the results of four SVOCs in summer and 15 VOCs, in both winter and summer, were accepted. In most cases, one or the other of these 19 substances was detected at only one or two plants (see tables 3.8, 3.9-W and 3.9-S). In addition, an examination of the results found that there is usually a wide variation in concentration between samples of days 1, 3 and 5, and the results obtained in a given season are often not confirmed by those obtained in another.

Although these two scanning analysis methods may be appropriate for industrial effluent characterizations, it appears that, in the case of municipal effluents, they are lacking in specificity and the great number of substances analysed results in a significant loss of resolution during measurement.

Nevertheless, there is a CCAL for 14 of the 19 substances for which the results were accepted, and only two presented exceedances: toluene, with three exceedances in winter at the CUM (5.4), the CUQ (15) and Martinville (2.8) plants, and nitrobenzene, with a single low amplitude exceedance in summer at the CUM plant (1.2). Also, 1,2-dichlorobenzene exhibited a result equivalent to the quality criteria obtained in winter at the CUM plant (1.0).

However, the detection limits for some compounds in the SVOC family could not be used to verify the quality criteria (especially for certain chlorobenzenes and phthalates). For VOCs, the method detection limits are low enough, in most cases, to allow verification that the quality criteria are being met.

NONIONIC AND ANIONIC SURFACTANTS

At those plants where surfactants were analysed (see Table 2.6), nonionic surfactants were detected in just over half of the municipal effluents, while anionic surfactants were detected at all plants, with the exception of Sawyerville in summer. The detection limits of these two methods could not be used to verify the quality criterion, but wherever they were detected, exceedances of the CCAL were quite high for the majority of plants. For the nonionic surfactants, the greatest exceedances were found at the Cookshire (190) and Farnham (67) plants in winter and at the Longueuil (189 and 95) and CUM (81 and 44) plants in summer. In the case of anionic surfactants, the greatest exceedances were found at the Cookshire and CUM plants in winter (exceedance of 53 in both cases) and at the Longueuil (383 and 79) and CUM (57 and 44) plants in summer.

Some of the largest concentrations of nonionic surfactants seem to be linked to the presence of textile mills (Farnham and Cookshire), which is not surprising, since this industry is known to use large amounts of these products (Correia *et al.*, 1994; Environment Canada, 1989; Malo, 1977). The use of surfactants however, is not exclusive to this industry. Very high concentrations of surfactants were found in the effluents of the CUM and Longueuil plants, which receive wastewater from several industrial plants and businesses. The domestic sector is another major source.

PAHS

Chronic water quality criteria for the protection of aquatic life are defined for only four specific PAHs: acenaphthene, fluoranthene, naphthalene and phenanthrene. No exceedance of the CCAL was observed for these substances.

PCBS AND CHLORINATED DIOXINS AND FURANS

Since no chronic water quality criteria for the protection of aquatic life are defined for either PCBs or chlorinated dioxins and furans, these substances do not appear in tables 4.4-W and 4.4-S.

4.2.1.4 Pesticides

Of the 15 pesticides detected at the CUM and Longueuil plants during the summer characterizations of 1999 (Tables 3.17 and 3.18), CCAL exceedances were reported for only three insecticides: diazinon, malathion and chlorpyrifos. Table 4.5 presents the amplitude of CCAL exceedances for the mean concentrations of these three insecticides measured at both plants.

In the case of herbicides, no exceedance of the chronic water quality criteria for the protection of aquatic life was observed for the nine substances detected.

Malathion exceeded the CCAL in two of the four composite samples drawn at the Longueuil plant on May 19, 1999. This corresponds to a mean concentration equivalent to the quality criterion value.

The detection limits of diazinon and chlorpyrifos are approximately ten times greater than the CCAL, and it is therefore impossible to verify that the quality criterion is being met. Consequently, this means that each time these substances are detected, the concentrations exceed the quality criterion. Such is the case for 23% and 37% of the samples at the CUM plant for diazinon and chlorpyrifos, respectively, as well as for 67% and 33% of the samples at the Longueuil plant. The mean concentrations measured exceed the CCAL by a factor of 10 to 55 times for diazinon and by 2.8 to 20 times for chlorpyrifos (Table 4.5).

Other studies have also reported the presence of diazinon in municipal effluents (Amato *et al.*, 1992; Burkhard and Jenson, 1993). It should be noted that the diazinon concentrations detected in the present study are generally lower than those measured in the Burkhard and Jenson study (1993).

TABLE 4.5: AMPLITUDES OF EXCEEDANCE OF CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE (CCAL) FOR PESTICIDES MEASURED AT THE CUM AND LONGUEUIL PLANTS IN 1999

Sample	**Exceedances of CCAL for pesticides**		
	Diazinon	**Malathion**	**Chlorpyrifos**
CUM treatment plant (1)			
May 17-19	LD	—	LD
May 25-27	10	—	8.6
May 31- June 2	10	—	5.7
June 7-9	25	—	2.8
June 14-16	LD	—	LD
June 21-22	LD	—	2.8
June 28-29	15	—	LD
July 5-7	LD	—	5.7
July 12-14	LD	—	LD
July 20-22	10	—	LD
July 26-27	LD	—	2.8
Longueuil treatment plant (2)			
May 19	55	1.0	11
June 28	20	—	20
September 7	LD	—	LD

(1): For the CUM plant, the mean concentrations were calculated from the results obtained with samples drawn over 2 or 3 consecutive days.
(2): For the Longueuil plant, the mean concentrations were calculated from the results obtained with 4 samples drawn in a single day during three rainfall events.
LD: Limit of detection does not allow for criterion verification.
—: No exceedance of the water quality criterion (i.e. exceedance < 1).

4.2.1.5 *Interpretation of exceedances of chronic water quality criteria for the protection of aquatic life*

Exceedances of CCAL were observed at all plants for 11 physico-chemical parameters, eight metals and four families of organic substances (SVOCs, VOCs, surfactants and pesticides). Exceedances were mostly infrequent and of low amplitude. However, a few substances regularly exhibited exceedances at several plants, both in winter and summer. In the case of ammonia nitrogen, phosphorus, hydrogen sulfide, aluminum, silver, chromium, copper and two insecticides (diazinon and chlorpyrifos), amplitudes were above 10. Such was also the case for surfactants, for which exceedances reached amplitudes of up to approximately 400 times the CCAL. Nitrites and cyanides also exhibited a periodic high amplitude exceedance (> 20).

The presence of these substances at such concentrations, added to the possible combined effects of many contaminants, suggests that the municipal wastewaters are potentially harmful in the long term to aquatic life in watercourses with a weak assimilative capacity.

4.2.2 Prevention of the contamination of aquatic organisms

Water quality criteria for the prevention of the contamination of aquatic organisms are defined to protect their consumption by humans and by piscivorous wildlife. The two following sections compare the results of the physico-chemical analyses to these quality criteria.

4.2.2.1 Human consumption of aquatic organisms

Water quality criteria for the prevention of the contamination of aquatic organisms (CPCOs) are defined to protect individuals who would, throughout their lifetimes, consume aquatic organisms exposed to such concentrations. In this way, aquatic organisms are protected from any contamination that would be hazardous to humans who consume them, now or in future. Consequently, the quality criteria for this use of the water are defined for substances that tend to accumulate in the food chain and that are known to have detrimental effects. The exceedance of a CPCO at the effluent does not mean that those who consume fish are currently at risk, but rather that the effluent contains substances that can potentially accumulate in aquatic organisms, and consequently, degrade the quality of the body tissues of organisms that are exposed to them.

There are CPCOs for toxic substances that can be potentially bioaccumulated in aquatic organisms. Tables 4.6-W and 4.6-S present the amplitudes of exceedances of all the substances analysed for which such a quality criterion exists.

PHYSICO-CHEMICAL PARAMETERS

For the physico-chemical parameter group (PCP), one CPCO is defined for cyanides. No exceedance was observed for this parameter.

METALS

In the case of metals, a CPCO exists for antimony (Sb), arsenic (As), mercury (Hg) and nickel (Ni). Exceedances were observed only for arsenic and mercury.

All seasons combined, three exceedances of the CPCO were recorded for mercury and there were exceedances for arsenic almost everywhere it was measured. These exceedances were generally of low amplitude, however. For mercury, the exceedances were observed at three plants with a large industrial loading. In the case of arsenic, the greatest exceedances were also recorded where industrial inputs are significant, except for the Martinville plant.

Table 4.6-W: Amplitudes of Exceedance of Water Quality Criteria for the Prevention of the Contamination of Aquatic Organisms (CPCO) for all Substances Analysed (Winter)

Treatment plant (winter)	Characteristics			Exceedances of CPCO for all substances analysed												
	TT	II	Deph	PCPs	Metals				SVOCs VOCs	PCBs	PAHs					Chlorinated dioxins and furans
				CN^-	Sb	As	Hg	Ni			Group 1	Anthra-cene	Fluoran-thene	Fluorene	Pyrene	
Farnham	AS	high	wo	—			LD	—	—	46	—	—	—	—	—	
La Prairie	AS	high	wo	—			LD	—	—	42	—	—	—	—	—	—
Magog	AS	high	with	—			5.9	—								
CUO	AS	low	with	—			LD	—								
Jonquière	AS	low	wo	—			LD	—								
Châteauguay	BF	low	wo	—			LD	—								
CUQ (East plant)	BF	low	wo	—			LD	—	—	53	—	—	—	—	—	2.7
Cookshire	AL	high	wo	—			LD	—	—	197						
Saint-J.-de-Beauce	AL	high	wo	—			LD	—								
Warwick	AL	high	wo	—			LD	—								
Saint-Gédéon	AL	low	wo	—			LD	—								
Sawyerville	AL	low	wo	—			LD	—								
Martinville	UL	low	with	—	—	13	—	—	—	12	—	—	—	—	—	1.3
CUM	PC	high	with	—			LD	—	—							
Longueuil	PC	low	with	—			LD	—	—	40	—	—	—	—	—	2.7

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
wo: without dephosphatization

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

TABLE 4.6-S: AMPLITUDES OF EXCEEDANCE OF WATER QUALITY CRITERIA FOR THE PREVENTION OF THE CONTAMINATION OF AQUATIC ORGANISMS (CPCO) FOR ALL SUBSTANCES ANALYSED (SUMMER)

Treatment plant (summer)	**Characteristics**			**Exceedances of CPCO for all substances analysed**												
				PCPs	**Metals**				**SVOCs VOCs**	**PCBs**	**PAHs**					**Chlorinated dioxins and furans**
	TT	**II**	**Deph**	**CN^-**	**Sb**	**As**	**Hg**	**Ni**			**Group 1**	**Anthra-cene**	**Fluoran-thene**	**Fluorene**	**Pyrene**	
Farnham	AS	high	with	—	—	3.6	2.0	—	—	24	—	—	—	—	—	11
La Prairie	AS	high	wo	—	—	4.3	—	—	—	14	—	—	—	—	—	1.0
Magog	AS	high	with													
CUO	AS	low	with	—	—	2.9	—	—	—	7.9	—	—	—	—	—	—
Jonquière	AS	low	wo	—	—	—	—	—	—	6.6	—	—	—	—	—	2.1
Châteauguay	BF	low	with	—	—	3.6	—	—	—	23	—	—	—	—	—	3.5
CUQ (East plant)	BF	low	wo	—	—	4.3	—	—	—	51	—	—	—	—	—	9.3
Cookshire	AL	high	wo	—	—	7.1	2.1	—	—	(1)	—	—	—	—	—	188
Saint-J.-de-Beauce	AL	high	with	—	—	1.4	—	—	—	8.1	—	—	—	—	—	5.8
Warwick	AL	high	with													
Saint-Gédéon	AL	low	wo	—	—	—	—	—	—	7.1	—	—	—	—	—	34
Sawyerville	AL	low	with	—	—		LD	—								
Martinville	UL	low	wo	—			LD	—								
CUM (1998)	PC	high	with	—	—	2.9	—	—	—	35	1.7	—	—	—	—	19
CUM (1999)	PC	high	with	—	—	6.4	—	—								
Longueuil (1998)	PC	low	with	—	—	5.0	—	—	—	50	—	—	—	—	—	23
Longueuil (1999)	PC	low	with	—	—	4.3	LD	—								

Treatment type (TT):

AS:	activated sludge
BF:	biofiltration
AL:	aerated lagoons
UL:	unaerated lagoons
PC:	physico-chemical

II:	industrial inputs
Deph:	dephosphatization
wo:	without dephosphatization

LD:	limit of detection does not allow for criterion verification
—:	no exceedance of water quality criterion (i.e. exceedance < 1)
*:	result rejected
Blank box:	parameter not measured
( ):	questionable result (quality control); to be considered with caution

(1): PCBs could not be measured at the Cookshire plant because samples contained too much organic matter.

It is not possible to assess the differences between the two characterization campaigns. On the one hand, arsenic was not analysed in 1996–97 and, on the other hand, the analysis method used during this campaign was not precise enough to measure mercury concentrations. For this reason, the results for mercury are always below the LD in 1996–97, except at the Magog plant, where, it should be noted, analyses were carried out in summer 2000 using a more sensitive analysis method than the one used in winter 1997. In the three samples analysed, mercury was never detected, which casts some doubt on the particularly high results obtained at the Magog plant in 1997.

SEMI-VOLATILE (SVOCS) AND VOLATILE (VOCS) ORGANIC SUBSTANCES

There are several CPCOs for these two families of substances, particularly for several chlorinated benzenes, phthalates and volatile organic substances. No exceedances of the CPCOs were observed for SVOCs or VOCs.

SURFACTANTS

No CPCO is defined for nonionic or anionic surfactants.

PCBS

Exceedances of the CPCO were recorded at every plant where PCB analyses were carried out, and they were of high amplitude in the majority of cases. By far the most significant exceedance was recorded at the Cookshire plant (197), which takes in a very large industrial loading. The other most significant exceedances were recorded at the Farnham (46 in winter), La Prairie (42 in winter) and CUM (35 in summer) plants, which all have substantial industrial loads, as well as at the CUQ (53 in winter and 51 in summer) and Longueuil (40 and 50) plants, where the industrial input is considered less significant. These plants, especially the one in Longueuil, still receive heavy loadings of industrial wastewater.

Industrial sources are not the only factors contributing to the concentrations found in effluents. As mentioned in Section 2.4.3.2, there are many sources of PCBs and these substances are already present in the environment because of their stability and persistent character. This observation is reflected in PCB concentrations measured in Quebec watercourses, which are often high relative to the water quality criteria (Quémerais *et al.,* 1994a and 1994b; Pham and Proulx, 1996; Cossa *et al.,* 1998), even exceeding them, in certain cases. Consequently, the concentrations of PCBs present in municipal wastewaters are in part due to the quality of the water supply and runoff water.

To measure the net input of PCBs by the treatment plants, it would be necessary to compare the concentrations with those of the receiving environment. The available information does not permit such an exercise for the vast majority of treatment plants in Quebec. This comparison can only be partially carried out at the CUM, La Prairie, Longueuil and CUQ plants. The Pham and Proulx study (1996) reported a mean concentration of 0.12 ng/L with a total of 13 congeners in the St. Lawrence River, upstream from the CUM effluent. In addition, the report on the mass balance of chemical contaminants in the St. Lawrence River (Cossa *et al.,* 1998) provides the means to obtain a mean concentration of 0.41 ng/L by summing 18 congeners common to the present study that are found in the St. Lawrence River just off Quebec City.

To compare these means, the total of the same 13 congeners in the Pham and Proulx study (1996) was calculated for the effluents of the CUM, La Prairie and Longueuil plants. Likewise, for the CUQ, the total of the 18 congeners in Cossa *et al.* (1998) was also calculated. Table 4.7 presents the exceedances of these concentrations compared with the mean ambient concentrations reported in the studies cited herein.

TABLE 4.7: COMPARISON BETWEEN MEAN CONCENTRATIONS OF PCBS MEASURED AT SOME TREATMENT PLANTS AND CONCENTRATIONS ALREADY PRESENT IN THE RECEIVING ENVIRONMENT

Treatment plant	**Mean concentration measured in effluent (ng/L)**		**Concentration in receiving waters (1) (ng/L)**	**Ratio of concentration in effluent:concentration in receiving waters**	
	Winter	**Summer**		**Winter**	**Summer**
Sum of 13 congeners					
CUM		1.78	0.12		15
La Prairie	1.52	0.39	0.12	13	3.3
Longueuil	2.34	3.33	0.12	20	28
Sum of 18 congeners					
CUQ (East plant)	3.96	3.73	0.41	10	9

(1) The value 0.12 ng/L represents the mean concentration in the environment measured upstream from the CUM effluent for 13 congeners (Pham and Proulx, 1996), and the value 0.41 ng/L was obtained at Quebec City by adding together the 18 congeners common to the present study (Cossa *et al.*, 1998).

These results show exceedances compared with concentrations found in the aquatic environment, but they are less significant than the exceedances of the quality criteria. Although the municipal treatment plants are not the only source, these results suggest nevertheless that there is a net discharge of PCBs into the receiving environment from these plants.

PAHs

A CPCO is defined for the total of the 16 Group 1 PAHs showing sufficient evidence of carcinogenicity (see Appendix 12). In the case of Group 2 PAHs, a CPCO was defined for anthracene, fluoranthene, fluorene and pyrene.

All plants and seasons combined, there were no exceedances of the CPCOs except for one very small exceedance (1.7) at the CUM plant in summer and only for Group 1 PAHs.

Although PAHs do not exceed quality criteria, except for one, the highest concentrations of PAHs were found in highly urbanized environments, with combined sewer systems. Atmospheric deposition and urban runoff may be accountable in part.

CHLORINATED DIOXINS AND FURANS

Chlorinated dioxins and furans were detected at all plants where they were analysed. With the exception of the CUO and La Prairie plants, the concentrations measured, expressed in toxic equivalents, exceed the CPCO by factors ranging from 1.3 to 188.

Just as for PCBs, Cookshire presents by far the most significant exceedance (188). As mentioned in Section 2.4.3.2, many industrial processes, including the production of colorants and pigments, can generate dioxins and furans. It is therefore plausible that industries that use colorants in large quantities, such as the textile mill in Cookshire, could discharge a substantial quantity of these substances in their wastewater.

The other largest exceedances were observed at plants having both large and small industrial inputs; that is, the CUM (19), Farnham (11), Longueuil (23) and Saint-Gédéon (34) plants. These results can be explained in part by the fact that the biggest sources of dioxins and furans seem related to waste incineration and wood combustion. Atmospheric deposition and urban runoff could therefore carry substantial quantities of dioxins and furans to the municipal treatment plants.

In fact, significant concentrations of chlorinated dioxins and furans were measured in a few watercourses in Quebec. As far as is actually known, concentrations of dioxins and furans in watercourses in urban areas are often close to or higher than their water quality criterion. For example, the median value (in toxic equivalent) estimated in the St. Lawrence River near Quebec City is 0.012 pg/L, a concentration close to the CPCO, which is 0.014 pg/L.

4.2.2.2 Consumption of aquatic organisms by piscivorous wildlife

Water quality criteria for the protection of piscivorous wildlife (CPPW) refer to the concentration of a substance in the water that will not cause multi-generational deleterious effects on the survival of the birds or mammals exposed thereto by their consumption of contaminated aquatic organisms. These criteria are defined to protect even the biggest fish-eaters, such as minks, otters and kingfishers. Exceedance of a CPPW at the effluent means that it contains highly bioaccumulable toxic substances that could be harmful to wildlife that feed on organisms to which they are exposed.

There are at present three substances or families of substances for which a CPPW has been defined: mercury, PCBs and chlorinated dioxins and furans. Table 4.8 presents the amplitudes of exceedances of the CPPW for these three parameters. Wherever they were analysed and detected, these parameters exceed the CPPWs, and the exceedances are of very high amplitude in the majority of cases.

TABLE 4.8: AMPLITUDES OF EXCEEDANCE OF WATER QUALITY CRITERIA FOR THE PROTECTION OF PISCIVOROUS WILDLIFE (CPPW) FOR ALL SUBSTANCES ANALYSED (WINTER AND SUMMER)

Treatment plant	**Characteristics**			**Exceedances of CPPW for all substances analysed**					
				Winter			**Summer**		
	TT	**II**	**Deph W/S**	**Hg**	**PCBs**	**Chlorinated dioxins and furans**	**Hg**	**PCBs**	**Chlorinated dioxins and furans**
Farnham	AS	high	wo/w	LD	65		77	34	47
La Prairie	AS	high	wo/wo	LD	59	4.0	12	20	4.4
Magog	AS	high	w/w	231					
CUO	AS	low	w/w	LD			25	11	3.5
Jonquière	AS	low	wo/wo	LD			6.2	9.4	9.5
Châteauguay	BF	low	wo/w	LD			30	32	16
CUQ (East plant)	BF	low	wo/wo	LD	75	12	38	73	42
Cookshire	AL	high	wo/wo	LD	280		85	(1)	847
Saint-Joseph-de-Beauce	AL	high	wo/w	LD			17	12	26
Warwick	AL	high	wo/w	LD					
Saint-Gédéon	AL	low	wo/wo	LD			8.5	10	151
Sawyerville	AL	low	wo/w	LD			LD		
Martinville	UL	low	w/wo	20	18	5.8	LD		
CUM (S-98)	PC	high	w/w	LD			10	50	87
CUM (S-99)	PC	high	w/w				13		
Longueuil (S-98)	PC	low	w/w	LD	57	12	15	71	103
Longueuil (S-99)	PC	low	w/w				LD		

Treatment type (TT):
AS: activated sludge
BF: biofiltration
AL: aerated lagoons
UL: unaerated lagoons
PC: physico-chemical

II: industrial inputs
Deph: dephosphatization
w: with dephosphatization
wo: without dephosphatization
W: winter
S: summer

LD: limit of detection does not allow for criterion verification
—: no exceedance of water quality criterion (i.e. exceedance < 1)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): PCBs could not be measured at the Cookshire plant because samples contained too much organic matter.

Exceedances of the CPPW were higher than exceedances of the CPCO, since fish-eating terrestrial wildlife are more likely to be affected by the contamination of aquatic organisms. For one thing, animals eat much more fish than do humans. Further, since they eat the entire organism, raw, they are more exposed to contamination because concentrations are higher in viscera and fat than in flesh alone. The protection limits for these consumers are consequently lower.

The case of mercury (Hg) is similar to that of PCBs and dioxins and furans, as discussed earlier. Mercury is bioaccumulable and persistent in the environment; high concentrations, which are significant relative to water quality criteria, were measured in a few watercourses in urban areas of Quebec. Concentrations of Hg measured in municipal wastewaters therefore have multiple sources, including the water supply, urban runoff, and industrial inputs.

Since both the CPPWs and CPCOs are defined for similar uses, the discussion concerning exceedances of the CPCOs for mercury, PCBs and chlorinated dioxins and furans also applies here (see Section 4.2.2.1 above).

4.2.2.3 Interpretation of exceedances of water quality criteria for the protection of aquatic organisms

An analysis of the amplitudes of exceedances of water quality criteria for the protection of aquatic organisms (CPCO and CPPW) shows that certain highly bioaccumulable toxic substances are a significant presence in municipal effluents. Measured concentrations of PCBs and chlorinated dioxins and furans may limit human consumption of the aquatic organisms exposed to these substances, because of their propensity to accumulate in the food chain. Mercury is also of concern for piscivorous terrestrial wildlife, for whom the toxic potential of these three parameters can be even more detrimental, for reasons explained in the preceding section.

The sources of these substances in municipal wastewaters are multiple and complex. They may originate, among other sources, in the water supply, from atmospheric deposition, urban runoff, and the industrial load received at the plant. In order to determine the actual contribution of municipal treatment plants, we need to know more about the potential sources as well as the concentrations already present in the receiving environments of the treatment plants.

4.3 Relationship between the Toxicity Measured and Exceedances of Water Quality Criteria

This section attempts to identify the possible relationships between the results of the toxicity tests and the exceedances of quality criteria, in order to identify which substances could be the cause of the toxicity measured. However, the identification of such a link is not an indication of causality since, on the one hand, quality criteria take into account a wider range of effects and aquatic species and, on the other hand, toxic responses may be attributed to other chemical substances not included in the analyses or even to interaction among contaminants. The purpose of this section, then, is to identify those contaminants that might be associated with toxic effects for organisms exposed thereto. No statistical analysis was performed because of the small number of samples.

For the purposes of this comparative analysis, quality criteria corresponding to the same effect threshold measured with the toxicity tests are used. Consequently, for the results of the chronic toxicity tests, chronic water quality criteria for the protection of aquatic life (CCAL) are used. In the case of acute lethality, for which the results are determined based on the LC_{50}, the final acute value (FAV) is retained. The latter corresponds to the concentration that could kill 50% of the sensitive organisms exposed to it (MEF, 1998)[7].

The results of this comparative exercise are given in the two following sections. BOD_5, SM and total phosphorus were excluded from the analysis since these parameters are not direct causes of toxicity in the test species.

4.3.1 Acute toxicity

Tables 4.9-W and 4.9-S present the *daily concentration measured:final acute value (FAV)* ratios relative to the daily results of the acute toxicity tests (i.e. result from samples of day 1 - day 3 - day 5). Only those samples with a ratio ≥ 1 are shown in the tables.

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[7] The final acute value (FAV) corresponds to twice the acute water quality criterion for the protection of aquatic life (ACAL) (MEF, 1998). ACAL represents the concentration of a contaminant at which aquatic organisms can be exposed for a short period of time without dying.

TABLE 4.9-W: RELATIONSHIP BETWEEN ACUTE TOXICITY TEST RESULTS AND EXCEEDANCES OF THE FINAL ACUTE VALUES (FAV) FOR ALL SUBSTANCES ANALYSED (WINTER)

Treatment plant (winter)	**Acute toxicity test results (acute toxic units: TUa) (day 1 – day 3 – day 5)**		**Exceedances of the final acute value (daily concentration / FAV ≥1) (day 1 – day 3 – day 5)**					
	D. magna	***O. mykiss***	**Physico-chemical parameters**			**Metals**		**Nonionic surfactants**
			$NH_3 – NH_4^+$ (1)	**NO_2^-**	**CN^-**	**Al**	**Cu**	
Farnham	nl - nl - nl	nl - nl - nl	—	—	—	—	∅ - ∅ - 1.0	∅ - 1.7 - 2.1
La Prairie	nl - nl - nl	nl - nl - nl	—	—	—	—	—	
Magog	nl - nl - nl	nl - nl - nl	—	—	—	—	—	
CUO	nl - nl - nl	nl - nl - nl	—	—	—	1.1 - 2.8 - 1.5	∅ - 1.6 - 1.4	
Jonquière	nl - nl - nl	nl - * - nl	—		—	—	—	
Châteauguay	nl - nl - nl	* - nl - nl	—	—	—	—	—	
CUQ (East plant)	nl - nl - nl	nl - <1 - nl	1.1 - 1.2 - 1.2		—	—	—	
Cookshire	3.2 - 1.6 - 2	>1 - * - >1	1.0 - 1.1 - 1.1		—	—	—	3.9 - 4.3 - 4.7
Saint-J.-de-Beauce	nl - nl - nl	>1 - >1 - >1	2.4 - 2.5 - 2.6		—	—	—	
Warwick	nl - nl - nl	>1 - >1 - *	1.3 - 1.2 - 1.4		—	—	—	—
Saint-Gédéon	nl - nl - nl	>1 - >1 - >1	∅ - 1.0 - 1.0		—	—	—	
Sawyerville	nl - nl - <1	<1 - <1 - *	1.0 - 1.0 - 1.1		—	—	—	
Martinville	nl - nl - nl	* - * - *	—	—	—	—	—	—
CUM	nl - nl - nl	nl - nl - ns	—	—	—	—	—	1.2 - ∅ - ∅
Longueuil	nl - nl - nl	ns - nl - ns	∅ - 1.1 - 1.1		—	—	—	

<1:	less than 50% of mortality
>1:	more than 50% of mortality in the undiluted effluent
nl:	non-lethal (0% of mortality)
ns:	non-significant
*:	result rejected
—:	no exceedance of the FAV for the three daily samples (day 1, day 3 and day 5)
∅:	no exceedance of the FAV for this daily sample (i.e. exceedance < 1)
Blank box:	parameter not measured

(1): The FAV value used for ammonia nitrogen is the threshold toxicity concentration of 10 mg/L of Beak and Canviro (1990).

TABLE 4.9-S: RELATIONSHIP BETWEEN ACUTE TOXICITY TEST RESULTS AND EXCEEDANCES OF THE FINAL ACUTE VALUES (FAV) FOR ALL SUBSTANCES ANALYSED (SUMMER)

Treatment plant (summer)	**Acute toxicity test results (acute toxic units: TUa) (day 1 – day 3 – day 5)**		**Exceedances of the final acute value (daily concentration / FAV ≥1) (day 1 – day 3 – day 5)**					
			Physico-chemical parameters			**Metals**		**Nonionic surfactants**
	D. magna	***O. mykiss***	**$NH_3 – NH_4^{+ (1)}$**	**NO_2^-**	**CN^-**	**Al**	**Cu**	
Farnham	nl - nl - nl	nl - nl - nl	—	—	—	—	—	—
La Prairie	nl - nl - nl	1.4 - 1.7 - 1.9	2.6 - 2.2 - 2.5	—	—	—	—	—
CUO	nl - nl - nl	nl - nl - nl	—	—	—	—	—	—
Jonquière	nl - nl - <1	nl - nl - <1	—	—	—	—	—	—
Châteauguay	<1 - nl - nl	<1 - 1.5 - <1	—	—	—	—	—	—
CUQ (East plant)	nl - nl - nl	nl - nl - nl	—	—	—	—	—	—
Cookshire	<1 - 2.9 - 1.4	nl - nl - nl	—	∅ - ∅ - 1.0	—	—	—	—
Saint-J.-de-Beauce	1.4 - 1.4 - <1	nl - nl - nl	—	21 - 19 - 9.2	3.1 - 2.5 - 3.4	—	—	—
Saint-Gédéon	nl - nl - <1	nl - nl - <1	—	—	∅ - 1.1 - 1.1	—	—	—
Sawyerville	<1 - nl - nl	* - nl - nl	—		—	—	—	* - * - *
Martinville	nl-nl-nl-nl	*-nl-nl-nl	—	—	—	—	—	
CUM (1998)	nl - nl - nl	nl - <1 - nl	—	—	—	—	—	∅ - ∅ - 1.1
CUM (1999)	nl - nl - nl	nl - nl - ns	—	—	—	—	—	3.5 - 1.4 - ∅
Longueuil (1998)	3 - 1.4 - 1.3	2.8 – 2.8 – 1.4	—	—	—	2.4 - 1.3 - 1.5	—	5.3 - 4.3 - 3.1
Longueuil (1999)	nl - nl - nl	1.3 - <1 - <1	∅ - 1.1 – 1.0	—	—	—	—	1.2 - 3.5 - 1.7

<1:	less than 50% of mortality
>1:	more than 50% of mortality in the undiluted effluent
nl:	non-lethal (0% of mortality)
ns:	non-significant
*:	result rejected
—:	no exceedance of the FAV for the three daily samples (day 1, day 3 and day 5)
∅:	no exceedance of the FAV for this daily sample (i.e. exceedance < 1)
Blank box:	parameter not measured

(1): The FAV value used for ammonia nitrogen is the threshold toxicity concentration of 10 mg/L of Beak and Canviro (1990).

In the case of ammonia nitrogen, the exceedances were first calculated using the FAV provided by the MENV (1998), which is determined according to the pH measured before each toxicity test and the temperature maintained during the tests. Exceedances were observed only at the La Prairie plant in summer and they coincided with toxic effects in *O. mykiss*. The exceedances were later calculated using the values 0.1 mg/L of non-ionized NH_3 and 10 mg/L of ammonia nitrogen (NH_3-NH_4^+). These values were taken from Ontario studies (Beak and Canviro, 1990; Orr *et al.*, 1992), which established that municipal effluents are generally toxic to rainbow trout (toxicity test with *O. mykiss*) when one of the values is exceeded. Finally, the exceedances retained and presented in tables 4.9-W and 4.9-S were calculated using the value 10 mg/L of ammonia nitrogen.

An analysis of the data in tables 4.9-W and 4.9-S shows that there is no clear relationship between FAV exceedances and the acute toxicity measured by the toxicity tests in the effluents, except for ammonia nitrogen and, to a lesser degree, nitrites and nonionic surfactants. For example, at the CUO plant, in winter, exceedances in more than one substance were observed without any toxicity being measured, while at Châteauguay, in summer, where one toxicity measurement was recorded, no exceedance was detected.

For several plants, exceedances of ammonia nitrogen (NH_3-NH_4^+) coincide with the observation of toxic effects in the toxicity tests. Of the 24 results with an equivalent value or that exceed the FAV value of 10 mg/L, 17 correspond to the observation of toxic effects in *O. mykiss*, which are associated, for the most part, with aerated lagoon effluents in winter. Four other exceedances correspond to toxicity tests for which the results were rejected or non-significant, and, finally, three do not correspond to lethal effects (Longueuil on day 3 in winter and CUQ on days 1 and 5 in winter). The results of the present study, as in others (Beak and Canviro, 1990; Orr *et al.*, 1992), suggest the existence of a relationship between the toxicity measured in *O. mykiss* and the exceedance of the value of 10 mg/L of ammonia nitrogen at the effluent.

The most substantial exceedances of the FAV were obtained in nitrites at the Saint-Joseph-de-Beauce plant in summer. Exceedance values of 21 and 19 were recorded with day 1 and day 3 samples, which match the toxic responses of 1.4 TUa in *D. magna* for these two sampling days. These high concentrations of nitrites could, therefore, partly explain the toxicity measured in *D. magna* at this treatment plant.

There is no FAV for anionic surfactants, but the value of 0.94 mg/L was defined for nonionic surfactants. Consequently, the concentration:FAV ratio could only be calculated for the latter. Among plants where analyses for surfactants were performed, the Cookshire plant in winter and the Longueuil plant in summer presented the greatest exceedances of the FAV (exceedances > 3.5), which coincide with high values of acute toxicity in daphnia (*D. magna*). These results are interesting in that daphnia could be particularly sensitive to surfactants, which might attack their shells.

As mentioned earlier, it is interesting to note that certain plants have significant exceedances of the FAVs without any toxicity being detected by the toxicity tests. These results might be explained by the fact that the contaminants are not bioavailable in the effluent or that the species used in the toxicity tests are less sensitive than those that were used to define quality criteria. Conversely, toxicity was detected in certain samples without any observed exceedance of the FAV. In this case, the results can be explained, at least in part, by the combined effect of several substances or by substances being present but not analysed in the effluent.

In summary, ammonia nitrogen appears to be the main contaminant responsible for the acute toxicity measured in *O. mykiss*, while nitrites and surfactants could contribute to the acute toxicity measured in *D. magna*.

4.3.2 Chronic toxicity

Tables 4.10-W and 4.10-S present the *mean measured concentration:CCAL* ratio for each contaminant having exceeded the quality criteria, in relation to the chronic toxicity test results. Only exceedances of CCAL > 2 appear in the tables to highlight the parameters most significantly related to the measured toxicity.

All seasons combined, there are positive chronic toxicity responses at all plants, with the exception of the Martinville plant. There were also exceedances of CCALs at all plants, a majority of which presented exceedances for several substances simultaneously. A relationship could therefore be established between the simultaneous presence of several contaminants at concentrations greater than the safe limits and the toxicity measured in *P. promelas* and *C. dubia*.

As with the acute toxicity results presented in the previous section, it is not possible to establish a precise relationship between exceedances of CCAL for one or more substances and the chronic toxicity measured. However, the presence of ammonia nitrogen, chromium, copper and anionic surfactants at concentrations greater than safe limits often corresponds with acutely toxic responses. For example, in *C. dubia*, 80% of the toxic responses ≥ 4 TUc coincide with simultaneous exceedances (> 2) of these four parameters.

In addition, substantial exceedances for several substances coincide with elevated toxic responses. Such is the case for nitrites (exceedance of 100) and cyanides (26), which could partly explain the chronic toxicity measured at Saint-Joseph-de-Beauce in summer. Aluminum, with CCAL exceedances of 31 and 30, could also explain part of the toxicity at the CUO and Longueuil plants, respectively. For the same reasons, hydrogen sulfide, silver and nonionic surfactants can be added to the list.

TABLE 4.10-W: RELATIONSHIP BETWEEN CHRONIC TOXICITY TEST RESULTS AND EXCEEDANCES (≥ 2) OF THE CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC (CCAL) LIFE FOR ALL SUBSTANCES ANALYSED (WINTER)

Treatment plant (winter)	**Chronic toxicity test results (TUc)**		**Exceedances of the chronic water quality criteria for the protection of aquatic life (mean concentration / CCAL ≥ 2)**													
			Physico-chemical parameters						**Metals**					**VOCs**	**Surfactants**	
	P. promelas	***C. dubia***	**NH_3^- NH_4^+ (1)**	**NO_2^- (2)**	**H_2S (3)**	**CN^-**	**F^-**	**Phenolic subst.**	**Al**	**Ag**	**Cr**	**Cu (4)**	**Fe**	**Toluene**	**Nonionic**	**Anionic**
Farnham	4	2	—	—		LD	2.3	—	9.0	LD	(8.0)	12	4.2	*	67	14
La Prairie	5.9	1	4.5	—		LD	—	—	—	LD	14	—	—	—		
Magog	2	1	—	—		LD	—	—	4.0	LD	(7.5)	(6.5)	3.9			
CUO	8	1	7.2	—		LD	—		31	20	(6.0)	18	11			
Jonquière	2	1	2.7			LD	—		2.3	LD	—	4.0	—			
Châteauguay	2	1	9.7	—		LD	3.7		—	LD	(8.5)	8.7	4.3			
CUQ (East plant)	> 17	2	14			LD	4.0	—	3.4	80	2.5	6.7	2.9	15		
Cookshire	8	16	12			LD	—	—	2.3	50	6.0	14	—	—	190	53
Saint-J.-de-Beauce	17	2	29			LD	—		—	50	—	3.5	4.1			
Warwick	7.7	2	15			LD	—		2.3	40	—	2.1	—		38	4.5
Saint-Gédéon	2	1	12			LD	—		—	30	—	5.3	—			
Sawyerville	2	1	12			LD	—		—	20	—	12	—		*	LD
Martinville	1	1	4.3	—	20	—	—	—	2.9	—	—	—	—	2.8	LD	4.3
CUM	(> 100)	4	7.7	—		LD	—	—	—	LD	13	5.6	5.8	5.4	48	53
Longueuil	11	2	11			LD	—	—	11	LD	13	2.9	—	—		

TUc:	chronic toxicity unit
LD:	limit of detection does not allow for criterion verification
—:	no exceedance of the water quality criterion or exceedance lower than 2 (i.e. exceedance < 2)
*:	result rejected
Blank box:	parameter not measured
( ):	questionable result (quality control); to be considered with caution

(1): CCAL for NH_3-NH_4^+ is determined at each treatment plant from the mean temperature and pH values measured during the chronic toxicity tests.
(2): CCAL for NO_2^- is determined at each treatment plant from the mean chloride concentration measured in the effluent.
(3): Non-ionized H_2S concentration is calculated from the mean concentration of dissolved sulfides measured in the effluent.
(4): CCAL for copper is calculated from the mean hardness measured at each plant.

TABLE 4.10-S: RELATIONSHIP BETWEEN CHRONIC TOXICITY TEST RESULTS AND EXCEEDANCES (≥ 2) OF THE CHRONIC WATER QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC (CCAL) LIFE FOR ALL SUBSTANCES ANALYSED (SUMMER)

Treatment plant (summer)	**Chronic toxicity test results (TUc)**		**Exceedances of the chronic water quality criteria for the protection of aquatic life (mean concentration / CCAL ≥ 2)**													
			Physico-chemical parameters						**Metals**					**VOCs**	**Surfactants**	
	P. promelas	***C. dubia***	**NH_3^- NH_4^+ (1)**	**NO_2^- (2)**	**H_2S (3)**	**CN^-**	**F^-**	**Phenolic subst.**	**Al**	**Ag**	**Cr**	**Cu (4)**	**Fe**	**Toluene**	**Nonionic**	**Anionic**
Farnham	1	1	—	—	LD	—	3.1	—	7.9	—	—	4.1	—	—	LD	13
La Prairie	4	4	28	—	LD	—	—	—	—	—	—	—	—	—	LD	5.9
CUO	4	1	5.7	—	LD	—	—	—	—	—	—	2.2	—	—	LD	2.9
Jonquière	16	16	(2.2)	—	LD	LD	(—)	—	—	—	4.0	3.6	—	—	LD	3.2
Châteauguay	2	2	11	—	2.1	—	4.6	—	6.7	4.0	—	3.1	—	—	11	23
CUQ (East plant)	4	1	11	—	LD	—	3.8	—	—	22	—	5.7	2.6	—	13	33
Cookshire	17	4	7.9	3.0	LD	—	—	2.0	—	—	10	9.9	—	*	LD	11
Saint-J.-de-Beauce	1	16	(—)	100		26	(—)	—	—	—	2.0	2.9	—	—	LD	7.0
Saint-Gédéon	4	16	(9.5)	2.9		10	(—)	—	—	—	2.5	4.7	—	—	LD	11
Sawyerville	1	2	2.1			4.0	—		—	(LD)	7.1	—	—			
Martinville	1	1	LD			LD	—		—	LD	11	—	—			
CUM (1998)		4	5.7	—	4.3	4.0	(—)	—	11	11	4.0	7.0	—	*	44	57
CUM (1999)	33	4	7.1	—	30	4.0	—	—	8.8	7.0	2.7	5.6	—		81	44
Longueuil (1998)		16	11	(—)	26	LD	(—)	2.0	30	7.0	13	3.6	—	*	189	383
Longueuil (1999)	2	2	12	—	39	—	—	2.0	11	—	2.4	—	—		95	79

TUc: chronic toxicity unit
LD: limit of detection does not allow for criterion verification
—: no exceedance of the water quality criterion or exceedance lower than 2 (i.e. exceedance < 2)
*: result rejected
Blank box: parameter not measured
( ): questionable result (quality control); to be considered with caution

(1): CCAL for NH_3-NH_4^+ is determined at each treatment plant from the mean temperature and pH values measured during the chronic toxicity tests.
(2): CCAL for NO_2^- is determined at each treatment plant from the mean chloride concentration measured in the effluent.
(3): Non-ionised H_2S concentration is calculated from the mean concentration of dissolved sulfides measured in the effluent.
(4): CCAL for copper is calculated from the mean hardness measured at each plant.

Finally, certain pesticides are also targeted because they were confirmed at concentrations greater than that of the CCALs at the CUM and Longueuil plants (Section 4.2.1.4). Although their presence may explain, in part, the measured toxicity, no parallel can be drawn in this case, since pesticides were analysed in different samples.

In summary, of the substances analysed, those suspected of significantly contributing to the chronic toxicity in *P. promelas* and *C. dubia* are ammonia nitrogen, surfactants and certain metals. Further, the simultaneous presence of several substances can also partly explain the toxicity measured.

4.3.3 Substances responsible for the toxicity measured

The analysis presented in the two previous sections shows that ammonia nitrogen is probably mainly responsible for the acute and chronic toxicity measured. Surfactants may be the second most widespread contaminant, while certain metals (mainly copper, chromium and aluminum) are suspected of chronic effects. In certain specific cases, nitrites, cyanides and hydrogen sulfide could also have played a role. Finally, the presence of pesticides in summer   diazinon and, more particularly, chlorpyrifos   could be an additional source of toxicity.

Only studies focused on toxicity identification, as described in the guide for evaluating and reducing toxic substances (*Guide d'évaluation et de réduction des toxiques*) (MENV, 1996c), would allow us to verify this, however, and to determine, on an individual basis, which substances are actually responsible for the acute and chronic toxicity.

It should be noted that such studies were conducted in the United States and elsewhere in Canada and that they corroborate several of the observations of the present study. Using acute toxicity tests and the occasional chemical analysis, these studies identified substances at the origin of the toxicity in certain municipal effluents. Ammonia nitrogen, chlorine, certain metals, surfactants and pesticides were identified again and again. The studies also demonstrated the variability of these effluents, given the many different sources of contaminants of which they are constituted (domestic wastewater, runoff water, and industrial wastewater). Indeed, the toxicity of a given effluent could sometimes be attributed to the presence of ammonia nitrogen, whereas it might later be linked to the presence of pesticides or metals (Burgess *et al*., 1995).

Ammonia nitrogen is probably the most commonly identified toxic compound in the municipal effluents surveyed in these studies (Burgess *et al*., 1995; Environment Canada, 1997; Fisher *et al*., 1998; Bailey *et al*., 1999).

Chlorine, when present, is almost always the primary cause of toxicity (Orr *et al*., 1992; Burgess *et al*., 1995; Asami *et al*., 1996). The absence of chlorination in Quebec wastewater treatment processes may explain the generally good results obtained in terms of acute and chronic toxicity.

The metals most commonly identified in some studies are copper, lead and zinc (Burgess *et al*., 1995; Environment Canada, 1997).

The organic compounds, particularly surfactants, that are sometimes identified as a cause for toxicity are often linked to the textile industry. Studies using more specific analytic techniques have identified nonyl-octyl phenol ethoxylates and carboxylates, among other substances. They are among the most targeted contaminants because of their disruptive effects on the endocrine system of organisms exposed thereto. They are generally detected in municipal effluents and in textile mill effluents. Their presence was confirmed in the water and sediments downstream of these effluents (Purdom *et al*., 1994; Jobling *et al*., 1998; Servos, 1998; Sekela *et al*., 1999).

Finally, certain pesticides were also occasionally identified. In two studies, diazinon (Burkhard and Jenson, 1993), and diazinon and chlorfenvinphos (Bailey *et al*., 1999) were identified as agents responsible for toxicity. In addition, diazinon and chlorpyrifos are also known to be present in treated and untreated water (overflow water) and for the additivity of their toxicity (Jones-Lee and Lee, 1999).

4.4 Effects of Treatment Plant Operation and Design Conditions on Toxicity

This section presents an evaluation of the following parameters affecting measured toxicity, based on data obtained during our study:

- wastewater treatment process type;
- season;
- significance of industrial BOD_5 load;
- chemical dephosphatization.

Since the effects of treatment process type and season of the year are closely linked, they are jointly analysed in the same section.

4.4.1 Effects of treatment process type and season

Table 4.11 presents the maximum acute toxicity measured in *D. magna* and *O. mykiss* in relation to treatment process type and season of the year. An analysis of the results indicates that aerated lagoons are the treatment type in which maximum acute toxicity is most frequently greater than 1 TUa (six of nine results) and in which recurrence occurs more frequently in winter (four of five results) than in summer (two of four results).

TABLE 4.11: MAXIMUM ACUTE TOXICITY MEASURED BY TREATMENT TYPE AND SEASON

Type of treatment process	**Treatment plant**	**Maximum TUa (1) by season**		**Number of results above 1 TUa**
		Winter	**Summer**	
Activated sludge	Farnham	nl	nl	**1/9 (11%)**
	La Prairie	nl	1.9	
	Magog	nl		
	CUO	nl	nl	
	Jonquière	nl	< 1	
Biofiltration	Châteauguay	nl	1.5	**1/4 (25%)**
	CUQ (East plant)	< 1	nl	
Aerated lagoon	Cookshire	3.2	2.9	**6/9 (67%)**
	Saint-Joseph-de-Beauce	> 1	1.4	
	Warwick	> 1		
	Saint-Gédéon	> 1	< 1	
	Sawyerville	< 1	< 1	
Unaerated lagoon	Martinville	nl (2)	nl	**0/2 (0%)**
Physico-chemical	CUM	nl	< 1	**1/4 (25%)**
	Longueuil	nl	3	
Number of results above 1 TUa		**4/15 (25%)**	**5/13 (38%)**	**9/28 (32%)**

(1): Highest result obtained of the three daily samples and the two acute toxicity tests performed.
(2): Non-lethal for *D. magna* and non-valid results for *O. mykiss*.
nl: Non-lethal.

For samples drawn under winter operating conditions, the only acute toxicity results above 1 TUa were observed at plants with aerated lagoons (13 results out of 27 above 1 TUa) (see Table 3.2-W). Rainbow trout (*O. mykiss*) was particularly sensitive to the effluent samples from aerated lagoons in winter since 10 of the 13 results exceeding 1 TUa were observed with this species.

Under summer conditions, aerated lagoon effluents were found to be less toxic than in winter, the number of responses exceeding 1 TUa being four results out of 23 (Table 3.2-S). In this case, there were no results higher than 1 TUa in *O. mykiss* since the four results were observed in the daphnia *D. magna*. However, an opposite phenomenon is observed at plants carrying out activated sludge, biofiltration and physico-chemical treatments, because certain results exceeding 1 TUa were obtained in summer (3 results out of 24, 1 result out of 12 and 7 results out of 24, respectively) compared to none in winter.

The greatest number of results exceeding 1 TUa in summer were obtained at plants performing physico-chemical treatment. However, six of the seven results greater than 1 TUa come from samples drawn at the Longueuil plant in the summer of 1998 (Table 3.2-S). A document reports that several studies reveal results above 1 TUa for such primary treatment effluents with acute toxicity tests using fish and daphnia (UMA, 1993).

No result above 1 TUa was recorded for the plant with unaerated lagoons during both the winter and summer sampling campaigns. It should be noted, however, that the toxicity tests with trout carried out on the effluent from the spring lagoon emptying (winter conditions) proved to be invalid.

As for the acute toxicity results, Table 4.12 presents the maximum chronic toxicity measured in *S. capricornutum, P. promelas* or *C. dubia* relative to treatment type and season of the year. The results reveal that all treatment process types, except for the unaerated lagoons, showed chronic toxicity to one of the species. An examination of these results found no apparent significant relationship between the chronic toxicity of the effluents and the various processes, except, perhaps, for plants using physico-chemical treatment. The results obtained at the two plants that employ such a treatment process all exceed 2 TUc (4 results out of 4), which are the highest, with values always greater than 10 TUc. No significant seasonal trend was established.

TABLE 4.12: MAXIMUM CHRONIC TOXICITY MEASURED BY TREATMENT TYPE AND SEASON

Type of treatment process	**Treatment plant**	**Maximum TUc (1) by season**		**Number of results above 2 TUc**
		Winter	**Summer**	
Activated sludge	Farnham	4	1	**6/9 (67%)**
	La Prairie	5.9	4	
	Magog	2		
	CUO	8	4	
	Jonquière	2	16	
Biofiltration	Châteauguay	2	2	**2/4 (50%)**
	CUQ (East plant)	> 17	4	
Aerated lagoon	Cookshire	16	17	**7/9 (78%)**
	Saint-Joseph-de-Beauce	17	16	
	Warwick	7.7		
	Saint-Gédéon	2	16	
	Sawyerville	2.2	2	
Unaerated lagoon	Martinville	1	1	**0/2 (0%)**
Physico-chemical	CUM	(> 100)	33	**4/4 (100%)**
	Longueuil	11	16	
Mean TUc:	**- with the CUM**	**13.2**	**10.2**	**-**
	- without the CUM	**7.0**	**8.3**	
Number of results above 2 TUc		**10/15 (67%)**	**9/13 (69%)**	**19/28 (68%)**

(1): Highest result obtained of the three chronic toxicity tests performed.

The relationship between toxicity, treatment type, and season of the year was also assessed using the toxic print of the PEEP Index. These results, presented in Table 4.13, show that the effluents from aerated and unaerated lagoons were almost 10 to 20 times more toxic, respectively, (mean toxic prints 41.9 and 72.4 ATU.bvu^{-1}) than those of plants performing physico-chemical, biofiltration or activated sludge treatments. In addition, a significant difference is noted with regard to the seasonal effect on effluents of aerated and unaerated lagoons. The mean toxic print for aerated lagoons in winter is more than twice what it is in summer, while the mean measured at unaerated plants was relatively high in winter (72.4), but nil in summer.

TABLE 4.13: INFLUENCE OF TREATMENT TYPE AND SEASON ON THE PEEP INDEX TOXIC PRINT

Treatment type	Number of treatment plants		Mean toxic print ($ATU.bvu^{-1}$)		Min - Max ($ATU.bvu^{-1}$)	
	Winter	Summer	Winter	Summer	Winter	Summer
Activated sludge	5	4	3.4	3.0	0.0–15.8	0.3–6.8
Biofiltration	2	2	3.4	1.3	0.0–6.8	0.0–2.6
Aerated lagoon	5	4	41.9	18.3	0.0–91.2	0.3–54.3
Unaerated lagoon	1	1	72.4	0.0	72.4	0.0
Physico-chemical	2	2	4.6	3.2	1.4–7.8	3.1–3.4

Overall, the results of the toxicity tests suggest that aerated lagoons are more likely to contain contaminants in sufficient concentrations to cause toxicity during the winter season, and, more particularly, to induce acute effects in *O. mykiss*. Furthermore, higher toxic responses seem to occur at physico-chemical treatment plants in summer and at unaerated lagoons in winter. Plants that use activated sludge and biofiltration treatment processes generally obtain the best results.

In order to understand these observations, the mean values of certain physico-chemical parameters that depend on the type of treatment or on biological activity were calculated. These values are presented in Table 4.14 by treatment type and season of the year. First, the high concentrations of ammonia nitrogen in the effluents of aerated lagoons in winter tend to confirm the previous observations and the role of ammonia nitrogen in the expression of toxicity at these plants (see sections 4.2.1.1 and 4.3.1). The mean in winter is the highest of all treatment types, while the mean in summer is one of the lowest. Second, relatively high concentrations of ammonia nitrogen are also noted in effluents of biofiltration plants, in both seasons.

Treatment processes without aeration equipment (unaerated lagoons and physico-chemical processes) yield the highest concentrations of sulfides, a good indication of the presence of high concentrations of hydrogen sulfide (H_2S). A concentration of total sulfide of 0.56 mg/L was measured during spring emptying (winter conditions) of the Martinville plant’s unaerated lagoons. Relatively high concentrations of total sulfides were also measured in the effluent samples drawn in summer at the two plants with physico-chemical treatment processes (mean of 0.19 mg/L).

TABLE 4.14: MEAN VALUES OF CERTAIN CONVENTIONAL PHYSICO-CHEMICAL PARAMETERS BY TREATMENT TYPE AND SEASON

Treatment type	NH_3-NH_4^+ (mg/L-N)		BOD_5 (mg/L)		COD (mg/L)		Total sulfides (mg/L)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Activated sludge	2.8	7.9	*	2.5	*	32.3	0.05	0.01
Biofiltration	10.0	9.2	30	5	85	49	0.03	0.05
Aerated lagoon	13.8	4.5	14.4	4.5	78.2	59.5	<	0.04
Unaerated lagoon	3.7	<	23	18	47	130	0.56	0.09
Physico-chemical	8.2	7.6	*	30.3	*	104.5	0.05	0.19

*: Too many results rejected to calculate a significant mean value.
<: All results were below the limit of detection.

The ammonia nitrogen and sulfide concentrations in continuous-draining unaerated lagoons in Quebec in winter[8] frequently exceed 10 mg/L and 2 mg/L, respectively, at the end of winter. An Ontario study shows similar results (Beak and Canviro, 1990). Also, relevant data from 1993 to 1995 on the monitoring of unaerated lagoons carrying out periodic emptying show high ammonia nitrogen concentrations, but rarely above 10 mg/L during the spring emptying process (MENV and MAMM, 1996). In the case of Martinville, the concentrations of ammonia nitrogen were lower than levels generally observed at plants with unaerated lagoons. The presence of H_2S could therefore explain, at least in part, the high toxic print obtained at this plant in winter.

At plants conducting physico-chemical treatment processes, sulfide concentrations are elevated in summer because of the higher temperatures of the wastewater. In addition, wastewater travel times in the CUM and Longueuil sewer systems are particularly long, which contributes to the production of hydrogen sulfide. These results and the design elements of these two plants could therefore account for part of the toxicity measured in summer. Plants with physico-chemical processes also obtained relatively high means for BOD_5 and COD, which may be explained by the absence of a biological treatment for such a process type.

Many studies corroborate these observations. In an Ontario study (Orr *et al.*, 1992), although no significant difference was noted between the activated sludge treatment plants (with or without tertiary filtration) and those with continuous-discharge unaerated lagoons, there were, nonetheless, fewer toxic responses in *O. mykiss* with the former treatment type. Also, the results obtained with effluents drawn in winter in unaerated lagoons were more toxic to *O. mykiss* (acute toxicity) and to *C. dubia* (chronic toxicity) than were the effluents drawn in summer. According to the authors, this could be explained by higher concentrations of ammonia nitrogen and sulfides in the effluents of unaerated lagoons with continuous discharge in winter.

In another study (Canviro Consultants, 1989), it was observed that activated sludge treatment plants were more effective in removing certain metals and organic substances than plants with

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[8] In Quebec there are still eight municipal treatment plants with unaerated lagoons that carry out continuous discharge rather than periodic emptying.

primary treatment processes. An analysis of the overall results of the present study indicates that the quality of the effluents of activated sludge and biofiltration plants is generally superior.

Finally, certain other observations related to treatment type or season are worth mentioning. The addition of chlorine prior to tertiary filtration at the Magog plant does not seem to have contributed in any significant way to the expression of toxicity. Indeed, during all the toxicity tests (acute, chronic and PEEP Index) carried out at that plant, few toxic effects were observed in the test organisms. However, the plant is the only one carrying out tertiary filtration, and that has probably contributed to obtaining good results.

Although it is not possible to draw any conclusions about the effectiveness of the plants using physico-chemical processes to remove surfactants, this type of treatment has yielded the highest concentrations of surfactants. Values are always in the range of 2 mg/L of anionic surfactants and 1 mg/L of nonionic surfactants at the CUM plant, and always higher than these values at the Longueuil plant (see Table 3.10). With the exception of Cookshire and Farnham in winter, concentrations of surfactants at the other plants are always well below those measured at plants that employ a physico-chemical treatment process.

No apparent seasonal variation is associated with the results of the physico-chemical analyses, except for certain substances. In fact, the measured concentrations of the majority of parameters vary significantly from one sampling day to another, but do not show stronger variations from one season to the next. The only seasonal variations were obtained with substances that depend on biological activity for the treatment of wastewater, such as ammonia nitrogen and hydrogen sulfide (see discussion above and Table 4.14), and with substances used seasonally. Such is the case for chlorides used in road de-icing agents (sodium chloride and calcium chloride). The concentrations of chlorides presented in tables 3.6-W and 3.6-S indicate a significant increase in winter, in the range of 75% higher on average in summer for the plants overall. The increase is even greater at plants operating in municipalities with combined sewer systems and where de-icing salts are used in substantial quantities (CUO, CUQ, CUM, etc.). Finally, although our results cannot support this assumption, a seasonal variation is assumed with regard to pesticides.

In summary, then, it seems that, in winter, plants with aerated lagoons present a greater toxicity potential than plants using other types of treatment. One reason for this would be the higher concentrations of ammonia nitrogen in cold water, probably due to the decreased activity of nitrifying bacteria. Processes with no aeration (unaerated lagoons and physico-chemical treatment) could themselves present a greater toxic potential during certain periods of the year (during spring emptying of unaerated lagoons, and in summer for physico-chemical plants) because of the biological production of hydrogen sulfide in anaerobic conditions. An analysis of the overall results of the present study indicates that activated sludge and biofiltration plant effluents are generally of better quality. Lastly, a seasonal variation is recorded for certain substances that depend on biological activity for wastewater treatment, such as ammonia nitrogen and hydrogen sulfide, and those that are used seasonally, such as chlorides used in road de-icing agents.

4.4.2 Effects of the presence of industries on the sewer system

The impact of treatment types and seasons on effluent toxicity must be analysed based on the industrial BOD_5 load received at each plant. The data being only fragmentary, it is difficult to draw any clear conclusions from them. The analysis can nevertheless serve to determine whether plants with high or low industrial BOD_5 input present noticeable differences in toxicity.

Table 4.15 shows that all seasons combined, 50% of the results relative to maximum acute toxicity (6 of 12 results) are higher than 1 TUa at plants with substantial industrial inputs, compared to 19% (3 of 16 results) for plants with a low industrial input.

Also, the results for acute toxicity (tables 3.2-W and 3.2-S) indicate that only the effluents that were proven toxic (significant mortality percentage in *O. mykiss* or *D. magna* for the three daily samples), in winter and summer, originate from two plants with substantial industrial loading (Cookshire and Saint-Joseph-de-Beauce). The effluent of the Warwick plant, which receives a substantial industrial load as well, was also found to develop acute toxicity under winter conditions, but was not characterized under summer conditions.

Table 4.15: Maximum Acute Toxicity Measured by Industrial BOD$_5$ Load

Treatment process	**Treatment plant**	**Maximum TUa (1) relative to industrial BOD$_5$ inputs**	
		High inputs (winter - summer)	**Low inputs (winter - summer)**
Activated sludge	Farnham	nl - nl	
	La Prairie	nl - 1.9	
	Magog	nl	
	CUO		nl - nl
	Jonquière		nl - <1
Biofiltration	Châteauguay		nl - 1.5
	CUQ (East plant)		<1 - nl
Aerated lagoon	Cookshire	3.2 - 2.9	
	Saint-Joseph-de-Beauce	>1 - 1.4	
	Warwick	>1	
	Saint-Gédéon		>1 - <1
	Sawyerville		<1 - <1
Unaerated lagoon	Martinville		nl (2) - nl
Physico-chemical	CUM	nl - <1	
	Longueuil		nl - 3
Number of results above 1 TUa		**6/12 (50%)**	**3/16 (19%)**

(1): Highest result obtained of the three daily samples and the two acute toxicity tests performed.
(2): Non-lethal for *D. magna* and non-valid results for *O. mykiss*.
nl: Non-lethal.

The results for maximum chronic toxicity (Table 4.16) show that 83% of the results above 2 TUc (10 of 12 results) are associated with substantial industrial loads while the ratio drops to 56% (9 of 16 results) for plants with smaller industrial BOD$_5$ loads. The mean TUc's are also low for the latter plants. Of the eight plants with lower industrial inputs, three present a maximum chronic toxicity of more than 2 TUc in both seasons: one activated sludge plant (CUO) with 8 and 4 TUc, one biofiltration plant (CUQ) with > 17 and 4 TUc and one physico-chemical plant (Longueuil) with 11 and 16 TUc (see Table 4.16). However, it should be noted that there are a substantial number of industries connected to the sewer systems at these three plants, even though the industrial BOD$_5$ loads are relatively small. The effluents of the other plants having few industries connected to the sewer system (Jonquière, Châteauguay, Sawyerville, Saint-Gédéon and Martinville), all present a chronic toxicity of 2.2 TUc or less, with the exception of the samples drawn in summer at the Jonquière and Saint-Gédéon plants, where results of 16 TUc were obtained.

Table 4.16: Maximum Chronic Toxicity Measured by Industrial BOD_5 Load

Treatment process	**Treatment plant**	**Maximum TUc (1) relative to industrial BOD_5 inputs**	
		High inputs (winter - summer)	**Low inputs (winter - summer)**
Activated sludge	Farnham	4 - 1	
	La Prairie	5.9 - 4	
	Magog	2	
	CUO		8 - 4
	Jonquière		2 - 16
Biofiltration	Châteauguay		2 - 2
	CUQ (East plant)		>17 - 4
Aerated lagoon	Cookshire	16 - 17	
	Saint-Joseph-de-Beauce	17 - 16	
	Warwick	7.7	
	Saint-Gédéon		2 - 16
	Sawyerville		2.2 - 2
Unaerated lagoon	Martinville		1 - 1
Physico-chemical	CUM	(>100) - 33	
	Longueuil		11 - 16
Mean TUc:	**- with the CUM**	**18.6**	**6.6**
	- without the CUM	**9.1**	
Number of results above 2 TUc		**10/12** **(83%)**	**9/16** **(56%)**

(1): Highest result obtained of the three chronic toxicity tests performed.

At the Longueuil plant, industrial inputs have probably increased since the plant was first designed, and seem greater than what was expected, although no data is available to confirm this assumption. The acute toxicity and the high concentrations of surfactants (average of 15 mg/L of anionic surfactants and 4 mg/L of nonionic surfactants) measured during the summer of 1998 campaign can hardly be explained other than by a significant industrial load.

The influence of the industrial BOD_5 load on the toxic potential of municipal effluents was also evaluated using the toxic print as a measurement of genotoxicity. The mean toxic print calculated at the plants receiving substantial industrial loadings is greater than at plants associated with smaller industrial BOD_5 load (Table 4.17). It is also interesting to note that no high industrial-load plants have obtained a nil toxic print (the lowest result is 0.2 $TUa.uvb^{-1}$ at La Prairie in winter), whereas there are 5 nil toxic prints out of the 16 results obtained at the plants with low industrial inputs.

TABLE 4.17: INFLUENCE OF INDUSTRIAL BOD_5 LOADING ON THE PEEP INDEX TOXIC PRINT

Industrial inputs	**Number of results**	**Mean toxic print ($ATU.bvu^{-1}$)**	**Min - Max ($ATU.bvu^{-1}$)**
Low inputs	16	11.0	0.0–81.5
High inputs	12	15.1	0.2–91.2

The overall results of the toxicity tests suggest that the industrial BOD_5 load may contribute significantly to the toxic potential of municipal effluents. Regarding aerated lagoons, the three plants categorized as having a substantial industrial BOD_5 load all have maximum chronic toxicity results greater than 7.7 TUc and maximum acute toxicity results above 1 TUa, while only one of the plants categorized as having a small industrial load presents a result above 2.2 TUc and one result above 1 TUa. It therefore seems that the industrial BOD_5 load has a greater effect than does treatment type on the toxicity tests used.

These results confirm those of Orr *et al.* (1992), which demonstrated that effluents associated with substantial industrial loads were more toxic to *O. mykiss*[9] (acute toxicity) and *C. dubia* (chronic toxicity) than effluents associated with low industrial loads.

The results of certain physico-chemical analyses were assessed on the basis of the industrial BOD_5 load. The mean results are presented in Table 4.18.

An analysis of the tabular data shows that higher values for BOD_5, COD and mineral oils and greases are obtained when there is a significant industrial input. The mean value for COD is particularly high, which means that substantial quantities of organic substances are found in the effluents of these plants. With regard to mineral oils and greases, the high mean value associated with a substantial industrial input can be explained by the results of the Cookshire plant alone, where concentrations of 16 to 17 mg/L were measured in winter.

As for metals, the industrial input does not seem to have a noticeable impact. The highest mean values are nevertheless found more often at plants with large industrial BOD_5 loads, except for aluminum, which is more influenced by dephosphatization (see Section 4.4.3). Apart from the data on the effluent samples drawn at the Longueuil plant in the summer of 1998, which may have been influenced by a particular phenomenon (probably a significant industrial discharge), the concentrations of surfactants are similar, although slightly higher at plants with large industrial loads.

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[9] In the case of trout, however, this trend was found to be statistically non-significant.

TABLE 4.18: MEAN VALUES OF CERTAIN PHYSICO-CHEMICAL PARAMETERS BY INDUSTRIAL BOD_5 LOAD

Parameter	**Industrial BOD_5 inputs**	
	Low inputs	**High inputs**
NH_3-NH_4^+ (mg/L-N)	6.9	8.0
BOD_5 (mg/L)	12	16
COD (mg/L)	56	86
Mineral oils and greases (mg/L)	0.18	1.42
Aluminum (mg/L)	0.53	0.34
Chromium (mg/L)	0.009	0.011
Copper (mg/L)	0.015	0.020
Lead (mg/L)	0.0006	0.0005
Silver (mg/L)	0.0011	0.0012
Zinc (mg/L)	0.021	0.050
Anionic surfactants (mg/L)	2.36 (2)	1.05
Nonionic surfactants (mg/L)	0.81	0.98
Total PCBs (ng/L)	4.75	8.92
Total PAHs (ng/L)	739	478
Chlorinated dioxins and furans (pg/L) (1)	0.122	0.524 (3)

(1): Chlorinated dioxins and furans are expressed in 2,3,7,8-TCDD equivalent.

(2): The mean value becomes 0.79 mg/L when eliminating the particularly high result obtained at Longueuil in 1998 (15 mg/L).

(3): The mean value becomes 0.104 pg/L when eliminating the particularly high result obtained at Cookshire in 1998 (2.6 pg/L).

The total PCB concentrations and the concentrations of chlorinated dioxins and furans are also higher where industrial loads are larger. These results are influenced by particularly high concentrations of PCBs and chlorinated dioxins and furans in the effluent of the Cookshire plant, where a large proportion of the wastewater comes from a textile mill.

Finally, total PAH concentrations are slightly higher with low industrial loads. In this one case, however, urbanization seems to play a more important role than industrial loading. The results presented in Table 3.12 show that total PAH concentrations at the CUM, Longueuil and CUQ (East plant) plants, which receive wastewater from highly urbanized combined sewers, range from 991 to 2731 ng/L, while means are lower than 250 ng/L everywhere else.

In summary, the industrial BOD_5 load appears to greatly increase the toxic potential of municipal wastewaters, and seems to be a determining factor in the potential toxicity of municipal effluents, even though effluents may be toxic where there is little or no industrial input.

4.4.3 Effects of chemical dephosphatization

The influence of chemical dephosphatization on the toxicity measured was also analysed in relation to the maximum acute toxicity (Table 4.19), the maximum chronic toxicity (Table 4.20), and the toxic print (Table 4.21). The overall results seem to indicate, on the surface, that effluents from plants that do no dephosphatization are slightly more toxic than those that employ this process. However, this trend is probably influenced more by other factors than by dephosphatization. Indeed, by eliminating the results of only three plants having aerated lagoons and large industrial inputs, characterized in winter (Cookshire, Saint-Joseph-de-Beauce and Warwick), the trend becomes non-significant in regard to the maximum TUa and TUc and it is even reversed with the mean toxic prints. This example shows that industrial input and the presence of ammonia nitrogen at higher concentrations in winter in aerated lagoons may have more influence on the toxicity measured than does chemical dephosphatization.

Table 4.19: Maximum Acute Toxicity Measured in relation to Dephosphatization

Treatment process	**Treatment plant**	**Maximum TUa (1) in relation with dephosphatization**	
		With dephosphatization	**Without dephosphatization**
Activated sludge	Farnham	nl	nl
	La Prairie		nl - 1.9
	Magog	nl	
	CUO	nl - nl	
	Jonquière		nl - <1
Biofiltration	Châteauguay	1.5	nl
	CUQ (East plant)		<1 - nl
Aerated lagoon	Cookshire		3.2 - 2.9
	Saint-Joseph-de-Beauce	1.4	>1
	Warwick		>1
	Saint-Gédéon		>1 - <1
	Sawyerville	<1	<1
Unaerated lagoon	Martinville	nl (2)	nl
Physico-chemical	CUM	nl - <1	
	Longueuil	nl - 3	
Number of results above 1 TUa		**3/12** **(25%)**	**6/16** **(38%)**

(1): Highest result obtained of the three daily samples and the two acute toxicity tests performed.
(2): Non-lethal for *D. magna* and invalid results for *O. mykiss*.
nl: Non-lethal.

Table 4.20: Maximum Chronic Toxicity Measured in relation to Dephosphatization

Treatment process	Treatment plant	Maximum TUc (1) in relation with dephosphatization	
		With dephosphatization	**Without dephosphatization**
Activated sludge	Farnham	1	4
	La Prairie		5.9 - 4
	Magog	2	
	CUO	8 - 4	
	Jonquière		2 - 16
Biofiltration	Châteauguay	2	2
	CUQ (East plant)		>17 - 4
Aerated lagoon	Cookshire		16 - 17
	Saint-Joseph-de-Beauce	16	17
	Warwick		7.7
	Saint-Gédéon		2 - 16
	Sawyerville	2	2.2
Unaerated lagoon	Martinville	1	1
Physico-chemical	CUM	(>100) - 33	
	Longueuil	11 - 16	
Mean TUc:	**- with the CUM**	**16.3**	**8.4**
	- without the CUM	**6.3**	
Number of results above 2 TUc		**7/12** **(58%)**	**12/16** **(75%)**

(1): Highest result obtained of the three chronic toxicity tests performed.

Table 4.21: Influence of Dephosphatization on the PEEP Index Toxic Print

Dephosphatization	Number of results	Mean toxic print ($ATU.bvu^{-1}$)	Min - Max ($ATU.bvu^{-1}$)
With	12	12.9	0.0–72.4
Without	16	15.9	0.2–91.2

Table 4.22 presents the mean values for total phosphorus, SM and the main metals detected at the five plants that used seasonal dephosphatization during the two characterization campaigns. In all these cases, alum served as the reagent. This table offers some appreciation of the effect of dephosphatization, assuming the seasonal effect is insignificant.

TABLE 4.22: EFFECT OF SEASONAL ALUM DEPHOSPHATIZATION: VARIATION OF THE CONCENTRATION OF CERTAIN PHYSICO-CHEMICAL PARAMETERS AND METALS WITH AND WITHOUT DEPHOSPHATIZATION

Treatment plant	**Mean concentrations (mg/L) with and without alum dephosphatization (1) and variation (%) (2)**																				
	Total phosphorus			**SM**			**Aluminum**			**Iron**			**Copper**			**Chromium**			**Zinc**		
	Wo	**With**	**Var.**	**Wo**	**With**	**Var.**	**Wo**	**With**	**Var.**	**Wo**	**With**	**Var.**	**Wo**	**With**	**Var.**	**Wo**	**With**	**Var.**	**Wo**	**With**	**Var.**
Farnham	*	0.2	—	11	10	- 9 %	0.78	0.690	- 12 %	1.26	0.343	- 73 %	0.048	0.016	- 67 %	(0.016)	0.0013	-108%	0.04	0.024	- 40 %
Châteauguay	*	0.66	—	11	10	- 9 %	0.06	0.587	+878%	1.30	0.250	- 81 %	0.040	0.014	- 65 %	(0.017)	0.0023	-114%	0.07	0.013	- 81 %
St-J.-de-Beauce	1.6	0.72	- 55 %	19	37	+ 95 %	<	0.057	—	1.23	0.497	- 60 %	0.012	0.010	- 17 %	0.002	0.004	+100%	<	<	—
Sawyerville	1.5	0.43	- 71 %	4	3.6	- 10 %	<	<	—	0.47	<	—	0.028	0.002	- 93 %	<	0.0142	—	0.02	<	—
Martinville	0.86	1.2	+ 40 %	46	18	- 61 %	0.040	0.253	+533%	0.40	0.193	- 52 %	<	0.003	—	0.022	0.001	- 95 %	<	0.003	—

*: result rejected
<: result below detection limit
( ): questionable result (quality control); to be considered with caution

(1): Summer dephosphatization at all treatment plants, except Martinville where dephosphatization occurred in spring (winter conditions).
(2): A negative variation indicates a decrease in mean concentration during dephosphatization.

An analysis of the data in Table 4.22 shows a negative variation in 80% of the results (20 results out of 25) of variation in the mean concentrations during the seasonal dephosphatization event. This suggests that dephosphatization has a beneficial effect, particularly on iron, copper, chromium and zinc concentrations, in addition to phosphorus. Surprisingly, dephosphatization appeared to have little effect on SM. At the Châteauguay and Martinville plants, alum dephosphatization (aluminum sulfide) seems to have significantly increased the aluminum concentrations in the effluent.

The CUM plant, which uses dephosphatization year-round, changed its chemical reagent between the winter of 1996 and summers of 1998 and 1999 sampling periods, switching from ferric chloride to alum. This change appears to have caused an increase in aluminum concentrations in the effluent (from 0.140 to 0.867 mg/L), but a decrease in iron concentrations (from 1.750 to 0.250 mg/L) (see Table 4.23). It should be mentioned that during the 1995–97 period, the CUM measured concentrations of approximately 1.5 mg/L for each of these parameters in its effluent (Deschamps *et al.*, 1998; Purenne, 1998). The metal serving as reagent seems therefore to be present at the outfall at concentrations on the same order of magnitude as at the inlet, but appears to have a beneficial effect on the other metal. Moreover, for 1995, 1996 and 1997, the CUM plant measured increases in iron concentrations of 37%, 5% and 19%, respectively, at the outfall, compared to the concentration at the inlet when dephosphatization was carried out with ferric chloride (Deschamps *et al.*, 1998; Purenne, 1998).

TABLE 4.23: MEAN ALUMINUM AND IRON CONCENTRATIONS MEASURED IN THE EFFLUENT OF THE CUM PLANT DURING EPISODES OF FERRIC CHLORIDE AND ALUM DEPHOSPHATIZATION

Treatment plant	**Ferric chloride dephosphatization (winter 1996)**		**Alum dephosphatization (summer 1998 and 1999)**	
	Aluminum (mg/L)	**Iron (mg/L)**	**Aluminum (mg/L)**	**Iron (mg/L)**
CUM	0.140	1.750	0.867	0.250

The same observation can be made by comparing the mean of all aluminum and iron concentrations at plants that were not using dephosphatization with mean concentrations at plants that did perform alum or iron dephosphatization (ferric chloride or sulfide). Table 4.24 shows that the aluminum concentration increases by 350%, from 0.18 to 0.81 mg/L, for all the plants using alum for dephosphatization, compared to those that do no dephosphatization at all. For these same plants, there has been a beneficial effect on the total mean concentration of iron, since the value dropped from 0.55 to 0.37 mg/L. For plants that use iron for dephosphatization, there was also an increase of some 200% in the concentration of the metal serving as a coagulant, going from 0.55 to 1.71 mg/L of iron. However, there was no beneficial effect on the aluminum concentration, one reason being a very high aluminum concentration measured at the CUO plant during the winter characterization, which increases the mean.

TABLE 4.24: MEAN ALUMINUM AND IRON CONCENTRATIONS MEASURED AT PLANT EFFLUENTS IN RELATION TO DEPHOSPHATIZATION

Treatment plant (winter and summer results)	**Mean concentration (mg/L)**	
	Aluminum	**Iron**
All plants without dephosphatization	0.18	0.55
All plants with alum dephosphatization	0.81	0.37
All plants with iron dephosphatization	1.42	1.71

To sum up, then, in addition to removing phosphorus, chemical dephosphatization appears to have a beneficial effect on metal removal. On the other hand, though, it appears to cause an increase in the concentration of the metal serving as a coagulant. Chemical dephosphatization may also have a beneficial effect on the toxic potential of municipal effluents, although it is impossible to say so with any certainty, based on our analysis, since the toxicity results appear to be influenced much more by the type of treatment used, the season and the industrial load, than by chemical dephosphatization.

5 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

OBJECTIVES AND INTERPRETATIVE LIMITATIONS OF THE STUDY

The objective of the study was to obtain a comprehensive and representative snapshot of the toxic potential of municipal treatment plant discharges that is, to assess the toxicity of undiluted effluents without taking account of the particularities of receiving environments or loads discharged. The approach adopted for this study made it possible to compare the municipal effluents on a common basis in order to:

- assess end-of-pipe toxicity (acute or chronic) of treated wastewater discharges of municipal treatment plants;
- point up the substances that are the likely sources of the measured toxicity;
- identify the common causes of toxicity and the effect of certain factors that might influence effluent toxicity.

This approach, however, does not allow for a cause-and-effect link to be made between measured toxicity and potential effects on the environment. The toxicity of various contaminants may be modified due to certain environmental characteristics of receiving environments, such as water hardness, pH, temperature, the presence of other substances, degradation of parent products into more or less toxic by-products, the health of populations present, etc. Concentrations alone are inadequate to assess the apprehended impact of an effluent on its receiving environment; consideration must also be given to loads discharged, and to the physical (flow, hydrodynamics, deposition zones) and chemical characteristics of the specific receiving environment.

This study looked only at the toxicity of effluents without taking account of other possible impacts of municipal wastewater discharges on a body of water. The physical impacts of effluents and overflow water [10] on habitats, as well as the thermal, aesthetic and microbiological impacts were not assessed. The toxicity aspect of overflow water was not addressed, either.

Lastly, due to the low sampling rate, we were unable to process the results statistically or to characterize the recognized variability of municipal wastewaters.

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[10] The term overflow, in this context, means the volumes of excess water released untreated during episodes of heavy rainfall or spring snowmelt by municipal sewers.

EXPERIMENTAL APPROACH AND TOOLS FOR ASSESSING TOXIC POTENTIAL

The 15 municipal wastewater treatment plants selected are representative of the main treatment processes used in Quebec. They were characterized over a period stretching from 1996 to 1999, mostly over two seasons, winter and summer. During these sampling campaigns, all plants functioned normally and, overall, respected the discharge requirements (BOD_5, SM and TP) for which they were designed.

Sampling was carried out over three inconsecutive days for each season. In all, seven toxicity tests were performed and up to 26 conventional physico-chemical parameters, 19 metals and eight families of chlorinated and unchlorinated organic substances were analysed in the samples drawn. While the comparison of results for certain substances may be biased due to changes in the analytical profile over the course of the project, our experimental protocol produces a representative snapshot of the quality and potential toxicity of municipal wastewaters under normal plant operating conditions.

Toxic potential is assessed using a complementary, three-pronged approach: studying the amplitude of exceedances of water quality criteria for the chemicals analysed, studying the amplitude of exceedances of overall toxicity criteria for toxicity tests, and studying the compilation of the toxic prints, which are toxicity-measuring components of the PEEP Index. With this approach, the substances proper to municipal wastewater treatment plants can be identified, as can the toxicity of the effluents and the substances likely to be responsible. The importance of treatment-process type, effect of industrial-source loading, presence of a chemical dephosphatization process or effectiveness of treatment by season of the year can also be determined.

RESULTS OF PHYSICO-CHEMICAL ANALYSES AND TOXIC POTENTIAL BASED ON THE AMPLITUDE OF EXCEEDANCES OF WATER-QUALITY CRITERIA FOR SUBSTANCES ANALYSED

The variable quality of municipal effluents was recognized upon examining the analytical results. The toxic responses and measured concentrations of several substances differed significantly from one sampling day to the next. Seasonal variations were also observed for some substances, including those that depend upon biological activity during wastewater treatment, such as ammonia nitrogen and hydrogen sulfide, or where their use is seasonal, like the chlorides used in road de-icing agents.

The substances most frequently detected in samples drawn at the 15 plants are shown in Table 5.1. Since they were detected in more than 85% of samples analysed, the results suggest that these substances are likely to be found in the wastewaters of a number of plants in Quebec.

Although these substances are practically ubiquitous in the wastewaters of all 15 plants, they are not necessarily found in effluent at concentrations deemed toxic or harmful. Many did not exceed water quality criteria (sulfates, barium, boron, and herbicides) or showed a few specific low-range exceedances (chlorides, fluorides, iron, and PAHs).

TABLE 5.1: SUBSTANCES DETECTED IN MORE THAN 85% OF SAMPLES ANALYSED

Nutrients	**Major ions**	**Metals**	**Organic substances**
Ammonia nitrogen Nitrites and nitrates Phosphorus	Chlorides Fluorides Sulfates	Aluminum Arsenic Barium Boron Chromium Copper Iron Mercury (1)	PCBs Chlorinated dioxins and furans Herbicides (2) PAHs Anionic surfactants

(1): Frequency exceeds 85% in samples drawn in 1998–99 due solely to the use of a method with a better detection limit.

(2): Pesticides (herbicides and insecticides) were analysed in 42 samples drawn from two plants alone. Only the herbicides 2,4-D and mecoprop were detected in more than 85% of samples.

Of those pesticides used in urban applications, seven were detected in effluents of the two treatment plants where these analyses were performed. These were herbicides 2,4-D, mecoprop and dicamba, all of which are contained in commercial lawn treatment mixtures, as well as the insecticides diazinon, carbaryl, malathion and chlorpyrifos. Other pesticides applied on field crops were also detected: in municipal effluents; their presence is probably attributable to atmospheric transport from the farmbelts surrounding urban areas. In summer, concentrations of pesticides, and most especially herbicides, appear to swell during rainfall events due to urban runoff. These results have been corroborated by other studies conducted in Ontario and the U.S.

An examination of the amplitude of exceedances of the quality criteria for the protection of aquatic life show that there are frequent exceedances for certain substances, with some attaining high amplitudes (> 10). This is true for ammonia nitrogen, phosphorus, hydrogen sulfide, aluminum, silver, chromium, copper, two insecticides (diazinon and chlorpyrifos) and, most especially, surfactants. Indeed, wherever nonionic and anionic surfactants were detected, they exceeded the water quality criteria, and the exceedances are substantial in the majority of cases. The presence of these substances at such concentrations suggests that municipal wastewater presents a toxic potential that is harmful to aquatic life in the long term, particularly in watercourses with only a moderate assimilative capacity.

Other substances known to be toxic and highly bioaccumulable appear to be ubiquitous, and were detected at significant concentrations relative to the quality criteria for the prevention of contamination of aquatic organisms. This is the case for PCBs and chlorinated dioxins and furans, and, to a lesser extent, mercury. These substances can contaminate the flesh or tissue of fish, molluscs and crustaceans, making them unfit for unrestricted consumption. These substances can be even more harmful to fish-eating land animals, as the quantity of fish they consume is greater than that consumed by humans and because they eat the entire organism, including those tissues where bioaccumulation is greater than in flesh.

The sources of these bioaccumulable substances in municipal wastewaters, especially PCBs and chlorinated dioxins and furans, are many and complex. Other than industrial discharges, these substances may come from relatively distant atmospheric sources and contaminate urban runoff waters as well as the aquatic receiving environments from which municipalities draw their water supply. Only mass balance studies of the municipal network would enable us to determine the inputs of various sources being channelled to municipal treatment plants.

TOXIC POTENTIAL FOR AQUATIC LIFE BASED ON TOXICITY TESTS OF THE MENV APPROACH FOR THE PROTECTION OF THE AQUATIC ENVIRONMENT

With acute toxicity tests, there were few exceedances of the overall toxicity criteria of one acute toxic unit (TUa) and they were of low amplitude, in the majority of cases. More than half of treatment plants (53%) had no result above 1 TUa. Twenty-two percent of samples were toxic to rainbow trout, with 11% being toxic to *Daphnia magna*. For purposes of comparison, a similar study in Ontario in 1992 shows corresponding percentages of 56% and 27%, respectively. These differences mainly have to do with the fact that, unlike many plants in Ontario, Quebec treatment plants use no chlorine treatment to disinfect their wastewater.

Ammonia nitrogen, at concentrations greater than 10 mg/L, appears to be mainly responsible for the acute toxicity measured. Surfactants may be the second most generalized contaminant while nitrites are suspected at one plant. The presence of pesticides in summer could be another cause of toxicity.

Chronic toxicity effects were measured in the undiluted effluents of almost all the plants, but, overall, exceedances of the overall toxicity criteria of 1 TUc are of low amplitude (responses of 1 to 2 TUc), which suggests that there will be few or no effects on the environment once the effluent mixes into the watercourse. All seasons combined, a little over one-third of the plants obtained results above 10 TUc, thereby making these effluents potentially harmful to aquatic life in watercourses with a weak assimilative capacity. One plant obtained results above 30 TUc.

Almost all the samples stimulated algal growth. This positive response in the algae *Selenastrum capricornutum* was not quantified in terms of toxic units, but it does nonetheless indicate the potential harm of the eutrophication process for aquatic life.

Those substances most likely to have contributed to the chronic toxicity measured are ammonia nitrogen, a few metals (mainly copper, chromium and aluminum), surfactants and, probably, certain pesticides including diazinon and chlorpyrifos. In some specific cases, nitrites, cyanides or hydrogen sulfide might have played a role. In all these cases, though, the expression of chronic effects coincides with the simultaneous presence of several substances at concentrations greater than safe limits.

Toxicity identification evaluations (TIEs) are the only way to determine, on a case-by-case basis, which substances are responsible for chronic and acute toxicity.

TOXIC POTENTIAL BASED ON TOXIC PRINTS OF THE PEEP INDEX

No threshold or criterion has yet been established to indicate a worrisome or harmful level relative to toxic prints of the Potential Ecotoxic Effects Probe (PEEP) Index. Although it is impossible to reach any conclusions about the toxic potential of municipal effluents in terms of toxic prints, this tool does allow us to better define wastewater quality, and has proven useful to interpreting the results.

The genotoxicity test was particularly sensitive to municipal wastewater, with toxic responses observed at more than two out of three plants. These results suggest that undiluted municipal effluents may contain substances at concentrations capable of altering bacterial DNA.

INFLUENCE OF SEASON, TREATMENT TYPE, INDUSTRIAL LOADING AND DEPHOSPHATIZATION ON TOXIC POTENTIAL

The results of the study indicate that the toxic potential of municipal effluents in Quebec varies from one plant to another. Effluents of aerated lagoons that were characterized during winter operating conditions are often acutely toxic for rainbow trout because of the elevated concentrations of ammonia nitrogen. Treatment processes that don’t include aeration equipment (unaerated lagoons and physico-chemical processes) may present a higher toxic potential at certain times of the year (during spring emptying for unaerated lagoons and in summer for physico-chemical treatment) due to the biological production of hydrogen sulfide under anaerobic conditions.

Plant effluents that are subject to major industrial loading were, overall, more toxic than those of plants with low industrial inputs. Our results show that industrial inputs appear to be a determining factor in the toxic potential of municipal effluents, although effluents may be toxic where there is little or no industrial input.

In addition to removing phosphorus, chemical dephosphatization had a beneficial effect on the removal of metals. In contrast, though, it does seem to lead to an increase in the concentration of metal serving as a coagulant. Although chemical dephosphatization also appears to have a beneficial effect on the toxic potential of municipal effluents, it is impossible to say so with any certainty, since the toxicity test results obtained in this study are much more influenced overall by treatment type, season of the year and industrial load than by dephosphatization.

CONCLUSION ON ANALYTICAL METHODS AND SAMPLES USED

The use of the best analytical techniques made it possible to lower detection limits and thus obtain a better snapshot of the quality of municipal wastewater, in addition to producing results that are comparable to defined safety limits (water quality criteria) for several substances and metals. Our use of these best techniques also allowed us to point up the presence of substances rarely quantified in this type of effluent (e.g. PCBs and chlorinated dioxins and furans).

Unlike studies conducted elsewhere, this study targeted pesticides that are likely to be found in the urban environment. This proved useful to the task of selecting the appropriate analytical methods to point up the presence of these pesticides in municipal wastewaters.

In the case of municipal effluents, scanning analytical methods for semi-volatile and volatile organic substances were found to be lacking in specificity and resolution. It might be better to target a small number of substances, e.g. the 20-odd VOCs used in laboratory accreditation processes.

The present study confirmed once again the importance of using a number of different toxicity tests to adequately assess effluent toxicity because of the variability of contaminants present in samples, which can a reaction in a given species but not in an other.

GENERAL CONCLUSIONS

The municipal cleanup initiatives begun in Quebec in 1979 have had positive effects on the quality of watercourses. Treatment plants built in the context of these cleanup programs were specifically designed to reduce the main contaminants contained in municipal wastewaters (i.e. conventional parameters: BOD_5, SM, phosphorus and fecal coliforms). Although these plants can attain a certain yield for the removal of other contaminants potentially contained in municipal wastewaters, they cannot eliminate them completely.

This study characterized the effluents of 15 different municipal treatment plants. The toxicity test results show that although the treated wastewaters of almost all the plants studied are toxic, they expressed, with only a few exceptions, low amplitude toxicity to the test species.

The main substance responsible for the toxicity measured appears to be ammonia nitrogen, at concentrations above 10 mg/L. During winter, when the nitrification process is reduced, concentrations of ammonia nitrogen are higher, especially in aerated lagoons. Anionic surfactants are next, followed, to a lesser extent, by nonionic surfactants. Surfactants are organic molecules that enter into the composition of hundreds of products used, among other things, as cleaning agents for both domestic and industrial purposes. Finally, other substances, like certain pesticides and metals, could also be responsible for the toxicity measured.

This study points up the ubiquitousness of a number of substances in the municipal wastewaters of 15 treatment plants, including certain organic substances rarely quantified in other studies and found at concentrations that could impair use of the water. These are, namely, surfactants, PCBs and chlorinated dioxins and furans. Certain pesticides may be added to the list in summer during rainfall events. However, to assess the actual impact of these substances, discharge loads must be considered and, in each case, sound information held on the biophysical and chemical characteristics of the respective receiving environments.

The significance of industrial inputs to treatment plants appears to be a determining factor in the toxic potential of municipal effluents, even though effluents may be toxic where there is little or no industrial input.

RECOMMENDATIONS

Those municipal treatment plants that do respect their discharge requirements may have a difficult time further reducing the toxicity of their effluents. Adding equipment to this end may be costly and relatively ineffective given the significance of the discharges and the dilution of contaminants. *The focus would be better directed toward at-source reduction* where intervention may be much cheaper and more effective, particularly with regard to industrial-source contaminants. In this way, public-education initiatives should also be envisaged to reduce the use of certain contaminants that are widely employed for domestic purposes, especially pesticides and surfactants.

Nonetheless, *other solutions must be found to problems inherent to certain treatment types in order to reduce effluent toxicity*. This is the case, for example, for aerated lagoons having concentrations of ammonia nitrogen that exceed 10 mg/L in winter. Although the selection criteria in this study rejected plants with elevated concentrations of ammonia nitrogen, we were nonetheless able to establish a link between this parameter and effluent toxicity. Several Quebec treatment plants show elevated concentrations of ammonia nitrogen. Based on all the data collected since 1995, 16 municipal treatment plants have obtained at least one result above 50 mg/L of ammonia nitrogen, and 27 plants (or 5% of plants in Quebec) obtained a general average greater than 10 mg/L. The highest concentrations are generally due to the presence of industrial plants, especially the agri-food sector, for which at-source reductions remain the best solution.

Just as in previous studies, the present study demonstrates that municipal treatment plants can be a source of contaminants at levels that are sometimes toxic or harmful to use of the water. We are not in a position to make any determinations on the impact of these effluents on their respective receiving environments. To do so, *the sampling frequency of a complete characterization of the effluents must be higher in order to consider variability, and the results should be analysed against environmental discharge objectives (EDO)*. EDOs are based on the quality criteria applicable to different uses of the water, and they take account of specifics of the effluent (especially flow rate) and characteristics of receiving environments.

The establishment of EDOs for the substances present in effluents and for overall toxicity, as measured by toxicity tests, is proving to be essential to determining the problems apprehended in a specific environment and to identifying the substances responsible, on a case-by-case basis. However, *municipal effluents are not the sole source of contamination of receiving environments. Inputs should be assessed as a function of other sources* such as sewer overflows of untreated wastewater, urban runoff, agricultural pollution, industries not connected up to municipal sewer systems, atmospheric deposition, upwellings of water on contaminated land, and sanitary landfill sites.

Lastly, *basic data on the water quality of receiving environments is also vital to this process.* Where it exists at all, real data on the majority of toxic substances in most water bodies is incomplete. *The MENV should continue to seek more such information and target problem substances on a priority basis.*

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