NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

INTRODUCTION TO THE YAMASKA RIVER PROJECT

R.J. Maguire

NWRI CONTRIBUTION 91-57

RRB 91-18

INTRODUCTION TO THE YAMASKA RIVER PROJECT

by

R.J. Maguire

Rivers Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario L7R 4A6

April 1991
NWRI Contribution 91-57

MANAGEMENT PERSPECTIVE

The Yamaska River, bordering the Eastern Townships of Quebec southeast of Montreal, is one of the most extensively studied rivers in Quebec, and its water quality has been a source of concern for some time. This report is the background report for the National Water Research Institute Yamaska River project, which is concerned with the occurrence, persistence, fate and effects of dyes, other industrial chemicals and pesticides. This project focusses on dyes and pesticides in particular. Canada's textile industry is concentrated in the Eastern Townships of Quebec, but there is no information on dyes in the Canadian environment. In addition, over one quarter of all pesticides used for agricultural purposes in Quebec are used in the relatively small Yamaska River basin.

This report reviews previously published information on the contamination of water in the Yamaska River basin by metals, PCBs and pesticides. In addition this report provides background information for the Yamaska River project and documents (i) coliform and volatile halocarbon concentrations, and (ii) Microtox toxicity data for various parts of the basin in the period 1985 - 1987 which spanned the time before construction of municipal wastewater treatment plants through the time that such plants were constructed in the major cities and towns in the basin. Based on past and present information the area downstream of Granby is the

most heavily contaminated and degraded part of the river, and there is substantial contamination from Waterloo, Saint-Hyacinthe, Cowansville, Farnham and Acton Vale.

PERSPECTIVE DE LA DIRECTION

La rivière Yamaska, qui arrose la région de l'Estrie située au sud-est de Montréal, est l'une des rivières les plus étudiées du Québec, et la qualité de ses eaux a été une source de préoccupation pendant un certain temps. Le présent rapport constitue le rapport préliminaire du projet de la rivière Yamaska de l'Institut national de recherche sur les eaux, qui porte sur la présence, la persistance, le devenir et les effets des colorants, d'autres produits chimiques industriels et des pesticides. Ce projet met principalement l'accent sur les colorants et les pesticides. L'industrie textile canadienne est concentrée en Estrie, mais nous ne disposons d'aucune information sur les colorants dans l'environnement au Canada. En outre, plus du quart de tous les pesticides utilisés en agriculture au Québec le sont dans le bassin relativement petit de la rivière Yamaska.

Le présent rapport étudie les informations publiées antérieurement sur la contamination de l'eau du bassin de la rivière Yamaska par des métaux, des BPC et des pesticides. Le rapport contient également des informations de base sur le projet de la rivière Yamaska et documente i) les teneurs en coliformes et en hydrocarbures halogénés volatiles, et ii) les données sur la toxicité à l'aide du système Microtox pour différentes parties du bassin, entre les années 1985 et 1987 qui couvre la période précédant la construction des usines d'épurations des eaux usées municipales jusqu'à leur construction dans les principales villes du bassin. D'après les informations antérieures et présentes, la région située en aval de Granby est la partie la plus fortement contaminée et détériorée de la rivière, et on observe une contamination importante au niveau de Waterloo, Saint-Hyacinthe, Cowansville, Farnham et Acton Vale.

ABSTRACT

The Yamaska River, bordering the Eastern Townships of Quebec southeast of Montreal, is one of the most extensively studied rivers in Quebec, and its water quality has been a source of concern for some time. This report is the background report for the National Water Research Institute Yamaska River project, which is concerned with the occurrence, persistence, fate and effects of dyes, other industrial chemicals and pesticides. This report reviews previously published information on the contamination of water in the Yamaska River basin by metals, PCBs and pesticides. In addition this report provides background information for the Yamaska River project and documents (i) coliform and volatile halocarbon concentrations, and (ii) Microtox toxicity data for various parts of the basin in the period 1985 - 1987 which spanned the time before construction of municipal wastewater treatment plants through the time that such plants were constructed in the major cities and towns in the basin. This study indicated (i) substantial contamination of the Yamaska River and its tributaries by coliform organisms (exceeding federal guidelines for recreational contact), (ii) generally low toxicity of river waters in the Microtox toxicity test (with the exception of Granby in 1985), and (iii) contamination downstream of municipalities such as Granby, Saint-Hyacinthe, Cowansville and Farnham by volatile halocarbons associated with water chlorination and by volatile halocarbons of industrial origin such as dichloromethane,

tetrachloroethylene and trichloroethylene.

RÉSUMÉ

La rivière Yamaska, qui arrose la région de l'Estrie située au sud-est de Montréal, est l'une des rivières la plus étudiées du Québec, et la qualité de ses eaux a été une source de préoccupation pendant un certain temps. Le présent rapport constitue le rapport préliminaire du projet de la rivière Yamaska de l'Institut national de recherche sur les eaux, qui porte sur la présence, la persistance, le devenir et les effets des colorants, d'autres produits chimiques industriels et des pesticides. Le présent rapport étudie les informations publiées antérieurement sur la contamination de l'eau du bassin de la rivière Yamaska par des métaux, des BPC et des pesticides. Le rapport contient également des informations de base sur le projet de la rivière Yamaska et documente i) les teneurs en coliformes et en hydrocarbures halogénés volatiles, et ii) les données sur la toxicité à l'aide du système Microtox pour différentes parties du bassin, entre les années 1985 et 1987 qui couvrent la période précédant la construction des usines d'épurations des eaux usées municipales jusqu'à leur construction dans les principales villes du bassin. Cette étude a révélé i) une contamination importante de la rivière Yamaska et de ses affluents par des coliformes (teneur supérieure aux normes fédérales concernant les eaux utilisées à des fins récréatives), ii) une toxicité généralement faible de l'eau de la rivière à l'aide de l'épreuve de toxicité Microtox (à l'exception de Granby en 1985), et iii) une contamination en aval des municipalités comme Granby, Saint-Hyacinthe, Cowansville et Farnham par des hydrocarbures halogénés volatiles associés à la chloration de l'eau et par des hydrocarbures volatiles d'origine industrielle comme le dichlorométhane, le tétrachloroéthylène et le trichloréthylène.

INTRODUCTION

The Yamaska River basin in Quebec lies between latitudes 45° 05' and 46° 05' N, and longitudes 72° 12' and 73° 07' W. It is bordered on the east by the Saint-Francois River basin, on the south and west by the Richelieu River basin, and on the north by the St. Lawrence River (cf. Fig. 1).

The watershed covers 4843 km^2 and comprises two distinct areas: a) an upper region which lies in the Appalachian Mountain range and is drained by the Noire River (cf. Fig. 2) and by the tributaries of the Yamaska River; and b) a lower region lying in the St. Lawrence River lowlands. The Yamaska River flows into the St. Lawrence River at lac Saint-Pierre. In the upper regions of the basin Ordovician, Silurian and Devonian sedimentary and metamorphic rocks are prevalent (e.g., schists, sandstone and quartzite), as are glacial and fluvioglacial deposits (> 200 m altitude) and marine calcareous clays (< 200 m). In the St. Lawrence River lowlands Ordovician and Cambrian sedimentary rocks such as shales, calcareous shales and sandstone are found covered by a thick layer (up to 70 m) of unconsolidated deposits of glacial tills and marine clays (1,2). The mean annual flow of the Yamaska River was 125 m^3/s in 1975 (2) and 78 m^3/s in 1978 (3). The Richelieu, Yamaska and Saint-Francois Rivers add about 15% to the flow of the St. Lawrence River, which is about 8800 m^3/s at the entrance to lac Saint-Pierre (3).

The source of the Yamaska (Centre) is lac Brome (cf. Fig 2). At Adamsville the Yamaska (Centre) meets the Yamaska North which comes from lac Waterloo. Then at Rainville the Yamaska meets the Yamaska South-East which comes from Mont Sutton and Cowansville. The principal tributary of the Yamaska River is the Noire River, whose basin accounts for one third of the area of the entire Yamaska River basin. The entire length of the Yamaska River is 180 km, and the height above sea level in the basin varies from 4 m to 900 m (4). Other physical data are given in Table 1. Hydrological, meteorological and other climatic data are available (5,6).

The population of the Yamaska River basin was 205,000 in 1966, and was estimated to be 377,000 by 2001 (7). The main cities are Granby and Saint-Hyacinthe (each with populations > 30,000), and the main towns are Farnham, Cowansville, Acton Vale, Waterloo and lac-Brome. Desmeules and Gelinas (4) have given a history of the colonization of the basin, with demographic data up to the 1970s. The Yamaska River basin is distinguished from that of the Saint-Francois River by the absence of mining activities, by its smaller drainage area, higher extent of deforestation, more intensive use of land for agricultural purposes, and higher population density (2). Agriculture is the main activity in the basin, but there is light industry, including textile mills (8). Contamination from textile mills and agriculture provided the impetus for the Yamaska River project, as discussed later.

The Yamaska River is one of the most extensively studied rivers in Quebec, and its water quality has been a source of concern for some time. In reviewing the information available on most aspects influencing water quantity and quality to 1971, Boisvert et. al (7) described parts of the river as "an open sewer". The same description was used fifteen years later (8). In 1971 only 2.8% of the population of the basin treated its wastewater. There were 156 untreated municipal effluents, and the majority of industries did not treat its effluent. In addition, farm waste discharge was uncontrolled. [In the 1970s the government of Quebec initiated measures to prevent the introduction of untreated farm wastes to the river, and in the 1980s it embarked on a massive program of construction of sewage treatment plants in various towns in the Yamaska River basin and elsewhere in the province (8).] Nutrient concentrations and their effects on aquatic life in the Yamaska River basin have been investigated extensively (1, 9-20).

Over the past fifteen years several surveys were made of the Yamaska River basin for heavy metals, PCBs and pesticides (16,17, 21-31). Details are given in the Appendix, and notable findings are discussed below.

(A) Metals

The most heavily contaminated area of the Yamaska River basin

is the Yamaska North from Waterloo to downstream of Granby. Significantly elevated levels of mercury, copper, chromium, cadmium, lead, nickel, zinc and arsenic have been detected in one or more "compartments" such as water, sediments, macrophytes, mussels and fish. The mercury content of some fish exceeded the Health and Welfare Canada human consumption guideline of 0.5 mg/kg. Electroplating operations in Waterloo and Granby are the probable sources of most of the metal contamination, but other industries may contribute, and elevated levels of lead are thought to be due to heavy vehicular traffic in this area relative to other parts of the basin. There was also metal contamination, but less so, downstream of Saint-Hyacinthe, and in other areas of the basin.

(B) PCBs

Although some fish caught in the basin in 1978 exceeded the Health and Welfare human consumption guideline for PCBs of 2 mg/kg, in general contamination appeared to be low, and certainly lower than other river basins in Quebec which are more heavily industrialized. The greatest contamination was in fish caught downstream of Saint-Hyacinthe, and at Saint-Pie on the Noire River.

(C) Pesticides

Pesticides are used heavily in the Yamaska River basin, as expected from the intensive agricultural activity. One quarter of

all pesticides sold for agricultural purposes in Quebec in 1982 were sold in the Yamaska River basin (32). Totals were 2,308,396 kg of active ingredient including oils for Quebec and 590,103 kg for the Yamaska River basin. [Totals were 1,701,091 kg of active ingredient excluding oils for Quebec and 447,125 kg for the Yamaska River basin.] Herbicides comprised 68% of all pesticides sold in Quebec. Table 2 shows the quantity of each class of pesticide sold (and presumably used) in 1982 in the Yamaska River basin. The triazine-triazole class was the most heavily used group of chemicals, and was used mainly on corn which is the major crop in the basin. Amide derivatives, carbamates, organophosphates and aryloxyacids were also used heavily.

Contamination of various "compartments" (e.g., sediment, aquatic plants, mussels, fish, etc.) of the Yamaska River and its tributaries by chlorinated pesticides is detectable but low. The same is generally true of organophosphate pesticides (30, 33), although diazinon has occasionally been detected above its water quality guideline of 0.08 μg/L for the protection of aquatic life (30). Carbamate pesticides were not found in river mouth water samples in the only survey in which they were sought (33).

The most common pesticide contaminant in water in the Yamaska River basin, and that observed at the highest concentration, has been atrazine (29-31, 33). It has occasionally been found at concentrations exceeding the water quality guideline of 2 μg/L for

the protection of aquatic life (30). Two studies have indicated that its concentration in water in the basin during the growing season reached a maximum in July (29, 31). Forrest and Caux (30) estimated an atrazine loading of 25 kg/day from the Yamaska River to the St. Lawrence river during the 1987-88 growing periods. The amide herbicide metolachlor, which has rarely been reported in Yamaska River water, may be detected more frequently in the future since it is rapidly growing in popularity after the Canadian ban on alachlor. For example, in Ontario in 1988 712,170 kg of metolachlor were used on corn, compared to 999,410 of atrazine (34). Metolachlor was the most heavily-used herbicide in all applications in Ontario in 1988, with 1,724,700 kg used. Atrazine use in all applications was 1,045,110 kg.

The Yamaska River Project

The National Water Research Institute Yamaska River project includes the following studies:

(1) an investigation of the environmental occurrence, persistence and fate of dyes

(2) an investigation of the suitability of various large-volume extraction methods and techniques (e.g., sequential extraction of filtered or centrifuged water at low pH and high pH) in the

determination of neutral and basic chemicals

(3) an investigation of the suitability of fish bile as an indicator of ecosystem contamination by relatively water-soluble pesticides

(4) the correlation of benthic community structure at various locations in the basin with inputs of pesticides, dyes, other organic contaminants and metals

(5) an investigation of the suitability of mussels as indicators of contamination by pesticides in the basin

(6) the use of a biochemical indicator (i.e., changes in concentrations of free amino acids) in mussels to detect stress from contaminants in aquatic ecosystems

(7) a study of the utility of chironomid deformities in the assessment of water quality

Some of these investigations are complete (35-37), and others are nearing completion.

The main thrust of the Yamaska River project was the investigation of the occurrence, persistence and fate of dyes. Dyes and pigments are high volume chemicals which may enter aquatic

environments in significant quantities. The distinction between dyes and pigments is largely made on the basis of solubility. Pigments have extremely low solubilities in water, and are not very soluble in organic solvents either, generally being applied in the solid state. Dyes are generally more soluble either in water or organic solvents. Global production of dyes in 1978 was estimated to be 6.4×10^8 kg of active ingredient (38). About 10^8 kg were produced in the United States in 1986 (39). It has been estimated that 90% of dyes applied end up in fabrics, with the remaining 10% discharged to waste streams (40). In 1982 about 6.5×10^6 kg of dyes and 2.5×10^6 of pigments were imported into Canada (41). Most dyes were imported into Quebec and most pigments were imported into Ontario.

Interest in the environmental behaviour of dyes arose largely from concerns about carcinogenicity. Some dyes are carcinogens (42) and others after transformation or degradation yield compounds such as aromatic amines which may be carcinogenic or otherwise toxic (e.g., (43)). Very little is known of the environmental occurrence, persistence and fate of dyes, largely because of difficulties in their determination at trace levels in environmental media. There is no environmental information on dyes in Canada. There is a good deal of interest in determining the occurrence, persistence and toxicity of dyes in rivers in the Eastern Townships of Quebec because much of Canada's textile industry is concentrated in the Eastern Townships, and there are

anecdotal accounts of widespread contamination of rivers in the area by dyes. In 1985 there were 12 textile or carpet mills and associated dyeing operations in the Yamaska River basin in Granby, Farnham, Saint-Hyacinthe, Cowansville and Acton Vale (44). Sample collection for the Yamaska River dye study was in the period 1985-87, spanning the time before construction of municipal wastewater treatment plants through the time that such plants were constructed in the major cities and towns in the basin.

The purpose of this report is (i) to provide background information on the Yamaska River basin, (ii) to describe the sampling sites chosen, and (iii) to document certain basic water quality characteristics, volatile chemical concentrations, Microtox toxicity results and coliform concentrations for each of the sampling locations in the period 1985-1987. Results from the main studies described above will be published separately.

EXPERIMENTAL SECTION

Figure 2 shows the sampling locations for different aspects of the Yamaska River project. These were chosen based on the experience of Environnement Quebec. The locations are described in Table 3. The dye and pesticide studies concentrated on sites 1-34 while sites 35-63 were used solely in some aspects of the indicator species and biochemical stress studies. Table 4 describes some

water quality characteristics at each dye/pesticide site for sampling periods in 1985-87.

At each sampling site the following kinds of samples were taken for chemical analysis:

- surface microlayer (unfiltered)
- subsurface water (200 L of centrifuged water in 1985-86; 20-40 L of filtered water in 1986-87) extracted under acidic and basic conditions
- suspended particulate material from either centrifuged or filtered water
- sediment (top two cm)
- small subsurface water samples for volatile halocarbons (45), coliforms (46) and Microtox analyses (47)

RESULTS AND DISCUSSION

(A) Coliform organisms

The Environment Canada water quality guideline for recreational contact is ≤ 200 fecal coliforms/100 mL (48) and the Health and Welfare Canada guidelines for drinking water are 0/100 mL for fecal coliforms and ≤ 10/100 mL for total coliforms (49). Table 5 shows concentrations of fecal coliforms and total coliforms

at various locations in the Yamaska River basin in the period 1985 - 1987. The 1986 and 1987 values are more reliable than the 1985 values since the 1985 samples were not preserved with thiosulfate. The results should be viewed with caution since it is generally felt that samples older than 48 hr may not be reliable, and none of the Yamaska River samples were analyzed until 3-5 days after collection.

The results indicate substantial contamination of the Yamaska River and its tributaries by coliform organisms, and even some minor contamination of drinking water supplies. In 1985, three Granby tap water samples from the same source taken over three consecutive days had 0, 0 and 28 fecal coliforms per 100 mL. In 1986, one tap water sample from the same source had 10 fecal coliforms per 100 mL and 220 total coliforms per 100 mL. In 1987, three tap water samples from the same source taken over three consecutive days had no fecal or total coliforms per 100 mL.

In 1985, federal guidelines for recreational contact with fecal coliforms were exceeded at sites 4, 5, 6, 7, 8, 9, 10, 12a and 15. The guidelines were not exceeded at sites 2, 3 and 11. Sites 5 and 6 had extremely high fecal coliform concentrations.

In 1986, federal guidelines for recreational contact with fecal coliforms were exceeded at all sites sampled except 15 and 30. Very high fecal coliform concentrations were found at sites 5,

7, 9, 11, 12a and 12b.

In 1987, federal guidelines for recreational contact were exceeded at sites 5, 12b, 32 and 34. Site 5 had an extremely high concentration of fecal coliforms. The guidelines were not exceeded at sites 13E, 13W, 30, 31 and 33.

(B) Microtox toxicity tests

Microtox toxicity test results for some locations in the Yamaska River basin in 1985 and 1986 are shown in Table 6. With reference to the scale relating maximum Γ values to toxicity to Photobacterium phosphoreum in Table 7, it is seen that in 1985 site 5 (downstream of Granby) was extremely toxic, sites 9 and 11 (downstream of Acton Vale and the confluence of the Yamaska and Noire Rivers, respectively) were moderately toxic, and the other sites were only slightly toxic. In 1986, no site was more than slightly toxic.

(C) Volatile halocarbon analyses

Water samples collected in 1985 - 1987 were analyzed for the 24 volatile chemicals shown in Tables 8 - 10. With the exception of carbon disulfide (which was not found), the chemicals were halogenated hydrocarbons associated with industrial processes and

the chlorination of drinking water and wastewater. In all three years the highest concentrations of halocarbons were found in drinking water and in water downstream of major cities and towns. Concentrations were typical of those that have been observed in the Great Lakes basin (50-53), and were orders of magnitude lower than those which are acutely toxic to aquatic organisms (51). Little contamination was evident in headwater areas of the Yamaska River, or in exclusively agricultural tributaries such as the a la Barbue, Runnets, Saint-Nazaire, Chibouet and Salvail Rivers.

In drinking water from Granby and Saint-Hyacinthe (sites 16 and 17, respectively) there were relatively high concentrations of chloroform, bromodichloromethane and dibromochloromethane, whose presence is usually attributed to chlorination for the purpose of disinfection (e.g., 53). It has been observed that the ratio of the concentrations of chloroform to bromodichloromethane in chlorinated water is about 4 (53). A larger ratio may indicate the presence of chloroform from an industrial source. Table 11 shows the ratios of concentrations of chloroform to bromodichloromethane for two tap water locations in Granby and Saint-Hyacinthe at five sampling dates in 1985 - 1987. The ratio occasionally, but not consistently, exceeded a value of 4. There was thus no clear evidence of an industrial source of chloroform in the drinking water of the two cities. However, elevated concentrations of dichloromethane in the drinking water samples were noted. Dichloromethane is used in paint, paint removers, aerosols and as

a general solvent. There was also minor, and inconsistent, contamination by some other volatile halocarbons. The extent of contamination of drinking water was generally the same in 1985, 1986 and 1987 except for samples collected in July 1987 in which there were markedly lower concentrations of total halocarbons.

Natural water downstream of municipal and industrial sources in the Yamaska River basin was more heavily contaminated with volatile halocarbons than upstream locations, as expected. In June 1985 the water downstream of Granby (sites 5 and 6), Cowansville (site 4) and Saint-Hyacinthe (site 12a) contained the highest concentrations of volatile halocarbons of all sites in the Yamaska River basin. In addition to chloroform and other halocarbons associated with the chlorination of water, the water downstream of Granby and Cowansville contained high concentrations of tetrachloroethylene (dry cleaning solvent, solder flux remover, chemical intermediate) and trichloroethylene (industrial degreaser, polyvinyl chloride polymerization modifier, heat transfer medium, general solvent). Very little contamination was noted at the mouth of the Yamaska River (site 13a).

In June 1986 the most heavily contaminated sites were downstream of Farnham (site 7), Cowansville (site 4) and Granby (site 5). In each location there was substantial contamination by dichloromethane. In addition to products of water chlorination, there were elevated concentrations of tetrachloroethylene and

trichloroethylene downstream of Cowansville, and tetrachloroethylene downstream of Granby. Dichloromethane was the predominant volatile halocarbon at the mouth of the Yamaska River (sites 13E and 13W), but its concentration had declined by about an order of magnitude from Saint-Hyacinthe.

In 1987 the field work was only concerned with Granby, Saint-Hyacinthe, the Yamaska River mouth and the five agricultural tributaries, the a la Barbue, Runnets, Saint-Nazaire, Chibouet and Salvail Rivers. Contamination of these tributaries was generally low in June, July and September. Water downstream of Granby and Saint-Hyacinthe contained elevated concentrations of dichloromethane, tetrachloroethylene and trichloroethylene, in addition to products of water chlorination. Water at the mouth of the river was less contaminated than water downstream of Saint-Hyacinthe, except in July. This may indicate another significant source of chlorinated halocarbons to the river downstream of Saint-Hyacinthe. In general, contamination of river water by volatile halocarbons was less in 1987 than in 1985 or 1986.

This background report has reviewed the state of contamination of the Yamaska River basin, has demonstrated contamination by coliforms and some volatile halocarbons, and has demonstrated substantial toxicity to bacteria by chemicals in some locations in the river. Further reports will focus on contamination by dyes, PCBs and pesticides.

ACKNOWLEDGEMENTS

The late R.J. Tkacz provided invaluable support during the field sampling. I thank G.A. Bengert, S.P. Batchelor, Y. Desjardins, B.H. Moore, L.J. Lomas and H.E. Greencorn for help with the sampling, A.A. Jurkovic for the coliform analyses, V.S. Palabrica for the Microtox analyses and M.E. Comba for help with the volatile chemical analyses. I also thank M. Sinotte of Environnement Quebec for information and advice on sampling locations.

REFERENCES

(1) Campbell, P.G.C., Couture, P., Talbot, L. and Caille, A. (1976). Nutrient dynamics in running waters: production, assimilation and mineralization of organic matter. Chapter 43 in Environmental Biogeochemistry, Vol. 2. Metals Transfer and Ecological Mass Balances. J.O. Nriagu, ed., Ann Arbor Science Publishers Inc., Ann Arbor, MI 48106, U.S.A., pp. 681-703.

(2) Tessier, A., Campbell, P.G.C. and Bisson, M. (1980). Trace metal speciation in the Yamaska and St. Francois Rivers (Quebec). Can. J. Earth Sci. 17, 90-105.

(3) Germain, A. and Janson, M. (1984). Qualite des eaux du fleuve Saint-Laurent de Cornwall a Quebec (1977 - 1981). Environment Canada, Inland Waters Directorate Report, Longueuil, Quebec, 227+ pp.

(4) Desmeules, J. and Gelinas, J.P. (1977). Caracteristiques physiques et demographiques - bassin versant de la Yamaska. Rapport E.B.-2, Ministeres des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 87+ pp.

(5) Ministere des Richesses Naturelles du Quebec (1977). Eau de surface - bassin versant de la Yamaska. Rapport E.B.-1, Direction Generale des Eaux, Quebec, Quebec, 137+ pp.

(6) Bergeron, G., Ferland, M., Gariepy, J., Jacques, G. and Lamb, P. (1979). Bassin versant de la Yamaska - hydrometeorologie. Rapport E.B.-8 (MP-56), Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 177+ pp.

(7) Boisvert, A., Brosseau, R., Courtemanche, A., Demers, J., Julien, S., Louchard, L., Pilon, U. and Tremblay, G.-A. (1971). Utilisation des eaux du bassin versant de la Yamaska. Office de planification et de developpement du Quebec, Quebec, Quebec, 203+ pp.

(8) Ministere de l'Environnement du Quebec (1985). La Yamaska - Une Riviere a Rajeunir. Ste-Foy, Quebec, ISBN 2-550-11711-5, 38+ pp.

(9) Caille, A., Campbell, P.G.C., Cluis, D., Couture, P. and Talbot, L. (1975). Impact de l'agriculture sur la qualite des eaux de surface du bassin de la riviere Yamaska. INRS-Eau Rapport Scientifique 50, Universite du Quebec, Ste-Foy, Quebec G1V 4C7.

(10) Cluis, D. (1975 or later). Les differentes sources d'apports en elements nutritifs du bassin de la riviere Yamaska. Conference No. 14, 25 pp.

(11) Campbell, P.G.C., Couture, P., Lachance, M. and Talbot, L. (1976). Etude integree de la qualite des eaux des bassins versants des rivieres Saint-Francois et Yamaska. Vol. 2: secteurs des substances nutritives. Rapport Q.E.-17, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 127+ pp.

(12) Lachance, M. and Sasseville, J.L. (1976). Etude integree de la qualite des eaux des bassins des rivieres Saint-Francois et Yamaska. Vol. 4: secteur des eaux atmospheriques. Rapport Q.E.-19, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 50+ pp.

(13) Gauthier, J.-P., Alain, J., Gentes, P., LeRouzes, M. and Mathieu, P. (1978). Etude limnologique - lac Waterloo. Rapport Q.E.-32, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 8+ pp.

(14) Gauthier, J.-P., Alain, J., Gentes, P., LeRouzes, M. and Mathieu, P. (1978). Etude limnologique - lac Roxton. Rapport Q.E.-31, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 8+ pp.

(15) Gauthier, J.-P., Alain, J., Gentes, P., LeRouzes, M. and Mathieu, P. (1978). Etude limnologique - lac Brome. Rapport Q.E.-33, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 7+ pp.

(16) Auger, P., Belanger, B., Durocher, H., Goulet, M., Magny, Y. and Provencher, M. (1979). Synthese des etudes de la qualite du milieu aquatique de la riviere Yamaska. Rapport E.B.-9, Ministere des Richesses Naturelles du Quebec, Direction Generale des Eaux, Quebec, Quebec, 75+ pp.

(17) Belanger, B. (1980). Rapport annuel (1979) de la qualite de l'eau des lacs et des rivieres du bassin Yamaska. Rapport 80-16, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, Quebec, Quebec, 59+ pp.

(18) Campbell, P.G.C., Cluis, D. and Couture, P. (1982). Transformation de la qualite d'une meme eau de riviere lors de son sejour dans deux reservoirs differents: (a) le lac Boivin et (b) la reserve de Granby, Quebec, Canada. Can. Water Resour. J. **7**, 127-150.

(19) Bobee, B., Lachance, M. and Cazaillet, O. (1983). Caracterisation globale des donnees de parametres geochimiques du bassin de la riviere Yamaska. Eau du Quebec **16**, 39-45.

(20) Bobee, B., Lachance, M. and Cazaillet, O. (1983). Analyse multivariee des donnees de parametres geochimiques de la riviere Yamaska. Eau du Quebec **16**, 56-69.

(21) Lapointe, R. and Sasseville, J.-L. (1976). Indices de danger environnemental sur les bassins des rivieres Yamaska et Saint-Francois. Rapport Scientifique 65, INRS-Eau, Universite du Quebec, Ste-Foy, Quebec G1V 4C7, 57+ pp.

(22) Harvey, G. (1979). Les metaux lourds et les composes organochlores dans la chair des poissons du bassin versant de la Yamaska. Rapport Technique 06-30, Ministere du Loisir, de la Chasse et de la Peche du Quebec, Service de l'Amenagement et de l'Exploitation de la Faune, Montreal, Quebec, 89+ pp.

(23) Goulet, M. and Laliberte, D. (1982). BPC: contamination du milieu aquatique au Quebec meridional. Rapport Q.E.-53, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, Ste-Foy, Quebec, 44+ pp.

(24) Goulet, M. and Laliberte, D. (1982). Metaux: contamination du milieu aquatique au Quebec meridional. Rapport Q.E.-51, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, Direction Generale des Inventaires et de la Recherche, Ste-Foy, Quebec, 115+ pp.

(25) Laliberte, D. and Goulet, M. (1983). Pesticides organochlores: contamination du milieu aquatique au Quebec meridional. Rapport Q.E.-54, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, Ste-Foy, Quebec, 73+ pp.

(26) Croteau, G., Goulet, M. and Laliberte, D. (1984). Biphenyles polychlores: contamination du milieu aquatique au Quebec meridional en 1980. Rapport 84-17, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, Ste-Foy, Quebec, 75+ pp.

(27) Croteau, G., Goulet, M. and Laliberte, D. (1984). Contamination du milieu aquatique au Quebec meridional en 1980: arsenic, cadmium, chrome, cuivre, mercure, nickel, plomb, zinc. Rapport 84-18, Ministere de l'Environnement du Quebec, Service de la Qualite des Eaux, 181+ pp.

(28) Paul, M., Laliberte, D. and Goulet, M. (1984). Reseau de surveillance des substances organochlores dans le milieu aquatique au Quebec meridional. Rapport 84-20, Ministere de l'Environnement du Quebec, Direction des Releves Aquatiques, Ste-Foy, Quebec, 59+ pp.

(29) Duval, D. and Gauthier, R. (1986). Presence des herbicides dans le fleuve Saint-Laurent et ses tributaires. Environment Canada, Inland Waters Directorate Report, Longueuil, Quebec, 30+ pp.

(30) Forrest, S. and Caux, P.-Y. (1990). Pesticides in tributaries of the St. Lawrence River. 1987-1988 program report. Environment Canada St. Lawrence River Action Plan Report, 134+ pp., 1001 rue Pierre Dupuy, Longueuil, Quebec J4K 1A1.

(31) Muir, D.C.G., Yoo, J.Y. and Baker, B.E. (1978). Residues of atrazine and N-deethylated atrazine in water from five agricultural watersheds in Quebec. Arch. Environ. Contam. Toxicol. 7, 221-235.

(32) Reiss, R., Perron, F., Pare, J. and St-Jean, R. (1984). Les pesticides en agriculture au Quebec en 1982. Environment Canada - Environnement Quebec report, Montreal, Quebec, ISBN 0-662-92576-9, 134+ pp.

(33) Maguire, R.J., Germain, A., Tkacz, R.J. and Forrest, S.I. (1989). PCBs and pesticides in water at the mouths of the Yamaska and Saint-Francois Rivers. NWRI Report 89-150, National Water Research Institute, Department of Environment, Canada Centre for Inland Waters, Burlington, Ontario L7R 4A6, Canada, 33 pp.

(34) Moxley, J. (1989). Survey of pesticide use in Ontario, 1988. Ontario Ministry of Agriculture and Food, Economics and Policy Coordination Branch, Queen's Park, Toronto, Ontario M7A 1B6, ISBN 0-7743-9959-7, 40 pp.

(35) Day, K.E., Metcalfe, J.L. and Batchelor, S.P. (1990). Changes in intracellular free amino acids in tissues of the caged mussel, Elliptio complanata, exposed to contaminated environments. Arch. Environ. Contam. Toxicol. 19, 816-827.

(36) Barton, D.R. and Metcalfe-Smith, J.L. (1991). A comparison of sampling techniques and summary indices for assessment of water quality in the Yamaska River, Quebec, based on benthic macroinvertebrates. Submitted for publication.

(37) Bird, G. (1989). Study on the utility of chironomid deformities in the assessment of water quality. NWRI Report 89-62, National Water Research Institute, Department of Environment, Canada Centre for Inland Waters, Burlington, Ontario L7R 4A6, 40+ pp.

(38) Clarke, E.A. and Anliker, R. (1980). Organic dyes and pigments. In "The Handbook of Environmental Chemistry", Vol. 3, Part A. O. Hutzinger, ed. Springer-Verlag, pp. 181-215.

(39) Reisch, M.S. (1988). Better times ahead for U.S. dye producers. Chem. Eng. News 66, 7-14.

(40) Porter, J.J. (1973). A study of the photodegradation of commercial dyes. U.S. Environmental Protection Agency Report EPA-R2-73-058, U.S. EPA Office of Research and Monitoring, Washington, 94+ pp.

(41) Statistics Canada (1982). Items 4160520-4274990, Ottawa, Ontario, Canada.

(42) C.E. Searle (1976). (Editor), "Chemical Carcinogens", American Chemical Society Monograph Series 173, Washington, D.C., U.S.A., 788+ pp.

(43) E.J. Weber (1988). Degradation of Disperse Blue 79 in anaerobic sediment-water systems. In Proc. 196th Natl. Mtg. Amer. Chem. Soc., Los Angeles, Sept. 25-30, Division of Environmental Chemistry **28**, 177-180.

(44) Sinotte, M. (1985). Personal communication, Environnement Quebec, Service etude du milieu aquatique, 3900, rue Marly, Sainte-Foy, Quebec G1X 4E4.

(45) Comba, M.E. and Kaiser, K.L.E. (1983). Determination of volatile contaminants at the ng/L level in water by capillary gas chromatography with electron capture detection. Inter. J. Environ. Anal. Chem. **16**, 17-31.

(46) American Public Health Association (1989). "Standard Methods for the Examination of Water and Wastewater", 17th ed., eds. L.S. Clescern, A.E. Greenberg and R.R. Trussel, 1015 Fifteenth Street N.W., Washington, D.C., U.S.A., ISBN 0-87553-161-X.

(47) Ribo, J.M., Zaruk, B.M., Hunter, H. and Kaiser, K.L.E. (1985). Microtox toxicity test results for water samples from the Detroit River. J. Great Lakes Res. **11**, 297-304.

(48) Environment Canada (1987). Canadian Water Quality Guidelines. Water Quality Branch, Department of Environment, Hull, Quebec K1A 0H3.

(49) Health and Welfare Canada (1979). Guidelines for Canadian Drinking Water Quality, 1978. Bureau of Chemical Hazards, Department of Health and Welfare, Ottawa, Ontario K1A 0L2.

(50) Kaiser, K.L.E., Comba, M.E. and Huneault, H. (1983). Volatile halocarbon contaminants in the Niagara River and in Lake Ontario. J. Great Lakes Res. **9**, 212-223.

(51) Kaiser, K.L.E. and Comba, M.E. (1983). Volatile contaminants in the Welland River watershed. J. Great Lakes Res. **9**, 274-280.

(52) Comba, M.E. and Kaiser, K.L.E. (1984). Tracking river plumes with volatile halocarbon contaminants: the Niagara River - Lake Ontario example. J. Great Lakes Res. **10**, 375-382.

(53) Comba, M.E. and Kaiser, K.L.E. (1985). Volatile halocarbons in the Detroit River and their relationship with contaminant sources. J. Great Lakes Res. **11**, 404-418.

Table 1. Physical characteristics of the Yamaska River basin.*

lakes (%)	2.0
ponds (%)	0.7
forests (%)	32.5
deforested (%)	62.3
urbanized (%)	2.5
mean altitude (m)	192
mean slope (%)	1.1
specific flow (1975)	0.105 $m^3s^{-1}km^{-2}$
population density (1975)	38.4 persons per km^2
grazing density	482 pop.-equiv. per km^2
cultivated area (%) (1975)	
total	36.0
fertilized	11.4

*Ref. 1.

Table 2. Quantities of pesticides sold in the Yamaska River basin in 1982.*

Pesticide Class	Quantity (kg)	%
alcohol derivatives	3,481	1
amide derivatives	80,875	14
aryloxyacids	30,337	5
benzoic acid derivatives	1,997	<1
benzonitriles	6,362	1
carbamates	73,155	12
diazines	3,370	1
halogenated organic acid derivatives	3,378	1
inorganic compounds	994	<1
mineral oils	142,978	24
miscellaneous	16,678	3
organochlorines	1,494	<1
organophosphates	31,548	5
organotins	1,067	<1
phthalic acid derivatives	96	<1
phthalimides	20,447	3
plant products	-	-
pyrethroids	254	<1
quaternary ammonium compounds and phenol derivatives	1,433	<1
triazines and triazoles	168,070	28
ureas (substituted)	2,090	<1
total	590,104	

*Ref. 32. There were also 11,040 billion international units of Bacillus thuringiensis (Berliner var. Kurstaki) sold in the Yamaska basin in 1982 (15% of Quebec's total).

Table 3. Yamaska River project sampling locations

Site No.	Latitude (deg/min/sec N)	Longitude (deg/min/sec W)	Location
1	45 25 55	72 21 35	Riviere Noire 10 m upstream of bridge 1.5 km northwest of Lawrenceville
2	45 16 45	72 30 40	head of Riviere Yamaska-centre (outlet of Lac Brome) 50 m downstream of bridge on highway 215
3	45 10 35	72 39 35	Riviere Yamaska sud-est 10 m upstream of bridge on highway 139 at Brome-Ouest
4	45 14 15	72 48 00	Riviere Yamaska sud-est 10 m upstream of bridge 2.5 km north of Fordyce Corners
5	45 21 14	72 46 20	Riviere Yamaska nord 10 m downstream of bridge on highway 139, 1.8 km north of Autoroute des Cantons de l'Est
6	45 19 00	72 49 20	Riviere Yamaska nord 10 m upstream of bridge 1.8 km downstream of St. -Alphonse-de-Granby
7	45 17 15	72 59 20	Riviere Yamaska, south side, at Canadian Forces Base at Farnham
8	45 30 50	72 22 25	Riviere Noire 10 m upstream of bridge 6 km downstream of Valcourt
9	45 39 10	72 35 35	Riviere le Renne 10 m upstream of bridge 2 km downstream of Acton Vale
10	45 31 00	72 55 30	Riviere Noire, north side, 3 km downstream of highway 235 bridge in Saint-Pie
11	45 33 40	72 58 55	Riviere Yamaska, east side, 2 km downstream of confluence with Riviere Noire
12a	45 38 05	72 56 15	Riviere Yamaska, west side, at Saint-Hyacinthe, 200 m downstream of highway 137 bridge
12b	45 41 15	72 55 05	Riviere Yamaska, west side, 4 km downstream of highway 20 bridge
13a	46 03 35	72 56 40	Riviere Yamaska, middle, 6.5 km downstream of Yamaska-Est

cont'd next page

Table 3 cont'd

Site No.	Latitude (deg/min/sec N)	Longitude (deg/min/sec W)	Location
13E	46 00 25	72 54 35	Riviere Yamaska, east side, 50 m downstream of highway 132 bridge at Yamaska-Est
13W	46 00 25	72 54 40	Riviere Yamaska, west side, 50 m downstream of highway 132 bridge at Yamaska
15	45 24 45	72 37 25	Riviere Yamaska nord 5 m upstream of bridge at Val-Shefford
16	45 24 40	72 45 10	(drinking water site) Hotel le Castel de l'Estrie, 901 rue Principale, Granby
17	45 37 55	72 57 35	(drinking water site) Esso gas station at corner of 17th Ave. (Ste. Anne) and 27th St. (Cartier), Saint-Hyacinthe
20	45 23 40	72 42 40	Riviere Yamaska nord, south side, in Granby, 50 m upstream of rue Church bridge
21	45 23 25	72 43 50	Riviere Yamaska nord, north side, in Granby, 50 m downstream of rue Saint-Charles sud bridge
22	45 23 30	72 44 15	Riviere Yamaska nord, south side, in Granby, 50 m upstream of rue Robinson sud bridge
23	45 23 10	72 44 45	Riviere Yamaska nord, south side, in Granby, at end of rue Edouard
30	45 28 50	72 58 50	Riviere a la Barbue 5 m upstream of bridge 0.2 km upstream of confluence with Riviere Yamaska
31	45 35 15	72 38 00	Ruisseau Runnets 5 m downstream of bridge 2 km upstream of confluence with Riviere Noire
32	45 40 45	72 38 40	Riviere Saint-Nazaire 5 m upstream of bridge 0.5 km upstream of confluence with Riviere le Renne
33	45 47 30	72 51 20	Riviere Chibouet 10 m downstream of bridge at Saint-Hughes, 2 km upstream of confluence with Riviere Yamaska

cont'd next page

Table 3 cont'd

Site No.	Latitude (deg/min/sec N)	Longitude (deg/min/sec W)	Location
34	45 49 35	72 57 45	Riviere Salvail 10 m downstream of bridge 100 m upstream of confluence with Riviere Yamaska
35	45 29 50	72 37 25	Ruisseau Runnets 5 m downstream of bridge 2.5 km downstream of Roxton -Sud
36	45 37 40	72 22 45	Riviere le Renne 10 m upstream of bridge 3 km upstream of Moose River
37	45 22 45	72 30 00	Riviere Yamaska nord 50 m upstream of highway 241/243 bridge at Warden
50	45 20 35	72 30 50	Riviere Yamaska nord 10 m downstream of highway 241 bridge at Waterloo
51	45 22 45	72 30 05	Riviere Yamaska nord 100 m upstream of highway 241/243 bridge at Warden
52	45 25 25	72 34 45	Reservoir Choiniere (Riviere Yamaska nord) at end of rang Brosseau off 8ieme rang est
53	45 24 15	72 30 35	Riviere Yamaska nord 5 m upstream of bridge on highway 241, 3 km downstream of Warden
60	45 16 05	72 47 50	Riviere Yamaska centre 5 m upstream of bridge 1 km downstream of Adamsville
61	45 17 15	72 51 20	Riviere Yamaska 5 m upstream of bridge 0.5 km downstream of confluence of Riviere Yamaska nord and Riviere Yamaska centre
62	45 16 15	72 55 25	Riviere Yamaska sud-est 3 km upstream of its confluence with Riviere Yamaska
63	45 17 25	72 56 10	Riviere Yamaska 1.5 km downstream of its confluence with Riviere Yamaska sud-est

Table 4. Some water quality characteristics of selected sampling locations in the Yamaska River, 1985-87

Site No.	Air Temp. °C	Water Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmho/cm	Eh-water mV	Eh-sediment mV
June 1985							
1	15	12	6.8	11.4	195	45	-20
2	14	15	7.6	10.2	125	30	-55
3	15	15	7.1	9.4	215	50	-10
4	17	14	6.6	8.4	370	20	-40
5	16	16	6.2	5.5	590	10	-310
6	16	15	5.8	4.1	540	10	-240
7	17	14	7.2	8.8	170	30	-90
8	14	11	7.6	10.0	165	40	-300
9	14	15	6.6	8.8	230	10	-285
10	18	14	6.4	7.9	210	30	-245
11	19	19	7.6	9.5	285	140	-205
12a	20	16	7.2	9.3	410	70	-300
13a	15	16	6.8	8.1	800	30	-195
15	13	13	6.7	10.4	225	50	-110
20	16	14	6.6	9.3	275	70	-100
21	16	14	6.6	8.9	300	60	-90
22	16	14	6.6	8.7	310	60	-130
23	16	14	6.6	9.2	340	70	-70
June 1986							
1	18	16	6.6	9.2	290	215	-20
2	20	17	6.5	8.6	375	210	-200
3	18	12	6.9	9.6	300	210	-210
4	22	20	7.6	6.8	585	210	-180
5	13	11	7.4	8.5	730	200	-120
7	24	20	6.3	8.4	700	210	no sed
8	20	17	8.0	9.0	410	220	-170
9	23	19	7.7	9.0	460	200	-260
10	17	16	6.9	9.3	510	210	-200
11	17	15	7.3	8.7	640	200	-180
12b	21	20	6.4	6.6	780	170	-100
13E	18	15	6.9	9.2	680	195	35
13W	18	15	6.9	9.1	675	190	-10
15	17	10	6.8	8.9	375	210	no sed
30	>14	14	7.7	8.6	925	210	-25
31	23	20	7.6	7.8	510	210	no sed
32	22	18	7.3	7.5	810	200	-210
33	29	24	6.9	7.5	1190	220	30
34	18	18	7.0	7.9	1360	210	-80
June 1987							
5	17	15	6.8	7.7	410	110	-270
12b	16	16	7.2	7.6	690	145	-185
13E	14	21	7.9	8.1	254	420	-165
13W	14	19	7.3	8.0	229	475	-175
30	15	14	7.4	8.3	288	150	-95
31	15	16	6.7	9.9	275	190	-110
32	14	17	7.4	8.9	259	380	-75
33	15	16	6.6	9.4	310	220	-145
34	15	14	7.1	8.7	640	140	-220

cont'd next page

Table 4 cont'd

Site No.	Air Temp. °C	Water Temp. °C	pH	Dissolved Oxygen mg/L	Conductivity µmho/cm	Eh-water mV	Eh-sediment mV
July 1987							
5	22	18	6.4	7.1	590	90	-310
12b	18	17	7.1	9.5	430	150	-210
13E	16	18	6.9	8.4	1100	140	-220
13W	16	18	6.9	8.1	1175	135	-195
30	21	19	6.8	9.4	260	110	-175
31	24	17	7.5	8.7	340	95	-120
32	23	16	7.4	10.8	455	75	-50
33	23	16	6.9	9.9	390	155	-80
34	24	17	6.2	7.4	815	95	-360
September 1987							
5	11	13	7.3	8.8	630	115	-250
12b	15	14	6.7	9.4	480	145	-115
13E	10	12	6.9	8.2	1300	115	-180
13W	10	13	6.9	8.0	1280	140	-200
30	13	15	7.3	9.2	670	110	-170
31	13	11	6.8	8.4	415	70	-155
32	12	9	7.7	9.3	140	160	-90
33	13	13	7.4	8.8	260	130	-240
34	12	10	6.8	7.9	970	105	-310

Table 5. Concentrations of fecal coliforms and total coliforms in the Yamaska River, 1985 - 1987

	COLIFORM COUNTS PER 100 mL				
	1985	1986		1987	
LOCATION	FECAL	FECAL	TOTAL	FECAL	TOTAL
1		$3.0x10^2$	$5.0x10^3$		
2	3	$2.0x10^2$	$6.0x10^3$		
3	$3.3x10^1$	$2.2x10^2$	$2.0x10^3$		
4	$2.6x10^2$	$9.2x10^3$	$9.2x10^4$		
5	$1.4x10^5$	$3.4x10^4$	$2.2x10^5$	$1.5x10^6$	$4.8x10^5$
6	$1.7x10^5$				
7	$1.4x10^3$	$3.0x10^4$	$9.3x10^4$		
8	$3.9x10^3$	$3.2x10^3$	$3.0x10^4$		
9	$6.5x10^3$	$1.0x10^4$	$4.6x10^4$		
10	$1.4x10^2$	$1.9x10^3$	$3.9x10^4$		
11	$5.0x10^1$	$1.8x10^4$	$3.6x10^4$		
12a	$6.3x10^3$	$2.6x10^4$	$1.4x10^4$		
12b		$2.6x10^4$	$2.8x10^4$	$2.8x10^3$	$1.0x10^5$
13a	3				
13E		$2.8x10^3$	$1.6x10^4$	$1.3x10^2$	$8.3x10^2$
13W		$5.6x10^2$	$8.0x10^3$	$1.6x10^2$	$3.3x10^2$
15	$1.1x10^2$	$1.2x10^2$	$1.0x10^3$		
20		$3.0x10^3$	$2.2x10^4$		
21		$2.4x10^3$	$7.0x10^3$		
22		$2.4x10^3$	$1.8x10^4$		
23		$4.0x10^2$	$5.0x10^3$		
30		$2.0x10^1$	$3.7x10^4$	$1.0x10^1$	$3.0x10^1$
31		$8.2x10^2$	$1.4x10^4$	$1.0x10^2$	$4.2x10^2$

cont'd next page

Table 5 cont'd

COLIFORM COUNTS PER 100 mL

	1985	1986		1987	
LOCATION	FECAL	FECAL	TOTAL	FECAL	TOTAL
32		$2.4x10^2$	$8.0x10^3$	$8.2x10^2$	$2.3x10^3$
33		$7.6x10^2$	$2.2x10^4$	$3.6x10^1$	$2.2x10^2$
34		$3.2x10^3$	$7.5x10^4$	$2.1x10^2$	$6.7x10^2$

*In June of each year.

Table 6. Microtox toxicity test results for some locations in the Yamaska River basin in 1985 - 1986.*

Location	Maximum Γ value	
	1985	1986
1	0.01	0.03
2	0.06	0.03
3	0.02	0.05
4	0.05	0.03
5	7.31	0.03
6	0.04	not done
7	not done	0.04
8	0.07	0.03
9	0.18	0.03
10	0.10	0.04
11	0.21	0.05
12a	0.10	not done
13a	0.05	not done
13W	0.02	not done
15	0.09	0.03
30	not done	0.002
32	not done	0.01
33	not done	0.02
34	not done	0.0003

*In June of each year. The 1985 and 1986 samples were analyzed 6 and 2 weeks after collection, respectively.

Table 7. A scale relating Γ values to toxicity to *Photobacterium phosphoreum*.*

Maximum Γ Value	Class	Interpretation
$\Gamma < 0$	0	non-toxic
$0 < \Gamma < 0.05$	1	slightly toxic
$0.05 < \Gamma < 0.10$	2	slightly toxic
$0.10 < \Gamma < 0.5$	3	moderately toxic
$0.5 < \Gamma < 1.0$	4	moderately toxic
$1.0 < \Gamma < 10.00$	5	quite toxic
$10.0 < \Gamma$	6	very toxic

*Ref. 47.

Table 8. Concentrations of volatile halocarbons in water (ng/L) from locations in the Yamaska River basin in 1985.*

Chemical	Location No.										
	1	2	3	4	5	6	7	8	9	10	11
dichlorodifluoromethane					16						
fluorotrichloromethane	1	2	1	15	9	6	12	11	6	8	16
dichloromethane		8				110					63
chloroform	3	15	6	72	490	70			18	4	49
1,1,1-trichloroethane	1	9	7		135	53		66	5		2
trichloroethylene				1560	82	6					
bromodichloromethane		2			67	9					4
1,1,2-trichloroethane					5						
dibromochloromethane											3
tetrachloroethylene	3	2	1	485	3080	180	15	7	3	1	13
Σ (all halocarbons)	8	38	15	2132	3884	434	27	84	32	13	150
Σ (chloroform + bromodichloromethane + dibromochloromethane)	3	17	6	72	557	79			18	4	56

Chemical	Location No.				
	12a	13a	15	16	17
dichlorodifluoromethane					
fluorotrichloromethane	41	5	14	20	14
dichloromethane	60			2400	600
chloroform	510	6	30	3840	2300
1,1,1-trichloroethane	20	2			14
trichloroethylene					
bromodichloromethane	130			480	410
1,1,2-trichloroethane					
dibromochloromethane	5			25	31
tetrachloroethylene	33	1	6		13
Σ (all halocarbons)	799	14	50	6765	3382
Σ (chloroform + bromodichloromethane + dibromochloromethane)	645	6	30	4345	2741

*Locations 16 and 17 are drinking water sources in Granby and Saint-Hyacinthe, respectively. The following compounds were not found in any sample: 1,1-dichloroethylene, carbon disulfide, cis-1,2-dichloroethylene, 1,1-dichloroethane, bromochloromethane, 1,2-dichloroethane, carbon tetrachloride, 1,2-dichloropropane, dibromomethane, bromotrichloromethane, 1,2-dibromoethane, 1,2-dibromoethylene, bromoform and 1,1,2,2-tetrachloroethane.

Table 9. Concentrations of volatile halocarbons in water (ng/L) from locations in the Yamaska River basin in 1986.*

Chemical	Location No.										
	1	2	3	4	5	7	8	9	10	11	12b
fluorotrichloromethane			1	5	5	3	3	1	3	2	3
dichloromethane	3		4	1040	560	2160	72	40	72	84	100
chloroform	2			100	98	250	15		13	4	230
1,1,1-trichloroethane	9		1	12	11	11	27	3	14	7	11
carbon tetrachloride					2		1				1
trichloroethylene				160	8	3	2				5
bromodichloromethane				1	2	7					1
dibromochloromethane						1					1
tetrachloroethylene				790	95	12	2		2	1	3
Σ (all halocarbons)	14		6	2108	781	2447	122	44	104	98	355
Σ (chloroform + bromodichloromethane + dibromochloromethane)	2			101	100	258	15		13	4	232

Chemical	Location No.									
	13E	13W	15	16	17	30	31	32	33	34
fluorotrichloromethane	1	1		3	3				2	
dichloromethane	132	52		328	88		8	1	2	1
chloroform	14	4		35	11	2	7		5	
1,1,1-trichloroethane	5	6		11	13		1		2	
carbon tetrachloride										
trichloroethylene										
bromodichloromethane				11	7					
dibromochloromethane					1					
tetrachloroethylene	1	1		1	35	1	2	1	2	9
Σ (all halocarbons)	153	64		389	158	3	18	2	13	10
Σ (chloroform + bromodichloromethane + dibromochloromethane)	14	4		46	19	2	7		5	

*Locations 16 and 17 are drinking water sources in Granby and Saint-Hyacinthe, respectively. The following compounds were not found in any sample: dichlorodifluoromethane, 1,1-dichloroethylene, carbon disulfide, cis-1,2-dichloroethylene, 1,1-dichloroethane, bromochloromethane, 1,2-dichloroethane, 1,2-dichloropropane, dibromomethane, bromotrichloromethane, 1,1,2-trichloroethane, 1,2-dibromoethane, 1,2-dibromoethylene, bromoform and 1,1,2,2-tetrachloroethane.

Table 10. Concentrations of volatile halocarbons in water (ng/L) from locations in the Yamaska River basin in 1987.

(A) June

Chemical	Location No.										
	5	12b	13E	13W	16	17	30	31	32	33	34
dichlorodifluoromethane	3	4									
fluorotrichloromethane	8	17			39	71					
dichloromethane	206	41			685	349	6		1	12	4
chloroform	82	390	36	60	1011	875					
1,1,1-trichloroethane	7	29	7	9							
trichloroethylene		213									
bromodichloromethane		6			115	89					
dibromochloromethane		1			3	9					
tetrachloroethylene	400	78	12	14	40	11	2	5		1	2
Σ (all halocarbons)	706	779	55	83	1893	1404	8	5	1	13	6
Σ (chloroform + bromodichloromethane + dibromochloromethane)	82	397	36	60	1129	973					

(B) July

Chemical	Location No.										
	5	12b	13E	13W	16	17	30	31	32	33	34
dichlorodifluoromethane	1										
fluorotrichloromethane	2										
dichloromethane	312	52			22	89					
chloroform	51	43	164	147	114	397				2	
1,1,1-trichloroethane	4	4			12	16					
trichloroethylene											
bromodichloromethane					24	69					
dibromochloromethane											
tetrachloroethylene	78	16	8	3	3	9				2	
Σ (all halocarbons)	448	115	172	150	175	580					
Σ (chloroform + bromodichloromethane + dibromochloromethane)	57	64	164	147	138	466				4	

cont'd next page

Table 10 cont'd

(C) September

Chemical	Location No.										
	5	12b	13E	13W	16	17	30	31	32	33	34
dichlorodifluoromethane	3				3	11					
fluorotrichloromethane	7	1			1	4					
dichloromethane	184	51	8	1	132	486					
chloroform	109	29	56	44	1230	2109				6	
1,1,1-trichloroethane	25	2	3		2	31					
trichloroethylene	41	11				12					
bromodichloromethane	17	4			275	437					
dibromochloromethane	6	1			3	18					
tetrachloroethylene	18		25	32	14	37					
Σ (all halocarbons)	410	99	92	77	1660	3145				6	
Σ (chloroform + bromodichloromethane + dibromochloromethane)	132	34	56	44	1508	2564				6	

Locations 16 and 17 are drinking water sources in Granby and Saint-Hyacinthe, respectively. The following compounds were not found in any sample: dichlorodifluoromethane, 1,1-dichloroethylene, carbon disulfide, cis-1,2-dichloroethylene, 1,1-dichloroethane, bromochloromethane, 1,2-dichloroethane, 1,2-dichloropropane, dibromomethane, bromotrichloromethane, 1,1,2-trichloroethane, 1,1-dibromoethane, 1,2-dibromoethylene, bromoform and 1,1,2,2-tetrachloroethane.

Table 11. Ratio of [chloroform]/[bromodichloromethane] for drinking water in Granby and Saint-Hyacinthe in 1985 - 1987.

Date	Granby	Saint-Hyacinthe
June 1985	8.0	5.6
June 1986	3.2	1.6
June 1987	8.8	9.8
July 1987	4.8	5.6
September 1987	4.5	4.8

FIGURE CAPTIONS

Figure 1. Location of the Yamaska River watershed in Quebec.

Figure 2. Map of the Yamaska River basin showing sampling stations for various aspects of the project.

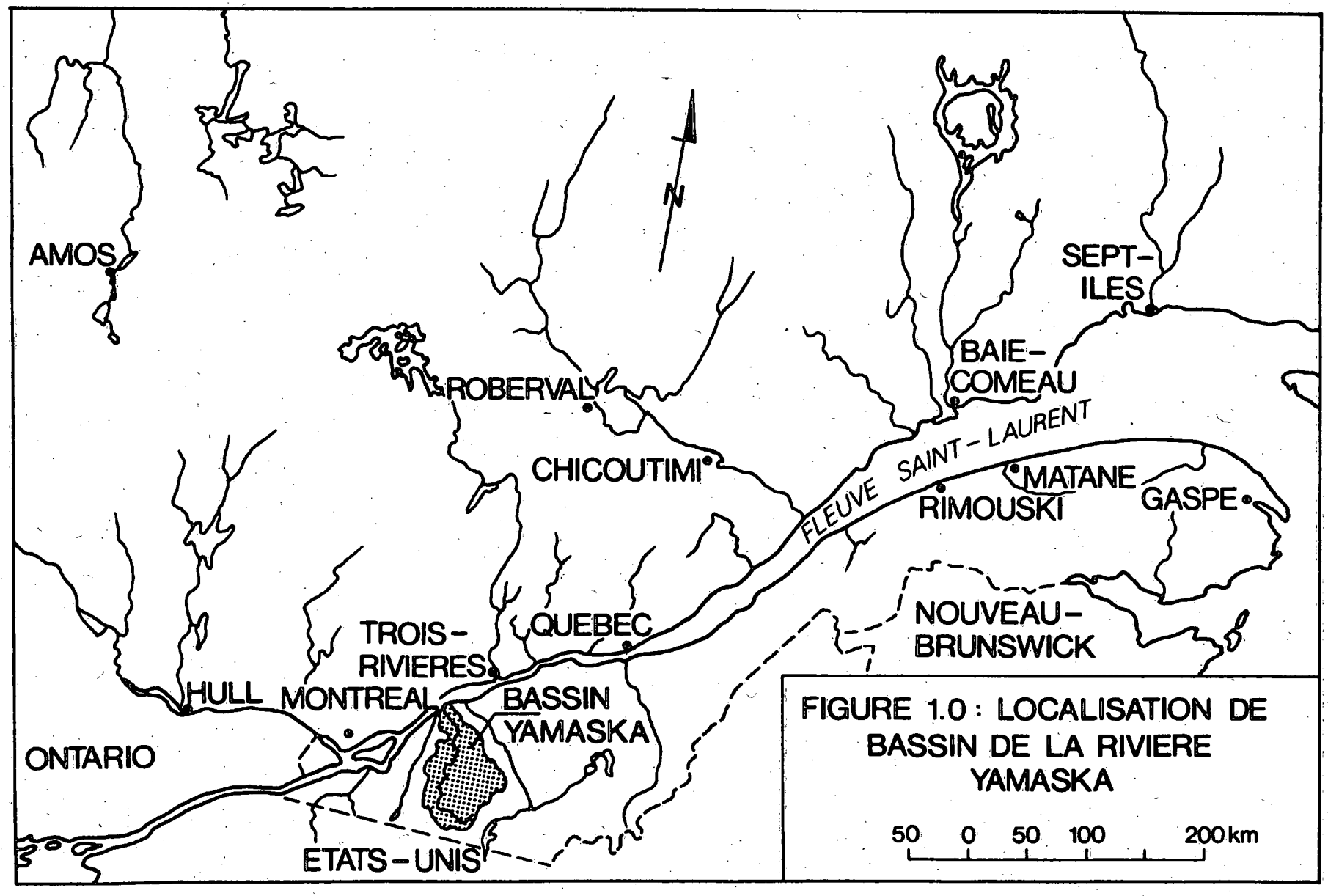
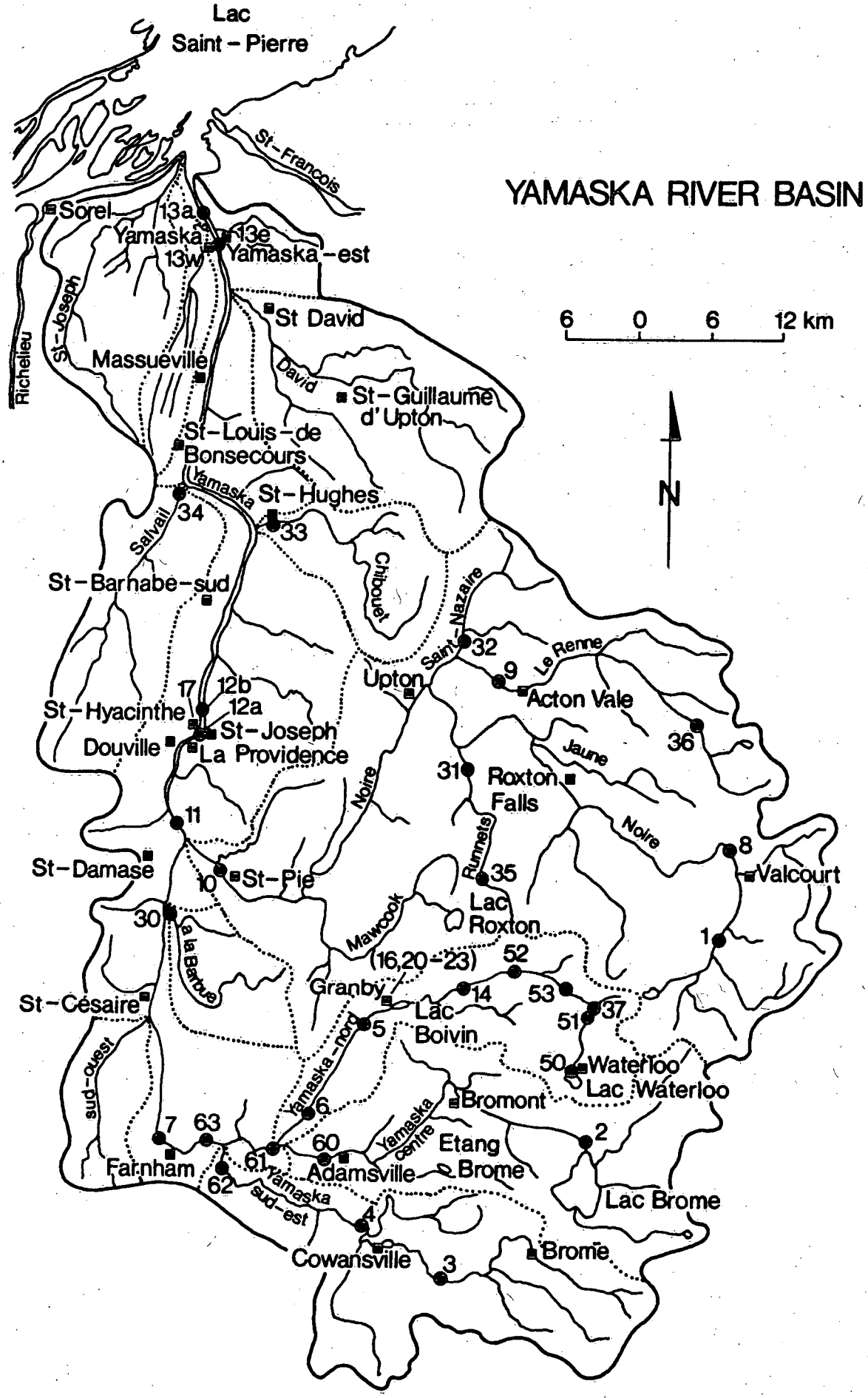


FIGURE 1.0 : LOCALISATION DE BASSIN DE LA RIVIERE YAMASKA


YAMASKA RIVER BASIN
Lac Saint-Pierre
St-François
Sorel
13a
Yamaska
13e
13w
Yamaska-est
St David
6 0 6 12 km
N
Richelieu
St-Joseph
Massueville
David
St-Guillaume d'Upton
St-Louis-de Bonsecours
Yamaska
St-Hughes
34
33
Salvail
Chibouet
St-Barnabe-sud
Saint-Nazaire
32
Le Renne
9
Upton
Acton Vale
17
12b
12a
St-Hyacinthe
St-Joseph
Douville
La Providence
36
Jaune
31
Roxton Falls
Noire
11
Noire
8
Valcourt
St-Damase
St-Pie
10
Runnels
35
Lac Roxton
30
La la Barbue
Mawcook
1
(16,20-23)
52
Granby
14
53
St-Césaire
Lac Boivin
51
37
5
50
Waterloo
Lac Waterloo
sud-ouest
Yamaska-nord
Bromont
6
7
63
Yamaska centre
Etang Brome
2
60
Farnham
61
Adamsville
62
Yamaska sud-est
Lac Brome
4
Cowansville
3
Brome

APPENDIX

BACKGROUND DATA ON TOXIC CHEMICAL CONTAMINATION OF THE YAMASKA RIVER AND ITS TRIBUTARIES

During the 1970s and 1980s there were several studies of contamination of the Yamaska River basin by heavy metals, pesticides and PCBs. The major work has been done by Environnement Quebec, including extensive studies in 1978 and 1980, as part of provincial surveys. There have also been studies by the Universite du Quebec, Environment Canada and others on the Yamaska River, its mouth at lac Saint-Pierre, and some of its major tributaries which flow through agricultural lands.

Lapointe and Sasseville (21) sampled water, sediment, macrophytes and fish from five locations at the mouth of the Yamaska River in July 1974, and analyzed the samples for lead and mercury. Concentration ranges are shown in Table A-1.

Harvey (22) analyzed sport fish caught in 1977-78 at 15 locations in the Yamaska River basin for heavy metals (Cr, Co, Cu, Mn, Ni, Zn, Cd, Hg, Pb), organochlorine insecticides and PCBs. There were many data on fish of different species and age. The general conclusion was that Hg and PCBs exceeded federal guidelines (which were 0.5 and 2 mg/kg, respectively). Average concentrations of these contaminants in fish from the Yamaska River are compared to those from the St. Lawrence River at lac St.-Pierre in Table A-

2. There were elevated levels of Cr in fish downstream of Waterloo in the Choiniere Reservoir and lac Boivin. There were elevated levels of Cu in water and sediment downstream of Granby and Waterloo, probably due to electroplating industries. This was not reflected in concentrations in fish. Mercury was present at 0.01 - 2.31 mg/kg, with an average of 0.38 mg/kg. There were higher concentrations in predators than in bottom-feeding fish. The highest concentrations of mercury were found in muskellunge and walleye, and the most heavily-contaminated regions were the Yamaska North below Waterloo, the Yamaska above Adamsville, and the Noire River. In general, water in the Yamaska basin contained < 0.002 mg/L Pb, except downstream of Waterloo (0.005 mg/L) and Granby (0.027 mg/L). Higher concentrations downstream of these two areas were attributed to automobiles. There were elevated levels (> 2 mg/L) of total PCBs in fish downstream of Farnham and Saint-Hyacinthe, and at the mouth of the Yamaska River, and at Saint-Pie in the Noire River.

Auger et al. (16) have presented a good summary of research on the Yamaska River in the 1970s, documenting the eutrophication of various parts of the basin and contamination by heavy metals and metalloids. In summary, the sediments of the Yamaska North were contaminated by copper, zinc, chromium, mercury and cadmium. The water of the Yamaska North was also contaminated by copper, zinc and nickel. In the Yamaska South-East sediments were contaminated by arsenic and mercury, while waters were contaminated by copper

and manganese. The results of various surveys are shown in Tables A-3a,b,c (water) and A-4a,b (sediment).

In 1980 Belanger reported on the water chemistry, nutrient status and sediment metal concentrations of major lakes in the Yamaska River basin as well as some tributaries and some locations in the Yamaska itself (17). These data are shown in Tables A-5a,b,c. The most notable finding was that of elevated concentrations of heavy metals in sediments downstream of Waterloo and Granby.

Tessier et al. (2) reported on the partitioning of various heavy metals in the Yamaska River basin in 1975 between the "dissolved" phase and suspended particulate material. The suspended sediment samples were subjected to a sequential extraction procedure designed to separate the particulate trace metals into five fractions: (1) exchangeable; (2) bound to carbonates; (3) bound to Fe-Mn oxides; (4) bound to organic matter; and (5) residual. Although suspended sediment levels as well as total soluble and particulate trace metal concentrations were highly variable, speciation patterns for each metal were fairly constant. Very small proportions of all metals, except Cd and Mn, were found in the exchangeable fraction, whereas high levels of all metals were present in the residual fraction; Fe-Mn oxides and organic matter constituted important transport phases for most metals. Deviations from this general behaviour occurred

with inputs of municipal sewage, in which case total particulate metal concentrations increased and the relative contribution of the residual fraction decreased. This is particularly the case downstream of Granby. The results are shown in Table A-6 for water and Table A-7 for suspended solids.

Goulet and Laliberte (23) analyzed mussels and fish (bottom feeding and predators) caught in 1978 in the Yamaska River basin for PCBs. PCB concentrations in fish from the Yamaska Basin were lower than those for some other basins studied. The Health and Welfare Canada temporary guideline for PCBs in 1978 was 2 mg/kg for the edible portion of fish. The highest concentrations of PCBs were found in walleye downstream of Saint-Hyacinthe (1.1 mg/kg wet weight - multifish homogenate) and at Saint-Pie on the Noire River (0.5 mg/kg - multifish homogenate); and white sucker from the mouth of the Yamaska River (0.8 mg/kg - composite) and downstream of Saint-Hyacinthe (0.8 mg/kg - composite). There was fairly low contamination of mussels (n.d. - 0.03 mg/kg wet weight - composites). Detailed results are shown in Table A-8.

Goulet and Laliberte (24) also analyzed water, sediment, macrophytes, mussels and fish samples taken from the Yamaska River basin in 1978 for Cd, Cr, Cu, Hg, Ni, Pb, Zn and As. In general, the Yamaska basin was most contaminated with these metals downstream of Waterloo, Granby and Farnham. The results are given in Tables A-9. Notable findings with each metal are described

below.

Arsenic: One species of macrophyte had elevated levels downstream of Saint-Hyacinthe (4 mg/kg)

Cadmium: There were elevated levels in sediment downstream of Waterloo (1.4 mg/kg) and Granby (1.1 mg/kg), probably due to electroplating operations.

Chromium: Contamination of water and sediment downstream of Waterloo (9.2 µg/L; 420 mg/kg) and Saint-Hyacinthe (60 mg/kg). Also contamination of macrophytes downstream of Yamaska (20 mg/kg). No contamination evident at Granby, perhaps because the Choiniere Reservoir and lac Boivin act as traps.

Copper: Four stations were contaminated: sediments downstream of Waterloo and Granby (58 and 60 mg/kg, respectively), mussels (3.9 mg/kg) and carp (1.4 mg/kg) downstream of Farnham and mussels (3.3 mg/kg) and walleye (2.1 mg/kg) upstream of Saint-Pie on the Noire River.

Mercury: Concentrations in sediment downstream of Waterloo, Granby and Farnham were 0.2, 0.2 and 0.1 mg/kg, respectively. There was some contamination of mussels downstream of Brigham and Farnham, and of walleye downstream of Brigham and upstream of

Saint-Pie on the Noire River.

Nickel: Contamination of water (26 μg/L) and sediment (210 mg/kg) downstream of Waterloo. Some contamination noted in mussels downstream of Yamaska.

Lead: Contamination of sediment downstream of Waterloo (105 mg/kg) and Granby (82 mg/kg).

Zinc: Contamination downstream of Waterloo (water 36 μg/L; sediment 630 mg/kg), downstream of Granby (sediment 264 mg/kg; macrophytes 324 mg/kg), downstream of Farnham (mussels 41 - 171 mg/kg).

Laliberte and Goulet (25) analyzed mussels and fish taken from various locations in the Yamaska River basin in 1978 for twelve chlorinated pesticides. The most notable finding was total DDT contamination downstream of Saint-Hyacinthe: white suckers were contaminated upstream of Saint-Pie (0.1 mg/kg), downstream of Saint-Hyacinthe (0.2 mg/kg) and downstream of Yamaska (0.1 mg/kg). Walleye were contaminated upstream of Saint-Pie (0.2 mg/kg) and downstream of Saint-Hyacinthe (0.2 mg/kg). There was little contamination with the other pesticides in any part of the river. The results are shown in Table A-10.

Croteau et al. (26) investigated total PCBs in sediments, macrophytes, mussels and fish collected from the Yamaska River basin in 1980. The general conclusion was that the Yamaska River was contaminated downstream of Saint-Hyacinthe, and that this contamination was slightly worse than in 1978. There was lesser contamination in the Yamaska North and downstream of Farnham. The results are shown in Table A-11.

Croteau et al. (27) also investigated As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in water, sediments, macrophytes, mussels and fish in the Yamaska River basin in 1980. The general conclusion for locations which were contaminated by three or more metals is that there were three fairly contaminated sites in the Yamaska River basin: downstream of lac Waterloo, downstream of Saint-Alphonse-de-Granby and downstream of Saint-Hyacinthe. The results are shown in Table A-12. Notable findings were:

Arsenic: an electroplating operation in Waterloo was suspected of being the sources of As.

Cadmium: There was little contamination.

Chromium: The most serious contamination in Quebec was in the Yamaska North downstream of lac Waterloo and Granby (in water, sediment and aquatic plants). The contamination was probably due to electroplating industries. There was also

contamination downstream of Saint-Hyacinthe. Lac Boivin and the Choiniere Reservoir probably acted as sinks for chromium. These results confirmed the 1978 results.

Copper: The Yamaska basin was mainly contaminated downstream of lac Waterloo and Saint-Alphonse-de-Granby. There was less contamination elsewhere in the basin. Results were similar to those from 1978.

Mercury: Contamination was observed at several sites in the basin. Highest concentrations in sediment were downstream of lac Waterloo. Results were similar to those of 1978.

Nickel: The highest contamination was found downstream of lac Waterloo. Results were similar to those of 1978.

Lead: Contamination was highest downstream of Saint-Alphonse-de-Granby. Results are similar to those of 1978.

Zinc: Appreciable contamination was evident downstream of Waterloo, Granby, Saint-Hyacinthe and at the mouth of the Yamaska. Results were similar to those of 1978.

Paul et al. (28) investigated organochlorine pesticide contamination of sediment, plants, mussels and fish collected from the Yamaska River basin in 1980. The general conclusion was that

there was contamination by total DDT at Waterloo and downstream of lac Waterloo, but little contamination by other chlorinated pesticides. These results were similar to those from 1978. The results are shown in Table A-13.

Duval and Gauthier (29) reported the analyses for various herbicides of water, sediment and mussel tissues collected from the mouth of the Yamaska River in 1976-81 for atrazine, de-ethyl atrazine, de-isopropyl atrazine, propazine, 2,4-D, 2,4,5-T and silvex. Samples were collected in the summer months. Water was the only "compartment" in which these herbicides were found. The concentrations of atrazine and its metabolites peaked in July, but there was no trend for propazine, 2,4-D, 2,4,5-T or silvex (cf. Table A-14).

Forrest and Caux (30) analyzed water, sediment, suspended solids and fish from the mouths of the Yamaska River and three of its tributaries in 1987-88 for pesticides. The results are shown in Table A-15. Herbicides were the most frequently detected chemicals, in particular atrazine. Atrazine and diazinon were found above their water quality guidelines for the protection of aquatic life. The estimated loading of atrazine residues to the St. Lawrence River from the Yamaska River was 25 kg/day during the growing periods of 1987-88. Atrazine was also found in suspended particulate material (0.04 mg/kg dry weight) and sediment (0.02 mg/kg dry weight) at the mouth of the Yamaska River in 1987. p,p'-

DDE and lindane were found in whole fish at the mouth of the Yamaska River in the period July - September 1987 at concentrations of 0.006 - 0.010 mg/kg wet weight.

In the most detailed study to date of pesticide contamination of tributaries of the Yamaska River, Muir et al. (31) monitored atrazine and de-ethylated atrazine in 1974 - 1975 in five rivers which drained agricultural areas in the Yamaska River basin. The rivers were the Saint-Nazaire, Chibouet, Salvail, a la Barbue and the Runnets. Some characteristics of these watersheds are given in Table A-16. The concentrations of the atrazine and de-ethyl atrazine were in the ranges 0.01 - 26.9 and < 0.01 - 1.34 μg/L, respectively. The highest concentrations of atrazine were observed in July each year and they coincided with the herbicide spraying season and with occasional heavy rainfall. Discharges of atrazine from the five rivers ranged from 0.1 to 2.9% of that which was estimated to have been applied to crops in each watershed.

Table A-1. Concentrations of total lead and mercury at the mouth of the Yamaska River, July 1974*

Sample		Lead µg/L or mg/kg	Mercury µg/L or mg/kg
water		15 - 53	n.d. - 0.4
sediment		< 0.15	0.2 - 0.7
macrophytes		0.1 - 20	n.d. - 0.07
fish (suckers)	muscle	< 0.002 - 0.01	0.6 - 1.2
	bone	< 0.002 - 0.07	0.1 - 0.4
	skin	0.09 - 2.8	0.04 - 0.09

*Ref. 21. Concentrations in sediment and tissue are dry and wet weight, respectively.

Table A-2. Average concentrations (mg/kg wet weight) of heavy metals, chlorinated insecticides and PCBs in fish in the Yamaska River basin and the St. Lawrence River, 1977-78*

Contaminant	Yamaska River	St. Lawrence River
Cd	< 0.04	< 0.05
Cr	0.06	0.4
Co	0.03	0.5
Cu	0.6	0.7
Mn	3.82	1.7
Hg	0.38	0.3 - 1
Ni	0.06	0.5
Pb	< 0.20	0.3
Zn	12.02	15
DDT total	< 1	< 1
PCB	0.59	0.5 - 5
other chlorinated insecticides	< 0.05	< 0.05

*Ref. 22.

Table A-3a. Average concentrations of metals in water (µg/L) of the Yamaska River basin in the 1970s.*

Contaminant	Location							
	Adamsville	St.-Alphonse	Granby	Warden	Brigham	Cowansville	St.-Damase	Farnham
Cu	1.1	10.7	20.7	8.3	4.0		2.3	
Zn	2.6	32	6.7	72.3	4.7		6.4	
Pb	< 1.0	8.8	3.2	4.7	< 1.0		1.6	
Ni	< 0.6	11.7	10.5	36.5	< 0.6		3.9	
Co	1.0	1.8	1.2	2.4	1.0		< 0.8	
Mn	60	210	200	260	90	180	110	100
Cd	0.1	0.2	< 0.6	< 0.6	< 0.1		0.2	
Hg	0.09	0.11	0.08	0.08	0.06			

*Ref. 16.

Table A-3b. Average concentrations of metals in water (µg/L) of the Yamaska River basin in the 1970s.*

Contaminant	Location						
	St.-Pie	St.-Hector	Roxton Falls	St.-Nazaire (mouth)	Yamaska	St.-Marcel	Hwy 20
Cu	2.0					3.6	
Zn	5.4					8.7	
Pb	1.6					2.3	
Ni	1.2					1.2	
Co	< 0.8					1.4	
Mn	80	80	90	110	80	80	80
Cd	0.4					< 0.1	
Hg	0.1						

*Ref. 16.

Table A-3c. Average concentrations of metals in water (µg/L) of the Yamaska River basin in the 1970s.*

Contaminant	Location			
	Douville	David River (mouth)	Salvail River (mouth)	Chibouet River (mouth)
Cu				
Zn				
Pb				
Ni				
Co				
Mn	130	70	110	120
Cd				
Hg				

*Ref. 16.

Table A-4a. Average concentrations of metals in sediment (mg/kg dry weight) of the Yamaska River basin in the 1970s.*

Contaminant	Location							
	Adamsville	St.-Alphonse	Granby	Warden	Brigham	Cowansville	St.-Damase	Farnham
As	2.25	2.47	2.17	5.10	1.45			
Cu	10	15.6	28.0	87.3	10.5			
Zn	80.5	82.3	109.6	666.0	46.5			
Pb	12	25	54	147	9.5			
Ni	18	13.6	18.6	271	11.5			
Co	7	5.3	5.3	8.0	4.5			
Mn	590	253	351	397	249			
Cd	0.1	0.5	0.5	1.8	0.1			
Cr	13.5	22.3	25.0	726	12.0			
Hg	0.03	0.09	0.1	0.3	0.06			

*Ref. 16.

Table A-4b. Average concentrations of metals in sediment (mg/kg dry weight) of the Yamaska River basin in the 1970s.*

Contaminant	Location						
	St.-Pie	St.-Hector	Roxton Falls	St.-Nazaire (mouth)	Yamaska	St.-Marcel	Hwy 20
As	0.5				1.45		0.6
Cu	5.0				19.0		8.0
Zn	33.0				70.5		52.0
Pb	7.0				13		31
Ni	8.0				32		11
Co	2.0				11		3.0
Mn	112				428		106
Cd	< 0.1				< 0.1		< 0.1
Cr	7.0				51.5		13
Hg	0.05				0.05		0.05

*Ref. 16. There were no analyses done on sediments from Douville or the David, Salvail and Chibouets Rivers.

Table A-5a. Concentrations of metals in sediment (mg/kg dry weight) in the Yamaska River basin.*

Metal	Location					
	Etang Brome	Lac Brome (81)	Lac Brome (02)	Lac Boivin	Lac Roxton (05)	Lac Roxton (09)
Mn	1232	488	984	986	1286	2108
Cu	23	10	22	27	27	17
Zn	168	106	180	306	180	78
Pb	51	33	105	88	95	34
Ni	40	19	38	180	31	10
Co	13	6	10	15	12	4
Cr	6	4	8	41	7	2
Cd	< 0.1	0.9	1.4	1.7	0.8	0.6
As	4.4	2.1	4.0	4.8	3.6	3.3
Hg	0.1	0.1	0.2	0.2	0.1	0.1

*Ref. 17.

Table A-5b. Concentrations of metals in sediment (mg/kg dry weight) in the Yamaska River basin.*

Metal	Location					
	Lac Waterloo (35)	Lac Waterloo (40)	Lac d'Avignon	St.-Pie	Shefford Vale	Granby (below)
Mn	630	700	700	346	4080	208
Cu	42	38	22	9	20	24
Zn	298	260	108	66	90	98
Pb	140	110	30	4	135	37
Ni	44	39	32	11	40	12
Co	10	10	12	5	9	5
Cr	10	10	7	3	5	5
Cd	2.0	1.7	< 0.1	< 0.1	0.4	0.6
As	4.9	4.6	4.0	1.5	5.5	1.2
Hg	0.5	0.3	0.07	0.03	0.04	0.1

*Ref. 17.

Table A-5c. Concentrations of metals in sediment (mg/kg dry weight) in the Yamaska River basin.*

Metal	Location						
	Yamaska	Brigham	Warden	Lac Brome (outlet)	Lac Choiniere (01)	(02)	(03)
Mn	554	626	560	440	1020	482	620
Cu	20	19	87	31	32	15	20
Zn	90	70	650	150	258	66	158
Pb	43	7	120	59	49	8	28
Ni	25	14	135	35	155	22	60
Co	10	6	9	8	15	10	9
Cr	9	3	80	8	41	5	19
Cd	< 0.1	0.6	1.8	0.6	0.8	< 0.1	0.8
As	1.9	1.3	4.8	1.5	4.3	2.0	2.8
Hg	0.04	0.03	0.3	0.2	0.1	0.04	0.08

*Ref. 17.

Table A-6. Concentrations (μg/L) of soluble (S) and particulate (P) metals in the Yamaska River basin.*

Metal	Location							
	Adamsville	St.-Alphonse-de-Granby	Brigham	St.-Damase	St.-Pie	St.-Marcel (1)	(2)	(3)
Cd (S)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
(P)	0.43	0.06	0.07	0.54	0.55	0.43	0.33	0.05
Cu (S)	0.2	1.5	1.9	0.9	0.6	1.9	0.6	2.2
(P)	0.23	0.25	0.25	0.32	0.21	0.93	3.55	2.8
Pb (S)	< 1.0	not measured	3.5	2.5	< 1.0	1.0	1.0	< 1.0
(P)	0.63	1.27	0.45	0.95	0.51	1.46	5.27	2.96
Zn (S)	1.6	22.6	3.1	4.5	4.5	5.4	< 0.5	8.0
(P)	0.94	1.82	0.73	1.24	1.04	4.38	16.95	12.48

*Ref. 2.

Table A-7. Concentrations of metals in suspended particulate material (mg/kg dry weight) from the Yamaska River basin.*

Metal	Location							
	Adamsville	St.-Alphonse-de-Granby	Brigham	St.-Damase	St.-Pie	St.-Marcel (1)	(2)	(3)
Cd	116	26	26	110	172	24	< 3.4	< 1.1
Co	< 45.8	< 49.3	< 40.5	< 22.5	< 29.7	< 20.1	< 16.9	< 17.6
Cu	63	105	94	64	66	51	31	35
Ni	255	190	103	257	122	88	79	55
Pb	169	532	168	193	159	80	46	37
Zn	252	766	270	252	322	240	148	156

*Ref. 2.

Table A-8. Average PCB concentrations in fish and mussels (mg/kg wet weight of edible portion) from the Yamaska River in 1978.

Location	White sucker	Walleye	Other fish	Elliptio	Lampsilis
03030045					
03030043					
03030031				0.009	
03030044				0.027	0.030
03030035	0.20	0.52		0.013	0.009
03030082	0.78	1.09			
03030042	0.81				

Ref. 23. The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030043	Yamaska North at Hwy 10 downstream of Granby
03030031	Yamaska South-East 3.2 km from its mouth, downstream of Brigham
03030044	Yamaska 3.0 km above the bridge at Farnham
03030035	Noire, about 3 km upstream of Saint-Pie
03030082	Yamaska 0.5 km above confluence with de l'Orme creek, downstream of Saint-Hyacinthe
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis river

Table A-9. Concentrations of metals in various samples from the Yamaska River basin.*

Metal/Location	Water	Sediment	Plants	Mussels	White sucker	Walleye	Other fish
Arsenic							
03030082			4				
Cadmium							
03030045		1.4					
03030043		1.1					
Chromium							
03030045	9.2	420					
03030044				1.6			
03030035						3.0	
03030082		60			2.5		
03030042			20				
Copper							
03030045		58					
03030043		62					
03030044				3.92			1.36 (carp)
03030035				3.33		2.07	
Mercury							
03030045		0.23					
03030043		0.23					
03030031				0.15		0.78	
03030044		0.13					
03030035						0.58	
Nickel							
03030045	26	210					
03030035						1.1	
03030042					1.0	1.0	
Lead							
03030045		105					
03030043		82					

cont'd next page

Table A-9 cont'd

Metal/Location	Water	Sediment	Plants	Mussels	White sucker	Walleye	Other fish
Zinc							
03030045	36	630					
03030043		264	324				
03030044				41-171			
03030082	50						

Ref. 24. Concentrations in water are given in µg/L; in sediment (dry weight), plants and tissues (wet weight), mg/kg. The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030043	Yamaska North at Hwy 10 downstream of Granby
03030031	Yamaska South-East 3.2 km from its mouth, downstream of Brigham
03030044	Yamaska 3.0 km above the bridge at Farnham
03030035	Noire, about 3 km upstream of Saint-Pie
03030082	Yamaska 0.5 km above confluence with de l'Orme creek, downstream of Saint-Hyacinthe
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis river

Table A-10. Concentrations of chlorinated pesticides in fish and mussels (µg/kg wet weight) from the Yamaska River basin.

Pesticide/Location	White sucker	Walleye	Other fish	Elliptio	Lampsilis
DDT total					
03030031				9	
03030044				6	5
03030035	106	233		18	24
03030082	176	235			
03030042	124				
DDT					
03030031				4	
03030044				2	2
03030035	32	33		3	10
03030082	47	62			
03030042	18				
DDE					
03030044				1	1
03030035	27	154		1	1
03030082	67	84			
03030042	51				
DDD					
03030031				5	
03030044				3	2
03030035	47	46		14	13
03030082	62	89			
03030042	55				
Dieldrin					
03030031				1	
03030035	11	15		2	2
03030082	14	34			
03030042	9				

cont'd next page

Table A-10 cont'd

Pesticide/Location	White sucker	Walleye	Other fish	Elliptio	Lampsilis
Hexachlorobenzene					
03030035	0.6	2.0			
03030082	0.6	2.4			
03030042	2.2				

Ref. 25. The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030043	Yamaska North at Hwy 10 downstream of Granby
03030031	Yamaska South-East 3.2 km from its mouth, downstream of Brigham
03030044	Yamaska 3.0 km above the bridge at Farnham
03030035	Noire, about 3 km upstream of Saint-Pie
03030082	Yamaska 0.5 km above confluence with de l'Orme creek, downstream of Saint-Hyacinthe
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis river

Table A-11. Concentrations of PCBs (mg/kg) in sediment, mussels and fish in the Yamaska River basin in 1980.*

Location	Sediment	Macrophytes	Mussels	White Sucker	Redhorse	Walleye	Pike
03030059	0.1	0.05		0.3			
03030040	0.2	0.2					
03030171	<0.02	<0.02					
03030028		0.13					
03030031	<0.02	0.06	<0.02		0.3	0.8	
03030044	<0.02	0.5					
03030035	<0.02	0.08	0.02	0.13			
03030082	0.2	0.4		1.1			
03030042	<0.02	0.1		0.8	0.7		

Ref. 26. The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030059	Yamaska North at Waterloo (Hwy 243 bridge)
03030040	Yamaska North at Hwy 243 bridge 2.9 km downstream of Waterloo
03030171	Yamaska North in Choiniere Reservoir
03030028	Yamaska North 1.9 km downstream of Saint-Alphonse-de-Granby
03030031	Yamaska South-East 3.2 km from its mouth, near Brigham
03030044	Yamaska 3.0 km downstream of Farnham
03030035	Noire River 1 km upstream of Emileville
03030082	Yamaska downstream of Saint-Hyacinthe 0.5 km above confluence with de l'Orme creek
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis River

Table A-12. Concentrations of metals in water, sediment, mussels and fish in the Yamaska River basin in 1980.

Metal/Location	Water	Sediment	Macrophytes	Mussels	White sucker	Redhorse	Walleye	Pike
Arsenic								
03030059	<6	16	<1		<0.02			
03030040	<2	17	9.1					
03030171	<2	9	3					
03030028	<2	17	5					
03030031	2	11	3	0.03		<0.02	<0.02	
03030044		2.5	<1					
03030035	<2	6.3	2	0.05	0.02			
03030082	<2	<1	2		<0.002			
03030042	<2	7.3	2		<0.02		<0.02	
Cadmium								
03030059	<2	<1	<0.5		0.007			
03030040	5	5	1.4					
03030171	<2	<1						
03030028	5	1.6	1.5					
03030031	<2	<1	<0.5	0.03		0.012	0.006	
03030035	<2	<1	<0.5	0.07	0.006			
03030082	<2	<1			0.007			
03030042	<2	<1	<0.5		0.016		0.008	
Chromium								
03030059	<10	37	3					
03030040	33	111	97					
03030171	<10	14						
03030028	37	239	140					
03030031	25	33	13	1.9				
03030044		16						
03030035	14	12	21	0.9				
03030082	13	39	28					
03030042	20	33	14					
Copper								
03030059	<40	22	<3					
03030040	210	578	678					
03030171	<40	21						
03030028	14	57	74					
03030031	5	27	11	0.2				
03030044		16						
03030035	16	20	18	0.1				
03030082	4	51	46					
03030042	<40	59	18					
Mercury								
03030059		0.97	<0.004		0.05			
03030040		0.52	0.42					
03030171		0.08						
03030028		0.58	0.27					
03030031		0.06	<0.004	0.19		0.08	0.54	
03030044		0.06	0.22					
03030035		0.08	0.12	0.08	0.24			
03030082		0.29	0.18		0.13			
03030042		0.03	0.10		0.12		0.22	

cont'd next page

Table A-12 cont'd

Metal/Location	Water	Sediment	Macrophytes	Mussels	White sucker	Redhorse	Walleye	Pike
Nickel								
03030059	<30	27	4					
03030040	90	171	196					
03030171	<30	26						
03030028	20	36	26					
03030031	39	25	16					
03030044		13						
03030035	20	19	19					
03030082	20	31	34					
03030042	20	39	19					
Lead								
03030059	<30	107	5		<0.05			
03030040	31	155	120					
03030171	<30	14						
03030028	300	150	103					
03030031	30	34	13	0.02		<0.05	<0.05	
03030044		13						
03030035	121	16	10	0.07	0.05			
03030082	58	46	31		<0.05			
03030042	58	28	10		<0.05		<0.05	
Zinc								
03030059	<30	140	34		17.1			
03030040	500	782	829					
03030171	<30	52						
03030028	190	406	339					
03030031	700	107	28	24.6		23.2	17.9	
03030044		63						
03030035	38	61	119	18.5	17.8			
03030082	134	147	285		19.1			
03030042	370	112	69		13.9		13.3	

Ref. 27. Concentrations are in µg/L for water and mg/kg for sediment (dry weight) and tissues (wet weight). The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030059	Yamaska North at Waterloo (Hwy 243 bridge)
03030040	Yamaska North at Hwy 243 bridge 2.9 km downstream of Waterloo
03030171	Yamaska North in Choiniere Reservoir
03030028	Yamaska North 1.9 km downstream of Saint-Alphonse-de-Granby
03030031	Yamaska South-East 3.2 km from its mouth, near Brigham
03030044	Yamaska 3.0 km downstream of Farnham
03030035	Noire River 1 km upstream of Emileville
03030082	Yamaska downstream of Saint-Hyacinthe 0.5 km above confluence with de l'Orme creek
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis River

Table A-13. Concentrations of chlorinated pesticides in sediment, macrophytes, mussels and fish from the Yamaska River basin, 1980.

Pesticide/Location	Sediment	Macrophytes	Mussels	White sucker	Redhorse	Walleye	Pike
DDT							
03030059	<4	<4		26			
03030040	<4	87					
03030171	<4	<4					
03030028		40					
03030031	<4	<4	<4			26	
03030044	<4	<4					
03030035	<4	<4	<4	30			
03030082	<4	<4		<4			
03030042	<4	<4		50		32	
DDE							
03030059	23	<4		189			
03030040	77	34					
03030171	<4	<4					
03030028		<4					
03030031	<4	<4	<4		9	104	
03030044	<4	<4					
03030035	<4	<4	8	38			
03030082	<4	7		94			
03030042	4	<4		61			
DDD							
03030059	<4	<4		284			
03030040	<4	260					
03030171	<4	<4					
03030028		<4					
03030031	<4	<4				13	
03030044	<4	6					
03030035	<4	<4	<4	12			
03030082	7	<4		47			
03030042	10	10		22		25	
DDT							
03030059	23	<4		499			
03030040	77	381					
03030171	<4	<4					
03030028		40					
03030031	<4	<4	<4			143	
03030044	<4	6		79			
03030035	<4	<4	8	141			
03030082	11	7		133			
03030042	5	10				132	
Dieldrin							
03030059				<4			
03030040							
03030171							
03030028							
03030031						7	
03030044							
03030035				<4			
03030082				<4			
03030042				6		13	

cont'd next page

Table A-13 cont'd

Pesticide/Location	Sediment	Macrophytes	Mussels	White sucker	Redhorse	Walleye	Pike
Hexachlorobenzene							
03030059				<4			
03030040							
03030171							
03030028							
03030031						<4	
03030044							
03030035				<4			
03030082				<4			
03030042				<4		<4	

Ref. 28. Concentrations are in µg/kg for sediment (dry weight) and tissues (wet weight). The site descriptions are given below:

Number	Location
03030045	Yamaska North 1.6 km above bridge on Hwy. 243 downstream of Waterloo
03030059	Yamaska North at Waterloo (Hwy 243 bridge)
03030040	Yamaska North at Hwy 243 bridge 2.9 km downstream of Waterloo
03030171	Yamaska North in Choiniere Reservoir
03030028	Yamaska North 1.9 km downstream of Saint-Alphonse-de-Granby
03030031	Yamaska South-East 3.2 km from its mouth, near Brigham
03030044	Yamaska 3.0 km downstream of Farnham
03030035	Noire River 1 km upstream of Emileville
03030082	Yamaska downstream of Saint-Hyacinthe 0.5 km above confluence with de l'Orme creek
03030042	Yamaska downstream of Yamaska, 1.6 km from Saint-Louis River

Table A-14. Concentrations of herbicides in water (µg/L) at the mouth of the Yamaska River, 1976 - 1981.*

Herbicide	Year				
	1976				
	May 12	June 7	July 4-5	August 2	September 6
atrazine	0.11	0.14	6.43	0.97	0.43
de-ethyl atrazine	0.10	0.15	1.74	0.36	0.24
de-isopropyl atrazine		<0.02	0.39	0.04	0.06
propazine			0.11		
2,4-D	0.028	0.036	0.009	<0.002	0.032
2,4,5-T			0.006	0.007	0.032
	1980				
	July 24		August 12	September 3	
atrazine	5.10		0.16	0.14	
de-ethyl atrazine	1.43		0.03	0.07	
de-isopropyl atrazine	1.00				
	July		August	September	
2,4-D	0.002		0.004	0.009	
2,4,5-T	<0.002		<0.002	<0.002	
silvex			<0.002	0.002	
	1981				
	July				
atrazine	3.77				
de-ethyl atrazine	1.43				
de-isopropyl atrazine	0.22				
2,4-D	0.011				
2,4,5-T	<0.002				
silvex	0.002				

*Ref. 29.

Table A-15. Concentrations of pesticides at the mouths of the Yamaska River and three of its tributaries in 1987-88.

River/Pesticide	Date	Concentration (µg/L)
Yamaska		
2,4-dichloropropionic acid	July 07/87	0.193
	July 14/87	1.200
	July 21/87	0.750
	July 28/87	0.523
2,4-D	June 30/87	0.38
picloram	June 30/87	0.62
metolachlor	June 30/87	0.14
	July 07/87	0.16
	July 14/87	0.10
	May 24/88	0.83
	June 07/88	0.36
	June 28/88	0.17
atrazine	June 30/87	3.60
	July 07/87	17.50
	July 14/87	6.40
	July 21/87	6.20
	July 28/87	3.53
	Aug 04/87	2.10
	Aug 06/87	2.90
	May 11/88	0.19
	May 17/88	0.18
	May 24/88	1.00
	Jun 21/88	2.10
	Jun 28/88	1.20
diazinon	May 17/88	0.08
	Jun 28/88	2.20
α-BHC	Oct 14/87	0.0014
cis-chlordane	Oct 14/87	0.0005
Yamaska South		
metolachlor	Jun 28/88	1.10
atrazine	May 17/88	0.44
	June 28/88	2.90
diazinon	May 17/88	0.20
	June 28/88	5.70
Chibouet		
metolachlor	June 28/88	0.24
atrazine	May 17/88	0.60
	June 28/88	1.60
diazinon	May 17/88	0.20
	June 28/88	2.40

cont'd next page

Table A-15 cont'd

River/Pesticide	Date	Concentration (µg/L)
David		
metolachlor	June 28/88	0.13
atrazine	May 17/88	0.50
	June 28/88	1.20
diazinon	May 17/88	0.20
	June 28/88	3.30

Ref. 30.

Table A-16. Characteristics of five agricultural watersheds in the Yamaska River basin (1974-75).*

Saint-Nazaire River

Total area (km^2)	109
Cultivated area (km^2)	53.8
Corn area (km^2)	8.4
Predominant soil types of corn-growing land:	
Series name	Taxonomic name
Courval sandy loam	Humaquept
Ste. Jude sand	Aquic orthod
Ste Damase sandy loam	
Topography & Elevation Range (m)	flat (60 - 100)
Discharge ($m^3 \times 10^{-6}$/yr)	1974: 74.01
	1975: 56.40

Chibouet River

Total area (km^2)	145
Cultivated area (km^2)	84.1
Corn area (km^2)	13.7
Predominant soil types of corn-growing land:	
Series name	Taxonomic name
Ste. Rosalie clay	Humaquept
Ste. Jude sand	Aquic orthod
Ste Damase sandy loam	Humaquept
Topography & Elevation Range (m)	flat, gullied (12-75)
Discharge ($m^3 \times 10^{-6}$/yr)	1974: 98.45
	1975: 75.05

Salvail River

Total area (km^2)	206
Cultivated area (km^2)	129.2
Corn area (km^2)	34.8
Predominant soil types of corn-growing land:	
Series name	Taxonomic name
Yamaska sandy loam	Aquic orthod
Ste. Jude sand	Aquic orthod
Topography & Elevation Range (m)	flat, gullied (8-30)
Discharge ($m^3 \times 10^{-6}$/yr)	1974: 139.87
	1975: 106.62

cont'd next page

Table A-16 cont'd. Characteristics of five agricultural watersheds in the Yamaska River basin (1974-75).*

---

a la Barbue River

Total area (km^2)	119
Cultivated area (km^2)	50.5
Corn area (km^2)	12.7
Predominant soil types of corn-growing land:	
Series name	Taxonomic name
Yamaska heavy clay loam	Aquic orthod
Ste. Rosalie clay	Humaquept
Ste Rosalie clay loam	Aquic orthod
Topography & Elevation Range (m)	flat (30-100)
Discharge ($m^3 \times 10^{-6}$/yr)	1974: 80.80
	1975: 61.59

Runnets Creek

Total area (km^2)	62.5
Cultivated area (km^2)	21.8
Corn area (km^2)	2.2
Predominant soil types of corn-growing land:	
Series name	Taxonomic name
Yamaska silt loam	Aquic orthod
Racine sandy loamloam	Aquic orthod
Topography & Elevation Range (m)	hilly (75-225)
Discharge ($m^3 \times 10^{-6}$/yr)	1974: 52.39
	1975: 26.89

---

*Ref. 31.

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Canada Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6