ECOTOXICOLOGICAL RISK ASSESSMENT OF CONTAMINATED SEDIMENTS IN THE CHAUDIÈRE RIVER AFTER THE LAC-MÉGANTIC RAILWAY ACCIDENT

Mélanie Desrosiers[1], Christian Bastien[1], Jean-Pierre Blouin[1], Patrice Couture[2], Christian Deblois[1], Charles Gauthier[2], Paule Emilie Groleau[1], Julie Moisan[4], Gabriel Munoz[3], Lyne Pelletier[4], Yvon Richard[4], Sylvain Roy[5], Sébastien Sauvé[3], Gaëlle Triffault-Bouchet[1]

[1]Centre d'expertise en analyse environnementale du Québec, Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC), 2700, rue Einstein, Québec, QC, Canada G1P 3W8;
[2]INRS-Centre Eau Terre Environnement, 490 rue de la Couronne, Québec, QC, G1K 9A9,
[3]Département de chimie, Université de Montréal, C.P. 6128 Centre-Ville, Montréal, QC, Canada H3C 3J7
[4]Direction générale du suivi de l'état de l'environnement, MDDELCC,
[5]Direction des opérations régionales faune Estrie-Montréal-Montérégie, Ministère des Forêts, de la Faune et des Parcs, 770, rue Goretti, Sherbrooke, Québec, J1E 3H4.

ABSTRACT

The railway accident of Lac-Mégantic on July 6th 2013, released a spill of approximately 100 000 L of light crude oil into the Chaudière River. An ecotoxicological risk assessment of the residual sediment contamination was therefore conducted in the Chaudière River one year following the accident. Several contaminants were measured in sediments, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and their alkyl derivatives, metals, and a vast array of poly and perfluoroalkylated surfactants (PFASs). Various ecotoxicological endpoints were also considered in the present study. Toxicity bioassays have demonstrated negative effects on the survival or growth of benthic organisms and an increase in the incidence of spinal deformities of brown trout larvae exposed to sediments contaminated with petroleum hydrocarbons above the acute reference value (ARV; 832 mg/kg). In areas of the river where the sediment contamination exceeded the ARV, the structure of the benthic macroinvertebrate community was modified compared to sediments with little or no contamination. Taken together, these results would tend to suggest an ecotoxicological risk associated with the presence of petroleum hydrocarbons in the sediments of the Chaudière River at concentrations above 832 mg/kg. However, at the end of 2014, an important reduction of the sediment contamination was observed in the Chaudière River and only a few sectors located primarily in the first fifteen kilometers of the river still displayed concentrations of petroleum hydrocarbons above the ARV and may therefore pose an ecotoxicological risk to aquatic organisms. Overall, these results imply the need for continuous monitoring programs for sediment contamination and benthic macroinvertebrate and fish communities' structure.

Keywords: Four or Five Keywords (First Characters of Each Word are in Capital/Uppercase Letters), Italic

INTRODUCTION

On July 6th 2013, a train of 72 wagons carrying 7.7 million liters of light crude oil derailed in downtown Lac-Mégantic, causing explosions and a spill of approximately six million liters of oil. While a large proportion of the spilled petroleum is believed to have burned, it is estimated that about one hundred thousand liters of oil reached the Chaudière River, whose headwaters are located in Lac-Mégantic.

During the summer and fall of 2013, decontamination teams have been cleaning up the shoreline and, whenever possible, entire sections of the river using manual methods. During the same period, a large number of visual observations and numerous samplings were carried out to assess the level and extent of environmental contamination by oil, its derivatives, and other relevant micropollutants.

In January 2014, the *Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques* (MDDELCC – The province of Québec's ministry of the environment) named an Expert Committee on the Chaudière River to generate a stream of status reports on the results obtained from 2013 onwards, determine the potential impacts to the ecosystem, and develop a residual contamination management plan. The plan proposed by the Expert Committee was adopted by the Ministry and published on May 12th 2014 [1].

Characterization studies conducted in 2013 in the Chaudière River revealed significant contamination of sediments by petroleum hydrocarbons [1]. In view of these findings, the MDDELCC expert committee has recommended further studies, namely: 1) additional chemical characterization of sediments; 2) monitoring the levels of contamination in fish muscle and liver tissues in the Chaudière River; 3) characterization of the toxicity of these sediments in the laboratory vis-à-vis the benthic organisms and young stages of fish; and 4) monitoring of benthic and fish communities in the Chaudière River. The Expert Committee also recommended the implementation of an Ecological Risk Assessment (ERA) associated with the residual contamination of sediments from the Chaudière River in order to integrate all the data gathered and provide guidance on the management of contaminated sediments [1].

Thus, the ERA presented in this document is associated with the residual sediment contamination of the Chaudière River. It addresses the risk to aquatic organisms associated with the presence of residual chemicals following the train derailment accident. Given the nature and the extent of the spill, petroleum hydrocarbons, including C_{10}-C_{50} hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), were of particular interest. Other contaminants that may be present in the sediments were also incorporated in this assessment, in particular poly and perfluoroalkyl compounds (PFASs) that are key components of high performance aqueous film forming foams (AFFFs) used to fight against fuel fires. The effects on aquatic organisms were evaluated using data generated in projects included in the Chaudière River Management Plan [1].

ECOLOGICAL RISK ASSESSMENT (ERA)

Many ERA frameworks adapted to contaminated sediments have been published, either for dredging or restoration activities [2-5]. It is a common approach in ERA for contaminated sediment consider several risk assessment tools such as chemical analysis, bioaccumulation potential of contaminants in aquatic toxicity tests and even community structure [3, 4, 6]. This approach is usually sequential, starting with chemical analyses and subsequent comparison to quality criteria to determine whether it is appropriate to further proceed with an assessment of effects on different ecological receptors [4, 7]. It is also possible to perform a simultaneous analysis of an earlier stage before moving to the next [8, 9]. This latter approach is the one that has been prioritized for risk assessment of the residual contamination in the sediments of the Chaudière River, following the Lac-Mégantic railway accident.

METHODOLOGY

Sediment sampling and analysis

Surface sediment (0-10 cm) were sampled in September and October 2014 at 20 locations, selected according to a gradient of sediment contamination by petroleum hydrocarbons [1], as well as preliminary results on the characterization of contaminated sediments performed in 2014 by Conestoga-Rovers & Associates. These sampling sites were located in the first 30 km of the Chaudière River. Note that the sampling of sediments in the sector KP 4.5 was made before the dredging operations in October 2014 to collect more contaminated sediments [10].

Sediments were collected with a shovel on the shore above the water or flooded shoreline (<15 cm of water), filled in 20 liter aluminum bucket and stored at 4°C upon arrival at the laboratory. Sediments were then sieved (4 mm), homogenized, divided into glass containers for various chemical and biological analysis, and stored frozen (-20 ° C).

The physicochemical parameters analyzed in sediment samples are the following: sediment grain size, total organic carbon (TOC), C_{10}-C_{50} petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) including alkylated PAHs, fluorinated surfactants (PFASs), and metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc, etc.).

Toxicity tests were carried out on the *Chironomus riparius* larval stage according to the SPE 1/RM/32 protocol [11] with some modifications from the AFNOR T90 339-1 method [12]. After seven days of exposure to contaminated sediments, survival and growth (length) of *C. riparius* larvae were determined.

Hyalella azteca toxicity tests were conducted in accordance with the SPE 1/RM/33 protocol [13]. The growth of amphipods was evaluated by measuring the length of each organism as recommended by the AFNOR method T90 339-1 [14]. After fourteen days of exposure to contaminated sediments, survival and growth (length) of the amphipods were determined [15].

To determine the toxicity of sediments for young fish stages, two species representing two trophic levels of the river food web were selected. The first species considered is the fathead minnow (*Pimephales promelas*), and the second one is the brown trout (*Salmo trutta*) [16].

The characterization of the structure of sediment-dwelling macroinvertebrate communities was conducted in 2014 in sedimentation areas following a contamination gradient by petroleum hydrocarbons.

At each station, sampling was performed by wading in the shallow area of the Chaudière River and taking three samples with an Eckman grab. The contents were transferred to a mesh bottom bucket (540 µm mesh). After rinsing to remove a portion of the fine sediments, the catch was transferred to pots and maintained in 95% alcohol colored with a Bengal pink solution. Samples were transported to the laboratory for sorting and identification [17].

Sediment quality guidelines

The results of metal analyses, dioxins/furans and PAHs were compared with the criteria for the assessment of sediment quality in Québec [18]. ERA was performed using specific management thresholds in the context of restoration, considering the probable effect level (PEL) and the frequent effect level (FEL; EC and MDDEP, 2007).

Lacking provincial sediment quality guidelines (SQGs) for C_{10}-C_{50} petroleum hydrocarbons, the MDDELCC [19] has recommended the utilization of reference values generated by studies of the Atlantic RBCA [20], based on the work of Di Toro et al [21, 22], namely:

- Chronic reference value (CRV): 164 mg/kg;
- Acute reference value (ARV): 832 mg/kg.

In the context of this ERA, these values were used to interpret the petroleum hydrocarbons concentrations in sediments of the Chaudière River and establish quality classes:

- Class 1: The concentration of contaminants falls lower than the CRV and PEL;
- Class 2: The concentration is higher than the CRV, but less than or equal to the ARV or higher than the PEL, but less than or equal to the FEL for at least one contaminant;
- Class 3: The concentration is higher than the ARV or FEL for at least one contaminant.

RESULTS AND DISCUSSION

Sediment contamination

Table 1 shows quality classes for the contaminants above SQGs investigated in the present study:

- Six sediment samples show Class 3 level of contamination;
- Seven sediment samples show Class 2 level of contamination;
- Seven sediment samples show Class 1 levels of contamination.

The evaluation of the biological effects was conducted according to the final quality classes in Table 1. Metals and dioxins/furans results were always classified in Class 1. Ranking for macroinvertebrates community structure was done on all characterization data available for 2013 and 2014 [23].

Table 1: Ranking of sediments sampled in the Chaudière River according to the concentration of C_{10}-C_{50} petroleum hydrocarbons, that of PAHs, and the final score according to the most stringent of the latter two criteria (Class 1: green; Class 2: yellow and Class 3: orange).

Sites	Ranking C_{10}-C_{50}	Ranking PAHs	Final ranking
STA4A-4B	1	1	1
9	1	1	1
394	1	1	1
STA3A-3B	1	1	1
121	1	1	1
301-302	1	1	1
95	1	1	1
469b/ZA-39	1	2	2
388	2	1	2
282	2	1	2
24	2	1	2
DR49	2	3	3
DR50	2	1	2
405-406	2	1	2
48-49	2	1	2
STA9A-9B	3	2	3
DR58	3	2	3
STA6A	3	1	3
DR57	3	3	3
DR42-56	3	2	3

Toxicity to macroinvertebrates

As evidenced in Figure 1, the results confirm a significant toxic effect on benthic organisms for three out of six sediments tested [23]. Overall, mortality was significantly higher in Class 3 sediments for the *C. riparius*. This trend was also observed for *H. azteca*, but it was not significant due to the higher variability observed for Class 3 sediments for this species.

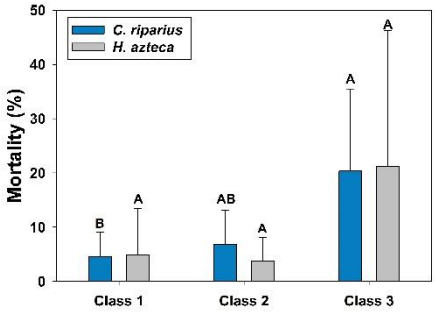

Fig 1. Average mortality (± standard deviation, SD) of *Chironomus riparius* and *Hyalella azteca* based on sediment final quality classes.

Toxicity to early life stages of fish

Figure 2 shows significantly longer fish egg hatching time, and a significantly higher percentage of scoliosis for larvae of brown trout (*Salmo trutta*) exposed to Class 3 sediments. In contrast, Class 1 and Class 2 sediments have shown little or no toxic effects for the fish species considered. Hence, long-term exposure of young stages of fish to water in contact with the most contaminated sediments of the Chaudière River (especially Class 3 sediments with higher content of C_{10}-C_{50} petroleum hydrocarbons or PAHs) could induce an increase in fry deformities and thus affect their survival and development.

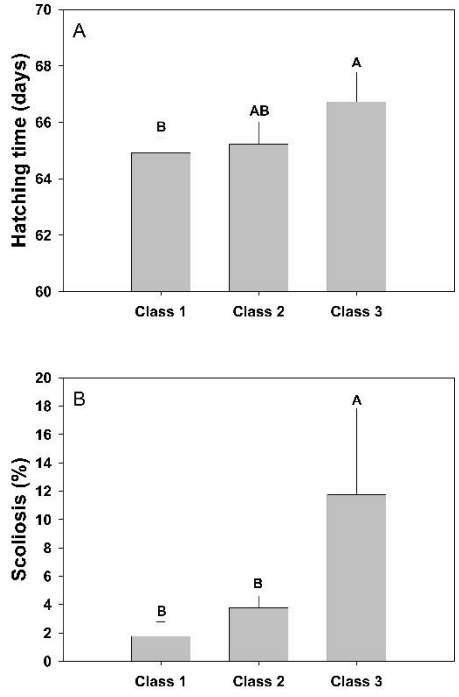

Fig. 2. Hatching time (average ± SD) (A) and incidence of scoliosis (B) in brown trout (*Salmo trutta*) exposed to sediments from the Chaudière River.

Impact on macroinvertebrates community

In sediments from the Chaudière River, at sites where sediments were of Class 1 or 2, the benthic macroinvertebrate community mainly comprised aquatic insects (larval and adult), accounting for 50 to 63% of the community (represented mainly by *Chironimidae* of tribe *Chironomini*), while worms (*Oligochaeta*) accounted for 15 to 40% of the community. At the six sites where sediments are highly contaminated (Class 3), abundance patterns were inverted, the percentage of aquatic insects representing 6-10% of the community, while *Oligochaeta* were predominant (68-83%) [17, 23]. Communities dominated by *Oligochaeta* are considered indicative of polluted habitats [24].

ECOTOXICOLOGICAL RISK ASSESSMENT

The results obtained in the present study were used to establish a weight of evidence grid (Table 2). Ratings were assigned to translate the level of sediment contamination and the effect level partly based on toxicity tests on benthic invertebrates and on eggs and fish larvae, and partly based on the study of effects on the structure of benthic macroinvertebrate communities in sediments. Since it is delicate to estimate the degree of exposure of *in situ* fish communities to residual contamination of petroleum hydrocarbons in sediments, the results from the fish community study were not included in the weight of evidence grid. Similar reasoning applies for bioaccumulation results in fish muscle or liver [23, 25].

Table 2 shows the overall results which support these conclusive remarks [23]:

- Class 1: effects close to the 20% threshold were observed for mortality or growth of amphipods at two stations only. No toxic effects were observed in fish or on the benthic community structure. Therefore, the risk for aquatic organisms associated with the exposure to Class 1 sediments appears limited and are not cause for concern.
- Class 2: a significant toxic effect on benthic invertebrates was observed at one sampling site. No effect was observed on fish eggs nor on benthic macroinvertebrate communities. These results altogether suggest that the risk for aquatic organisms associated with exposure to Class 2 sediments appears relatively low and not overly alarming.
- Class 3: deleterious effects on the survival of benthic organisms, the development of fish larvae and the structure of benthic macroinvertebrate communities were observed.

These results indicate that the risk associated with exposure to Class 3 sediments appears relatively high and quite worrisome for the aquatic species considered in the present study.

Table 2: Weight of evidence grid for the different tools used for the Chaudière River Ecological Risk Assessment (○: no effect; ●: moderate effect; ●●: high effect)

Chemical analysis	Class 1 ○	Class 2 ●	Class 3 ●●
Toxicity on macroinvertebrates	Significant toxicity on 2/7 stations Only for one endpoint ●	Significant toxicity on 1/7 stations Only for one endpoint ●	Significant toxicity on 3/6 stations On many endpoints ●●
Toxicity on young stage of fish	No significant toxicity ○	No significant toxicity ○	Significant toxicity (scoliosis) Hatching time increased ●●
Impact on macroinvertebrates community	No significant toxicity ○	No significant toxicity ○	Increased : oligocheta Decreased : Insects and chironomids ●●

CONCLUSIONS

This study indicates an ecotoxicological risk associated with the presence of petroleum hydrocarbons and PAHs in sediments of the Chaudière River as a result of the Lac-Mégantic railway accident, principally for sediments with concentrations that exceeded ARV or FEL for at least one contaminant.

Therefore, in the Chaudière River, some sectors, mainly located within the first fifteen kilometers of the river in 2014, are characterized by elevated concentrations of C_{10}-C_{50} petroleum hydrocarbons or PAHs (Class 3 sediments). These findings further underscore the need for continued monitoring programs to assess sediment contamination and the health status of benthic macroinvertebrate communities and fish populations, as proposed by the Expert Committee for the ongoing 2015-2017 period [10].

REFERENCES

[1] MDDELCC, 2014. *Tragédie ferroviaire de Lac-Mégantic – Rapport du comité expert sur la contamination résiduelle de la rivière Chaudière par les hydrocarbures pétroliers – Constats, Recommandations, Actions proposées. Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 40 p. + annexes.*

[2] Babut, M.P., et al., 2006. *Characterizing the risks to aquatic ecosystems: A tentative approach in the context of freshwater dredged material disposal.* Integrated Environmental Assessment and Management, **2**(4): p. 330-343.

[3] Chapman, P.M. and J. Anderson, 2005. *A decision-making framework for sediment contamination.* Integrated Environmental Assessment and Management, **1**(3): p. 163-173.

[4] Environment Canada and Ontario Ministry of the Environment, 2007, *Canada-Ontario decision-making framework : For assessment of Great Lakes contaminated sediment,* Environment Canada; Ontario Ministry of the Environment. p. 84.

[5] MDDEFP and EC, 2013. *L'évaluation du risque écotoxicologique du rejet en eau libre des sédiments, en soutien à la gestion des projets de dragage en eau douce. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, 35 p. + annexes.*

[6] Chapman, P. and S.A. Mostert, 1990. *Does freezing of nutrient samples cause analytical errors?* S. Afr. J. mar. Sci., **9**: p. 239-247.

[7] Hull, R.N. and S. Swanson, 2006. *Sequential Analysis of Lines of Evidence—An Advanced Weight-of-Evidence Approach for Ecological Risk Assessment.* Integrated Environmental Assessment and Management, **2**(4): p. 302-311.

[8] Karjalainen, A.-M., et al., 2009. *Ecological risks of an old wood impregnation mill: Application of the Triad approach, Ecological risks of CCA-contaminated soil.* p. 1-45.

[9] Semenzin, E., et al., 2007. *Development of a site-specific ecological risk assessment for contaminated sites: Part II. A multi-criteria based system for the selection of bioavailability assessment tools.* Science of the Total Environment, **379**(1): p. 34-45.

[10] MDDELCC, 2015. *Tragédie ferroviaire de Lac-Mégantic – Deuxième rapport du Comité expert sur la contamination résiduelle de la rivière Chaudière par les*

hydrocarbures pétroliers - Constats - Recommandations - Actions proposées pour 2015 - 2017. 36 pages et annexes.

[11] EC, 1997. *Méthode d'essai biologique : essai de survie et de croissance des larves dulcicoles de chironomes (Chironomus tentas ou Chironomus riparius) dans les sédiments, Environnement Canada, Centre de technologie environnementale, Section de l'élaboration et de l'application des méthodes, rapport SPE 1/RM/32, 133 p.*

[12] AFNOR, 2004, *Détermination de la toxicité des sédiments d'eau douce vis-à-vis de Chironomus riparius - XP T90-339-1*, Rapport Technique, AFNOR: Paris, France.

[13] EC, 2013. *Méthode d'essai biologique : essai de survie et de croissance de l'amphipode dulcicole Hyalella azteca dans les sédiments et l'eau, Environnement Canada, Direction générale de la science et de la technologie, rapport SPE 1/RM/33, deuxième édition, 180 p.*

[14] AFNOR, 2004. *Détermination de la toxicité des sédiments d'eaux douces vis-à-vis de Hyallela azteca - Partie 1 : sédiment naturels – XP T90-339-1. Paris, France, Rapport technique, AFNOR.*

[15] MDDELCC, 2015. *Tragédie ferroviaire de Lac-Mégantic – Évaluation de la toxicité des sédiments de la rivière Chaudière pour deux organismes benthiques. Centre d'expertise en analyse environnementale du Québec. 14 pages + Annexes.*

[16] Gauthier, C. and P. Couture, 2015. *Évaluation de la toxicité des sédiments de la rivière Chaudière pour les jeunes stades de deux espèces de poissons. Rapport de recherche INRS - ETE No R1535. 18 pages + Annexes.*

[17] MDDELCC, 2015. *Tragédie ferroviaire de Lac-Mégantic – Évaluation in situ de la toxicité des sédiments de la rivière Chaudière sur les communautés de macroinvertébrés benthiques, un an après le déversement, 14 pages + annexes.*

[18] EC and MDDEP, 2007, *Critères pour l'évaluation de la qualité des sédiments au Québec et cadres d'application : prévention, dragage et restauration*. p. 39.

[19] MDDEFP, 2013. *Lignes directrices pour l'évaluation de la qualité des sédiments du Lac-Mégantic et de la rivière Chaudière, en lien avec l'accident ferroviaire du 6 juillet 2013. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, 7 p.*

[20] Atlantic RBCA, 2012. *Ecological screening protocol for petroleum impacted sites in Atlantic Canada-Scientific Rationale, Version 3, 44 pages.*

[21] Di Toro, D.M., J.A. McGrath, and D.J. Hansen, 2000. *Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. I. Water and tissue.* Environmental Toxicology and Chemistry, **19**(8): p. 1951-1970.

[22] DiToro, D.M. and J.A. McGrath, 2000. *Technical basis for narcotic chemicals and polycyclic aromatic hydrocarbon criteria. II. Mixtures and sediments.* Environmental Toxicology and Chemistry, **19**(8): p. 1971-1982.

[23] MDDELCC, 2015. *Tragédie ferroviaire de Lac-Mégantic – Évaluation du risque écotoxicologique associé à la contamination des sédiments de la rivière Chaudière. Centre d'expertise en analyse environnementale du Québec. 46 pages + annexes. .*

[24] Masson, S., et al., 2010. *Relating macroinvertebrate community structure to environmental characteristics and sediment contamination at the scale of the St. Lawrence River*. Hydrobiologia, **647**: p. 35-50.

[25] MDDELCC, 2015. *Tragédie ferroviaire de Lac-Mégantic - Impact sur les communautés piscicoles de la contamination résiduelle de la rivière Chaudière par les hydrocarbures pétroliers. 21 pages + Annexes.*