Chemical and Biological Hazard Prevention

Studies and Research Projects

REPORT **R-894**

Assessment of Worker Exposure to Disinfection Byproducts at Indoor Swimming Pools in Québec

Robert Tardif
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Manuel Rodriguez

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PEER REVIEW

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* Made up of stakeholders involved in the research, the follow-up committee provides its field expertise to the researchers during the definition, design and realization phases of the research, in the transfer and application of the results to the workplace and finally, in the assessment of the impact of this transfer. The composition of the committee is based on joint representation, the presence of organizations that can pass on information, and diverse points of view.

ABSTRACT

Chlorination disinfection byproducts (DBPs) are the inevitable result of chemical reactions between the chlorine added to swimming pool water and the organic and/or nitrogeneous matter that is naturally present or introduced by bathers.

DBPs can be broken down into numerous categories and even more components (>600), which have led to concerns from legislators and scientists worldwide about the impact of these substances on workers' health. The problems of irritation associated with exposure to chloramines (CAM) that pollute the ambient air are the most often cited. However, the potential health impacts related to chronic trihalomethane (THM) or haloacetic acid (HAA) exposure should not be neglected. The list of emerging disinfection byproducts keeps getting longer and we still know little about these substances, which, even in low quantities, have potentially serious toxic properties. Few studies on this subject have been carried out to date in Québec, and information about exposure of swimming pool staff to various DBPs remains very limited.

In that context, two major campaigns were set up to document levels of environmental contamination (in water and air) in swimming pools, and biological contamination (in urine and exhaled air) in workers, and to provide an overview of the situation.

During the first campaign (A) (fall 2012), we visited 41 indoor pools in Montréal and Québec City. At these pools, concentrations of a wide range of DBPs were measured during periods of average attendance. These included (i) among "traditional" DBPs: THMs and chloramines in both water and air, and HAAs (non-volatile) in water; (ii) among the emerging DBPs: haloacetonitriles (HAN), halonitromethanes (HNM) and haloketones (HK). These analyses were systematically accompanied by measurements of common physiochemical parameters used to characterize water quality (pH, temperature, etc.).

The second campaign (B) (spring 2013), focused on a subset of eight swimming pools chosen from among the 41 pools visited during campaign A. The levels of environmental contamination in these eight facilities were investigated again, in order to compare the findings with those observed during the first campaign, among others. At this point, *N*-nitrosodimethylamine (NDMA) was added to the list of DBPs assessed, while some additional measures enabled contamination levels in the air in rooms around the pool to be recorded.

Workers were recruited at each of these eight swimming pools (a total of 35 subjects) to voluntarily provide urine and/or alveolar air samples. The samples were collected at time zero (when the sampling staff or the worker arrived at the site), and then again after periods of activity (and thus exposure) of variable durations. The THM concentrations in the samples were then measured.

These data, particularly those concerning chloroform (TCM), were modelled to reconstruct and simulate the exposures encountered; the predictions were then validated against the field data. This made it possible for the model to be used to predict various exposure scenarios and to assess their impact on the dose absorbed.

The main results of this study included the following:

- Extremely variable environmental DBP contamination levels were found from one pool to another (both quantitatively and in terms of speciation). The levels were generally relatively high compared to standards and benchmark values from other countries, and they point to a relatively atypical presence of brominated compounds;

- DBP contamination was found in the biological matrices examined, clearly reflecting previous environmental exposure. With respect to estimations and monitoring of this contamination, an improvement in the current sampling and analysis methods is required;

- The modelling tools available provided relatively reliable predictions for reconstructing and simulating the exposure of subjects.

A massive database was constituted and it could be very useful to further explore the issue of exposure to DBPs in swimming pools from other analytical perspectives. This project enabled us to provide a preliminary diagnosis.

Until the real risks of DBPs can be better identified, we recommend putting into practice actions that will minimize exposure, mainly through reducing their formation or facilitating their elimination. Bathers must do their part by adopting responsible hygienic behaviour (showering before swimming, wearing bathing caps, etc.). The implementation of more effective and deep-seated technical solutions (increased water and air exchange) and management of more appropriate disinfection methods (e.g., chlorine dosage strategies) calls for concerted action by the various stakeholders based on an analysis of the cost-benefit ratio of interventions. With respect to research, one suggestion is to document the health problems experienced by swimming pool staff in Québec. Another suggestion is to assess the impact of different water treatment processes on environmental contamination. Finally, with respect to management, we recommend the implementation of initiatives to adopt and apply regulatory standards for certain DBPs (e.g., THM in water, NDMA in water, CAM in air).

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LIST OF ACRONYMS AND ABBREVIATIONS

11DCPone	1,1 -dichloro-2-propanone
111TCPone	1,1,1 -trichloro-2-propanone
AFSSET	Agence française de sécurité sanitaire de l'environnement et du travail (French agency for environmental and occupational health and safety)
BCA	Bromochloroacetic acid
BCAN	Bromochloroacetonitrile
CAM	Chloramine
CDBM	Chlorodibromomethane
CPK	Chloropicrin (trichloronitromethane)
DBA	Dibromoacetic acid
DBAN	Dibromoacetonitrile
DBP	Disinfection byproducts
DCA	Dichloroacetic acid
DCAM	Dichloramine
DCAN	Dichloroacetonitrile
DCBM	Dichlorobromomethane
eDBP	Emerging disinfection byproducts
EHESP	École des hautes études en santé publique (French School of Public Health)
HAA	Haloacetic acid
HAN	Haloacetonitriles
HK	Haloketones
HNM	Halonitromethanes
HS	Headspace
INRS	Institut national de recherche et de sécurité pour la prévention des accidents du travail et des maladies professionnelles (French institute for research into prevention of industrial accidents and occupational diseases)
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail (Québec institute for research into occupational health and safety)
LERES	Laboratoires d'étude et de recherche en environnement et santé (research laboratories into the environment and health, France)
MAC	Maximum acceptable concentration

MBA	Monobromoacetic acid
MCA	Monochloroacetic acid
MCAM	Monochloramine
NDMA	*N*-nitrosodimethylamine
PBTK	Physiologically based toxicokinetic (model)
SPME	Solid-phase microextraction
TBM	Tribromomethane (bromoform)
TCA	Trichloroacetic acid
TCAM	Trichloramine
TCAN	Trichloroacetonitrile
TCM	Trichloromethane (chloroform)
TDI	Tolerable daily intake
THM	Trihalomethane
TTHM	Total trihalomethanes (the four chief constituents together)

1. INTRODUCTION

1.1 Swimming Pool Exposure Compared to Domestic Exposure

The evidence of exposure to disinfection byproducts (DBP) through chlorination is troubling and raises questions about the safety and comfort of swimming pool employees, in terms of health, given the suspected harmful effects of these contaminants (see Section 2.2). It is extremely important to quantify the still relatively unknown scale of contact with DBPs at swimming pools, including how much such an environment contributes to total exposure, taking into account the more well-known and documented domestic environment (through water consumption, bathing/showering). There is no doubt that the population of workers concerned is more at risk than the general public, as they regularly work for several hours in environments where these compounds are omnipresent. However, until now, the main subjects of studies about this issue have been swimmers, such as competitive swimmers and young people, and not swimming pool workers.

Swimming pools are facilities with potentially high numbers of visitors, in which the conditions amplify the risks of exposure to various substances. Numerous factors (related to the technical demands of maintenance and/or individual behaviour) may combine to exacerbate (i) the formation and diffusion of large amounts of contaminants in environmental media (water, air), and (ii) their absorption by people. The recirculation of water, an unavoidable hydraulic practice to limit wastage, contributes to increasing the concentrations of these pollutants in swimming pools. In addition, high doses of disinfecting agents (precursors to DBPs) are added to purify the water, in microbiological terms. Added to this is bathers' non-compliance with basic rules of hygiene, which makes it impossible to minimize their continuous input of organic or nitrogenous matter (the precursor components to the formation of DBPs) into swimming pools. It is unlikely that the ventilation conditions (especially at indoor pools) always ensure effective evacuation of volatile DBPs when even the turbulence engendered by bathers' activities can accentuate the transfer of these contaminants from the pool water to the ambient air (aerosols, fine droplets). Along the same line, showering, which is recommended for hygienic reasons, has been identified as a major source of exposure of individuals to certain volatile DBPs, and they undeniably contribute to increasing contamination of the ambient air. Thus, conditions for a healthy and safe work climate (in the first sense of the term) with respect to DBP exposure (in the short- or long-term) cannot be guaranteed without investigations.

1.2 Workers Compared to Other Groups of Interest

It is highly probable that swimming pool workers do several minutes of physical activity in the workplace on a regular basis, in addition to the energetic expense associated with their activities or tasks (such as teaching swimming classes). The impact of the underlying physiological effort (e.g., increase in alveolar ventilation) may heighten the absorption capacity of some contaminants by the organism and must not be neglected (Tardif et al., 2008). Because of the diversity of tasks they perform while at work, there is no certainty that the employees onsite can take advantage of the upside of the immediate and positive effects of swimming, unlike recreational swimmers. There is a concern that the balance between risks (associated with DBP exposure) and benefits (associated with physical exercise), which is still uncertain and difficult to

establish in groups of “occasional” swimmers, may be tipped against pool staff who are working in the environment for longer periods, and, in the specific case of lifeguards, under constant stress while on the job.

It is reasonable to assume that swimming pool workers are mainly people who have been frequenting these types of facilities since they were very young, have continued as they got older, and who may also use them outside their working hours. Their prolonged presence onsite can only increase the probabilities of significant exposure.

All of these elements make the matter of exposure to DBPs at swimming pools an issue that cannot be ignored and that should be documented in more detail, in particular with respect to workers in these environments.

1.3 The Issue in Québec Compared to the Rest of the World

The international scientific community is mobilizing around this topic, and interest has not waned over the past five years, especially regarding the impact on respiratory health (e.g., asthma) and the mutagenic and genotoxic potential of DBPs (Bougault et al., 2009; Cantor et al., 2010; Fernandez-Luna et al., 2013; Font-Ribera et al., 2010; Kogevinas et al., 2010; LaKind et al., 2010; Liviac et al., 2010; Parrat et al., 2012; Richardson et al., 2010; Weisel et al., 2009).

In Europe, the subject, which has been receiving attention since the 1980s and 1990s, in particular, in Italy (Aggazzotti et al., 1990; Aggazzotti et al., 1993; Aggazzotti et al., 1995, 1998; Fantuzzi et al., 2001), is the focus of an increasing number of studies.

In France, after a study by an important group of experts, the Agence française de sécurité sanitaire de l’environnement et du travail (AFSSET), [today the Agence nationale de sécurité sanitaire, de l’alimentation, de l’environnement et du travail (ANSES); in English, the French Agency for Food, Environmental and Occupational Health and Safety] issued a comprehensive report concerning the health risks incurred at swimming pools. They included the chemical risk associated with DBPs that have been deemed of primary concern (AFSSET, 2010). The report points to exposure that could increase the frequency and gravity of respiratory diseases (bronchitis and asthma, recognized as industrial diseases among lifeguards since 2003 in France) and eczema in workers. In the first notice, the AFSSET relayed the numerous recommendations issued by the group of experts.

Specifically for workers categorized as populations at risk, taking into account the problems identified above, i.e., “asthma, rhinitis, ocular irritation, etc.,” there was a recommendation to ensure “increased medical screening at hiring, and monitoring during and after the activity.” There was also a suggestion to provide “specific training to those in charge of maintenance, water treatment and ventilation,” and to regularly measure certain contaminants. In addition, studies to obtain exposure data were encouraged to improve knowledge and complete the assessment of health risks.

The Institut national de recherche et de sécurité (INRS) for the prevention of occupational accidents and diseases, author of several studies on the health of swimming pool staff (Gérardin

et al., 2005; Massin et al., 2001; Thoumelin et al., 2005), continues its investigations into the issue. In the study by Demange et al., (2009), a group of lifeguards working at indoor pools was used as the reference for a preliminary, but conclusive study to explore the possibility of using fractional exhaled nitric oxide as a marker of respiratory passage inflammation in the scope of workplace exposure. The subject, also very topical in Spain and Belgium, will be developed in more detail in the following section and should be heeded in Québec, where the situation is at least comparable to that of many other countries.

The number of workers potentially affected by the problem is not negligible. There are over 500 swimming pool employees in Québec City alone. According to the Lifesaving Society, in the province as a whole, there are more than 18,000 lifeguards and swimming instructors, etc., whose ages vary, for the most part, from between 16 to 24 years old, working in approximately 3300 aquatic facilities, including close to 850 indoor pools. This is a considerable population for which data on DBP exposure remain basically inexistent. The absence of data and joint action in this area in Québec constitutes a shortcoming, at a time in which interest in the issue is growing and attracting the interest of people working in occupational health and safety.

2. CURRENT SCIENTIFIC OR TECHNICAL KNOWLEDGE

2.1 The Various Classes of DBPs

DBPs result from chemical reactions among disinfecting agents, such as chlorine, and the organic or nitrogenous material naturally present in the water or introduced by bathers. Among the numerous contaminants ($n > 600$) found in large quantities in swimming pools, we differentiate between compounds that are qualified as "traditional" and other byproducts referred to as "emerging" (eDBP), which have been discovered more recently through advances made in analytical procedures (Mercier Shanks et al., 2013; Richardson et al., 2007; Richardson et al., 2010; Weaver et al., 2009; Zwiener et al., 2007).

Habitually, three classes of "traditional" compounds are identified: trihalomethanes (THM), including, in particular, chloroform (TCM), chlorodibromomethane (CDBM), dichlorobromomethane (DCBM) and bromoform (TBM); haloacetic acids (HAA), including, in particular, monochloroacetic acid (MCA), monobromoacetic acid (MBA), dichloroacetic acid (DCA), trichloroacetic acid (TCA), bromochloroacetic acid (BCA), and dibromoacetic acid (DBA); and chloramines (CAM), which include monochloramine (MCAM), dichloramine (DCAM) and trichloramine (TCAM). The THMs, which are very volatile compounds, can disperse in the air, while the HAAs are mainly concentrated in the water. In the CAM group, we find mainly MCAM in water and TCAM in the air.

In the long list of eDBPs, we find, in particular: haloacetonitriles (HAN), including trichloroacetonitrile (TCAN), dichloroacetonitrile (DCAN), dibromoacetonitrile (DBAN) and bromochloroacetonitrile (BCAN); halonitromethanes (HNM), including chloropicrin or trichloronitromethane, as well as the haloketones (HK), including 1,1-Dichloro-2-propanone (11DCPone) or 1,1,1-trichloro-2-propanone (111TCPone); and *N*-nitrosodimethylamine (NDMA).

2.2 Health Impacts Associated with DBP Exposure

Recent reviews of the literature have focused on the health effects related to DBP exposure in swimming pools (Florentin et al., 2011; Villanueva and Font-Ribera, 2012). Despite the divergences in the data found in the literature and the difficulty of establishing strong causal links, the data appear to minimize the potential risks related to the presence of DBPs and to prioritize controlling the microbiological risk, even though the benefits of swimming are highlighted.

2.2.1 Impact of CAMs

At swimming pools, exposure to CAMs, and specifically to TCAMs, have been the focus of attention for managers and researchers with respect to the probable health impacts (Kaydos-Daniels et al., 2007; Kohlhammer et Heinrich, 2007; Nemery et al., 2002).

In France, the investigations conducted (several of which specifically targeted swimming instructors/lifeguards) leave few doubts about the irritating effects (respiratory and ocular) of

TCAM exposure (Gérardin and Subra, 2004; Héry et al., 1992; Héry et al., 1994; Héry et al., 1995; Massin et al., 1998; Massin et al., 2001; Pommier de Santi et al., 2004; Thoumelin et al., 2005). British, Dutch and Swiss investigations dealing specifically with occupational exposure at swimming pools support the probability of the suspected link (Jacobs et al., 2007; Parrat, 2008; Parrat et al., 2012; Thickett et al., 2002). The only study on the subject carried out in Québec to date on a population of swimmers comes to the same conclusions (Lévesque et al., 2006). Studies carried out in Belgium recently emphasized the strong possibility of a link between this exposure and the emergence of allergies and asthma in young people (Bernard et al., 2006; Bernard and Nickmilder, 2006; Bernard, 2007; Bernard et al., 2009; Nickmilder and Bernard, 2007; Voisin and Bernard, 2008). The studies were widely covered in the media and attracted international interest in the subject (Font-Ribera et al., 2011; Kaydos-Daniels et al., 2007; Kohlhammer and Heinrich, 2007; Schoefer et al., 2007; Weisel et al., 2009). Note that asthma caused by CAM exposure has been recognized as an industrial disease since 2003 in France.

2.2.2 Impact of THMs and HAAs

To date, studies dealing with THMs and HAAs, associated with possible carcinogenic (bladder cancer) and reprotoxic effects (intrauterine growth restriction), have mainly documented exposure to these contaminants in domestic settings (Levallois et al., 2012; Savitz et al., 2005; Tardiff et al., 2006; Villanueva et al., 2004; Villanueva et al., 2007a; Villanueva et al., 2007b). Epidemiological investigations rarely, or to a very limited extent, take into account exposure at work and/or in the pool, and therefore neglect people working at swimming pools. Studies carried out in this setting mainly consist of documenting, in semi-experimental conditions, the relative contribution of various absorption paths for THMs (Erdinger et al., 2004; Lévesque et al., 1994; Lindstrom et al., 1997). They have confirmed the importance of percutaneous absorption and possible inhalation of these contaminants in much more marginal ingestion (Dorevitch et al., 2011; Dufour et al., 2006; Schets et al., 2011). Efforts have been made, in particular by an Italian team in the 1990s, and more recently by Spanish researchers, to identify the best exposure biomarkers (i.e., urine, blood, alveolar air), as well as to validate and improve their use (Aggazzotti et al., 1990; Aggazzotti et al., 1993; Aggazzotti et al., 1995, 1998; Caro et al., 2007; Caro and Gallego, 2008a, 2008b). The subjects under study were mainly recreational swimmers and competitive swimmers.

Very few studies specifically measure workplace exposure to THMs at swimming pools (Caro and Gallego, 2007, 2008a; Fantuzzi et al., 2001; Fantuzzi et al., 2010). Table 1 shows the levels of exposure to TCM (ambient and biological) reported in these studies involving workers. In addition to the apparent variability between the environmental concentrations of the contaminant, it reveals the influence workers' tasks have on the intensity of exposure (from simple to double).

Table 1 – Environmental (water, air) and biological (alveolar air, urine) concentrations of chloroform (TCM) measured in cases of work-related exposure reported in the literature

Reference	C_{water} (µg/L)	C_{air} (µg/m^3)	Population sample	Alveolar air (µg/m^3)		Urine (ng/L)	
				Before exposure	After exposure	Before exposure	After exposure
Fantuzzi et al., 2001	17.8-70.8	58.0 (pool basin) 26.1 (reception area) 25.6 (engine room)	5 swimming pools 32 employees = 16 H + 16 F (21-58 years old) -19 lifeguards -9 managers -4 technicians		 25 15 15		
Caro and Gallego, 2007	100-145		1 pool 14 employees = 11 H + 3 F (23-43 years old) -10 lifeguards - 3 managers -1 technician			 455-532 510 516	 837-1028 575-622 585
Caro and Gallego, 2008a	122	230	1 pool 15 employees = 9 H + 6 F (21-40 years old) - 11 lifeguards - 3 managers - 1 technician	 2.4-5.6 4.83 3.9	 35-56 7.5-30.4 6.4	 497 490 445	 942-1302 557-597 567
Fantuzzi et al., 2011 *	7-134	30-81	20 pools 115 employees		 23.9		

* The concentrations reported in the Fantuzzi et al. study (2011) are of THM (and not TCM).

The most recent studies concentrated on identifying the genotoxic impact of these compounds, in particular brominated THMs, which appear to be of the greatest concern (Khallef et al., 2013; Patelarou et al., 2011; Plewa et al., 2010; Rivera-Nunez and Wright, 2013; Stayner et al., 2013).

2.2.3 Impact of eDBPs

An important review by Richardson (2007), which specifically deals with the genotoxicity and carcinogenicity of eDBPs, points out that the toxic potentials associated with these compounds could be much greater than those of traditional DBPs, and could thus, even in much smaller quantities, pose significantly higher risks to human health. Mercier-Shank et al., (2013) stress

that this concern relates especially to HANs, the most abundant nitrogenous DBPs, and HNMs, which have a toxic potential even greater than HANs. NDMA is mutagenic and, of all the eDBPs (and even all the DBPs), is the compound with the highest risk; according to the classification of carcinogenic compounds of the International Agency for Research on Cancer (IARC) it is listed in group 2A: probably carcinogenic to humans) (Florentin et al., 2011).

2.3 Regulation of DBPs in Swimming Pools

Worldwide, regulations in force that deal with levels of DBP are mainly focused on drinking water distribution networks. The ambient levels of DBP in swimming pools are regulated in very few countries.

Among the countries that regulate levels of THM in swimming pool water, Germany is the strictest, with a standard of 20 µg/L, just slightly stricter than Switzerland (30 µg/L, for indoor pools). The United Kingdom, Finland and Denmark recommend concentrations below 100 µg/L. Belgium has set a limit of 100 µg/L for TCM only, but has no legislation regarding HAA levels in swimming pool water. In Québec, legislation requires levels of CAM to remain below 0.5 mg/L in indoor swimming pool water and to 1 mg/L in outdoor pools. No country has regulations specific to TCAM in the water, despite the World Health Organization recommendation of 0.5 mg/L. Canada recently adopted a maximum acceptable concentration (MAC) of NDMA in drinking water of 40 ng/L. In Ontario, this compound is subject to an even stricter standard (9 ng/L), while Soltermann et al. (2013) report that Japan's objective is to apply the guideline proposed by the World Health Organization (100 ng/L).

There are no regulations concerning levels of THM or TCAM in the air of indoor pools. However, a Swiss study, one of the most complete and robust carried out to date, recently recommended setting the threshold value limit of exposure in the workplace for this contaminant at 0.3 mg/m^3, and to carry out additional research and take regular measurements of atmospheric concentrations of TCAM in aquatic facilities (Parrat, 2008; Parrat et al., 2012). This value limit is lower than the "comfort value" of 0.5 mg/m^3, below which employees do not report respiratory discomfort or ocular irritation. It was proposed by French researchers in the 1990s and has since become the benchmark (Thoumelin et al., 2005). In fact, a recent study found that the recommendation of 0.5 mg/m^3 was adequate for preventing the irritating effects linked to occupational TCAM exposure (Fantuzzi et al., 2013).

2.4 Expertise and Previous Investigations by Our Team

It was in this context that our team began primary investigations, supported by the Agence française de sécurité sanitaire de l'environnement et du travail (AFSSET) (Project EST-2007-79/AFSSET), in order to develop modeling tools to simulate DBP, and specifically THM, exposure (Tardif et al., 2010) at swimming pools. Exploratory modeling work done in the scope of this study first confirmed the considerable contribution of swimming pool exposure compared to domestic exposure, showing that internal biological levels resulting from an exposure of one or two hours at a swimming pool were at least comparable to, or even higher than, those resulting from domestic exposure (e.g., by showering, drinking tap water). The authors also pointed out the variable relative contributions of absorption routes (through inhalation and

percutaneously) depending on the situation, and thus advocated closer investigation within the modeling framework (Catto et al., 2012a). At the same time, our team carried out an intermittent measurement campaign to first characterize/quantify the presence of DBP in the water of some 50 swimming pools in the Québec City region. This campaign provided original quantitative information on the occurrence of DBPs in the water of swimming pools in Québec City (Simard, 2009; Simard et al., 2013). To compare this with the other data previously reported, the concentrations (annual means) of THM and HAA measured in indoor swimming pool water fluctuated between 18 and 217 µg/L and between 34 and 1536 µg/L, respectively. In outdoor swimming pools, the study reported concentrations that could exceed 300 µg/L for THM and 2100 µg/L for HAA. Following from this work, a new study was set up at two swimming pools to analyze the levels of DBP contamination in both the water and the air, and the associated variations (hourly and daily) (Catto et al., 2012b).

Building from these investigations, the goal of this project is to further study the issue specific to Québec, where data on the subject remain very limited, although the particular treatment conditions require a causal analysis of the situation (especially given the generalized use of chlorine as a disinfectant) and by taking an interest in the case of workers, who appear to be the most exposed group of those who spend time at swimming pools.

3. RESEARCH OBJECTIVES

3.1 General Objective

The goal of this project is to assess the exposure of swimming pool workers to DBPs (e.g., THM, CAM) and to consider preventive strategies.

3.2 Specific Objectives

More specifically, the study is based on carrying out sampling campaigns in parallel to or in support of the use and development of physiologically based environmental and toxicokinetic modeling tools, in order to:

- Draw up a typical profile of environmental DBP contamination (THM (water and air), CAM (water and air), HAA (water only) from a sample of public swimming pools in Québec;

- Document the biological levels of THM present in various categories of workers in the environments under study;

- Develop and apply biological markers to assess exposure to THMs.

This research will help to identify the health risks for workers exposed to DBP at swimming pools through analyses of the data gathered in light of standards and recommendations in force in different countries.

4. METHODOLOGY

The study is based on two major campaigns that measured the levels of the various DBPs and on the analysis of the extensive databases that resulted from these two campaigns. The first of the two campaigns (campaign A) consisted of measuring the environmental levels of DBP at a wide range of swimming pools to put the differences and variations observed into perspective. The second (campaign B) focused on a subset of swimming pools from campaign A. Besides carrying out an additional series of measurements of environmental levels of DBP, it provided the opportunity to investigate biological levels of THM in a sample of workers from these swimming pools. Physiologically based toxicokinetic models (PBTK) were utilized for more detailed analysis of these data.

4.1 Description of Measurement Campaigns

4.1.1 Environmental Segment: First Campaign (A)

The first campaign (A) consisted of drawing up as representative and as complete a portrait as possible of the DBP contamination in swimming pool water and air in the province of Québec, in terms of occurrence and speciation of the compounds under study. The campaign took place in October and November 2012.

4.1.1.1 Selection of Sites

It was agreed to exclude outdoor pools from the study and to restrict it to indoor pools, which elicited the most concern from professionals in the field, particularly because of the proven health impacts due to poorer air quality in confined spaces. The selection of swimming pools was made on a voluntary basis. The environment department of the Ville de Montréal invited public swimming pools in the city to participate in the study. An invitation was also addressed to all of the indoor public pools of Québec City, as well as to two university swimming pools. For logistical reasons, the number of swimming pools was set at 41, with 26 in Montréal and 15 in Québec City.

4.1.1.2 Parameters Measured

The contaminants measured in the water included (in priority) the traditional DBPs, i.e., the four principal THMs (TCM, DCBM, CDBM and TBM) and six HAAs (MCA, MBA, DCA, TCA, BCA, and DBA). The research was also broadened to include several eDBPs. The following were documented: (i) for HANs, TCAN, DCAN, BCAN and DBAN; (ii) for HNMs, CPK; and (iii) for HK, 11DCPone and 111TCPone.

In addition, the following physicochemical parameters were measured in the water: conductivity, turbidity, UV 254 nm absorbency (indicative of the presence of organic matter, precursors to DBPs), and dissolved organic carbon, in addition to pH, temperature and, of course, free chlorine, residual chlorine and monochloramine.

In the air, the levels of CAM and the same four types of THM previously measured in the water were assessed.

The numbers of bathers were counted during the visit by the staff responsible for sampling. A questionnaire (see Appendix C) was submitted online afterward to each of the participating facilities to collect information about the age of the facility, its bather load and the practices/recommendations issued to bathers with respect to hygiene, the configuration of the site and the swimming pool basin, the ventilation conditions and the treatment devices used.

4.1.1.3 Sampling Plan

Each of the participating facilities was visited during the campaign. Each visit lasted approximately two and a half to three hours. The visits took place during the week, with the objective of covering at least one hour of activities in the pool (free swims or classes), to ensure that there was a minimum bather load (and subsequently, that the water was being agitated enough to diffuse the more volatile contaminants into the air).

Water samples were taken at the beginning and again at the end of the visit to measure traditional DBPs (i.e., THM, HAA), in addition to monochloramine, free chlorine, residual chlorine and pH. The water temperature was also recorded. For eDBPs and physicochemical parameters other than those cited previously, a single sample was taken in the middle of the visit. Water samples were taken at a depth of 30 cm, generally at the foot of the most centrally located lifeguard chair beside the pool.

Air measurements were carried out by taking samples continuously for 95 minutes (for THMs) and 120 minutes (for CAMs) during the visit. The pumps were systematically positioned at the height of the most centrally located lifeguard chair to capture the air in the respiratory zone of a person standing at the edge of the swimming pool (approximately 150 cm above the water's surface). For THMs, a pump was installed at the foot of the same chair to capture the air at approximately 30 cm above the water's surface. For CAMs, another pump set at a low position was used, but only in one-third of the swimming pools investigated, depending on the availability of the pumps.

4.1.2 Biological Segment: Second Campaign (B)

The second campaign (B) first consisted of drawing up a representative portrait of the biological levels of THM observed in two matrices (alveolar air and urine) of the employees of different swimming pools, before and after exposure periods of variable duration. The levels were taken within the scope of a variety of normal activities at the facilities. This campaign (B) also provided the opportunity to enrich the environmental database generated during the first campaign (A) in order to make an inter-seasonal comparison of contamination levels. Campaign B took place between the end of April and the end of May 2013.

The protocol of the second part of the research, involving human subjects, was examined and approved by the health research ethical committee of the Université de Montréal (# certificate 11T-013-CERES D).

4.1.2.1 Selection of Sites and Recruitment of Subjects

A sample of swimming pools was selected from among all of the facilities that had participated in campaign A. The selection was based on practicality (accessibility to the site and access to rooms that would be appropriate for the collection of biological samples) and by taking into account the diversity of levels and types of contamination found during the first campaign.

Those responsible in the borough and/or for the participating swimming pools made the announcements and postings to recruit subjects. All workers aged 18 and over at the selected swimming pools were eligible: lifeguards (including those working during free swims and classes), maintenance staff and office staff in administration and reception. The case of lifeguards was, however, considered as the priority. The logistical constraints related to the availability and transportation of the material necessary to collect samples limited our investigations to a maximum of five subjects per swimming pool.

4.1.2.2 Parameters Measured

The environmental parameters were the same as those used during campaign A, with the addition of NDMA in the swimming pool water, an analysis that was unavailable during campaign A.

With respect to biological measurements, the parameters targeted were those of THM in alveolar air and in urine.

After the samples were taken, the subjects who agreed to participate were asked to provide, in a brief interview, the following information: gender, age, weight, height, seniority at the facility visited, total number of years they had worked at or frequented swimming pools, numbers of hours spent in the water in the course of their job (if relevant), and numbers of hours spent at the swimming pool for recreation (outside of work). The questionnaire also took into account the activities performed during their work shift the day of our visit in order to be able to trace their exposure conditions.

4.1.2.3 Sampling Plan

Each swimming pool selected was visited again. The visits were of variable durations from two to five hours, depending on the schedules of the participating sites and the volunteer subjects, and the availabilities of the team responsible for sampling. As during campaign A, the visits were carried out in priority during periods of free swims and/or classes, to guarantee a minimum of activities in the pool. Each visit was split up into one to four periods (depending on the duration of the visit).

The THMs and CAMs in the ambient air around the swimming pool were measured in an integrated manner over each of the periods at the breathing height of a man standing beside the swimming pool. As in campaign A, the pumps were positioned on the lifeguard chairs at approximately 150 cm above the surface of the water. At least two measurements were taken around each swimming pool basin. At each swimming pool facility, and for each contaminant, a

sample was systematically taken in the room reserved for lifeguards, or, if it was not the same room, in the room where the biological samples were collected.

In the water, THMs were measured at the beginning and the end of each visit, and at each change of period. With respect to eDBPs, samples were systematically taken at the beginning and the end of the visit. The same rationale applied to measuring HAAs, for which samples were sometimes also taken at the middle of the visit. For the analysis of NDMA levels, water samples were collected only at midpoint of the visit, at the same time the physiochemical parameters were measured. All the water samples were taken at the side of the pool, at the foot of a centrally located lifeguard chair.

The biological measurements involved the collection of two urine samples and two alveolar air samples. A first sample was requested when we arrived on the site (when the subject had already begun his or her work shift) or upon the arrival of the subject to the site (when we were able to get there beforehand). The second sample was taken after an exposure duration that varied from 55 minutes to up to five hours, depending on the subject's work schedule, the swimming pool schedule, and the possibilities of the sampling team. The subjects under study were not constrained during their tasks and remained entirely free to go about their normal activities.

4.2 Analytical Methods

The analyses of the water samples were the responsibility of the research chair on drinking water of Université Laval in Québec City, which is accustomed to performing these types of investigations. The procedures to analyze the samples of ambient air that were to be used to measure the THMs and the biological matrices were developed and operationalized at the laboratory of the inhalation unit of the environmental and occupational health department of the Université de Montréal. The analyses of the samples to measure CAMs were subcontracted to various laboratories that had the instrumentation and the expertise required.

4.2.1 Measurements in the Water

4.2.1.1 Analysis of THMs in the Water

The samples that were to be used to measure the levels of THM in the water were collected at approximately 30 cm below the surface of the water in 40 mL borosilicate vials. Ammonium chloride (NH_4Cl) had previously been added to the vials (166 µL of NH_4Cl to 30 g/L) to neutralize the free chlorine and to block the formation of the compounds under study. The samples were kept refrigerated at 4°C. For the analysis, 0.8 mL of a sample was taken and transferred into a 2 ml chromatography micro vial. A volume of 20 µL of the internal standard (EPA fortification solution, cat. no. 47358-U) at a concentration of 0.8 µg/mL, containing a mixture of fluorobenzene, 4-bromofluorobenzene and 1,2-dichlorobenzene-d4, was added to the samples. The compounds were extracted from the water using solid-phase microextraction (SPME), which consists of adsorption of THM with an extraction fibre as a solid support (PDMS 100 µm Supelco, cat. no. 57341-U), in headspace mode using an automatic autosampler (CTC-Combipal). The SPME was carried out in the headspace of the micro vial, at ambient temperature (~ 21°C) with an extraction time of 10 minutes. The compounds were desorbed at

250°C for 4 minutes in the gas chromatograph injector (Varian 3900 with a 1177 injector) with injection in splitless mode for 2 minutes. The desorbed compounds were then drawn through a capillary column (DB-5ms: 30 m x 0.25 mm DI, 0.25 µm film, Agilent #122-5532 or equivalent) by the helium gas (1 mL/min). The temperature program of the oven was 35°C (2 min.), 15°C/min. to 250°C (0.5 min.). Once the compounds were separated, they were introduced into an ion trap mass spectrometer (Varian 2100T), which enabled the analyzed compounds to be identified and quantified. The parameters for the analysis for the mass spectrometer (MS) were as follows: ion trap at 250°C, manifold at 45°C, Xfer line at 300°C. The quantitative analysis of the chromatograms were carried out in RIC mode (Reconstructed Ion Chromatogram) using the following ions: TCM – 83 m/z; DCBM – 83 m/z; CDBM – 129 m/z; TBM – 173 m/z; fluorobenzene – 96 m/z; 4-bromofluorobenzene – 95 m/z; 1,2-dichlorobenzene-d4 – 150 m/z. The method detection limits (MDL) are for TCM, DCBM, CDBM and TBM, 1.1 µg/L, 0.6 µg/L, 1.0 µg/L and 0.8 µg/L, respectively. The quantification limits (MQL) are 3.7 µg/L, 2.0 µg/L, 3.3 µg/L and 2.7 µg/L, respectively, for the same compounds.

4.2.1.2 Analysis of HAAs in the Water

The samples were collected with the same 40 mL-pretreated vials as those used for the analysis of THMs. The analysis method was adapted from the Environmental Protection Agency's (EPA) 552.3 method, which is the benchmark. A 20 µL volume of 2-bromopropionic acid (Supelco, cat. no. 47645) at a concentration of 68 µg/mL (ppm) was added to each sample to be extracted (surrogate internal standard). Samples of 40 mL (acidified with 2 mL of H_2SO_4) in the presence of a salt (18 g Na_2SO_4) were extracted with 4 mL of methyl-*tert*-butyl-ether (MTBE) to assist their transfer to the organic phase. Afterward, 3 mL of 10% sulphuric acid in methanol solution (derivatization reagent) was added to the organic phase. After being added, the temperature of the samples was raised to 50°C (water bath) for two hours. Then, 7 mL of Na_2SO_4 (solution of 150 g/L) was added to each sample. The organic phase was rapidly recovered. Next, 1 mL of a saturated sodium bicarbonate solution was added to the organic phase. A precise volume of the organic phase (1 mL) was taken and transferred into a 2 mL micro vial. At the end of extraction, 10 µL of internal standard, 50 µg/mL (ppm) in 1,2,3-trichloropropane (injection standard, Supelco, cat. no. 47669-U), was added to the extracted 1 mL samples. After extraction, the 1 mL extracts were analyzed by gas chromatography (PSS injector, capillary column DB-1701: 30 m x 0.32 mm DI, 0.25 µm film, J&W cat. no. 123-0732) equipped with an electron capture detector (Autosystem XL from Perkin Elmer with a ^{63}Ni radioactive source). The chromatographic conditions were the following: 1 µL split-splitless injection (splitless at -0.25 min. and split at 30 mL/min., hold for 0.75 min.), a temperature gradient at the injector: 175°C (2 min.), 50°C/min. to 240°C (12 min.), a temperature gradient in the oven: 40°C (6 min.), 5°C/min. to 100°C, 20 °C/min. to 200°C, the helium carrier gas pressure in program flow mode at a rate of 1 mL/min. in the column, a rate of 30 mL/min of argon-methane gas (purity 99.99% Praxair cat. no. iG P5C-K) in the electron capture detector with a ^{63}Ni radioactive source (detector temperature at 280°C, attenuation set at -4). The quantification limit was identical for the six compounds measured, i.e., 1 µg/L.

4.2.1.3 Analysis of eDBPs in the Water

The analysis method was developed by Université Laval's research chair on drinking water, by adapting EPA 551.1 and Health Canada's methods. A 50 mL volume from a 60 mL water sample tempered in a water bath at 25°C (borosilicate amber vial for volatile substances containing NH4Cl and a phosphate buffer) was used for the extraction. A 10 µL volume of the internal standard solution, 1-chloro-2-bromopropane (Sigma-Aldrich cat. no. 48088), at a concentration of 50 mg/L was added to each sample to be extracted. The 50 mL samples were mixed with 3 mL of MTBE and a salt (20 g Na_2SO_4), which was then removed through liquid-liquid-extraction to assist the transfer of the compounds to the organic phase. The samples were then shaken for 5 minutes. Next, a 1 mL volume of the organic phase (MTBE) was taken and transferred into a 2 mL micro vial. At the end of extraction, a 10 µL internal injection standard of 1,2,3-trichloropropane (Supelco, cat. no. 47669-U) at a concentration of 25 mg/L was added to each of the extracts. These extracts were then analyzed using a gas chromatograph (Perkin Elmer Clarus 500 with PSS injector and a DB-1 capillary column: 30 m x 0.25 mm DI, 1.0 µm film, J&W cat. no. J1221033 and confirmation column: DB-5: 30 m x 0.25 mm DI, 1.0 µm film, J&W cat. no. J1225033) equipped with an electron capture detector (^{63}Ni radioactive source). The chromatographic conditions were the following: injection of 1 µL split-splitless (splitless for -0.25 min. and split for 30 mL/min., hold for 0.5 min.), pulse at 3 mL/min. during injection (1 min.) then return to 1 mL/min., a temperature gradient at the injector: 90°C (2 min.), 50 C/min. up to 240°C (15 min.), a temperature gradient in the oven: 35°C (22 min.), 6°C/min. to 115°C, 45°C/min. to 200°C (0.78 min), the pressure of the helium carrier gas in program flow mode with a rate of 1 mL/min in the column, a nitrogen rate (purity 99.99%, Praxair cat. no. NI 5.0UH-T) of 30 mL/min. in the detector, with a detector temperature of 300°C (attenuation set at -5). The quantification limit was identical for the six compounds measured, i.e., 0.01 µg/L.

4.2.1.4 Analysis of NDMA in the Water

The samples for the measurements of NDMA in campaign B were collected in 1 L bottles into which 80 mg of sodium thiosulfate had previously been added. Each time, two bottles were filled in order to obtain the best detection limit (0.8 ng/L). Analyses of NDMA concentrations were subcontracted to SGS Canada Inc. The analysis method was derived from Plomley et al. (1994) and the extraction method was adapted by their laboratory from section 6410B of *Standard Methods for the Examination of Water and Wastewater*.[1] The NDMA was extracted from the 2 L water sample at a pH>12 with methylene chloride. Controlled evaporation (with TurboVap®) made it possible to concentrate the extract, which was then analyzed by GC/MS/MS (in a positive chemical ionization mode (use of isobutane)).

4.2.1.5 Other Physicochemical Analyses

4.2.1.5.1 Direct Measurements Onsite

[1] *Standard methods for the examination of water and wastewater, 18th ed. - Section 6410B.* Published by the American Public Health Association (APHA), the American Water Works Association (AWWA) and the Water Environment Federation (WEF), Washington, DC, USA, 1992.

The pH, temperature, residual chlorine, free chlorine and MCAM were measured through direct readings onsite. The pH was measured with a Denver Instrument pH-meter (AP15 pH/mV/FET meter) equipped with a gel probe (gel-filled combination pH electrode, epoxy body, 1 metre cable with BNC connector, Thermo Scientific # 9106BNWP). The measurements of residual free chlorine and total chlorine (in mg/L Cl2) were taken using a HACH DR890 colorimeter with DPD free chlorine and DPD total chlorine reagents (10 mL powder pillows) (HACH method 8021). Monochloramine measurements, expressed in mg/L Cl2, were performed using a HACH DR890 colorimeter with Monochlor F reagents (10 mL powder pillows) (HACH method 10200).

4.2.1.5.2 Laboratory Measurements

Turbidity, conductivity, absorbency and dissolved organic carbon were measured in the laboratory within 48 hours after collection of 1 litre of swimming pool water in a Nalgene bottle, kept refrigerated. Water turbidity (in NTU) was measured with a 2100N turbidimeter (HACH) using a 40 mL cell (sample cells for ratio turbidimeter: HACH # 20849-00). Water conductivity was measured using a conductivity cell (Tetracon model 325) with a portable multimeter (WTW model multi 340i). The absorbency of the sample was measured with a spectrophotometer (DR500, HACH) at a wavelength of 254 nm using a 1 or 5 cm quartz cell (Sterna Cells # 1-Q-50). The carbon contained in the water was measured using a Sievers 5310C (General Electric-GE) carbon analyzer. This technology measures carbon through chemical oxidization (persulfate) and organic carbon levels in a range of 4 ppb to 50 ppm (linear range). The sample was filtered through a 2 µm fiberglass filter (GMF-Whatman) before analysis with the instrument was performed.

4.2.2 Measurements in the Ambient Air

4.2.2.1 Analysis of THMs in the Ambient Air

THMs in ambient air (TCM, CDBM, DCBM, TBM) were measured through gas chromatography with electron capture detection (ECD). Using a pump previously calibrated with a low flow (165 mL/min.$^{-1}$), the air was aspirated for 95 minutes through an activated charcoal tube to absorb the THM vapours contained in the ambient air. Following our stability study, the tubes of activated charcoal (ORBO™ 32, 100/50 mg, Sigma-Aldrich, St-Louis, MO), which had been used for sampling, were sealed and conserved at -20°C for analysis within 14 days. The THMs were desorbed with carbon disulphide (CS_2). The detection limits of the instrument (GC 7890A, Agilent Tech., He: 1.0 mL/min., HP-5ms column 30 m [L] × 0.25 mm [ID] × 0.25 µm [Film]) are 0.6 µg/m^3 (TCM), 0.03 µg/m^3 (DCBM), 0.03 µg/m^3 (CDBM) and 0.03 µg/m^3 (TBM). The quantification limits are 2.00 µg/m^3 (TCM), 0.09 µg/m^3 (DCBM), 0.098 µg/m^3 (CDBM) and 0.097 µg/m^3 (TBM).

4.2.2.2 Analysis of CAMs in the Ambient Air

The reference method was developed by Héry et al., (1994). The air was pumped at a rate of approximately 1 L/min. for 120 minutes through a device consisting of a Teflon filter that captured the particulate pollution (droplets of chlorinated compounds) that could interfere with the dosage, and then through two cellulose filters impregnated with sodium carbonate. These two

filters were desorbed with doubly distilled water. After percolation over an ion exchange resin, the desorbate was analyzed using ion chromatography. The preparation of cassettes and the analyses were subcontracted either to the Laboratoire d'étude et de recherche en environnement et santé (LERES) at the École des hautes études en santé publique (EHESP) (the first 14 swimming pools in campaign A) or the laboratory of the Ville de Montréal's environment department (all others). The method detection limit was 0.05 mg/m^3.

4.2.3 Measurement of Biological Markers

4.2.3.1 Analysis of THMs in Alveolar Air

For the collection of alveolar air, the subjects had to inhale and then hold their breath for 10 seconds. The total duration of continuous and regular exhalation of each subject was used as a reference in order to collect only the last third of the air exhaled. The exhaled air was collected through a three-way valve, which enabled only the last third to be transferred into a Tedlar bag (Concept Controls Inc.). The THMs contained in the alveolar air were adsorbed on an ORBO™ 403 tube (Sigma-Aldrich, St-Louis, MO), using a pump (SKC 222-3, Concept Controls Inc.) with a flow rate of 150 mL/min. for 5 minutes. The tubes were hermetically sealed and conserved at -20°C until analysis. The THMs in the alveolar air were analyzed using gas chromatography (HP-7890, Agilent Inc.) with electron capture detection (µECD). After pre-concentration of the volatile substance in the solid phase (ORBO™ 403 Tenax® TA (60/80), 100/50 mg), the analysis method consisted of a headspace (HS) solid phase micro-extraction (SPME) (CAR/PDMS; 85 µm) (Barro et al., 2004; Barro et al., 2009). The Tenax® TA matrix was incubated in HS bottles at 100°C for 15 minutes, to volatilize the THMs. The SPME fibre sampled and desorbed the THMs in the injector at a high temperature (300°C). The operational temperature of the GC was maintained at 40°C for 1.5 min., followed by programming at 10°C/min., up to 100°C, and programming at 25°C/min. to 210°C, held for 3 min. (He: 1.5 mL/min.; column: HP5ms 30 m [L] × 0.25 mm [ID] × 0.25 µm [film], Agilent Inc.). Benchmarking was carried out by injecting known volumes of VOC into bags with a known volume of purified air, and processed according to the sampling procedure. In the analysis conditions, the detection limits of the instrument, estimated from a standard prepared using the same procedure, are 2.3 µg/m^3 (TCM), 0.03 µg/m^3 (DCBM), 0.16 µg/m^3 (CDBM), 1.6 µg/m3 (TBM) for an air sample of 750 mL. The quantification limit was established at 7.6 µg/m^3 (TCM), 0.10 µg/m^3 (DCBM), 0.53 µg/m^3 (CDBM), 5.27 µg/m^3 (TBM). Special attention was paid to the preparation of the glass and the pre-treatment of the ORBO™ 403 tubes with ultrapure helium.

4.2.3.2 Analysis of THMs in Urine

The participants were asked to provide a sample of their urine after drying themselves off properly first, to avoid contaminating the sample with swimming pool water; the sample was then frozen until analysis. Urinary THM was determined quantitatively through gas chromatography with mass spectrometric detection (MS SIM mode), coupled with automatic injection by HS-SPME (Caro and Gallego, 2007, 2008a; Cho et al., 2003). The calibration curve was prepared daily, by adding an aliquot of 12 mL of urine, saturated with 4 g of KCL, 15 µL of methanolic solution at different concentrations of THM and the internal standard

(Fluorobenzene, Sigma-Aldrich). The urine samples were prepared using the same procedure, but excluding the THM. It was prepared in an HS-type bottle, on ice, and hermetically sealed afterward. After incubating the solutions at 45°C for 30 minutes, the THM were adsorbed by the fibre (CAR/PDMS; 85 µm) and injected into the gas chromatograph (HP 7890, Agilent Tech. Inc.; Combi-Pal, CTC Analytics). The analysis conditions were as follows: He: 1.5 mL/min; DB-624, 30 m [L] x 0.32 mm [ID] x 1.8 µm [film], Agilent Tech. Inc. The temperature of the operation was 90°C, followed by programming at 15°C/min, until reaching a final temperature of 230°C, maintained for 2 minutes. The injection port and the MS detector were maintained at 290°C and 150°C, respectively. The retention times were as follows: TCM: 4.69 min; DCBM: 5.5 min; CDBM: 6.52 min; TBM: 7.65 minutes; fluorobenzene: 5.1 minutes. The quantification is carried out using a calibration curve prepared in the urine blank. The transition ions used were as follows: TCM: 82.9 m/z, DCBM: 82.9 m/z, DCBM: 128.9 m/z, TBM: 172.8 m/z, fluorobenzene: 96.0 m/z. The detection and quantification limits for the urinary THM were estimated at 5.8 and 19.2 ng/L (TCM), 1.1 and 3.6 ng/L (DCBM), 1.0 and 3.3 ng/L (CDBM) and 11.0 and 36.5 ng/L (TBM).

4.3 Statistical Analyses and Modelling Work

4.3.1 Statistical Analyses

Spearman correlation analyses were carried out using SAS 9.3 software (SAS Institute Inc.) between the various concentrations of DBP measured during campaign A.

4.3.2 Modelling Work

The data from campaign B was used in the modelling exercises that aimed to simulate real exposure of the volunteer subjects in order to compare the biological levels predicted by the PBTK models with those measured experimentally during the study.

The hypothetical exposure scenarios, using environmental data that was genuinely measured during campaigns A and B, were also considered to estimate the biological doses potentially encountered by typical workers. In this part of the study, the modelling work was limited to the case of TCM, for which the PBTK model is the best documented and the most reliable.

4.3.2.1 Description of the PBTK Model

The already proven PBTK models were designed by our team to be used in a domestic context (i.e., to simulate taking a shower, drinking water and inhaling ambient air) in order to predict the biological levels of THM in different tissues and matrices of the human body (Haddad et al., 2006). These models were previously used to study cases of exposure at swimming pools (Catto et al., 2012a; Lévesque et al., 2000).

This type of modelling consists of a mathematical representation of the human body divided into compartments (each corresponding to an organ or a group of organs) interlinked by the circulatory system. The resolution of a set of differential equations translating mass balances between the quantity of contaminants entering and leaving each compartment enable the progress

of the concentrations of contaminants in each of the compartments to be followed over time. It is possible to set up these models to take into account the physiological characteristics specific to each individual (e.g., weight, body surface, level of physical effort). They also help us to consider the following three absorption routes: percutaneous, oral and pulmonary.

The model used, previously described by Haddad et al., (2006), was modified to respond to the specific conditions of workers in the aquatic environment. A kidney compartment was added to the five compartments initially represented, which are the adipose tissues, liver, richly perfused tissues, poorly perfused tissues and the skin (Figure 1), the lungs represent the entry portal. The addition of the kidney compartment enables urinary excretion of unchanged TCM to be included, as previously described for acetone (Kumagai and Matsunaga, 1995):

Equation (1) RMe= (KUR/1000)*(CE*1000)* PRu

where RMe = Level of urinary excretion of TCM (ng/h)
KUR = urinary output (mL/h)
CE = Renal concentration of TCM (µg/L)
PRu = Urine:Kidney partition coefficient

The use of modified physiological parameters for an effort of 100 watts allows us to describe a swimmer in training, as was the case for some workers (Table 2).

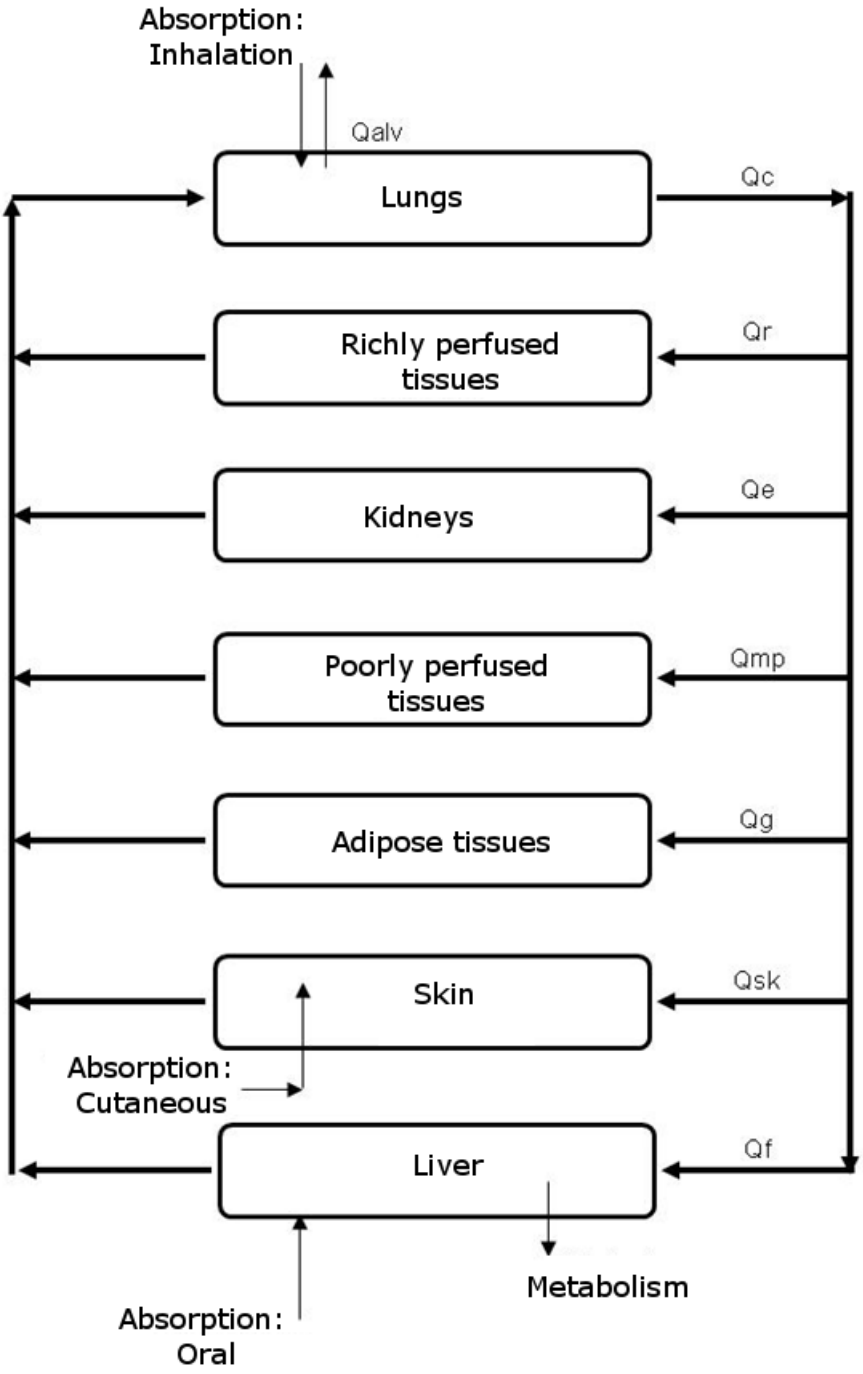


Figure 1 – Conceptual representation of the PBTK model of TCM. Qalv: alveolar output; Qc: cardiac output; Qr: richly perfused tissue output; Qe: kidney output; Qmp: poorly perfused tissue output; Qg: adipose tissue output; Qf: liver output; Qsk: skin output

Table 2 – Parameters of the PBTK model of TCM to model workers in swimming pools in Montréal and Québec City

Parameters	Abbreviations	Rest [a]	100 W [b]
Body weight (kg) [a]	BW	70	
Body surface (cm^2) [d]	SURF	17938	
Physiological parameters			
Alveolar output (L/h/kg) [KQalv * $BW^{(0.70)}$]	KQalv	18	103.6
Cardiac output (L/h/kg) [KQCR * $BW^{(0.70)}$]	KQc	18	42.9
Fraction of cardiac output for each compartment			
Adipose tissues	KQg	0.050	0.050
Liver	KQf	0.260	0.093
Richly perfused tissues	KQr	0.200	0.129
Kidneys [b]	KQe	0.240	0.064
Poorly perfused tissues	KQmp	0.216	0.524
Skin [b e]	KQsk	0.034	0.140
Fraction of body volume for each compartment [a]			
Adipose	KVg	0.19	
Liver	KVf	0.026	
Richly perfused tissues	KVr	0.0456	
Kidneys [e f]	KVe	0.0044	
Skin	KVsk	0.100	
Poorly perfused tissues	KVmp	0.520	
Physicochemical parameters [a]			
Blood: air	PRB	10.7	
Adipose: air	KPRg	280	
Liver: air	KPRg	17	
Kidneys: air [f g]	KPRe	11	
Richly perfused tissues: air	KPRr	17	
Skin: air	KPRsk	19.76	
Poorly perfused tissues: air	KPRmp	12	
Water: air	KPeu	3.66	
Urine: air [h]	KPRu	3.14	
Absorption and metabolic parameters			
Oral absorption constant (if relevant) [KKOR * $BW^{(-0.25)}$)]	KKOR	1.92	
Skin permeability constant (cm/h)	KP	0.16	
Urinary output (mL/h) [i]	KKUR	measured	
Metabolic constant in the liver (mg/h/kg) [KVMAX * $BW^{(0.70)}$]	KVMAX	12.68	
Michaelis–Menten affinity constant in the liver (mg/L)	KM	0.448	

a) (Haddad et al., 2006)
b) Values modified for an effort of 100 watts (Astrand, 1983)
c) Body weight of individual subjects (otherwise 70 kg)
d) (Costeff, 1966)
e) Skin output at 100 W is calculated proportionately to the output at rest, defined by Astrand (1983)
f) (Roy et al., 1996)
g) (Corley et al., 1990)
h) (Batterman et al., 2002)
i) Individual measurements during the study

4.3.2.2 Simulations

PBTK modeling was first used to reproduce TCM exposure in subjects who had participated in the biological segment of campaign B, in order to estimate the biological levels of TCM in the alveolar air and urine of these subjects and to compare them with the levels measured. Information was gathered about the workers concerning their weight, the time and the interval between the biological sampling, their activity level during the exposure period. The exposure concentrations (water, ambient air) before and during the collection of samples were included in the model so as to describe the kinetics of TCM individually. The workers who were on lifeguard duty beside the pool were considered as being (physiologically) at rest (no excessive physical effort beside or in the swimming pool). The measurement of concentrations in the swimming pool water enabled the percutaneous contribution of TCM to be included during training periods in the pool. In view of equation 1, urinary output is a very sensitive factor in the description of TCM elimination through the urine. This parameter was extremely variable during our sampling (82.5±75.8 mL/h), therefore, the urinary output calculated individually for each subject was used in each of the scenarios to replace a theoretical value, which would be less representative.

PBTK modelling was also used to simulate exposure of typical individuals (a 70 kg male and a 55 kg female) on lifeguard duty beside a pool for two 3.5-hour periods, broken up by a one-hour break. These simulations were conducted for all of the swimming pools in campaign B, as well as for the swimming pools with maximum and minimum TCM contamination in the swimming pool air during campaign A. The exercise was also carried out by using mean and median values of TCM concentrations in the air during campaign A. A lifeguard's exposure while on a break was considered as nil because of the lack of information on contamination in the offices for the simulations using data taken from campaign A. The concentration in office air was the exposure concentration considered for simulations using data from campaign B.

5. RESULTS

From this section on, in the relevant figures and tables, P*i* will systematically represent the swimming pool *i* and S*j* the subject *j*.

5.1 Results of Campaign A – Environmental Segment

5.1.1 Recruitment Results and the Data Generated

A total of 41 facilities were visited during this first campaign (A). In addition to swimming pools from the two university campuses, the 13 public indoor pools in Québec City were visited. The Repentigny municipal swimming pool was also part of the study. For swimming pools in Montréal, given the logistical constraints and the means available, we limited participation to the first 25 respondents.

In this sample of 41 swimming pools, 12 did not respond to the questionnaire, i.e., eight did not return it at all and four did not return it to us quickly enough for the data to be included in this report. Of the 29 respondents, two did not cover all the sections of the questionnaire and barely a dozen responded to all the questions in a more or less specific manner. The data gathered showed wide variability in the ages of the facilities visited (from 4 to 100 years old) and in bather load (from about 5000 visitors to 146,000 visitors per year). With a few rare exceptions, all of the swimming pool basins are rectangular and measure 25 m in length. Variations in width and depth meant there are significant differences in volume (based on the information provided, between 100 and 3340 m^3 of water, for an average of 910 m^3). Information related to the dimensions of the swimming pool hall and its ventilation was often not provided. The source of water (network) supplying the swimming pool was not always known (only in about 15 cases). With the exception of two facilities (which used diatomaceous earth or crushed glass), sand filtration is used for water treatment. However, the characteristics and maintenance methods reported varied considerably; some filters had not been changed in 23 years. All the swimming pools (including, according to our sources, all those that did not respond to the questionnaire) use chlorine (liquid or solid) for water disinfection. Seven also use UV lamps. Several of these reported using sodium thiosulfate to decrease the concentration of the disinfectant and/or other products to control turbidity (LOOK, PASS) or the pH (CO_2 or pH-). At most, 12 swimming pools are emptied annually. Some had not been emptied for ten years, or never. With respect to regulations for bathers, 23 facilities stated that wearing a bathing cap was not obligatory; only three do not have a dress code (generally, bathing suits are required and shorts are prohibited). Showering is often obligatory, but that regulation does not always appear to be respected, and soap is not systematically available.

At each swimming pool (and at each visit), 18 water samples (counting replicates) and three or four air samples were collected. Thus, almost 900 samples were taken and 3500 analyses were performed to constitute one of the most extensive databases on DBP contamination in the water and air of swimming pools.

5.1.2 Occurrence and Speciation of Compounds

5.1.2.1 Findings

5.1.2.1.1 Overall Results

Table 3 presents the mean concentrations of DBP measured at all of the participating facilities and Table 4 provides the mean values of the physicochemical parameters and the number of bathers counted during our visits to all of these facilities. The DBP concentration values reported at each of these facilities (Appendix A) and which enabled calculation of the means presented in Table 3 are, themselves, the results of the means of concentrations measured in two samples systematically taken at each of these facilities (with the exception of CAM and HAN concentrations, for which only a single sample was available at 28 of the facilities visited).

The results show substantial levels of eDBP in the water, in particular, HANs. It was impossible to accurately quantify the 11DCPone. The HAAs, non-volatile compounds, are the class of DBP with the highest concentrations in swimming pool water, more than the THMs, which volatilize in the air. Potentially significant levels of brominated THMs (the sum of DCBM, CDBM, and TBM) were measured in the swimming pool water and air (see also sections 5.1.2.3.1 and 5.1.2.3.5). In every case, considerable variability is observed in levels of contamination from one swimming pool to another. Air contamination by CAMs is no exception. For the physicochemical parameters, this variability is not as apparent, but it is significant (with the exception of temperature and pH).

Table 3 – Mean concentrations of DBP in the air (µg/m^3) and water (µg/L) at 41 indoor swimming pools in the province of Québec

Variable	n [1]	Mean	Median	Standard deviation	Minimum	Maximum	CV(%) [2]
Air (µg/m^3)							
Total THM	**41**	**191.3**	**167.3**	**101.9**	**58.1**	**552.2**	**53.3**
TCM	41	119.4	105.4	74.2	20.3	320.4	62.2
DCBM	41	31.0	15.2	34,3	1.3	154.6	110.9
CDBM	41	27.0	3.4	43.4	<QLM [3]	204.8	160.8
TBM	41	13.9	0.46	24.4	<QLM	102.8	175.6
Brominated THM	41	71.8	20.8	99.1	1.5	462.2	137.9
CAM *(mg/m^3)*	**40**	**0.23**	**0.18**	**0.15**	**<QLM**	**0.56**	**66.9**
Water (µg/L)							
Total THM	**40**	**64.7**	**58.6**	**26.7**	**21.7**	**132.4**	**41.3**
TCM	40	38.1	35.2	25.7	6.7	126.5	67.4
DCBM	40	9.7	6.9	8.1	<QLM	30.1	83.6
CDBM	40	10.7	2,1	14.3	<QLM	51.3	134.3
TBM	40	6.6	0.6	10.4	<QLM	45.6	157.6
Brominated THM	40	26.5	9.1	31.6	<QLM	109.1	119.0
Total HAA	**41**	**294.8**	**252.5**	**157.6**	**109.2**	**886.2**	**53.5**
MCA	41	17.1	13.0	15.1	2.1	77.5	88.8
MBA	41	3.8	2.5	4.0	<QLM	14.8	104.7
DCA	41	133.5	87.0	112.0	27.4	500.0	83.9
TCA	41	107.0	94.9	66.1	24.1	249.6	61.7
BCA	41	31.3	23.2	31.9	1.2	117.5	102.0
DBA	41	16.8	4.2	22.6	<QLM	69.6	134.7
Total HAN	**41**	**21.4**	**17.6**	**13.9**	**3.4**	**78.6**	**64.9**
TCAN	40	0.03	0.03	0.03	<QLM	0.12	81.7
DCAN	41	9.8	10.3	5.2	2.3	22.4	52.7
BCAN	41	5.8	3.4	6.1	0.28	29.4	105.2
DBAN	41	5.8	0.6	8.1	<QLM	30.8	140.0
HNM (CPK)	**41**	**0.35**	**0.20**	**0.6**	**0.02**	**3.7**	**172.2**
HK (TCPone)	**41**	**1.9**	**1.6**	**1.3**	**0.33**	**7.3**	**69.6**

[1] n is the number of swimming pools for which a mean concentration is available
[2] CV is the coefficient of the variation expressed in %
[3] QLM = Quantification limit of the method

Table 4 – Physicochemical parameters and the number of bathers counted at the swimming pools visited

Variable	n [1]	Mean	Median	Standard deviation	Minimum	Maximum	CV(%) [2]
Free chlorine (mg/L)	41	1.6	1.54	0.45	0.49	2.67	28
Total chlorine (mg/L)	41	2.2	2.14	0.46	1.44	3.17	21.03
MCAM (mg/L)[3]	41	0.15	0.13	0.06	0.07	0.32	38.08
pH	41	7.52	7.47	0.19	7.21	7.95	2.55
Temperature (°C)	41	27.19	27.1	1.07	23.7	29.2	3.94
Conductivity (µS/cm)	41	1379.9	1259	653.39	542	2900	47.35
Turbidity (NTU)	41	0.2	0.17	0.1	0.06	0.54	49.66
Absorption (cm^{-1})	41	0.04	0.03	0.02	0.01	0.14	57.22
Dissolved organic carbon (ppm)	41	4.01	3.55	1.68	1.36	10	41.91
Number of bathers	41	30	25	19	5	103	64

[1] n is the number of swimming pools for which a mean concentration is available
[2] CV is the coefficient of variation expressed in %
[3] The individual values are presented in Appendix A under the acronym MonoCl

5.1.2.2 Speciation of the Various Groups of Compounds

5.1.2.2.1 THM in the Water

Figure 2 presents the concentrations of the various types of THM measured in the water at each swimming pool. While chloroform is, on average, the most abundant compound (37.9±25.7 µg/L), brominated THM represents more than 25% of total THMs at almost half the facilities visited (19 cases). In 13 of the swimming pools, or almost a third of the facilities, the levels of brominated THM (66±24.2 µg/L) greatly outweigh the levels of TCM (15.2±6.31 µg/L). TCMs do not represent more than 20% of total THM, although on average they make up 85% of them at the 20 other sites. CDBM is always the most common compound (approximately 35% of total THM), while the concentration and the preponderance of other THMs fluctuate around the same values.

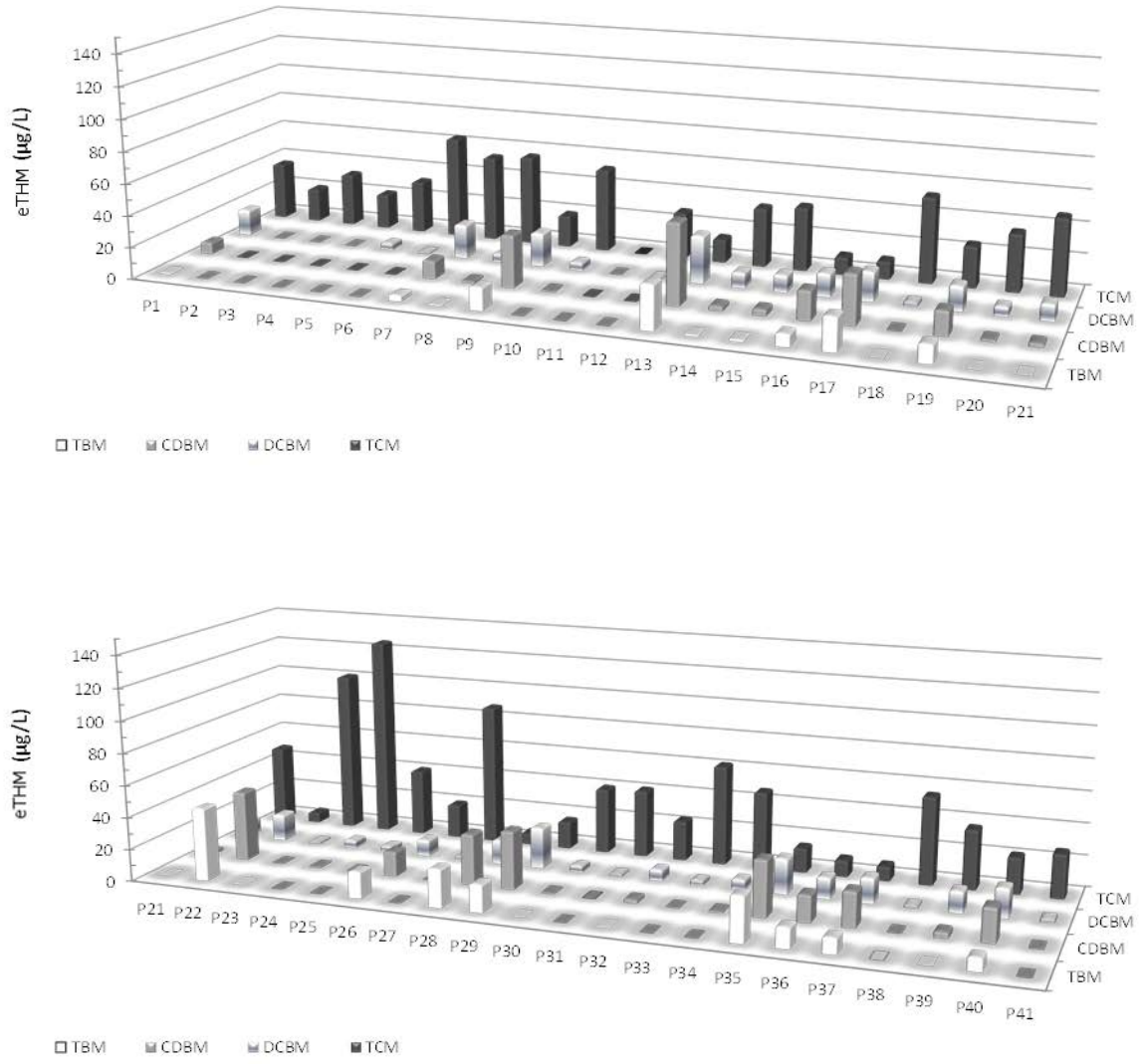


Figure 2 – THM concentrations in the water of the 41 swimming pools visited

5.1.2.2.2 HAA in the Water

Figure 3 presents the concentrations of the various types of HAA measured in the water of each swimming pool. Among the six HAA analyzed, TCA and DCA are the dominant compounds, the two of them representing, on average, approximately 80% of total HAA. There is a preponderance of brominated HAA (especially DBA and BCA) in the swimming pools where more brominated THMs are also observed. In those swimming pools, DBA and BCA comprise, on average, over 35% of total HAA, while TCA and DCA combined drop to only 57%. In the other swimming pools, TCA and DCA made up, in almost equal parts, 90% of total HAA (49% and 41%, respectively).

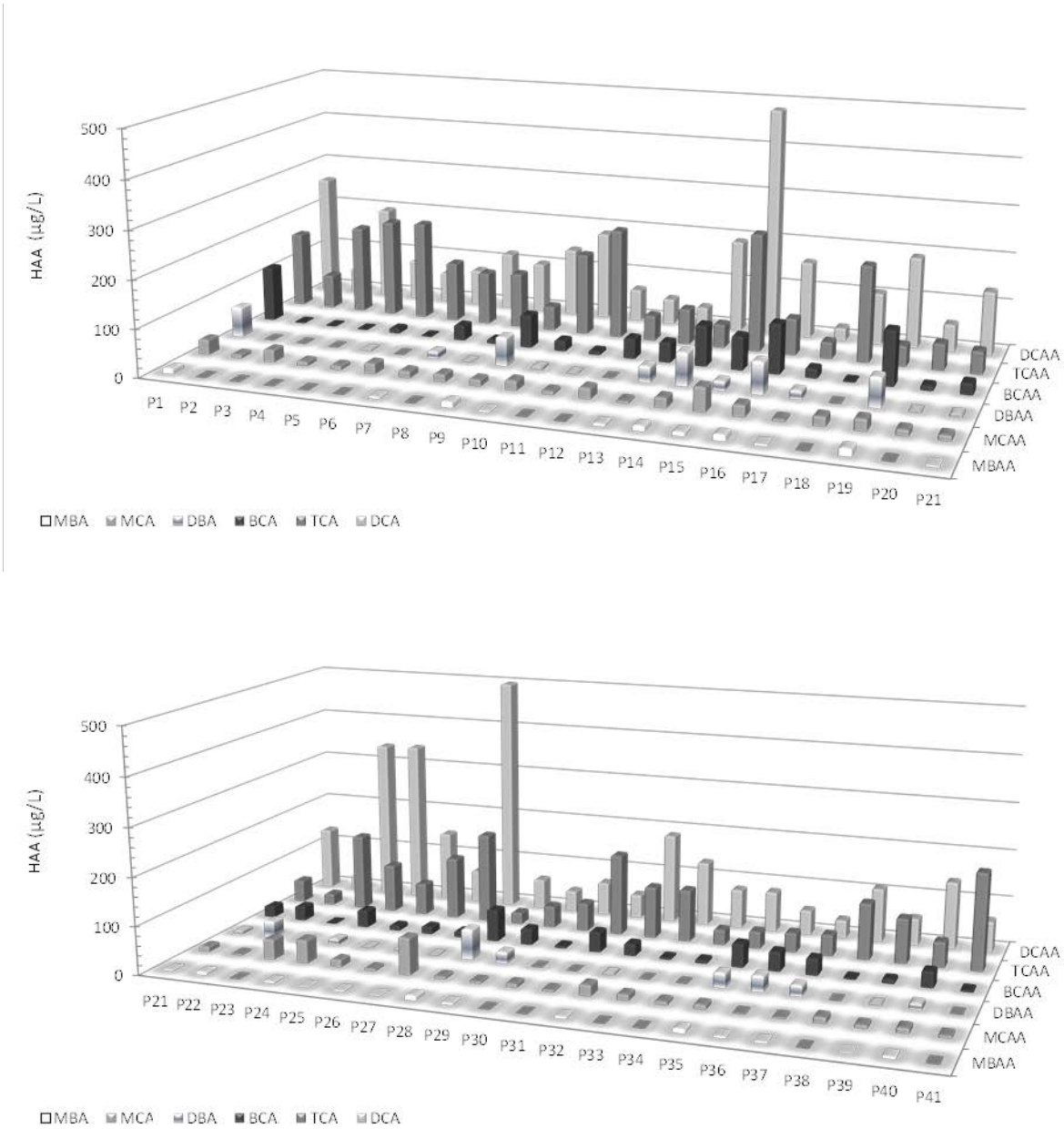


Figure 3 –HAA concentrations in the water of the 41 swimming pools visited

5.1.2.2.3 HAN in the Water

Figure 4 presents the concentrations of different types of HAN measured in the water of each swimming pool. DCAN is, overall, the principal HAN (46% of the total amount) followed, in almost equal parts, by DBAN (31%) and BCAN (27%). TCAN is present in very low quantities (<0.12 µg/L).

As in the case of THMs and HAAs, the presence of higher levels of brominated HANs in the same subset of swimming pools was observed, with higher proportions, on average, of DBAN

(47%) and BCAN (35%). This has repercussions on the levels of total HANs, which, on average, are twice as high as those measured in the 28 other swimming pools (33.75±15.61 µg/L compared to 15.70±8.44 µg/L). In those 28 swimming pools, DCAN (75%) predominates over BCAN (20%) and DBAN by a wide margin.

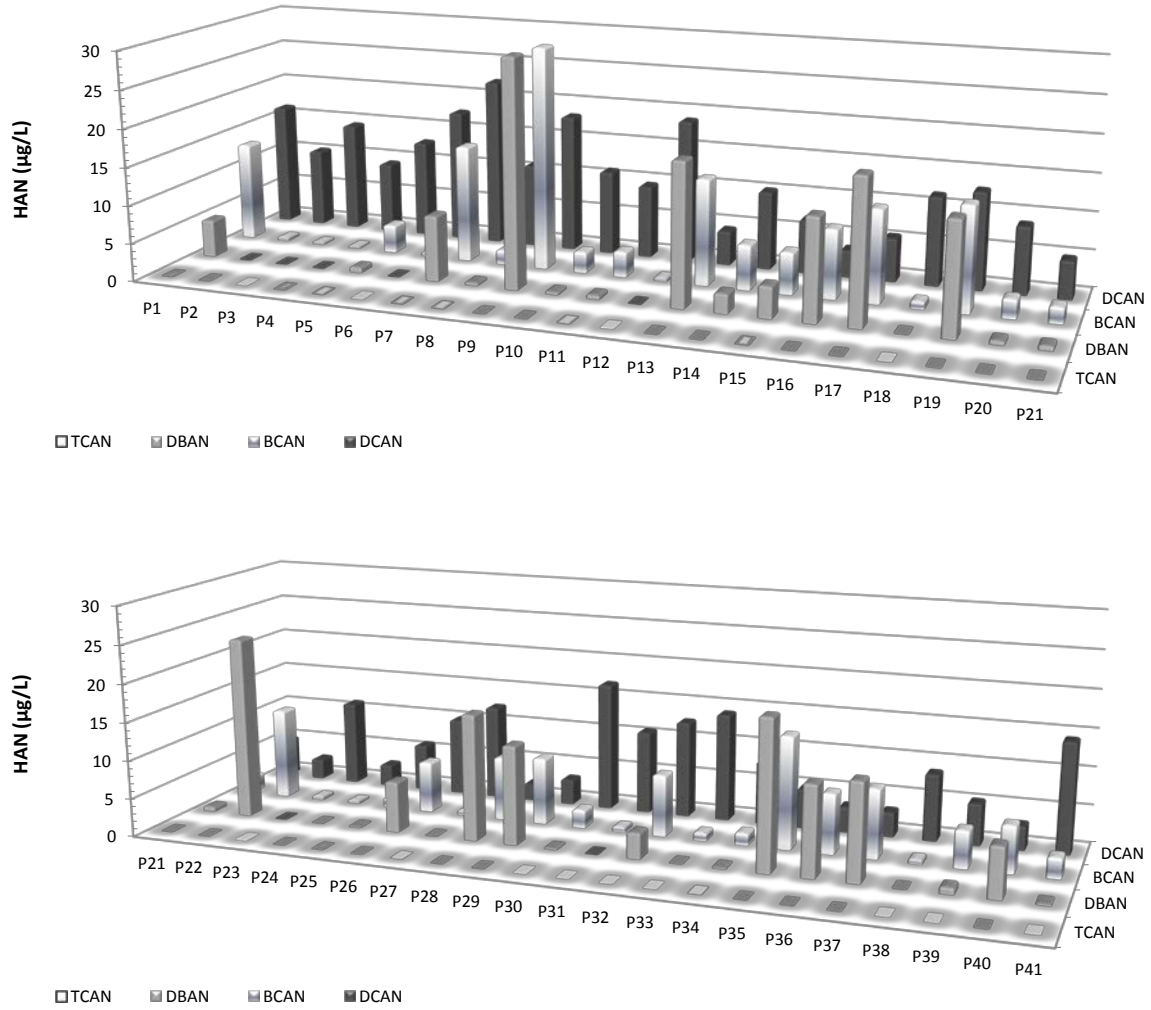


Figure 4 –HAN concentrations in the water of the 41 swimming pools visited

5.1.2.2.4 HK and HNM in the Water

Figure 5 presents the concentrations of HKs and HNMs measured in the water of each swimming pool. With respect to HKs, it was not possible to quantify 11DCPone with the available method in the swimming pool water because, in the two chromatographic columns, this compound, present in low concentrations, appears at the end of an enormous peak of a non-quantified compound (chloral hydrate).

The levels of 111TCPone remained relatively low compared to those of the other DBPs, remaining below the value of 2 µg/L except in 13 cases, and only going over 4 µg/L once. With respect to HANs, CPK is present in relatively low quantities, generally below 1 µg/L, except at three sites.

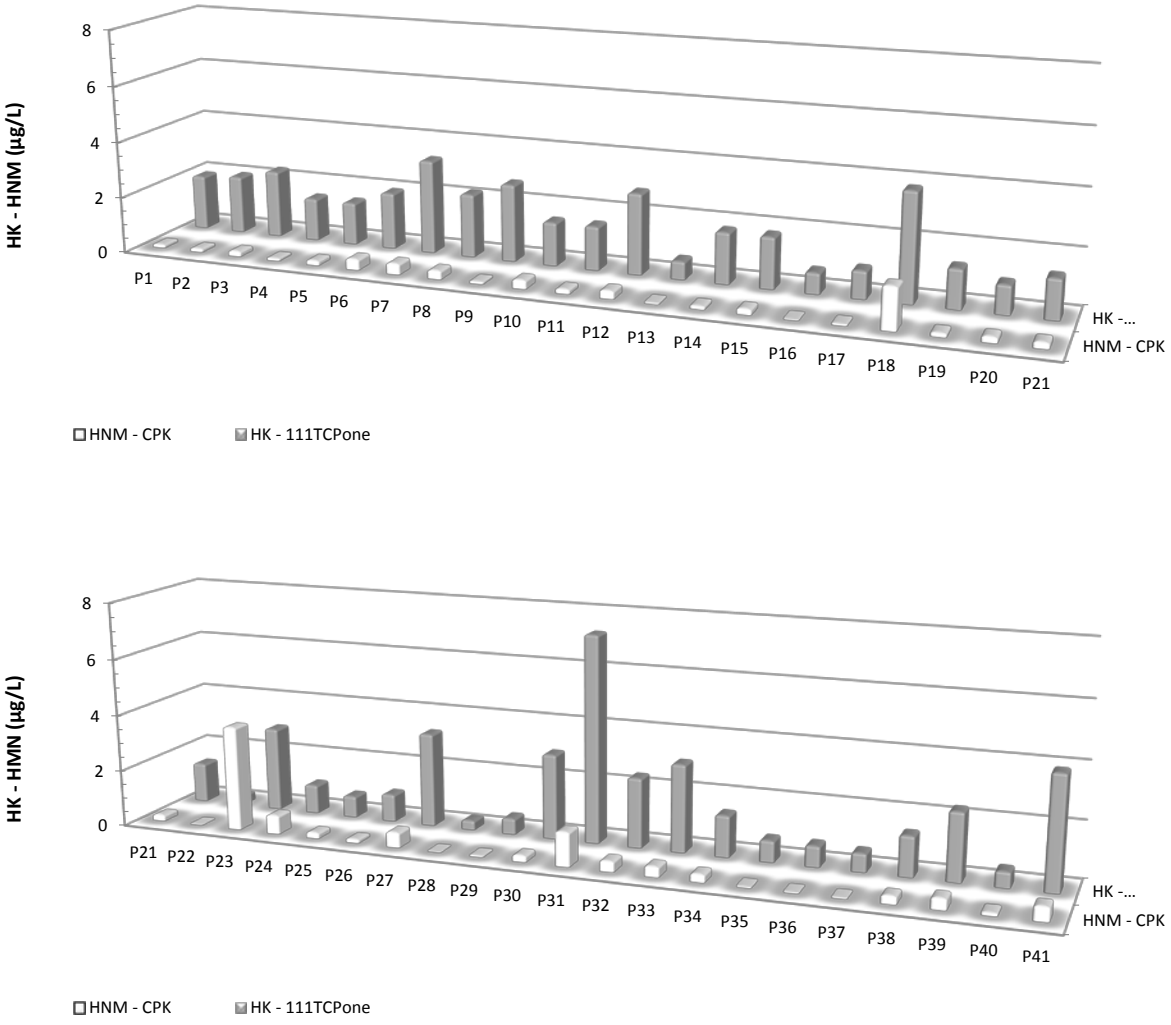


Figure 5 –HK and HNM concentrations in the water of the 41 swimming pools visited

5.1.2.2.5 THM in the Air

The presence of THMs in the water and their speciation has repercussions on the ambient air. This can be observed in the levels of TCM and brominated THM contamination. Interestingly, in this medium (Table 3), in all of the swimming pools, the maximum concentration of brominated THMs measured (460 µg/m^3) is well above that measured for TCM (320 µg/m^3).

Figure 6 presents the concentrations of the various types of THM measured in the air of each swimming pool. The results were consistent with those obtained for THM in the water. On average, chloroform is the most abundant compound (119.4±74.2 µg/m^3) but significant levels of brominated THM are also observed. In the group of 13 swimming pools in which levels of brominated THM predominated over the concentration of TCM, their levels in the air also constituted at least 47% of total THMs. In those swimming pools, CDBM is no longer systematically the major brominated compound among the THMs, as was the case in the water, even though on average its level (30%) remained proportionately higher than the others. In those cases, the amount of TBM (20%) is very close to that of TCM (25%). In the other swimming pools, TCM, which counts for almost 90% of THM concentrations in the air, far surpasses the levels of brominated compounds (10% of DCBM, 4% of CDBM, 1% of TBM).

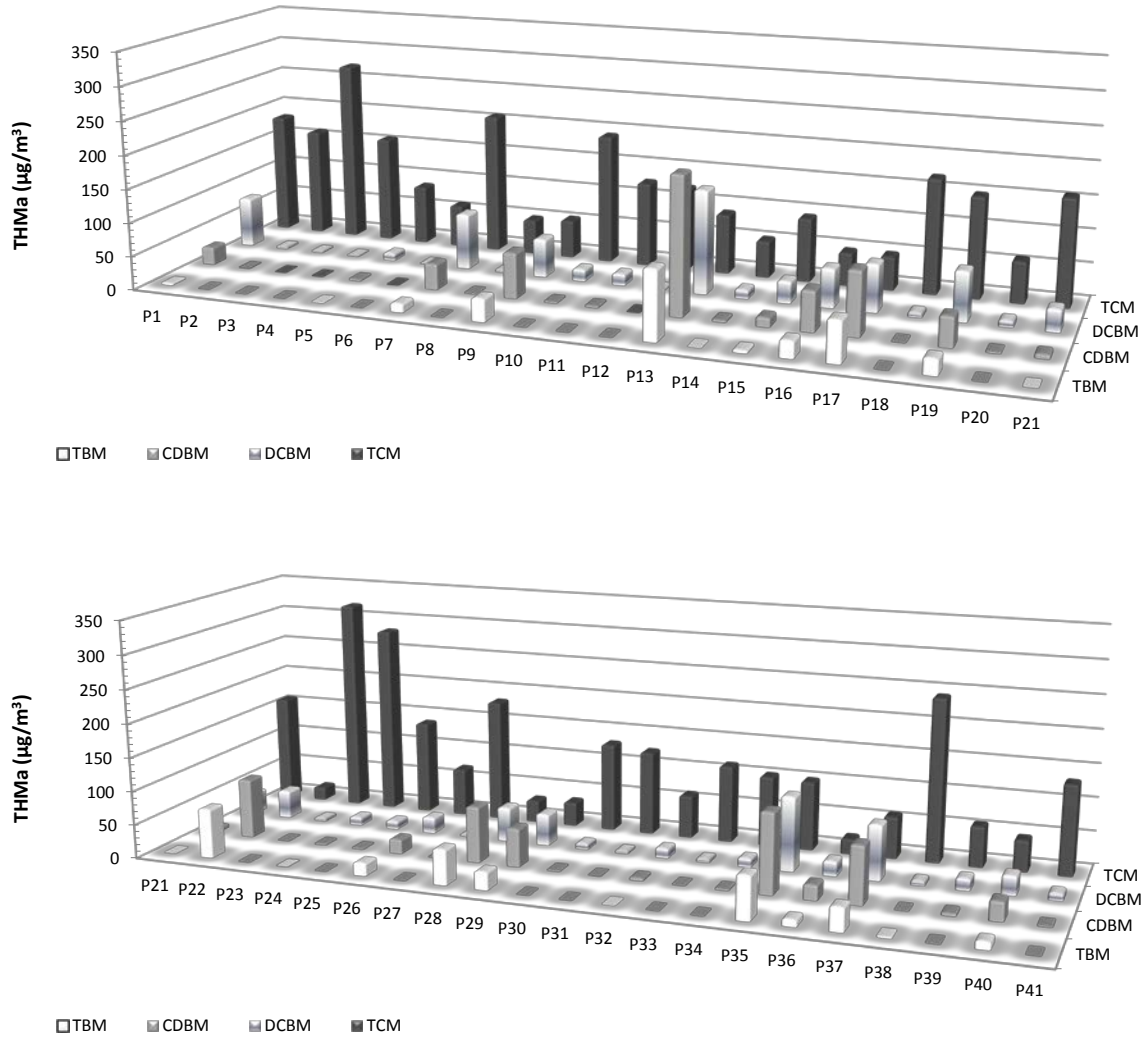


Figure 6 – THM concentrations in the air of the 41 swimming pools visited

5.1.2.2.6 CAM in the Air

Figure 7 presents the results of measurements of CAM (mainly TCAM) in the air of each of the swimming pools visited. As previously pointed out (Section 5.1.2.1.1), we again observe great variability from one swimming pool to the other. Although a sampling problem meant we were unable to obtain a value for a third swimming pool (P16), in three cases, the CAMs measured were below or just at the detection limit (P6, P8 and P39). These three cases show some of the lowest THM contamination in the air (between 58 and 84 µg/m^3). The other swimming pools in which concentrations of THM in the air are situated in this range (P14, P20, P36) also have among the lowest levels of CAM (between 0.08 and 0.12 mg/m^3). However, other swimming pools with just as low levels of CAM concentrations have much higher levels of THM (e.g., P11, P22, P29).

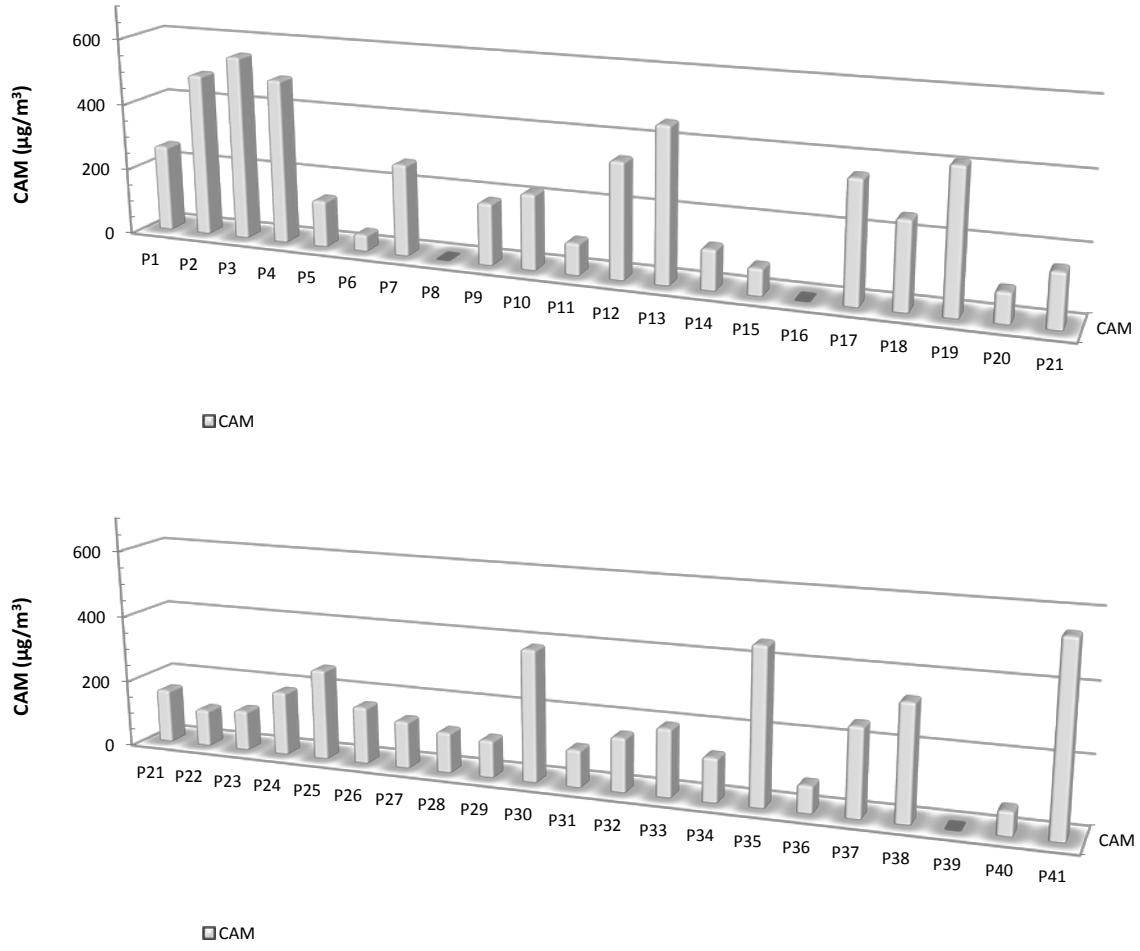


Figure 7 – CAM concentrations in the air of the 41 swimming pools visited

5.1.3 Relationships Among the Various DBPs

Given the previous results, Spearman's correlation analyses, which highlight the relationships among the various DBPs, were conducted separately on all of the 13 swimming pools in which brominated DBPs predominated, and then on all of the others. This section takes only the statistically significant correlations that were observed ($p<0.05$) into account.

5.1.3.1 Correlations among Compounds in the Air

In the air of swimming pools where the predominant contaminant is TCM, there are strong and exclusive correlations among the airborne concentrations of brominated compounds. Obviously, total THM concentrations are closely correlated with chloroform concentrations ($r=0.97$, $p<0.001$), and we also observed a correlation between these two concentrations and that of CAM in the air ($r=0.53$, $p=0.0035$ with TTHMs, and $r=0.59$, $p=0.0009$ with TCM). There is a strong correlation between the average number of bathers present during the sampling session and CAM concentrations ($r=0.61$, $p=0.0006$) but this is less evident with TCM ($r=0.38$, $p=0.0448$). This relationship is not significant in the case of TTHMs ($r=0.32$, $p=0.09$).

In the air of swimming pools where brominated DBPs are more common than TCMs, again, the concentrations of these compounds correlate, but they are now (and logically) also just as closely correlated with total THMs ($r=0.87$, $p<0.0001$ with all of the brominated compounds), while the relationship between this last variable and TCM weakens ($r=0.60$, $p=0.0306$). The concentration of CAM remains strongly correlated with that of total THMs ($r=0.89$, $p<0.0001$), especially with that of TCMs ($r=0.82$, $p=0.001$), but there is a more significant relationship with each of the brominated compounds, and most significant with DCBM ($r=0.87$, $p=0.0001$). In the previous group of swimming pools (where TCM is predominant), the correlations observed between the number of bathers and CAM concentrations on one hand, and TCM concentrations on the other, are the only ones that are significant for the swimming pools in which brominated DBPs dominate ([$r=0.61$, $p=0.0359$] and [$r=0.65$, $p=0.0154$], respectively).

5.1.3.2 Correlations Among Compounds in the Water

At swimming pools where brominated DBPs are even slightly present, the level of total THMs in the water logically correlates with that of TCM ($r=0.91$, $p<0.0001$), and also, to a lesser extent, with CPK ($r=0.48$, $p=0.0114$), DCA ($r=0.55$, $p=0.0029$) and MCA ($r=0.43$, $p=0.023$), but not with TCA or total HAA. The brominated THMs are, of course, closely correlated, in addition to being systematically correlated with other brominated HANs and HAAs. We also observe that brominated THM concentrations are inversely correlated with TCAN levels ($r=-0.40$, $p=0.039$) and the number of bathers reported when sampling took place ($r=-0.40$, $p=0.037$). The concentration of total HAAs is mainly related to that of DCA ($r=0.80$, $p<0.0001$), which is significantly correlated with concentrations of MCA, MBA and DBA. The only significant correlation observed for TCA, or one of the two most abundant HAAs, is, logically, with total HAA ($r=0.54$, $p=0003$).

Obviously, the brominated HAAs are strongly correlated, as are brominated HANs. The concentration of total HAN is linked to that of these predominant compounds, especially DCAN

(r=0.81, p<0.0001), but is also somewhat linked to low concentrations of 111TCPone (r=0.48, p=0.0087). Concentrations of CPK correlate somewhat with 111TCPone (r=0.53, p=0.0036) and with TCM (r=0.61, p=0.0007), and thus, in this case, with total THMs (r=0.48, p=0.0114). A correlation coefficient of 0.39 (p=0.0396) is also observed between the level of DCAN and the numbers of bathers.

At the 13 swimming pools where brominated THMs predominate, their levels in the water are strongly correlated among each other, but not with that of TCM. The concentration of the latter is closer to the levels of CPK and DCA ([r=0.92, p<0.0001] and [r=0.62, p=0.0196], respectively) than in the previous case. There is then a significant correlation between the TCM concentration and that of total HAAs (r=0.58, p=0.0398), but it is weaker with respect to DCAN (r=0.62, p=0.0241). The concentrations of brominated THM are significantly correlated with brominated HANs but not with any HAA. Instead, there is an inverse correlation between the concentrations of total HAAs and those of all of the brominated compounds (r=-0.60, p=0.0287). The concentration of TCA correlates only with that of TCM (r=0.57, p=0.0422). There are strong correlations among the levels of other HAAs. Correlations appear between HAN and THM levels, for example, between DBAN and CDBM (r=0.62, p=0.0235). Correlations between the levels of CPK and TCM on one hand, and 111TCPone on the other, increase ([r=0.92, p<0.0001] and [r=0.59, p=0.0325], respectively). Correlations involving CPK appear with the two least abundant HANs, i.e., TCAN (r=0.80, p=0.0018) and DCAN (r=0.68, p=0.0012). In that case, the level of DCAN remains correlated with the number of bathers (r=0.64, p=0.0185).

5.1.3.3 Correlations among Compounds in the Water and Those in the Air

At swimming pools where there is more TCM than brominated DBP, we observe that the concentration of CAM is inversely correlated with concentrations of brominated THMs in the water (with coefficients in the range of -0.4 and p in the range of 0.03 for the various compounds) but not with TCM. TTHMs and TCMs in the air are correlated, in a statistically significant manner, exclusively with total HAAs and DCAA (r=0.48 in both cases). The various brominated DBPs in the air show that, in this case, there are strong correlations with all the different brominated compounds in the water, in all classes of DBPs.

In the second case, in which brominated THMs are dominant, there are significant correlations linking CAMs and THMs in the air with BCAN and total HANs in the water (with correlation coefficients on the order of 0.7). These significant correlations with BCAN and total HANs are found for each THM in the air (with the exception of TCM). Total THM concentrations in the air also correlate, as do those of TBM and CDBM, with DBAN in the water (with coefficients on the order of 0.7, once again). The levels of CDBM and TBM in the air correlate with those of the different brominated compounds of the THM class in the water. However, this is not the case for DCBM in the air. TCM in the air correlates with TCM in the water (r=0.57, p=0.0398) as well as with CPK (r=0.59, p=0.03), TCPone (r=0.63, p=0.02) and DCAN (r=0.71, p=0.007).

5.2 Results of Campaign B – Biological Segment

5.2.1 Recruitment Results and Data Generated

5.2.1.1 Selection of Swimming Pools and Environmental Data

For the second campaign (B), eight swimming pools were chosen from among the 41 facilities initially visited, including the swimming pools on two university campuses, two public swimming pools in Québec City, and four in Montréal. These swimming pools were chosen to take into account basins with different relative proportions of TCM and brominated THMs. Table 5 lists the eight swimming pools and the proportions of THM that were initially measured in campaign A. Out of these eight swimming pools, five responded to the questionnaire and none had been emptied between campaigns A and B, nor, more generally, made any changes to their treatment process.

Table 5 – Proportion of different THMs compared to total THMs measured during campaign A, for the eight swimming pools selected for campaign B

Swimming Pool	Proportion in the WATER (% total THM)				Proportion in the AIR (% total THM)			
	TCM	DCBM	CDBM	TBM	TCM	DCBM	CDBM	TBM
P4	100	0	0	0	99	1	0	0
P10	89	9	2	0	90	8	1	0
P13	12	24	41	22	16	28	37	19
P15	71	19	8	2	65	22	10	3
P23	98	1	0	0	98	2	0	0
P30	89	9	2	0	92	7	1	0
P35	15	22	35	28	26	28	30	16
P38	97	3	0	0	96	3	0	1

In all, almost 200 water samples and over 60 air samples were taken at these eight swimming pools in the scope of the campaign, generating more than 500 analysis results for the environmental data.

5.2.1.2 Selection and Characteristics of Participants and Biological Data

Given the logistical constraints and the analyses, out of a maximum of 40 potential subjects (a maximum of five subjects per swimming pool), 37 volunteers were recruited. Two subjects were excluded because of abnormal results. The analysis of results was thus restricted to those of the 35 remaining participants, 16 women (23.4 years old, 1.65 m tall and 59 kg on average) and 19 men (27.7 years old, 1.81 m tall and 81 kg in weight on average). Table 6 describes the characteristics of the participants in detail. Most of the subjects were lifeguards; only three office employees and one maintenance employee were included in the study.

At the time of the campaign, the participants reported that, on average, they worked 26 hours a week at the swimming pool, and spent another four hours there for recreation (swimming). On average, the subjects had worked as lifeguards for approximately eight years. Six of the 35 subjects were in the water during our visit (between 30 minutes and three hours) and 18 of them were already on site when we arrived (up to 335 minutes before).

Table 6 – Characteristics of the volunteer subjects in campaign B

Swimming pool	Subject	Gender	Age (yrs)	Weight (kg)	Height (m)	Duration of exposure before sampling (min)	Exposure time between the 2 sampling periods (min)	Total time spent in the water during the visit (min)
P4	**S1**	F	18	43.5	1.52	0	230	60
P4	**S2**	M	18	90.7	1.83	0	225	180
P4	**S4**	F	18	52.2	1,68	0	155	45
P4	**S5**	M	29	72.6	1.80	0	130	0
P10	**S1**	F	32	67.6	1.68	110	95	0
P10	**S2**	F	27	63.5	1.68	195	55	0
P10	**S3**	M	30	83.9	1.78	360 (office)	130	0
P10	**S4**	M	29	100.0	1.83	20 (office)	65	0
P10	**S5**	M	25	104.3	1.83	20	130	60
P13	**S1**	M	21	99.8	1.91	270	140	0
P13	**S2**	F	19	62.6	1.65	0	225	0
P13	**S3**	F	22	56.7	1.63	0	180	0
P13	**S4**	F	21	56.7	1.68	0	150	0
P13	**S5**	F	24	69.4	1.63	0	100	0
P15	**S1**	F	18	50.8	1.63	0	215	0
P15	**S2**	F	23	56.7	1.67	110	180	0
P15	**S3**	M	57	70.3	1.88	180	220	0
P15	**S4**	M	21	70.3	1.72	0	195	30
P15	**S5**	M	23	72.6	1.78	0	135	0
P23	**S1**	M	29	88.5	1.88	335	145	0
P23	**S2**	M	20	79.4	1.87	130	175	0
P23	**S3**	M	18	79.4	1.83	0	100	0
P30	**S1**	M	49	95.3	1.75	260	140	0
P30	**S2**	F	27	58.1	1.65	195	160	0
P30	**S3**	F	38	60.8	1.63	165	105	0
P30	**S4**	F	19	53.5	1.63	0	165	0
P35	**S1***	F	NA	NA	1.60	240	150	0
P35	**S2**	M	20	55.8	1.83	5	150	0
P35	**S3***	M	42	90.7	1.88	315	120	0
P35	**S4**	M	21	80.0	1.87	0	120	0
P38	**S1**	M	27	64.0	1.73	60	300	45
P38	**S2**	M	22	73.5	1.68	0	315	0
P38	**S3**	F	22	71.7	1.75	0	300	0
P38	**S4**	M	26	75.0	1.75	120	280	0
P38	**S5**	F	23	63.0	1.70	0	230	0

5.2.2 Environmental Occurrence

Tables 7, 8 and 9 compare the values of mean concentrations of the various DBPs measured at each swimming pool during campaigns A and B. They highlight the existence of potentially major inter-seasonal variations. For CAMs, the levels measured in the air could thus vary twofold from one campaign to the other (e.g., P13, P15, P23, P38). With respect to THMs in the water, the levels measured during campaigns A and B appear to be about the same, except for swimming pool P30, where the TCM level more than doubled, and swimming pool P35, where the concentration was five times higher in campaign B than in campaign A. In the second case, a change in the speciation of THMs was observed in the swimming pool water (see Table 5 compared to Table 10), with a considerable decrease in the proportion of brominated THMs compared to total THMs from campaign A to campaign B. It was the same for swimming pool P15, where, although less marked, an increase in the proportion of TCM was observed from campaign A to campaign B, with a corresponding drop in the proportion of brominated THMs in the water. These proportional changes inevitably have repercussions on the composition of THMs in the air (Table 7). However, we remark that the levels of THM in the air systematically varied much more, almost doubling, such as in the case of CAMs in the air.

Table 7 – Concentrations of CAM and THM in the air and THM in the water during campaigns A and B in the eight swimming pools selected for the second campaign

		CAM (mg/m^3)	THM in the air ($\mu g/m^3$)					THM in the water ($\mu g/L$)				
			TCM	DCBM	CDBM	TBM	TTHM	TCM	DCBM	CDBM	TBM	TTHM
(A)	P4	0.36	160.2	2.4	<QLM[1]	<QLM	162.6	22.61	<QLM	<QLM	<QLM	22.61
(A)	P10	0.20	194.2	18.3	2.6	0.2	215.3	53.10	5.20	1.00	0.10	59.40
(A)	P13	0.51	90.0	154.6	204.8	102.8	552.2	15.05	30.05	51.25	27.80	124.15
(A)	P15	0.08	95.6	33.1	14.5	4.6	147.8	40.50	11.00	4.40	1.30	57.20
(A)	P23	0.12	320.4	5.3	0.3	<QLM	326.0	102.20	1.30	0.30	0.30	104.10
(A)	P30	0.39	133.0	9.7	1.7	0.2	144.6	41.60	4.30	0.90	0.20	47.00
(A)	P35	0.46	103.2	110.8	119.2	64.3	397.5	15.70	22.20	35.25	28.15	101.30
(A)	P38	0.34	243.7	7.5	0.6	2.4	254.2	55.70	1.65	0.20	0.15	57.70
(B)	P4	0.28	111.8	4.5	0.3	<QLM	116.7	28.90	1.15	<QLM	<QLM	29.67
(B)	P10	-	117.4	3.8	0.3	<QLM	121.5	48.55	1.70	<QLM	<QLM	50.24
(B)	P13	0.25	53.7	86.3	95.4	36.1	271.5	21.86	37.60	55.62	24.61	139.70
(B)	P15	0.45	241.3	46.3	23.0	8.9	319.6	60.59	5.78	1.39	<QLM	67.75
(B)	P23	0.06	154.5	3.8	0.2	<QLM	158.4	100.06	2.45	<QLM	<QLM	102.51
(B)	P30	0.45	234.0	23.2	2.4	0.2	259.8	93.20	8.49	<QLM	<QLM	101.69
(B)	P35	0.18	98.5	25.2	7.2	1.6	132.6	87.81	20.41	6.22	1.49	115.92
(B)	P38	0.19	170.5	5.3	0.4	1.2	177.4	61.75	1.91	<QLM	<QLM	63.66

[1] QLM = Quantification limit of the method

With three exceptions (P13, P30 and P38), the differences in levels measured between campaigns A and B are at least 100 µg/L for total HAAs, which remain the most abundant compounds. Their speciation occurs in proportions that are, all in all, comparable between the two campaigns.

Table 8 – Concentrations of HAAs in the water during campaigns A and B in the eight swimming pools selected for the second campaign

		HAA in the water (µg/L)						
		MCA	**MBA**	**DCAA**	**TCA**	**BCAA**	**DBA**	**HAA6**
(A)	P4	9.8	<QLM[1]	87.0	207.6	1.2	<QLM	315.7
(A)	P10	20.5	2.5	187.7	173.3	23.2	6.3	400.8
(A)	P13	5.4	5.5	43.0	75.7	42.9	33.2	206.6
(A)	P15	50.7	7.6	483.6	249.6	71.5	19.7	886.2
(A)	P23	42.6	<QLM	342.0	162.7	1.2	<QLM	547.1
(A)	P30	8.7	<QLM	70.6	60.4	5.5	<QLM	141.6
(A)	P35	10.6	8.6	85.4	36.8	50.1	30.9	221.6
(A)	P38	13.5	<QLM	114.2	119.2	3.5	<QLM	250.4
(B)	P4	10.2	<QLM	150.9	289.1	8.7	1.0	459.8
(B)	P10	9.4	<QLM	68.9	80.4	1.9	<QLM	160.6
(B)	P13	4.4	4.0	32.1	23.3	34.8	24.5	123.1
(B)	P15	32.8	3.3	281.1	244.5	34.7	9.4	605.8
(B)	P23	23.5	<QLM	153.5	136.5	1.8	<QLM	315.3
(B)	P30	9.7	<QLM	80.1	70.5	6.2	<QLM	166.5
(B)	P35	19.3	4.7	167.4	95.7	35.3	10.7	333.0
(B)	P38	7.9	<QLM	80.1	172.0	2.4	<QLM	262.3

[1] QLM = Quantification limit of the method

With the exception of swimming pool P23, where a clear increase in eDBP levels in the water is observed (Table 9), concentrations in the other swimming pools remained the same during the first and second campaigns. As for the previously mentioned THMs, there is a change in speciation of the HANs between the two campaigns at swimming pools P15 and P35. In both cases, the proportion of brominated compounds decreased, while chlorinated compounds increased.

Table 9 –HAN, HNM, HK and NDMA concentrations in the water during campaigns A and/or B at the eight swimming pools selected for the second campaign

		HAN (µg/L)					HNM (µg/L)	HK (µg/L)	NDMA (ng/L)
		TCAN	DCAN	BCAN	DBAN	T-HAN	CPK	111TCPone	
(A)	P4	0.03	9.51	0.28	<QLM[1]	9.8	0.10	1.53	
(A)	P10	0.02	11.21	2.83	0.40	14.5	0.32	1.55	
(A)	P13	<QLM	4.59	14.04	18.73	37.4	0.06	0.64	
(A)	P15	0.03	7.09	5.57	4.16	16.9	0.20	1.82	
(A)	P23	0.12	11.35	0.51	<QLM	12.0	3.71	2.99	
(A)	P30	0.08	17.01	2.45	0.22	19.8	0.23	3.00	
(A)	P35	<QLM	5.26	14.75	19.50	39.5	0.05	0.75	
(A)	P38	0.06	8.85	0.62	0.04	9.6	0.29	1.42	
(B)	P4	0.04	8.77	0.85	Iv[2]	9.66	0.12	1.52	105
(B)	P10	0.04	10.06	0.53	<QLM	10.63	0.37	1.75	13.9
(B)	P13	0.01	4.13	11.18	14.49	29.82	<0.01	0.93	12.4
(B)	P15	0.05	12.31	3.08	1.75	17.19	0.25	2.77	71.5
(B)	P23	1.14	23.57	1.03	Iv	25.71	5.04	11.13	79.3
(B)	P30	0.34	14.53	1.85	Iv	16.71	0.28	3.89	2.4
(B)	P35	0.04	11.70	6.74	3.86	22.34	0.22	1.83	57.5
(B)	P38	0.05	7.44	0.56	Iv	8.05	0.22	0.91	2.8

[1] QLM = Quantification limit of the method

[2] Iv = Invalid (value excluded because quality control was not respected)

Table 10 – Proportions of the different THMs compared to total THMs measured during campaign B

Swimming pools	Proportions of THMs in the WATER (%)				Proportions of THMs in the AIR (%)			
	%TCM	%DCBM	%CDBM	%TBM	%TCM	%DCBM	%CDBM	%TBM
P4	97	4			96	4	0	
P10	97	3			97	3	0	
P13	16	27	40	18	20	32	35	13
P15	89	9	2		76	14	7	3
P23	98	2			98	2	0	
P30	92	8			90	9	1	0
P35	76	18	5	1	74	19	5	1
P38	97	3			96	3	0	1

Additional environmental measurements were carried out in campaign B: (i) concentrations of volatile DBPs in the rooms near the swimming pool basin, where the biological samples were

collected (most often the lifeguards' offices) and (ii) the concentrations of NDMA in the swimming pool water.

Table 11 presents the first of these two results. The CAM levels measured in those rooms were negligible, or very low, for the entire series of sampling. The data show that THM levels in the air, influenced by TCM levels in particular, varied more widely. In the rooms at each facility, the levels are lower than those found in the swimming pool hall (approximately 30% of those measured around the swimming pool basin). We observed that the highest levels of THM measured in the offices corresponded to those of the highest levels of CAM. NDMA levels in the water varied widely between 2.8 ng/L and 105 ng/L in this series of measurements (Table 9).

Table 11 – Concentrations of CAM (mg/m^3) and THM (µg/m^3) in office air during campaign B

			CAM (mg/m^3)	THM in the air (µg/m^3)				
				TCM	DCBM	CDBM	TBM	TTHM
(B)	P4	Office	<0.05	2.8	0.10	<QLM[1]	<QLM	2.9
(B)	P10	Office	-	29.4	1.12	0.17	<QLM	30.7
(B)	P13	Corridor	<0.05	2.67	3.69	4.04	1.82	12.2
(B)	P15	Office	<0.05	16.3	3.62	2.23	0.88	23.0
(B)	P23	Office	<0.05	65.9	1.69	<QLM	<QLM	67.6
(B)	P30	Office	0.11	126.0	12.2	1.4	0.6	140.2
(B)	P35	Office	0.06	67.6	16.22	4.76	1.11	89.7
(B)	P38	Office	0.07	134.2	4.44	0.38	1.37	140.4
(B)	P38	Corridor	<0.05	31.7	1.15	0.16	1.10	34.1

[1] QLM = Quantification limit of the method

5.2.3 Biological Measurements

For each matrix considered, the first sample gathered at our arrival on the site represented zero time; the second sample gathered after a variable period of work was considered as post-exposure time.

5.2.3.1 Alveolar Air

All the participants provided samples of alveolar air (n=35). Figure 8 presents the levels of THM measured in the alveolar air at zero time and at post-exposure time for each of these 35 subjects. TBM was systematically below the quantification limit of the method and is therefore not presented. The TCM, DCBM and CDBM levels measured at zero time are on average 19±20.7 µg/m^3, 1.6±1.5 µg/m^3, and 0.8±0.4 µg/m^3, respectively. At post-exposure time, these average levels reach 32±20.5 µg/m^3, 3.2±2.9 µg/m^3, and 1.7±1.7 µg/m^3, respectively.

On average, based on these empirical data, we calculate the increasing factors of concentrations in alveolar air as 2.83 for TCM, 2.44 for DCBM and 1.89 for CDBM, which attests to the impact of environmental exposure biologically. However, in four individuals, the post-exposure concentration of TCM is lower than the concentration corresponding to zero time. In these four cases, the first sample was taken (zero time) when the subject had already been working for at least 165 minutes and the relative variation of concentrations is minimal. Generally, we observe that for TCM, post-exposure concentrations are close to the concentrations at zero time in subjects who had already been exposed before the first sample was taken. However, the data does not show that longer exposure times would induce higher factors of increase, which suggests that a steady state occurs after a relatively short exposure time. The same is found in the case of DCBM. The only other case in which a post-exposure level that was less than the zero time level corresponds to very low environmental contamination by that compound. By the same token, the generally very low environmental levels of CDBM do not appear to cause noticeable differences in biological levels between zero time and post-exposure time. High levels of these brominated compounds in the ambient air (P13, P15, P35) have, however, a demonstrable biological impact.

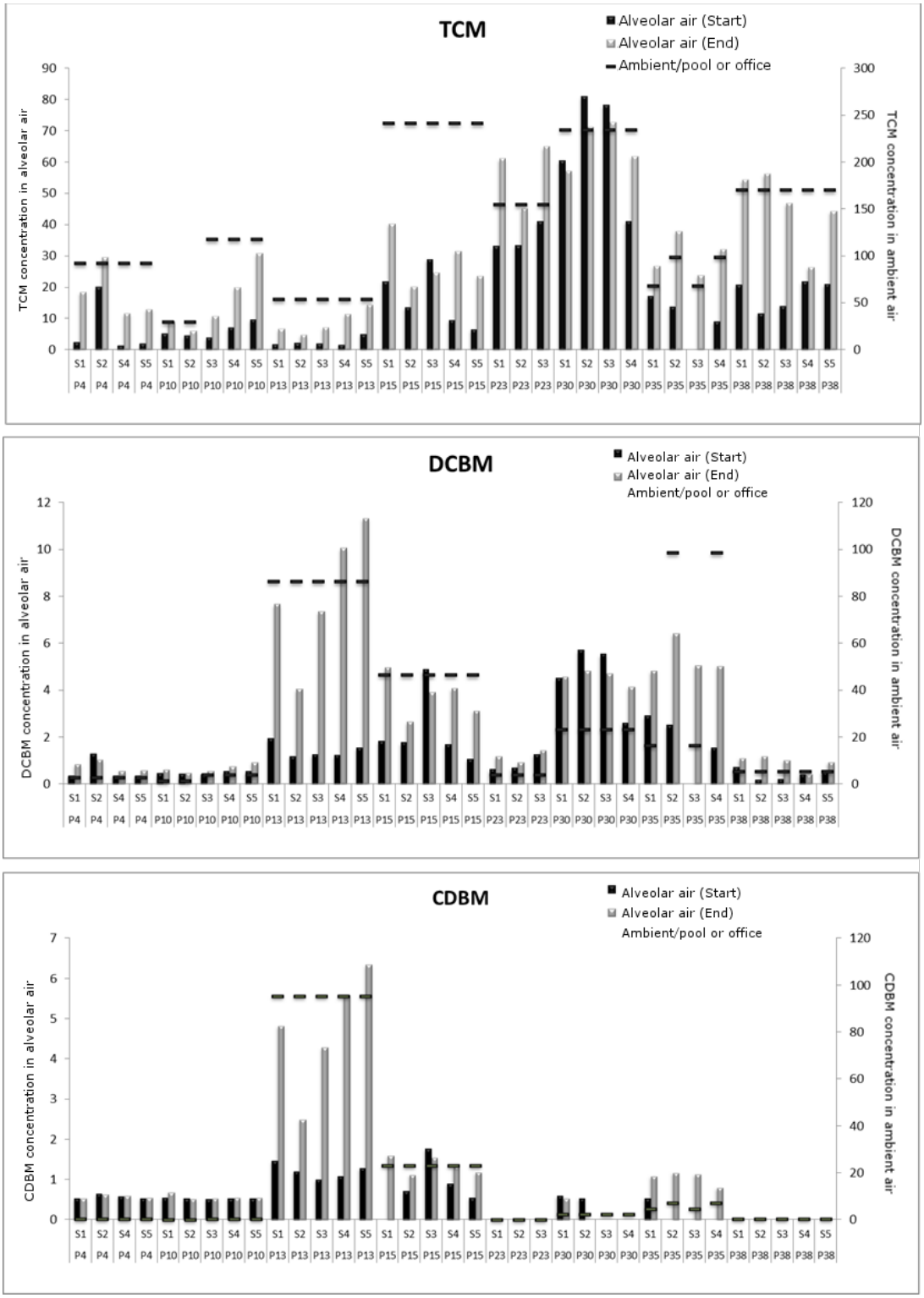


Figure 8 –TCM, DCBM and CDBM concentrations in the alveolar air of 35 subjects at zero time and post-exposure time, as well as in the ambient air

5.2.3.2 Urine

Out of the 35 volunteers, two subjects did not provide urine samples and one sample was lost due to technical problems. One sample was excluded because of an abnormal value. This left 31 subjects whose urinary concentrations of THM were recorded. Figure 9 presents the THM levels measured in the urine collected for each of the subjects at zero time and that collected at post-exposure time. TBM was systematically below the method's detection limit and was therefore not represented. The levels of TCM, DCBM and CDBM measured at zero time are on average 115.1±61.6 ng/L, 12.5±7.1 ng/L, and 7.5±3.6 ng/L, respectively. At post-exposure time, these average levels reached 151.8±78.2 ng/L, 21.6±16.2 ng/L, and 14.6±8.5 ng/L, respectively.

The results obtained for TCM showed systematic but highly variable increases in the urinary concentration of this compound between zero time and post-exposure time, except in five cases, in which a decrease was observed. One of these cases (P35, S3) is that of a maintenance employee, for whom we also consistently observed a decrease in the urinary concentrations of DCBM and CDBM. Generally, variations were minor in the urinary concentrations of THM in subjects who do not work directly around the swimming pool basin (office employee). In a second subject (P13, S4) at a swimming pool where brominated THMs predominate, the urinary TCM concentrations decreased, while there was an increase in concentrations of DCBM and CDBM. This increase was also seen in the other subjects of that swimming pool, while their urinary concentrations of TCM varied little. Generally, in swimming pools in which the environmental contamination is marked by the presence of brominated THMs (P13, P15, P35), their presence has a noticeable impact on urinary concentrations of DCBM and CDBM, as they do in alveolar air. The three other subjects whose urinary concentrations of TCM decreased between the two sampling periods worked at the same swimming pool (P4), which had the lowest THM contamination (in both the water and the air) of the facilities visited during campaign B. The urinary concentration of THM remained almost unchanged in the fourth participant at that swimming pool (P4, S2).

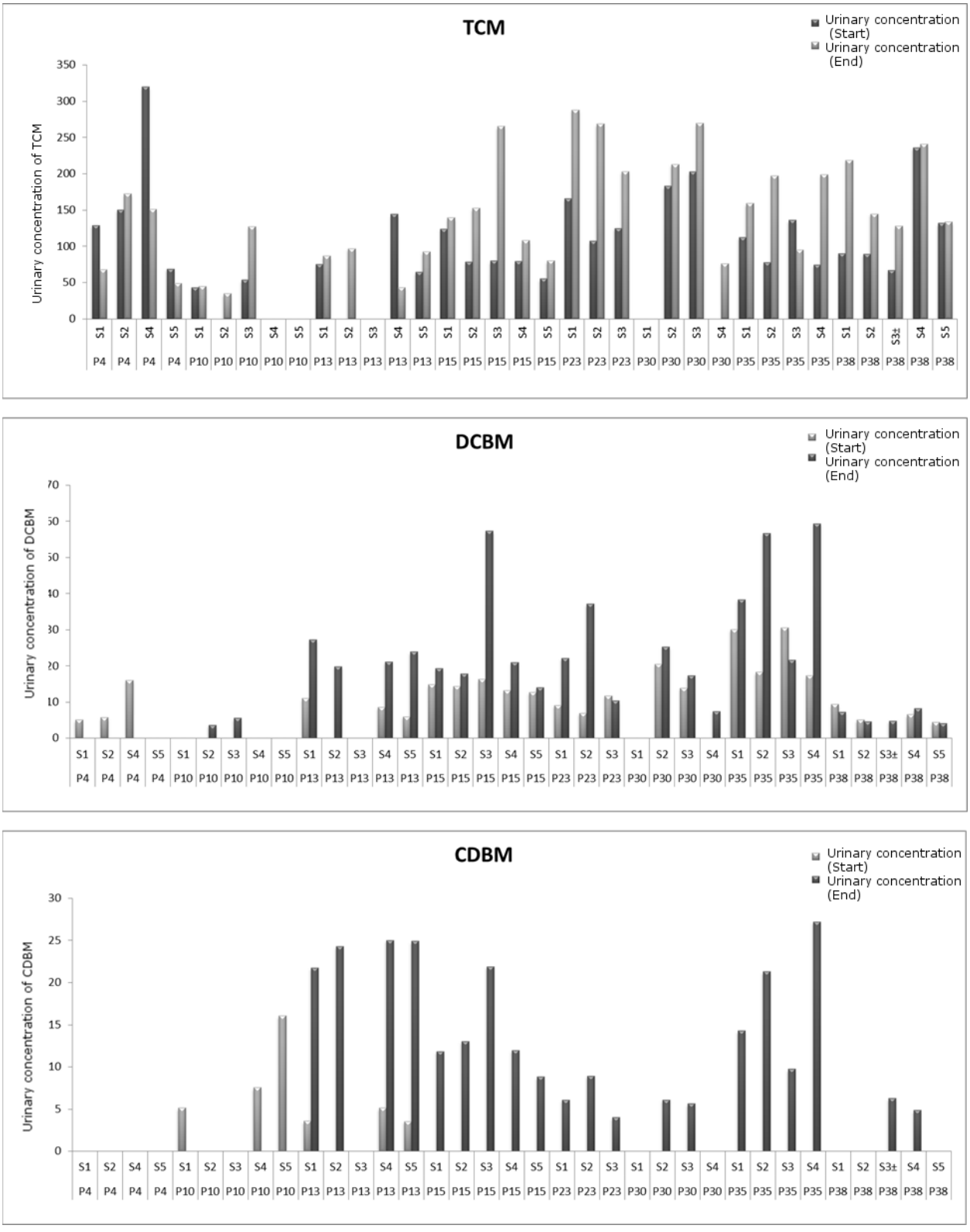


Figure 9 - TCM, DCBM and CDBM concentrations in subjects' urine at zero time and post-exposure time

5.2.4 Physiologically Based Toxicokinetic Modeling

One aspect of this project was assessing the use of PBTK modeling as a tool to simulate and predict TCM exposure in workers. This modeling aspect is based on the data for alveolar concentrations of TCM in all of the 35 subjects and on quantities of TCM in the urine, per period, for 29 of them. The results from the urine samples of two subjects (out of the 31 for whom the data out was initially available) were excluded because their urine was highly diluted (urinary output: >310 mL/h).

5.2.4.1 Comparison of Predictions and Experimental Results

The predictions of the model for alveolar concentrations (n=35) and quantities of TCM in the urine per period (n=29) in each of the workers were compared to the biological data measured by integrating the conditions and scenarios of specific exposure of each individual into the model as closely as possible and in also taking into account the time between the beginning/end of exposure and sample-taking.

5.2.4.1.1 TCM in Alveolar Air

Figure 10 presents some of the results of the simulation of alveolar TCM in workers in different cases. At the beginning of the simulation, blood contamination and, consequently, alveolar air contamination by TCM is immediate (Ramsey and Andersen, 1984) and its concentration reaches a relatively high value in a few seconds, depending on the concentration in the ambient air. For the subjects presumed not to have been exposed, the model predictions are therefore equal to zero by default and cannot be compared to the actual measured mean of 10.79±10.8 µg/m^3. For the 18 others already working during the first alveolar air sampling, TCM concentrations in alveolar air were generally well described by the model (Figure 11), with a correlation coefficient *r* of 0.903 between the data and the predictions. However, the model tends to underestimate the experimental data when it calculates the post-exposure value of the concentration in alveolar air (Figure 12). The correlation coefficient obtained between the results and the predictions then drops to 0.616.

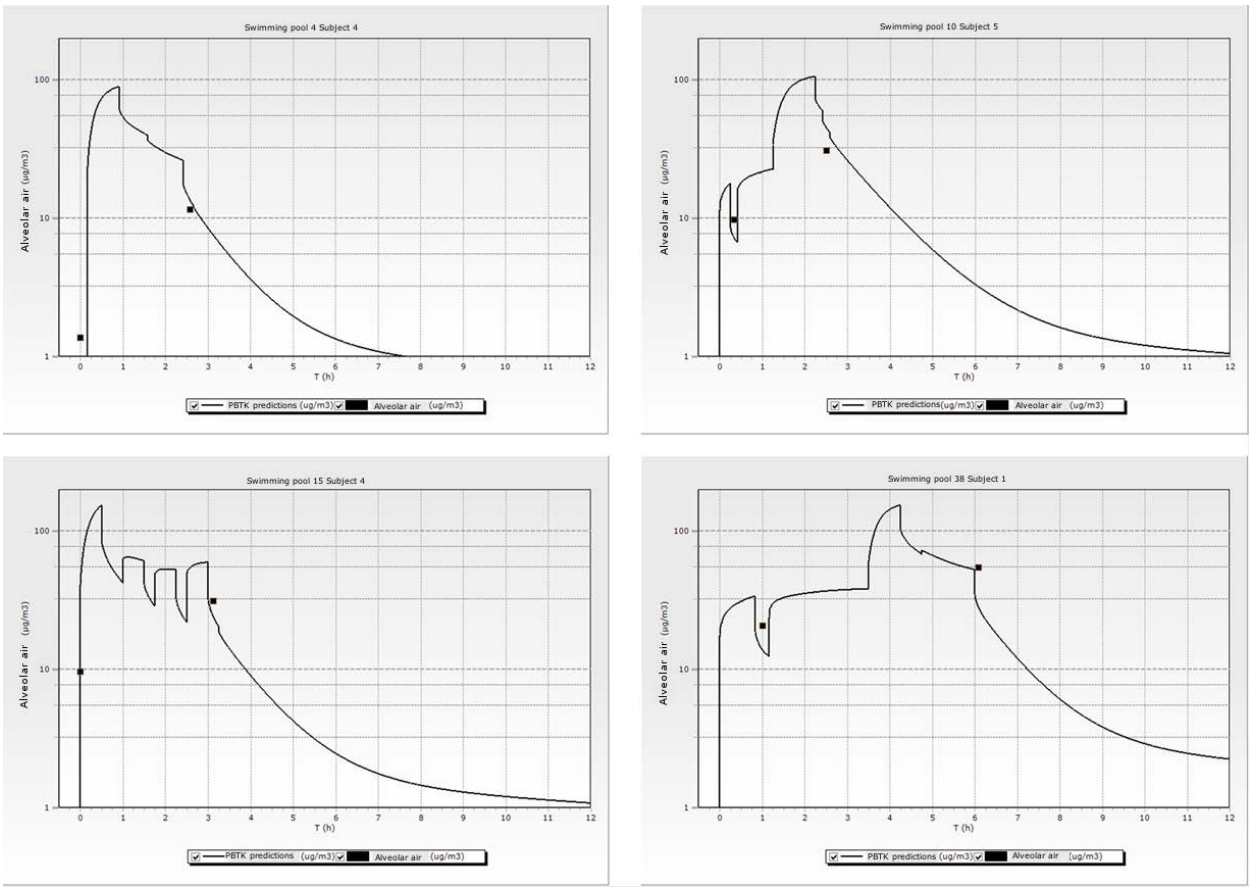


Figure 10 – Comparison of concentrations of alveolar TCM (µg/m^3) predicted by the PBTK model (lines) with the biological values measured (points) in the subjects in different cases. Each of the scenarios presented includes a period of intense training activity in the pool. (A) P4_S4; (B) P10_S5; (C) P15_S4; (D) P38_S1

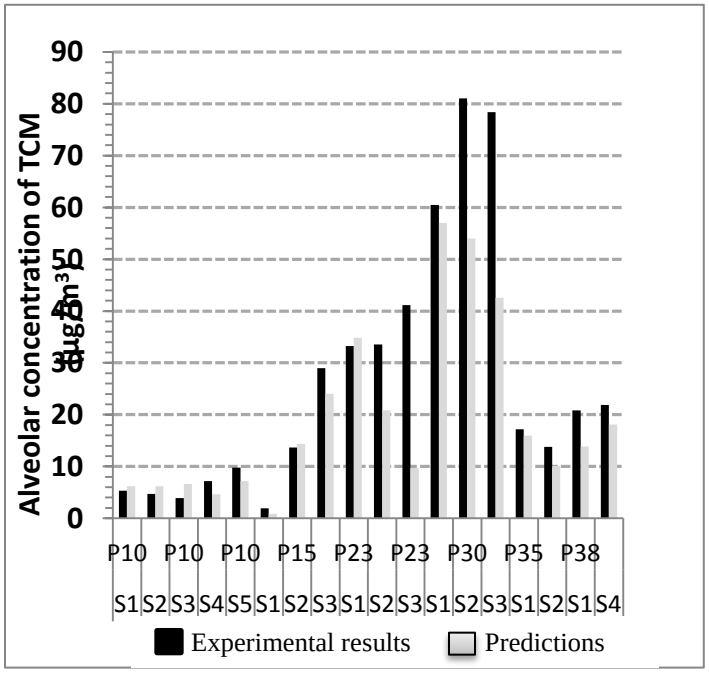


Figure 11 –Comparison between experimental measurements (black) of the alveolar concentration of TCM (µg/m^3) and the predictions of the PBTK model (grey) during the first sampling of subjects already at work (correlation coefficient *r*=0.903)

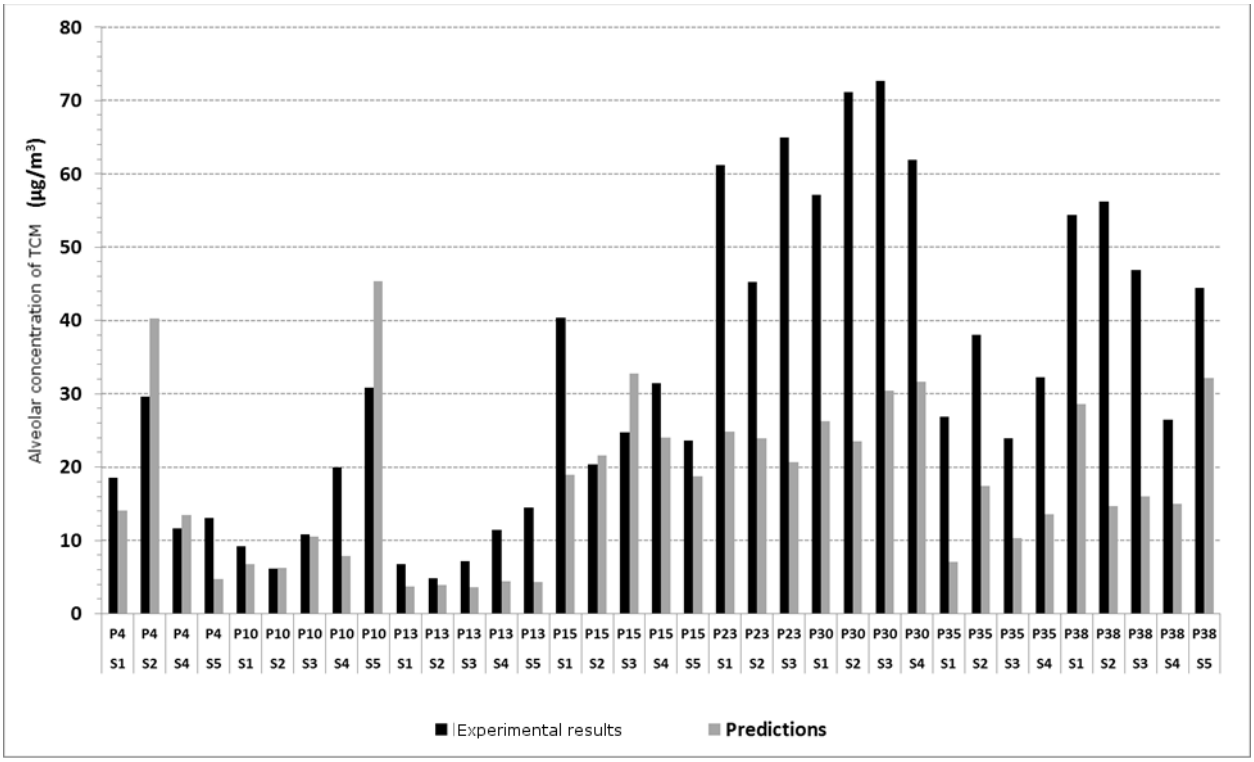


Figure 12 – Comparison between experimental measurements (black) of the alveolar concentration of TCM (µg/m^3) and the predictions of the PBTK model (grey) at post-exposure time (correlation coefficient *r*=0.616)

5.2.4.1.2 Urinary TCM

The model enables the quantity of TCM in the urine excreted during the sampling period (r=0.824) (Figure 13) to be described. However the PBTK model underestimates the quantities of urinary TCM on average by 59±30% of the experimental value (ng/period) (Figure 14).

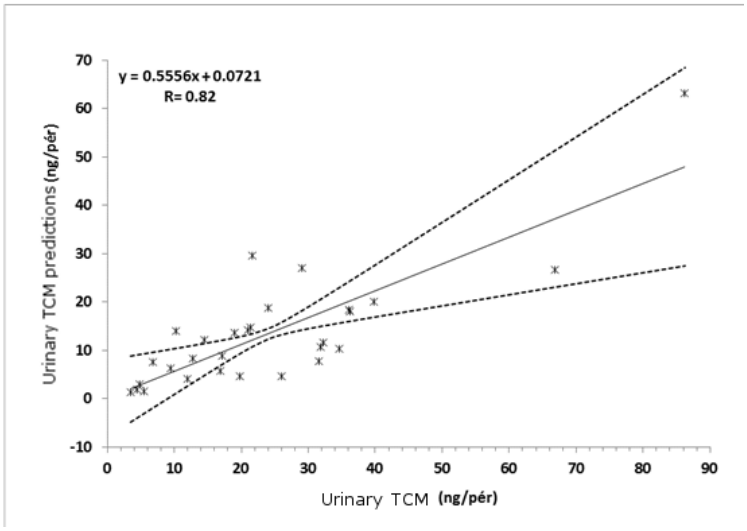
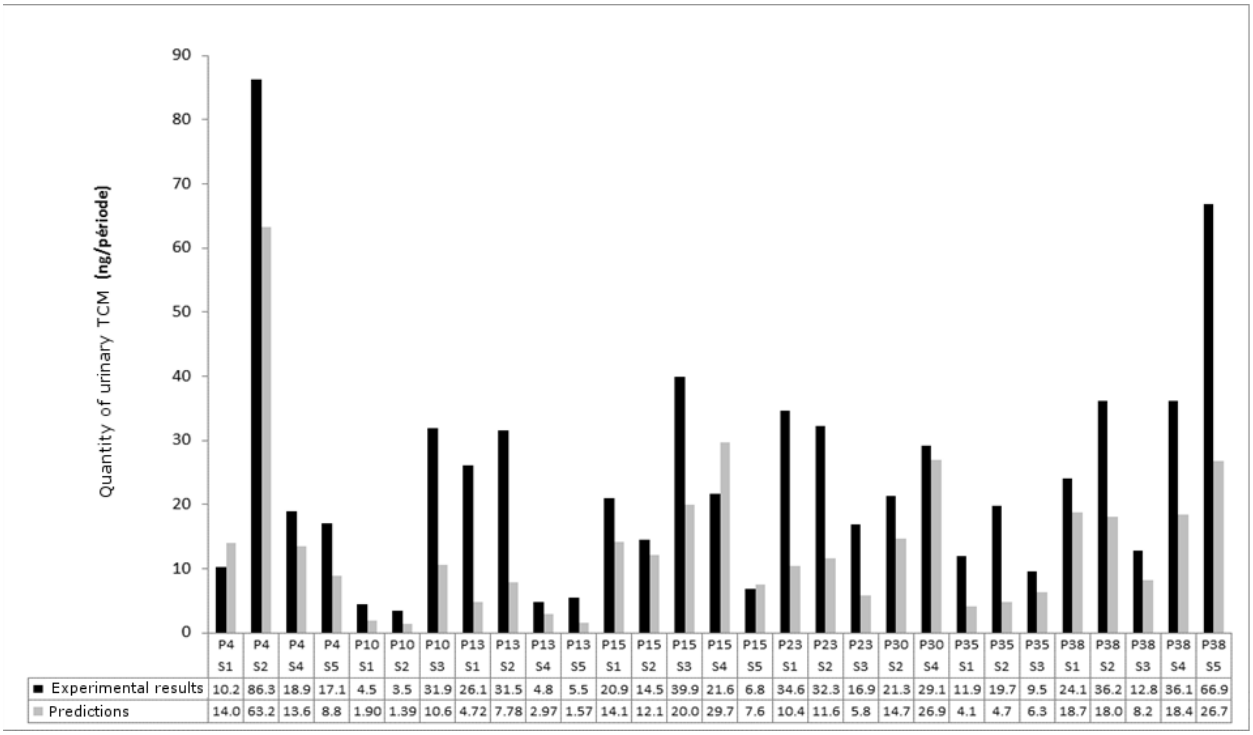


Figure 13 – Regression line between the predictions of the PBTK model and the quantities of TCM measured in the subjects' urine (ng/period)



	P4 S1	P4 S2	P4 S4	P4 S5	P10 S1	P10 S2	P10 S3	P13 S1	P13 S2	P13 S4	P13 S5	P15 S1	P15 S2	P15 S3	P15 S4	P15 S5	P23 S1	P23 S2	P23 S3	P30 S2	P30 S4	P35 S1	P35 S2	P35 S3	P38 S1	P38 S2	P38 S3	P38 S4	P38 S5
Experimental results	10.2	86.3	18.9	17.1	4.5	3.5	31.9	26.1	31.5	4.8	5.5	20.9	14.5	39.9	21.6	6.8	34.6	32.3	16.9	21.3	29.1	11.9	19.7	9.5	24.1	36.2	12.8	36.1	66.9
Predictions	14.0	63.2	13.6	8.8	1.90	1.39	10.6	4.72	7.78	2.97	1.57	14.1	12.1	20.0	29.7	7.6	10.4	11.6	5.8	14.7	26.9	4.1	4.7	6.3	18.7	18.0	8.2	18.4	26.7

Figure 14 – Comparison between the quantities of TCM measured (ng/period) (black) and the predictions of the PBTK model (grey) (correlation coefficient *r*=0.824; n=29)

Given that the average urinary concentration measured in the first urine sample (workers who had not been exposed when we arrived) is equal to 96.8±33 ng/L, with a maximum value of 150 ng/L and a minimum value of 55 ng/L, the contribution of TCM from external sources was explored using a model to analyze its impact on our predictions. Different scenarios were simulated: oral absorption of drinkable water, inhalation of air in a home contaminated with

TCM, and showering, which would cause an increase in ambient concentrations of TCM and absorption through the skin. The TCM concentrations in household air and in the shower were estimated using a static model (Lyman et al., 1982; McKone, 1987) for TCM concentrations in drinking water of values of 22.7 µg/L and 121 µg/L, respectively (Haddad et al., 2006).

Table 12 shows the urinary concentration of TCM in a 70 kg man with a urinary output of 60.22 mL/h (Hamelin et al., 2005) for sample taken between 7:00 a.m. and 9:00 a.m. following the oral absorption of five glasses of water spread out from 7:00 a.m. to 7:00 p.m. (A,B), absorption by inhalation of TCM at home (C,D) and percutaneous and inhalation absorption while showering (10 minutes), followed by inhaling air in the home (E,F). The predicted urinary concentrations of TCAM are low compared to the average measured in our study, except for the showering scenario, which gives concentrations of 18.22 ng/L and 97.12 ng/L, for drinking water concentrations of 22.7 µg/L and 121 µg/L, respectively. Only scenario (F) could result in concentrations similar to those obtained at the start. The concentration of urinary TCM could come from an accumulation of TCM in these workers, who are repetitively exposed five days a week. The model of a worker exposed five days a week for one month did not reveal a significant accumulation of TCM in the urine, which could explain our results. The addition of a production constant of TCM (14 ng TCM/h) in the renal compartment to mathematically compensate gives a urinary concentration of TCM 60 ng/L. This scenario is equivalent to the absorption of high doses of TCM (360 µg/24 h) and seems highly improbable.

Table 12 – Estimate of the total dose of TCM and the urinary concentration of TCM, for a period of 2 hours, between 7:00 a.m. and 9:00 a.m., according to various TCM exposure scenarios following day-to-day activities within a home

			A	B	C	D	E	F	G
	TCM concentration, drinking water	(µg/L)	22.7	121.0	22.7	121.0	22.7	121.0	80.0
	Glasses of water	(mL)	300	300	-	-	-	-	300
	TCM concentration, household air	(µg/m^3)	-	-	1.34	7.16	1.34	7.16	4.73
	TCM concentration, shower air	(µg/m^3)	-	-	-	-	242.4	1292.3	854.4
	Shower	(min)	-	-	-	-	10	10	30
	Total dose of TCM	(µg/kg/d)	0.48	2.57	0.15	0.79	0.47	2.50	5.40
7-9 am	**Urinary TCM**	(ng)	0.051	0.27	0.10	0.52	2.19	11.70	22.08
7-9 am	**Concentration of urinary TCM**	(ng/L)	0.42	226	0.81	4.32	18.22	97.12	183.37

5.2.4.2 Simulations of Scenarios of Hypothetical Exposure of Workers

Table 13 deals with doses of TCM predicted by the PBTK model in “average” workers (a male and female, distinguishable from each other by their “typical” respective weight during the simulation), according to a hypothetical scenario of exposure by inhalation only. The value of that dose is extremely variable from one swimming pool to another, and of course is dependent

on the level of TCM contamination at the swimming pool. The lowest dose was measured in the case of the swimming pool most highly contaminated with THM (water and air) among those visited during campaign B, mainly because of the dominance of other brominated compounds. In general, the estimated doses are close to the tolerable daily intake (TDI) considered by Health Canada to determine the maximum concentration in drinking water, set at 6.2 µg/kg/day.

Table 13 – Estimate of the dose of TCM absorbed by two average subjects (a 55 kg female, and a 70 kg male), in a 24-hour period, for an exposure of 3 hours and 30 minutes in the swimming pool, followed by a 1 hour break and 3 hours and 30 minutes in the swimming pool, at concentrations measured in each of the swimming pools of campaign B and at concentrations representative of campaign A

	Pool	Break*	Female	Male
	TCM air µg/m^3		TCM dose µg/kg/day	
Campaign A (n=41)				
Minimum	20.3	0.0	0.70	0.65
Maximum	320.4	0.0	11.01	10.25
Mean	119.4	0.0	4.10	3.82
Median	105.4	0.0	3.62	3.37
Campaign B (n=8)				
P4	91.7	2.8	3.16	2.94
P10	117.4	29.4	4.18	3.89
P13	53.7	2.7	1.86	1.73
P15	241.3	16.3	8.37	7.79
P23	154.5	65.9	5.63	5.24
P30	234.0	126.0	8.66	8.06
P35	98.5	67.6	3.72	3.46
P38	170.5	31.7	6.02	5.60

*Concentration in the office air during sampling

6. DISCUSSION

The sampling campaigns that were central to this project enabled us to produce an exceptional database, undoubtedly one of the most complete there is in terms of environmental and biological occurrences of DBPs in swimming pools. To our knowledge, no other study to date has documented the levels of such a large number of compounds in the water and/or the air in such a diverse and extensive sample of swimming pools.

6.1 Considerations Related to the Environmental Occurrence of DBPs

This study documented the occurrence in swimming pool water of almost 20 DBPs from seven different classes, as well as five of the most volatile compounds in the air. Given the absence of standards in Québec for these various contaminants in swimming pools, the levels measured in this study were compared to standards in force for swimming pool and/or drinking water in other countries.

With respect to CAM, which is the contaminant of greatest concern at these facilities, 11 of the 41 swimming pools visited showed ambient levels above the 300 µg/m^3 suggested by Parrat (2008) and Parrat et al., (2012) as the recommended value to minimize the health impact of these compounds, and the levels of 17 of them were above the Swiss tolerance value of 0.2 mg/m^3 (Building code: SIA 985_9).

The levels of THM found in the air are comparable to those found in the literature (Catto et al., 2012b; Fantuzzi et al., 2010; Hamel, 2007; Sa et al., 2011). However, most studies on airborne DBPs have mainly reported on TCM. The few investigations to have quantified brominated THMs in the air note relatively low levels with respect to those of TCM, which are much higher (Bessonneau et al., 2011; Caro and Gallego, 2007), or of levels on the order of 10-15 µg/m^3 for each of the three brominated compounds (DCBM, CDBM, TBM) in chlorinated swimming pools (Font-Ribera et al., 2010; Richardson et al., 2010). A TBM level in the air in the range of 75 µg/m^3 was, however, measured at a brominated swimming pool (Richardson et al., 2010).

The lowest concentration of total THM measured in the water exceeds the German standard, currently the strictest worldwide for these compounds in swimming pools (20 µg/L) (DIN 19643, 1997). The mean value of that concentration was actually three times higher than the German benchmark, but remains below the standard for drinking water in Québec (80µg/L). For information and comparison purposes, the Swiss standard (30 µg/L in swimming pool water) was exceeded at 39 of the 41 swimming pools visited during campaign A; seven of the eight swimming pools in campaign B exceeded that benchmark during campaign A and remained above it during the second campaign. The Danish standard has been set at 25µg/L since 2012. In the United Kingdom and Finland, the standard enforced for water in swimming pools is 100µg/L for total THMs. Of the swimming pools studied in Québec, 12% (five cases) exceeded that value. For TCMs, only half of those five cases would be over the Belgian standard, which limits TCM concentrations to 100µg/L.

It is important, however, to stress the consistency of the data gathered, which reveal high levels of brominated THM contamination in both the water and the air of these facilities (the presence of these compounds in the first medium logically has repercussions on the second). Once again, while the levels of TCM in the water are similar to those habitually noted in the literature, the levels of brominated THM, are, to the best of our knowledge, atypically high (Aprea et al., 2010; Florentin et al., 2011; Font-Ribera et al., 2010; Hamel, 2007; Kanan and Karanfil, 2011; Richardson et al., 2010; Weaver et al., 2009), except in brominated swimming pools (Richardson et al., 2010; Weaver et al., 2009) or in swimming pools using seawater, where the levels reach record heights (Parinet et al., 2012). In any case, according to the information we have, all of the sites visited used chlorine (and not bromine) for disinfection. This suggests that the contamination by brominated substances comes from the water sources supplying the swimming pools concerned (before being exacerbated by shock treatments or recirculation of water in these environments). Although this hypothesis could not be verified with certitude, it appears that the swimming pools contaminated with brominated THMs are situated along the same water distribution systems. Five swimming pools from among the 13 swimming pools with the highest brominated contamination confirmed in the questionnaire that they were supplied by the same water treatment plant. Two other swimming pools are also supplied by the same plant, but unlike the five others, they both use a UV system in their treatment process. One of them displays slight brominated contamination, while the other has almost inexistent levels of these compounds. Four others, which did not respond to the questionnaire, are in neighbouring boroughs. In any case, such high levels of brominated compounds require a degree of vigilance, given recent concerns linking their presence to possible health impacts (Kogevinas et al., 2010; Rivera-Nunez and Wright, 2013).

Still in the category of traditional DBPs, the high values of HAA measured are consistent with the significant accumulation of these non-volatile contaminants previously reported in the literature (Catto et al., 2012b; Florentin et al., 2011; Kanan, 2010; Prieto-Blanco et al., 2012; Simard et al., 2013). Québec's standard for drinking water (60 µg/L) was systematically exceeded. The lowest measurement of HAA corresponds to a concentration that is almost two times greater than this standard and the highest is almost 15 times higher. Given an average concentration of 350 µg/L in swimming pool water and assuming ingestion of about 40 mL per hour of swimming, we estimate that in that hour, an individual would absorb 15% of the dose that he or she could absorb drinking 1.5 L of water with an HAA concentration of 60 µg/L in a standard day.

Among the eDBPs, HANs are present in amounts that are quite similar to those measured by Kanan (2010) in U.S. swimming pools. They should be examined more closely, given the considerably higher levels (on average 15 times more, and up to 50 times higher) than those reported in drinking water (Mercier Shanks, 2012). In the HNM category, CPK levels measured in swimming pools are comparable on average to those reported in drinking water, generally about 0.5 µg/L. The same was found for 111TCPone, the only component from the family of HK that it was possible to quantify in swimming pool water.

NDMA, quantified only in campaign B, shows, on the basis of the few measurements made, levels comparable to those reported by Kanan (2010), also extremely variable from one site to another, but below the maximum level reported in the literature (Soltermann et al., 2013). This

compound, a powerful mutagen, is present at levels higher than the standard of 9 ng/L for drinking water in Ontario in six of the eight cases examined. In four of these six cases, the levels are at least six times higher (also above the acceptable maximum concentration of 40 ng/L in drinking water set by Health Canada in an analysis that took into account that this compound can also be absorbed by the skin). The recommendation of 100 ng/L by the World Health Organization is slightly exceeded in a single case.

The list of contaminants measured could of course have been expanded, especially in purely scientific terms, by the inclusion of other DBPs (e.g., aldehydes, halobenzoquinones, halonitroalkanes, halonitriles, haloamides, bromate, chlorite, chlorate) recently described in the scientific literature (Garcia-Villanova et al., 2010; Richardson et al., 2010; Righi et al., 2014; Serrano et al., 2011, 2013; Shah et Mitch, 2012; Wang et al., 2013). However, our list provides a detailed portrait of the situation and highlights the elements that deserve particular attention.

Of course, the implications related to the one-off and casual nature of the sampling must be kept in mind with respect to these data, which could appear alarming, given the previously mentioned standards and benchmarks. The “snapshots” of the contamination at each swimming pool during a single visit provide only a representative value at a given point in time, although the value is robust, in that it almost systematically represents a mean between different sampling points for each contaminant. Previous work has already revealed intra-day and weekly variations that could be substantial. (Catto et al., 2012b). There is, therefore, a possibility that each “snapshot” may have captured moments that represent either the maxima or the minima of contamination, related to exceptional situations. However, given that the sampling was generally carried out during periods of average attendance and never during heavier attendance periods on weekends, there is reason to believe that the levels of contamination measured could be higher than those reported and therefore are even more concerning.

The comparison of the results of campaign A (fall 2012) with those of campaign B (the end of spring 2013) suggest that, for an extremely reduced subset of swimming pools, if the sometimes significant variations in terms of concentration are set aside, the global profile of DBP contamination in a single swimming pool remains, as well as the issues that are specific to it. More concretely, in these cases, the presence of brominated compounds in substantial quantities is clearly confirmed in both the water and the air.

The data gathered concerning intra-spatial variation enabled us to document DBP concentrations in the air of some rooms close to the pool (most often the lifeguards' offices), where the biological sampling was carried out. This brought to light notable differences from one swimming pool to the other regarding these contaminants in those spaces. Of course, conclusions must be drawn in this respect to ensure cleaner air in these offices and thus contribute to reducing the exposure of lifeguards during their breaks.

6.2 Considerations Related to Biological Measurements of THM

6.2.1 Approach Using Biomarkers

The project enabled us to document the biological levels of THM in the alveolar air and urine of various workers. The results obtained are similar to those found in the scientific literature available on the subject (see Table 1).

In alveolar air, we observed that the TCM level is higher at zero time compared to other data related to pre-exposure (Caro and Gallego, 2008a; Font-Ribera et al., 2010). This difference is probably associated with the fact that the biological sampling was carried out in rooms that were not necessarily well insulated from the swimming pool hall, and samples were sometimes taken from subjects who were already at work. The protocol in force in the other studies limited the subject's exposure before the first sample as much as possible, such as by doing the sampling in spaces that were carefully separated from the pool and before the subject had access to it. The post-exposure TCM levels in exhaled air, taking into account (or despite) the variability of contamination levels in the environment, are quite similar to the values reported in the literature (Aprea et al., 2010; Caro and Gallego, 2007, 2008a; Fantuzzi et al., 2001; Fantuzzi et al., 2010; Font-Ribera et al., 2010). Out of all those studies, the lowest levels (4.5±1.7 µg/m^3) were reported by Font-Ribera et al. (2010), in a case of low TCM environmental contamination (35±12.3 µg/m^3). Despite these low levels, the study brought to light slight changes in markers of pulmonary epithelium permeability. In the same population, Kogevinas et al., (2010) observed, for two different biomarkers, increased signs of genotoxicity associated with the level of brominated THM in exhaled air, but not with the level of TCM. While the swimming pool used as a reference in their study presented with marked brominated THM contamination, which brought it closer to the levels of the cases of P13 and P15 than the six other facilities that we examined, the levels of brominated compounds in exhaled air remained quite comparable with those measured here.

The urinary TCM results confirmed the data previously reported by other authors in terms of the presence of appreciable quantities of TCM in the urine even before swimming pool exposure, probably associated with domestic exposure (showering, bathing, ingestion of treated water) and/or a possible accumulation during the preceding days at work. However, the TCM levels measured in this study are situated overall in a lower bracket than that reported previously. (Aprea et al., 2010; Caro and Gallego, 2007, 2008a; Charisiadis and Makris, 2014). This is also confirmed with other brominated compounds.

The non-negligible variations in the measurements obtained show a broad diversity of genuine exposure conditions, especially in terms of environmental contamination, but also regarding each

subject's activities; a wide range of situations in a relatively small sample (which was deliberate, for reasons of logistical efficiency) of swimming pools and subjects. It is important to point out that the design of the study and the process of recruitment, which sometimes only took place on site, did not enable us to control other possible sources of THM exposure, although this would have been desirable. For example, a subject taking a shower at home before going to work or drinking water (from a bottle/directly from the tap) could not be controlled, limited or known, which could lead to confusing results, especially for urinary concentrations. As soon as the subjects arrived at work or when they came to provide their samples, they were probably (and rapidly, although less so than around the pool) exposed in the hallways, change rooms and other spaces adjacent to the pool, for lengths of time that it was not always possible to know and include in this study.

There are inherent difficulties in setting up this type of sampling. For example, we know that the timing of the sampling to capture the "right" level of THM in alveolar air is critical, because the concentration can rise very rapidly (or fall just as quickly) as soon as exposure occurs (or ceases). The technique for sampling the exhaled air was found to be more difficult to master by the workers than initially anticipated. Several samples of exhaled air often had to be added to obtain the volume of air required for the THM analyses. A cohort of workers studied over a continuous period would have been an asset to improve the participants' expertise and that of the staff responsible for the sampling. While urine collection was less technical, it was more unpleasant for the subjects, who could therefore be more reluctant to provide it. Given the levels of THM in the urine (in ng/L) compared to that in the water (approximately 10^3 times greater), any water contamination of the samples had to be avoided. The subjects were therefore requested (if necessary) to carefully dry themselves off.

6.2.2 Approach Using PBTK Modelling

The simulation exercise was conducted along the same lines and following the same principles that had been tested during a previous investigation based on data from the literature (Catto et al., 2012a). Once again, but using data generated for this occasion, and despite the unknowns related to biological sampling in the workplace, the PBTK model provides a good estimate of alveolar concentrations in the workers. However, the difficulty of adequately describing the zero time concentrations found in workers who were unexposed before the samples were collected demonstrates the need for investigations into this aspect. The model tends to underestimate the experimental urinary data, possibly because of the external contribution of TCM from taking a shower before arriving at the workplace (Table 12). The model also describes a rapid dissipation of TCM in alveolar air and marginal accumulation of TCM in the urine. Studies should be undertaken to better describe the kinetics of TCM ensuing from low levels of exposure.

The values estimated by the absorbed daily dose (ADD) model during a lifeguard's hypothetical day of work, while close to the predictions of doses absorbed in the previous investigation (Catto et al., 2012a), compare less favourably with Health Canada's ADD model, which would be significantly overshot in several cases. However, the hypothetical exposure scenario tested is extreme (but not impossible) in terms of a lifeguard's presence at the swimming pool. Other scenarios could of course be envisaged. It should be kept in mind that only the case of TCM was examined. The smallest dose predicted by the model on the basis of data from campaign B

corresponds to the swimming pool with the highest brominated THM environmental contamination, a sign that the proposed indicator is not enough to take into account all the DBP exposure problems that could occur. Additional tests should be carried out to validate the models for the other THMs and to use them in similar prediction exercises.

6.3 Considerations Related to the Study's General Design

The active and often enthusiastic collaboration of the participants in this project is a clear sign of interest in the subject. Their involvement was valuable, and even necessary, given the many hurdles to be overcome. These included the multitude of intermediaries between the facilities' staff and the research team, the diversity of modes of governance and organization between and within the various facilities visited, and the sharing of information related to the technical operation of each site (which often was divided up among several actors and not always easily accessible at the administrative level).

Given that the exposure of the staff working at swimming pools occurs mainly through inhalation (with the exception of staff who give classes in the water), and that the health issues identified as priorities for workers concern irritation that is probably attributable to volatile DBPs (in particular, CAMs), it was a logical decision to restrict this study to indoor pools, because their confined areas make it more likely that exposure to contaminants in the air will be higher. Nevertheless, more attention should be paid to environmental DBP contamination in outdoor pools, especially with the surprisingly high levels previously reported, in particular in Québec City, in the scope of another investigation by our research team (Simard et al., 2013). The originality and diversity of the contamination portrait of swimming pool water drawn up in this study, and which will be dealt with in more detail further on, provide more reasons to pursue this avenue.

A very diverse range of indoor pools was visited, particularly in terms of configuration, maintenance, bather load and/or swimming regulations, thanks to the voluntary participation of the facilities. The diversity, which provides added value to this research work by giving it a wider scope, does not, however, guarantee that all possible cases have been taken into account and illustrates the difficulty of overgeneralizing the conclusions and of defining a "one-size-fits-all" solution to solve the problem of DBP exposure.

To the contrary, this diversity, which is also reflected in the results obtained and in the problems, which differ from one swimming pool to another, calls for a technically appropriate response to take into account the specificities of each site (and which considers the financial resources available). Such a response could be expressed through implementing measures that would have potentially dramatic effectiveness (see 7.2: Recommendations). These measures could be put into practice through guidelines and a regulatory framework adapted to the issue of DBP exposure in swimming pools, and which address the contribution of domestic exposure (drinking water, showering).

6.4 Considerations Related to Controlling the Problem

These considerations bring us back to two fundamental points: (i) how to better understand and diagnose the problem and (ii) what avenues to explore to control it. The first point involves deciding the method to be used and the issues related to monitoring exposure through collecting information about and in the environments, and modeling. The second point involves the issue of the availability of technical means in terms of the costs associated with them.

In addition to the careful collection of samples is the broader matter of the feasibility of routine monitoring. Setting up a monitoring system, which could be beneficial to better pinpoint the actual link between DBP exposure and its impacts on worker health, would require a simplification of the analysis methods.

Another difficulty with respect to the issue of DBP exposure has to do with the specificities of each compound, both in terms of the intrinsic properties regulating their diffusion in the environment and the possible health impacts of each one. Estimating the biological level of TCM will not help in understanding other exposure issues concerning other compounds. Moreover, while significant correlations have been found between certain compounds, it would likely not be feasible to diagnose and classify the exposure situation of each swimming pool on the basis of the measurements of a single compound used as an indicator. It remains to be seen whether the health problems that may be present at a swimming pool are, in fact, more related to a mixture of the compounds in the environment than the independent and specific effect of one or another of them (Schmalz et al., 2011).

Better control of the problem would require a more collegial and concerted management of the information required to improve the situation within each facility. To that end, a questionnaire was developed. The first version was tested and deemed too ambitious in its effort to exhaustively cover all aspects, so a second more simplified version was given to swimming pool workers. However, we were only able to collect some of the information we requested, and it took longer then expected. In fact, the multiplicity of intermediaries and the lack of accessibility of some of the information holders made the process more complex, despite the active mobilization and the interest of most of the participants. Some questions were not answered, especially those dealing with ventilation (e.g., the dimensions of the swimming pool hall). In fact, the management of a swimming pool mobilizes a variety of skills and the information is often divided up among the various stakeholders. Investing in efforts to better gather, share and systematically update the information related to all the subjects that were included in the questionnaire would enable the “life” of swimming pools to be better accounted for and to identify the optimal operational conditions or which parameters to prioritize.

While the development of different forms of modeling could help to better grasp the context (Dyck et al., 2011; Hsu et al., 2009), the differences observed from one swimming pool to another and the multitude of factors involved in the formation and diffusion of contaminants within facilities makes the development of a generic model particularly complicated. Such a model, which does not yet exist, would enable all of the factors that could be applied at each swimming pool to be integrated, to optimize their operation. However, for the time being,

nothing can replace the employees' knowledge of their workplace, especially those in charge of the maintenance and technical upkeep of the facility.

In terms of mitigation to minimize DBP exposure, actions to reduce precursors and/or the contaminants themselves should be encouraged. With respect to precursors, our results suggest that special attention should be paid to the drinking water source supplying the swimming pool, which, in some cases, may contain bromines and thus possibly be responsible for atypical brominated DBP contamination, which deserves attention. Working with those responsible for the water supply network would be a positive development. Also, requiring swimmers to wear bathing caps and take showers (although showering could of course cause individual exposure of the bather to DBPs) would help reduce the amount of anthropogenic precursors of DBPs. Various procedures are being developed to remove at least some of the contaminants that can form (Gérardin et al., 2013; Tang et al., 2013). Caution must be taken if changes are made to disinfectants. There must be certainty that they will improve the situation without decreasing their effectiveness on the microbiological level. Additionally, the problem should not simply be shifted by changing the DBP contamination profile, which could lead to the formation of lesser-known contaminants while decreasing better-known ones. Reducing the formation of DBPs through simple means, such as changing the pool water more often and improving ventilation, should be the priority.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

7.1.1 A Database for Multiple Uses and Interests

This study describes a somewhat atypical portrait (in terms of the levels observed and the presence of brominated compounds) of swimming pool workers' exposure to the various DBPs that inevitably form. The impressive database it engendered is, without a doubt, one of the richest and most complete to have ever been constituted. Without being alarmist, and while it is important to realize that the health impacts of different exposures to DBPs must still be more clearly and precisely established, this portrait calls for some vigilance and should stimulate even more interest in the subject, in addition to encouraging more research efforts into possible mitigation methods. Better control of this undesirable chemical pollution as a precautionary measure would provide swimming pool workers, and more broadly, the public frequenting these facilities, with a healthier and safer environment.

While a significant amount of work was required to build this colossal database, and it offers a wide range of possibilities in terms of exploitation, the analyses presented in this report were only those that the research team considered as priorities. This database could certainly be explored again from many other angles and it could be used beyond the context in Québec and the case of workers. For example, it could be used to provide empirical data for risk analyses and further modeling work that exceed the scope of this study. It provides a foundation for continued investigations to more adequately protect swimming pool workers from DBPs.

7.1.2 Scale and Understanding of the Contamination

7.1.2.1 Environmental Level

As previously mentioned, the levels of environmental contamination measured justify and confirm the interest the subject has raised.

Besides the relatively high levels of HAA, eDBPs, and in particular, NDMA, the substantial presence in the water and air of brominated THMs is unquestionably significant.

In the swimming pools concerned, this presence is combined with a surplus of brominated HAAs, which is even more striking given that none of the swimming pools visited used bromines to our knowledge, leaving us to suspect that the influx of brominated THM precursors is directly linked to the sources of water supplying the swimming pools.

It is unrealistic to think that overall DBP environmental contamination can be assessed on the basis of only one or two compounds, or from a series of minimal measurements taken from the field samples (water and air).

While the data related to seasonal variations (stability of measurements between campaign A and campaign B) are too limited for broad conclusions to be drawn, and although these variations are

demonstrable with respect to quantities observed, it appears that the typical contamination profiles remain relatively constant (especially regarding THM speciation and, in particular, the relationship between brominated THMs and TCM).

In every case, THM measurements reach levels that remain high in terms of the various standards and values it was possible and more or less relevant to compare them with.

7.1.2.2 Biological Level

The environmental THM contamination has biological repercussions in each of the two matrices examined (alveolar air and urine). The difficulties related to collecting samples of these matrices following the analytical procedures developed in our laboratory lead us to believe that it would be problematic to systematically implement them in the field without simplifying them or further validating them. There is also a question of the value of such procedures given their limited relevance for DBPs other than THM.

The PBTK modeling approach provides encouraging results for simulating biological exposure in workers, at least in the case of TCM. The predictions are quite accurate in describing the results of the measurements carried out. Nevertheless, improvements must be made to obtain more precise predictions.

On the basis of these data and the available environmental information, as well as on the hypothetical scenario of a worker's exposure to TCM, it appears that the absorbed dose of TCM estimated by the model in different cases, although it does not necessarily take into account other issues related to exposure to other DBPs, reveals values that compare with and exceed the ADD value set by Health Canada for TCM, at 6.2 µg/kg/day (in all exposure pathways).

7.2 Recommendations

Our recommendations are two-pronged. This study provided an initial diagnostic of the actual situation of workers' exposure to DBPs. The next step is to learn more about the true scale and impact of this issue. In addition, all actions that could help minimize exposure to DBPs should be encouraged and undertaken in a concerted and reasonable manner until the real risks they represent can be defined, without creating others. In other words, we recommend further research and new management initiatives to support and complement concrete and preventive actions on the ground.

7.2.1 Subsequent Research Initiatives

To better define the implications of the issue of occupational DBP exposure of swimming pool workers, research work dealing with the following activities should be undertaken:

- Documenting the occurrence of health problems in swimming pool workers in Québec, to find relationships between the exposure noted and the potential effects (reported or diagnosed);

- Assessing the relative situation of DBP exposure at other sensitive sites and in contexts that have either been summarily investigated or not investigated at all, such as outdoor swimming pools, swimming pools in private hotels and spas;

- Adapting sampling strategies and analytical methods that are complex to implement, to facilitate their use in the field and in the workplace, and thus obtain more effective measurements of DBPs, in particular, in biological matrices;

- Continuing the modeling work already underway in order to (i) analyze other possible exposure scenarios; (ii) include other DBPs; (iii) better define the kinetics of TCM at low levels of exposure; (iv) better understand and describe the mechanisms of urinary excretion of unchanged TCM; and (v) carry out a robust risk analysis;

- Assessing the impact of different treatment processes on DBP environmental contamination.

7.2.2 Future Initiatives

Despite the absence of a regulatory framework in Québec, given the current state of knowledge about the possible effects of DBPs, and taking into account the levels of contamination observed in this study, practical initiatives that would contribute to minimizing DBP pollution, from the most simple to the most far-reaching, can only be encouraged. These initiatives would be structured around two guidelines: (i) reducing DBP formation by better controlling the precursors; (ii) suppressing and/or removing DBPs in the water and/or the air.

With regard to the first point (i), as a priority, we recommend reducing the amount of precursors transported by bathers. To that end, bathers should be encouraged to adopt responsible hygienic behaviour, by raising their awareness of the problem or by using coercive measures, such as stricter regulations at facilities. Taking a 60-second shower before swimming appears to have some effect in limiting DBP precursors in the swimming pool (and would probably also have a positive effect microbiologically) (Keuten et al., 2012). Wearing a bathing cap and prohibiting the wearing of shorts are other possibilities that would help limit this contribution, and are already in force to varying degrees at some facilities. The reduction of precursors naturally present in the water supply to the swimming pool represent a technical challenge that is more complex and more expensive to implement. Closer relationships between the managers of water networks supplying swimming pools and the swimming pool managers would help to better understand and identify the problems that could be emanating from the source itself, as may be the case with brominated THM (Parinet et al., 2012).

With regard to the second point (ii), apart from changing the disinfectant, which, while failing to totally solve the problem, may simply shift it, research into technical solutions to suppress the various DBPs reveals several avenues (Gérardin et al., 2013; Tang et al., 2013) that could be explored. Caution is necessary however, given the costs associated with the implementation of novel procedures. Above all, functional, unobstructed and effective ventilation of swimming pools to exhaust volatile contaminants, as well as vigilant and regular upkeep of the various water treatment devices (e.g., filters), or more regular water renewal in larger volumes are to be encouraged. Emptying swimming pools, which is not common practice, would undoubtedly be beneficial for the facilities in terms of health, and even more so because changing the water could have a positive impact with respect to the first guideline (i).

Another idea would be to provide access to lifeguards who work in rotation around the swimming pool with minimally insulated break rooms (at least without a direct opening to the pool area). Lifeguards could be encouraged to take regular breaks in these spaces, which would be better protected from air contaminants. This measure would not minimize the formation and diffusion of environmental contamination, but would reduce the biological exposure that could result.

All of these initiatives could serve as the basis of a code of best practices for which the implementation, reasonably adapted to each case, should enable a reduction in exposure levels.

7.2.3 Initiatives to Better Frame the Issue

This report suggests approaches to better frame and manage the issue.

The issue of establishing standards for DBPs in Québec should be raised with respect to levels observed and the provisions that have been or that are being implemented by other countries. Based on current knowledge, a recent report on modifying the *Regulation respecting water quality in swimming pools and other artificial pools* (Q-2, r. 39) resulted in the following recommendations [translation]: “not to include a standard pertaining to the maximum concentration applicable to trihalomethanes in swimming pool water” and “not to impose requirements on the technologies to be implemented to remove chloramines” (M.D.D.E.P, 2013). With respect to both recommendations, the report pointed to the absence of data about exposure in workers and indicated concern about the advancement of knowledge in the field and how the concerns associated with concentrations of CAM in indoor air are taken into account. In our opinion, the results of this study should prompt initiatives to adopt and apply regulatory standards for certain DBPs (e.g., THM and NDMA in the water, CAM in the air).

Given that this issue is influenced by many parameters, whose supervision involves a number of actors, better compilation of the data possessed by these various stakeholders into a single file would encourage, through the circulation of information and regular updating, a rewarding collaboration among the stakeholders, in addition to providing a valuable source of information to better analyze the various situations. Such a file should include the information compiled in the questionnaire that was drawn up for this project. It could also be used to collect, catalogue and keep track of complaints from workers.

Finally, and above all, given the great variability observed from one swimming pool to another, a case-by-case approach should be prioritized to correct situations that are deemed problematic. The most effective solution would be through formulating a mitigation strategy that would combine the radical effects of changing the water and/or the air to purify the media contaminated by DBPs. This strategy would be adapted to each site (and to each season) and, of course, optimized in terms of costs and benefits. The definition of such a strategy would involve bringing together all of the stakeholders in swimming pool management and adding the skills of hydraulic and ventilation experts.

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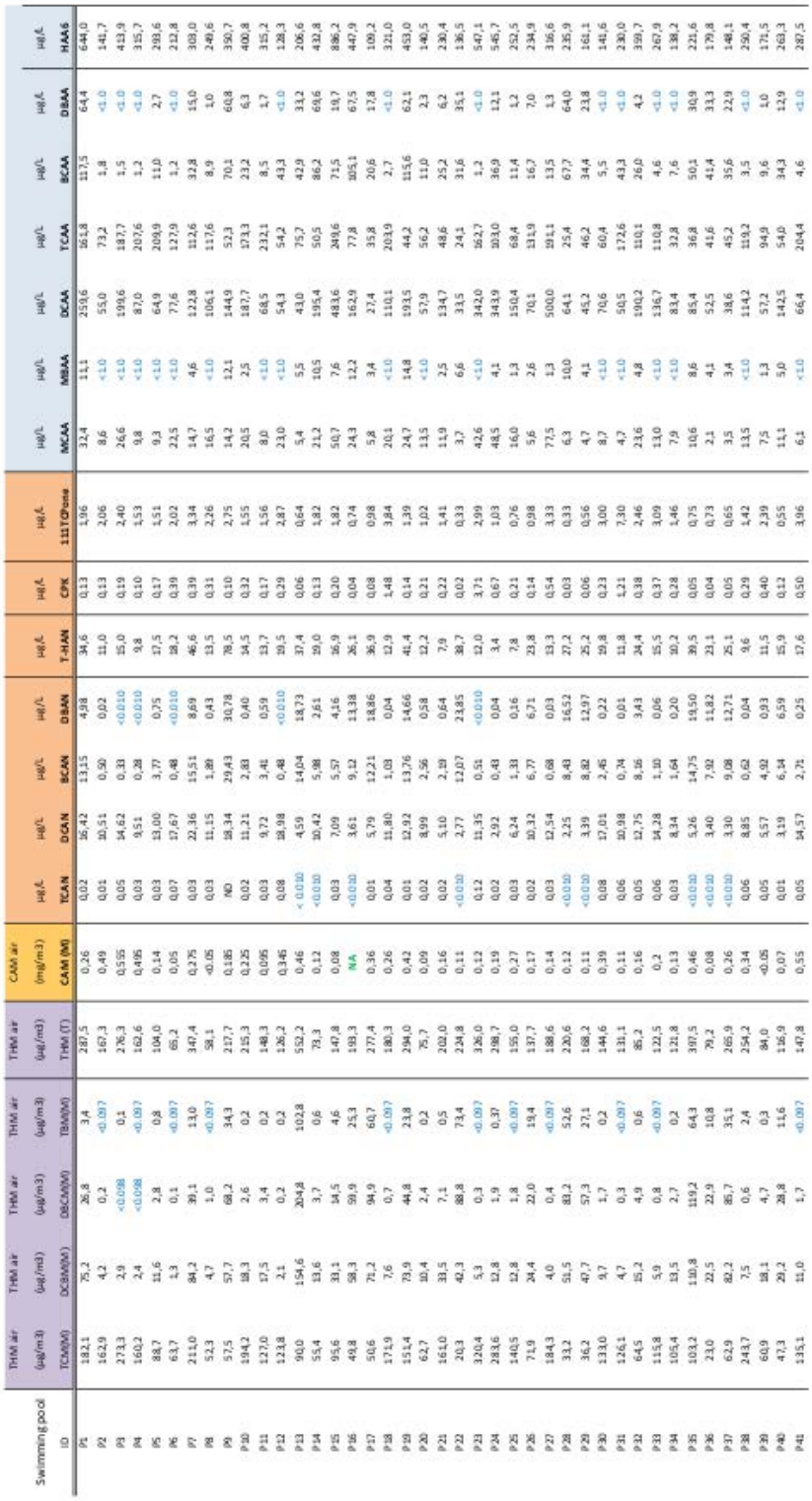
APPENDICES

Appendix A – Detailed Results of the Environmental Measurements from Campaign A

Appendix B – Detailed Results of the Biological Measurements from Campaign B

Appendix C – Questionnaire Submitted to the Participating Facilities

Appendix A – Results of the Environmental Measures from Campaign A



Swimming pool ID	THM air (µg/m3) TCM(M)	THM air (µg/m3) DCBM(M)	THM air (µg/m3) DBCAM(M)	THM air (µg/m3) TBM(M)	THM air (µg/m3) THM (T)	CAM air (mg/m3) CAM (M)	µg/L TCAN	µg/L DCAN	µg/L BCAN	µg/L DBAN	µg/L T-HAN	µg/L CPK	µg/L 111TCPmme	µg/L MCAA	µg/L MBAA	µg/L DCAA	µg/L TCAA	µg/L BCAA	µg/L DBAA	µg/L HAA6
P1	182,1	75,2	26,8	3,4	287,5	0,26	0,02	16,42	13,15	4,98	34,6	0,13	1,96	32,4	11,1	259,6	161,8	117,5	64,4	644,0
P2	162,9	4,2	0,2	<0.097	167,3	0,49	0,01	10,51	0,50	0,02	11,0	0,13	2,06	8,6	<1.0	55,0	73,2	1,8	<1.0	141,7
P3	273,3	2,9	<0.098	0,1	276,3	0,555	0,05	14,62	0,33	<0.010	15,0	0,19	2,40	26,6	<1.0	199,6	187,7	1,5	<1.0	413,9
P4	160,2	2,4	<0.098	<0.097	162,6	0,495	0,03	9,51	0,28	<0.010	9,8	0,10	1,53	9,8	<1.0	87,0	207,6	1,2	<1.0	315,7
P5	88,7	11,6	2,8	0,8	104,0	0,14	0,03	13,00	3,77	0,75	17,5	0,17	1,51	9,3	<1.0	64,9	209,9	11,0	2,7	293,6
P6	63,7	1,3	0,1	<0.097	65,2	0,05	0,07	17,67	0,48	<0.010	18,2	0,39	2,02	22,5	<1.0	77,6	127,9	1,2	<1.0	212,8
P7	211,0	84,2	39,1	13,0	347,4	0,275	0,03	22,36	15,51	8,69	46,6	0,39	3,34	14,7	4,6	122,8	112,6	32,8	15,0	303,0
P8	52,3	4,7	1,0	<0.097	58,1	<0.05	0,03	11,15	1,80	0,43	13,5	0,31	2,26	16,5	<1.0	106,1	117,6	8,9	1,0	240,6
P9	57,5	57,7	68,2	34,3	217,7	0,185	ND	18,34	29,43	30,78	78,5	0,10	2,75	14,2	12,1	144,9	52,3	70,1	60,8	350,7
P10	194,2	18,3	2,6	0,2	215,3	0,225	0,02	11,21	2,83	0,40	14,5	0,32	1,55	20,5	2,5	187,7	173,3	23,2	6,3	400,8
P11	127,0	17,5	3,4	0,2	148,3	0,095	0,03	9,72	3,41	0,59	13,7	0,17	1,56	8,0	<1.0	68,5	232,1	8,5	1,7	315,2
P12	123,8	2,1	0,2	0,2	126,2	0,345	0,08	18,98	0,48	<0.010	19,5	0,29	2,87	23,0	<1.0	54,3	54,2	43,3	<1.0	128,3
P13	90,0	154,6	204,8	102,8	552,2	0,46	< 0.010	4,59	14,04	18,73	37,4	0,06	0,64	5,4	5,5	43,0	75,7	42,9	33,2	206,6
P14	55,4	13,6	3,7	0,6	73,3	0,12	<0.010	10,42	5,98	2,61	19,0	0,13	1,82	21,2	10,5	195,4	50,5	86,2	69,6	432,8
P15	95,6	33,1	14,5	4,6	147,8	0,08	0,03	7,09	5,57	4,16	16,9	0,20	1,82	50,7	7,6	483,6	249,6	71,5	19,7	886,2
P16	49,8	58,3	59,9	25,3	193,3	NA	<0.010	3,61	9,12	13,38	26,1	0,04	0,74	24,3	12,2	162,9	77,8	105,1	67,5	447,9
P17	50,6	76,2	94,9	60,7	277,4	0,36	0,01	5,79	12,21	14,86	36,9	0,08	0,98	5,8	3,4	27,4	35,8	20,6	17,8	109,2
P18	171,9	7,6	0,7	<0.097	180,3	0,26	0,04	11,80	1,03	0,04	12,9	1,48	3,84	20,1	<1.0	110,1	203,9	2,7	<1.0	321,0
P19	151,4	73,9	44,8	23,8	294,0	0,42	0,01	12,92	13,76	14,66	41,4	0,14	1,39	24,7	14,8	193,5	44,2	115,6	62,1	453,0
P20	62,7	10,4	2,4	0,2	75,7	0,09	0,02	8,99	2,56	0,58	12,2	0,21	1,02	13,5	<1.0	57,9	56,2	11,0	2,3	140,5
P21	161,0	31,5	7,1	0,5	202,0	0,16	0,02	5,10	2,19	0,64	7,9	0,22	1,41	11,9	2,5	134,7	48,6	25,2	6,2	230,4
P22	20,3	42,3	88,8	73,4	224,8	0,11	<0.010	2,77	12,07	23,85	38,7	0,02	0,33	3,7	6,6	33,5	24,1	31,6	35,1	136,5
P23	320,4	5,3	0,3	<0.097	326,0	0,12	0,12	11,35	0,51	<0.010	12,0	0,33	2,99	42,6	<1.0	342,0	162,7	1,2	<1.0	547,1
P24	283,6	12,8	1,9	0,37	298,7	0,19	0,02	2,92	0,43	0,04	3,4	0,67	1,03	44,5	4,1	343,9	103,0	36,9	12,1	545,7
P25	140,5	12,8	1,8	<0.097	155,0	0,27	0,03	6,24	1,33	0,16	7,8	0,21	0,76	16,0	1,3	150,4	68,4	11,4	1,2	252,5
P26	71,9	24,4	22,0	19,4	137,7	0,17	0,02	10,32	6,77	6,71	23,8	0,14	0,98	5,6	2,6	70,1	131,9	16,7	7,0	234,9
P27	184,3	4,0	0,4	<0.097	188,6	0,14	0,03	12,54	0,68	0,03	13,3	0,54	3,33	77,5	1,3	500,0	191,1	13,5	1,3	316,6
P28	33,2	51,5	83,2	52,6	220,6	0,12	<0.010	2,25	8,43	16,52	27,2	0,03	0,33	6,3	10,0	64,1	25,4	67,7	64,0	235,9
P29	36,2	47,7	57,3	27,1	168,2	0,11	<0.010	3,39	8,82	12,97	25,2	0,06	0,56	4,7	4,1	45,2	46,2	34,4	23,8	161,1
P30	133,0	9,7	1,7	0,2	144,6	0,39	0,08	17,01	2,46	0,22	19,8	0,23	3,00	8,7	<1.0	70,6	60,4	5,5	<1.0	141,6
P31	126,1	4,7	0,3	<0.097	131,1	0,11	0,06	10,98	0,74	0,01	11,8	1,21	7,30	4,7	<1.0	50,5	172,6	43,3	<1.0	230,0
P32	64,5	15,2	4,9	<0.097	85,2	0,16	0,05	12,75	8,56	3,43	24,4	0,38	2,46	23,6	4,8	190,2	110,1	26,0	4,2	399,7
P33	115,8	5,9	0,8	<0.097	122,5	0,2	0,06	14,28	1,10	0,06	15,5	0,37	3,09	13,0	<1.0	136,7	110,8	4,6	<1.0	267,9
P34	105,4	13,5	2,7	0,2	121,8	0,13	0,03	8,14	1,64	0,20	10,2	0,28	1,46	7,9	<1.0	83,4	32,8	7,6	<1.0	138,2
P35	103,2	130,8	119,2	64,3	397,5	0,46	<0.010	5,26	14,75	19,50	39,5	0,05	0,75	10,6	8,6	85,4	36,8	50,1	30,9	221,6
P36	23,0	22,5	22,9	10,8	79,2	0,08	<0.010	3,40	7,92	11,82	23,1	0,04	0,73	2,1	4,1	52,5	41,6	41,4	33,3	179,8
P37	62,9	82,2	85,7	35,1	265,9	0,26	<0.010	3,30	9,08	12,71	25,1	0,05	0,65	3,5	3,4	38,6	45,2	35,6	22,9	148,1
P38	243,7	7,5	0,6	2,4	254,2	0,34	0,06	8,85	0,62	0,04	9,6	0,29	1,42	13,5	<1.0	114,2	119,2	3,5	<1.0	250,4
P39	60,9	18,1	4,7	0,3	84,0	<0.05	0,05	5,57	4,92	0,93	11,5	0,40	2,39	7,5	1,3	57,2	94,9	9,6	1,0	171,5
P40	47,3	29,2	28,8	11,6	126,9	0,07	0,01	3,19	6,14	6,59	15,9	0,12	0,55	11,1	5,0	142,5	54,0	34,3	12,9	263,3
P41	135,1	11,0	1,7	<0.097	147,8	0,55	0,05	14,57	2,71	0,25	17,6	0,50	3,96	6,1	<1.0	66,4	204,4	4,6	<1.0	287,5

Swimming pool ID	mg/L TOM	mg/L DCBM	mg/L CDBM	mg/L TBM	mg/L TTHM	µS/cm Conductivity	NTU Turbidity	5 cm cell UV absorbance	Reported in cm-1 at 254 nm	ppm COD	Free chlorine	Total chlorine	Monocl	Ph	Temp	Public
P1	36,85	26,76	7,62	0,79	62,01	2050	0,187	0,253	0,051	7,20	0,49	1,47	0,11	7,35	28,33	42
P2	21,67	<0,6	<1,0	<0,8	21,67	606	0,124	0,129	0,026	3,55	1,52	1,95	0,13	7,26	27,80	31
P3	33,85	<0,6	<1,0	<0,8	33,85	2100	0,348	0,191	0,038	5,60	1,41	1,57	0,13	7,30	28,40	42
P4	22,61	<0,6	<1,0	<0,8	22,61	629	0,169	0,156	0,031	3,74	1,67	2,14	0,15	7,64	27,80	46
P5	33,53	4,47	<1,0	<0,8	37,99	820	0,094	0,177	0,035	3,85	1,13	1,76	0,24	7,53	28,60	37
P6	65,10	0,90	<0,10	<0,10	66,00	1287	0,350	0,242	0,048	4,43	1,16	1,87	0,10	7,37	29,20	15
P7	54,45	21,70	11,75	3,85	91,75	2060	0,107	0,210	0,042	4,68	1,40	2,14	0,13	7,21	28,40	20
P8	56,95	5,25	1,45	0,75	64,40	1084	0,095	0,125	0,025	3,01	1,90	2,54	0,16	7,44	27,30	11
P9	20,40	21,40	33,10	14,60	89,50	906	0,203	0,196	0,039	5,20	1,77	2,66	0,19	7,30	28,20	15
P10	53,10	5,20	1,00	0,10	59,40	722	0,241	0,172	0,034	4,92	1,32	2,14	0,07	7,90	27,60	25
P11	NA	NA	NA	NA	NA	970	0,540	0,253	0,051	4,20	1,10	1,83	0,08	7,82	26,90	25
P12	29,70	0,50	<0,10	<0,10	30,20	953	0,204	0,291	0,058	3,68	1,34	2,03	0,10	7,47	27,60	64
P13	15,05	30,05	51,25	27,80	124,15	1344	0,230	0,241	0,048	3,39	1,44	2,03	0,07	7,74	27,00	60
P14	37,60	9,65	3,40	0,90	51,55	1035	0,172	0,186	0,037	3,67	1,30	1,88	0,10	7,66	28,20	24
P15	40,50	11,00	4,40	1,30	57,20	2200	0,059	0,194	0,039	8,64	1,61	2,80	0,13	7,67	26,80	35
P16	11,40	34,80	18,60	7,80	52,60	1590	0,117	0,169	0,034	4,76	2,67	3,17	0,15	7,44	26,80	25
P17	11,40	18,70	31,40	20,90	82,40	1259	0,290	0,162	0,032	3,10	1,24	2,06	0,13	7,32	27,70	42
P18	54,40	2,60	0,40	0,20	57,60	760	0,187	0,072	0,014	3,00	2,47	3,00	0,13	7,43	27,10	35
P19	26,40	15,60	15,60	11,40	69,00	1315	0,319	0,218	0,044	5,58	1,46	2,22	0,21	7,36	27,10	40
P20	36,70	6,05	1,60	0,25	44,60	2370	0,265	0,154	0,031	2,70	1,06	1,53	0,12	7,35	26,50	15
P21	49,10	10,50	2,60	0,20	62,40	1621	0,165	0,127	0,025	3,32	1,74	2,09	0,13	7,42	26,90	15
P22	6,70	17,15	44,00	45,60	113,45	1625	0,120	0,140	0,028	3,03	1,77	1,90	0,19	7,28	26,30	5
P23	102,20	1,30	0,30	0,30	104,10	1483	0,114	0,054	0,011	4,76	2,60	2,76	0,09	7,95	26,70	45
P24	126,50	5,00	0,80	0,10	132,35	1068	0,098	0,138	0,028	3,16	2,58	2,94	0,22	7,82	28,10	25
P25	42,30	3,65	0,55	<0,10	46,50	1473	0,280	0,194	0,039	2,86	1,81	2,43	0,14	7,67	27,70	25
P26	21,50	10,40	15,80	16,70	64,40	1104	0,150	0,193	0,039	3,96	1,45	2,25	0,20	7,46	26,40	28
P27	88,95	1,85	0,25	0,10	91,10	573	0,109	0,191	0,038	10,00	1,57	2,44	0,16	7,42	25,75	28
P28	7,40	15,30	32,00	23,80	78,50	1301	0,115	0,132	0,026	3,13	1,26	1,68	0,28	7,50	26,40	12
P29	17,60	25,90	36,50	17,30	97,30	1216	0,184	0,151	0,030	2,87	1,50	2,15	0,12	7,44	28,50	5
P30	41,60	4,30	0,90	0,20	47,00	613	0,293	0,193	0,039	4,12	1,58	2,58	0,26	7,30	27,25	66
P31	42,70	1,50	0,10	<0,10	44,30	2900	0,144	0,032	0,006	1,36	1,28	1,44	0,17	7,52	26,50	17
P32	25,30	7,20	2,70	0,40	35,60	2850	0,144	0,100	0,020	5,88	1,54	1,91	0,11	7,63	25,80	45
P33	63,30	3,10	0,50	<0,10	66,90	696	0,235	0,194	0,039	4,82	1,56	2,45	0,13	7,46	26,80	45
P34	48,80	6,50	1,30	0,10	56,70	542	0,360	0,138	0,028	2,82	1,56	2,21	0,32	7,54	28,60	10
P35	15,70	22,20	35,25	28,15	101,30	984	0,112	0,150	0,030	3,48	1,87	2,51	0,14	7,44	26,25	28
P36	10,65	13,35	17,05	12,75	53,80	1932	0,192	0,144	0,029	2,80	1,32	1,79	0,21	7,47	23,70	25
P37	9,50	15,90	22,10	9,90	57,40	2340	0,174	0,115	0,023	2,46	1,61	2,18	0,12	7,65	24,95	8
P38	55,70	1,65	0,20	0,15	57,70	1303	0,307	0,175	0,035	3,01	2,36	3,16	0,09	7,95	27,85	103
P39	37,80	13,90	4,10	0,20	55,60	2710	0,123	0,038	0,008	1,51	1,37	1,52	0,15	7,60	26,45	9
P40	23,20	18,30	21,40	8,10	71,00	842	0,127	0,137	0,027	3,14	1,86	2,59	0,21	7,58	27,80	18
P41	28,10	2,40	0,40	<0,10	30,90	1241	0,174	0,700	0,140	3,12	1,92	2,65	0,18	7,69	26,85	30

Appendix B – Results of the Biological Measurements from Campaign B

THM in Alveolar Air (µg/m3)

			TCM			DCBM			CDBM			TBM		
			Alveolar air (Start)	Alveolar air (End)	Increase Factor	Alveolar air (Start)	Alveolar air (End)	Increase Factor	Alveolar air (Start)	Alveolar air (End)	Increase Factor	Alveolar air (Start)	Alveolar air (End)	Increase Factor
			(µg/m³)	(µg/m³)		(µg/m³)	(µg/m³)		(µg/m³)	(µg/m³)		(µg/m³)	(µg/m³)	
P4	S1	**	2,6	18,5	7,3	0,38	0,84	2,2	0,54	0,54	0,99	<5.3	<5.3	n.a.
P4	S2		20,2	29,6	1,5	1,30	1,04	0,8	0,66	0,65	0,98	<5.3	<5.3	n.a.
P4	S4	**	1,4	11,6	8,5	0,38	0,58	1,5	0,60	0,61	1,01	<5.3	<5.3	n.a.
P4	S5	**	2,0	13,0	6,4	0,36	0,60	1,7	0,55	0,56	1,01	<5.3	<5.3	n.a.
P10	S1	**	5,3	9,2	1,7	0,49	0,63	1,3	0,56	0,70	1,23	<5.3	<5.3	n.a.
P10	S2	**	4,7	6,2	1,3	0,45	0,47	1,1	0,54	0,54	0,99	<5.3	<5.3	n.a.
P10	S3	**	3,9	10,8	2,8	0,42	0,56	1,4	0,53	0,54	1,01	<5.3	<5.3	n.a.
P10	S4	**	7,2	20,0	2,8	0,56	0,76	1,4	0,55	0,56	1,02	<5.3	<5.3	n.a.
P10	S5		9,7	30,9	3,2	0,55	0,95	1,7	0,54	0,56	1,04	<5.3	<5.3	n.a.
P13	S1	**	1,9	6,7	3,5	1,95	7,67	3,9	1,48	4,83	3,27	<5.3	<5.3	n.a.
P13	S2	**	2,2	4,8	2,2	1,21	4,06	3,4	1,22	2,50	2,06	<5.3	<5.3	n.a.
P13	S3	**	2,1	7,2	3,5	1,27	7,36	5,8	1,01	4,29	4,23	<5.3	<5.3	n.a.
P13	S4	**	1,7	11,4	6,9	1,25	10,06	8,1	1,09	5,58	5,12	<5.3	<5.3	n.a.
P13	S5	**	5,2	14,5	2,8	1,56	11,33	7,3	1,29	6,35	4,92	<5.3	<5.3	n.a.
P15	S1		22,0	40,4	1,8	1,83	4,97	2,7	<0.53	1,61	n.a.	<5.3	<5.3	n.a.
P15	S2		13,6	20,3	1,5	1,78	2,66	1,5	0,72	1,13	1,56	<5.3	<5.3	n.a.
P15	S3		29,0	24,7	0,85	4,89	3,93	0,8	1,78	1,56	0,88	<5.3	<5.3	n.a.
P15	S4		9,6	31,4	3,3	1,70	4,08	2,4	0,91	1,34	1,47	<5.3	<5.3	n.a.
P15	S5		6,6	23,6	3,6	1,07	3,13	2,9	0,56	1,19	2,12	<5.3	<5.3	n.a.
P23	S1		33,2	61,2	1,8	0,66	1,20	1,8	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P23	S2		33,5	45,3	1,3	0,70	0,94	1,3	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P23	S3		41,1	64,9	1,6	1,29	1,44	1,1	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P30	S1		60,5	57,1	0,95	4,53	4,57	1,0	0,61	0,54	0,90	<5.3	<5.3	n.a.
P30	S2		81,1	71,1	0,88	5,71	4,84	0,8	0,55	<0.53	n.a.	<5.3	<5.3	n.a.
P30	S3		78,4	72,7	0,93	5,54	4,72	0,9	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P30	S4		41,2	61,9	1,5	2,62	4,16	1,6	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P35	S1		17,2	26,9	1,6	2,92	4,84	1,7	0,55	1,09	1,98	<5.3	<5.3	n.a.
P35	S2		13,8	38,0	2,8	2,52	6,42	2,5	<0.53	1,18	n.a.	<5.3	<5.3	n.a.
P35	S3		n.a.	24,0	n.a.	n.a.	5,07	n.a.	n.a.	1,14	n.a.	n.a.	<5.3	n.a.
P35	S4		9,2	32,2	3,5	1,56	5,04	3,2	<0.53	0,80	n.a.	<5.3	<5.3	n.a.
P38	S1		20,8	54,4	2,6	0,73	1,11	1,5	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P38	S2		11,7	56,3	4,8	0,20	1,19	6,0	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P38	S3		14,1	46,9	3,3	0,21	1,03	4,9	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P38	S4		21,9	26,5	1,2	0,42	0,42	1,0	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.
P38	S5		21,0	44,4	2,1	0,53	0,95	1,8	<0.53	<0.53	n.a.	<5.3	<5.3	n.a.

*** LQM (7,6 µg/m3), LDM(2,3µg/m3)*

Urinary THM (ng/L)

		TCM	TCM	TCM	DCBM	DCBM	DCBM	CDBM	CDBM	CDBM	TBM	TBM	TBM
		Urinary conc. (Start)	Urinary conc. (End)	Increase Factor	Urinary conc. (Start)	Urinary conc. (End)	Increase Factor	Urinary conc. (Start)	Urinary conc. (End)	Increase Factor	Urinary conc. (Start)	Urinary conc. (End)	Increase Factor
		(ng/L)	(ng/L)		(ng/L)	(ng/L)		(ng/L)	(ng/L)		(ng/L)	(ng/L)	
P4	S1	129,3	68,2	0,5	5,1	<3.58	n.a.	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P4	S2	150,7	172,5	1,1	5,7	<3.58	n.a.	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P4	S4	320,2	151,6	0,5	16,0	<3.58	n.a.	6,4	<3.32	n.a.	n.a.	n.a.	n.a.
P4	S5	69,0	49,0	0,7	<3.58	<3.58	n.a.	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P10	S1	43,3	44,9	1,0	<3.58	<3.58	n.a.	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P10	S2	n.a.	34,7	n.a.	n.a.	3,6	n.a.	n.a.	<3.32	n.a.	n.a.	n.a.	n.a.
P10	S3	53,5	127,7	2,4	<3.58	5,6	n.a.	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P10	S4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
P10	S5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
P13	S1	75	86,9	1,2	11,0	27,3	2,5	15,1	21,8	1,4	n.a.	n.a.	n.a.
P13	S2	n.a.	97,1	n.a.	n.a.	19,9	n.a.	n.a.	24,3	n.a.	n.a.	n.a.	n.a.
P13	S3	excluded	excluded	excluded	excluded	excluded	excluded	excluded	excluded	excluded	n.a.	n.a.	n.a.
P13	S4	144,3	43,4	0,3	8,6	21,2	2,5	8,5	25,0	2,9	n.a.	n.a.	n.a.
P13	S5	64,7	92,3	1,4	5,9	23,9	4,0	8,7	24,9	2,9	n.a.	n.a.	n.a.
P15	S1	124,4	139,5	1,1	14,8	19,4	1,3	8,1	11,8	1,5	n.a.	n.a.	n.a.
P15	S2	78,8	152,8	1,9	14,3	17,8	1,2	5,0	13,0	2,6	n.a.	n.a.	n.a.
P15	S3	80,2	265,7	3,3	16,3	57,3	3,5	5,0	21,9	4,4	n.a.	n.a.	n.a.
P15	S4	79,8	108,0	1,4	13,2	21,0	1,6	9,6	12,0	1,2	n.a.	n.a.	n.a.
P15	S5	55,4	80,3	1,4	12,8	14,0	1,1	4,3	8,8	2,0	n.a.	n.a.	n.a.
P23	S1	165,6	288,2	1,7	9,1	22,2	2,4	3,6	6,1	1,7	n.a.	n.a.	n.a.
P23	S2	107,2	269,0	2,5	6,9	37,2	5,4	4,5	8,9	2,0	n.a.	n.a.	n.a.
P23	S3	125,1	203,4	1,6	11,8	10,4	0,9	5,2	4,0	0,8	n.a.	n.a.	n.a.
P30	S1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
P30	S2	183	213	1,2	20,5	25,3	1,2	4,4	6,1	1,4	n.a.	n.a.	n.a.
P30	S3	202,8	269,7	1,3	13,9	17,3	1,2	4,3	5,6	1,3	n.a.	n.a.	n.a.
P30	S4	n.a.	77	n.a.	n.a.	7,5	n.a.	n.a.	<3.32	n.a.	n.a.	n.a.	n.a.
P35	S1	112,8	159,2	1,4	30,1	38,4	1,3	16,1	14,3	0,9	n.a.	n.a.	n.a.
P35	S2	78,0	197,4	2,5	18,2	56,7	3,1	8,7	21,3	2,5	n.a.	n.a.	n.a.
P35	S3	136,1	95,1	0,7	30,6	21,7	0,7	13,2	9,8	0,7	n.a.	n.a.	n.a.
P35	S4	74,6	199,2	2,7	17,3	59,4	3,4	7,5	27,2	3,6	n.a.	n.a.	n.a.
P38	S1	90,2	218,8	2,4	9,4	7,3	0,8	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P38	S2	89,8	144,9	1,6	5,1	4,6	0,9	<3.32	<3.32	n.a.	n.a.	n.a.	n.a.
P38	S3±	66,8	127,9	1,9	<3.58	4,8	n.a.	<3.32	6,3	n.a.	n.a.	n.a.	n.a.
P38	S4	236,5	240,9	1,0	6,6	8,2	1,3	<3.32	4,8	n.a.	n.a.	n.a.	n.a.
P38	S5	132,1	133,7	1,0	4,4	4,2	0,9	5,1	<3.32	n.a.	n.a.	n.a.	n.a.

Appendix C – Questionnaire Submitted to Participating Facilities

DBP Exposure Study – Questionnaire

1-General information about the swimming pool

1.1 Swimming pool name:

1.2 Age of the facility (age of the swimming pool in years or year of opening):

1.3 Date (year) of latest renovations:

1.4 What did the renovations consist of?

1.5 Number of employees on site (by category)

- Administrative staff:
- Lifeguards:
- Janitorial and maintenance staff:
- Other:

2-General information about attendance

2.1 Maximum capacity:

2.2 Numbers (on average) of bathers per year

i. 2013 =
ii. 2012 =
iii. 2011 =

2.3 Information about bather hygiene

- Is wearing of a bathing cap obligatory?: Y or N
- Are there any rules about bathing suits (e.g., no shorts allowed)? Y or N - if *Yes, please provide details:*
- Is a shower required before swimming? Y or N -
  if Yes, is the recommendation generally followed?
- Is soap available in the showers? Y or N

3- Ventilation and temperature conditions in the swimming pool hall

3.1 Dimensions of the swimming pool hall:

Length (m or ft.) x width (m or ft.) = Height (m or ft.) =

Area (approx.) ($ft.^2$ or m^2) = Volume of the hall (approx.)(m^3) =

3.2 Where are the fresh air intakes (e.g., from floor level, the ceiling)?

3.3 Where are the air exhaust exits?

3.4 What is the ideal temperature in the swimming pool hall?

4. Hydraulic conditions of the swimming pool basin

4.1 Form of the swimming pool basin

(rectangular/other? *If other, please provide as much detail as possible*)

4.2 Dimensions of the swimming pool basin:

Length (m or ft.) = Width (m or ft.) =

Depth (m or ft.): min = max =

Swimming pool area ($ft.^2$ or m^2) = Volume of water in the pool (m^3)=

4.3 For special configurations and multiple basins, to the best of your ability, please specify what the various sections look like in the box below.

4.4 By which device and from which part/level (height) does water enter the swimming pool?

4.5 How often do you add fresh water to the pool AND in what volume?

4.6 Please specify which recirculation devices your pool is equipped with

- Gutters: Y/N
- Skimmer: Y/N
- Bottom drain: Y/N
- Other (please specify):

4.7 How often is the swimming pool completely drained?

4.8 When was the pool completely drained before OCTOBER 2012? (Note that the year in question is 2012 and not 2013)

4.9 Has the pool been completely drained between October 1, 2012 and June 1, 2013? If so, how many times?

5. Water treatment methods

5.1 Which water treatment plant or municipal network supplies fresh water to the swimming pool?

5.2 Briefly describe the water treatment process used at your facility between October 1, 2012 and June 1, 2013 (e.g., sand and gravel filtration; chlorine disinfection; stripping)

5.3 Have any changes been made to the water treatment process since June 2013?

5.4 Questions about disinfection:

- Type and form (liquid/solid/gas) of disinfectant used:
- Desired concentration of disinfectant in the pool:
- Use of a chlorinator: Y/N (*if Yes, what model is used?:*_____)
- Targeted concentration of residual free chlorine in the pool:
- Frequency that chlorination is adjusted (change in dosage):

5.5 Questions about filtration:

- Type of filtration used:
- Dimension of filters:
- Volume of water filtered per hour and per day (filtration capacity):
- Frequency filters are cleaned (backwashed):
- Is the backwash water pumped down the drain or recirculated through the filtration system?
- Frequency of filter replacement:

5.6 Questions about dechloramination

- Use of a dechloraminator: Y/N (*if Yes what model is used?:*_____)
- Frequency UV lamps are changed:
- Other processes/devices: Y/N (*if Yes, please provide details:*_____)

5.7 Questions about other treatments:

- Do you use products to dilute the concentration of disinfectant when it is too high in the water? (*If Yes, please provide details:*_____)
- Do you use products to dilute the concentration of chloramines in the water? Y/N (*If Yes, please provide details:*_____)
- Do you use products to control turbidity in the water? Y/N (*If Yes, please provide details:*_____)
- Do you use products to control the pH? Y/N (*If Yes, please provide details:*_____)