UNIVERSITÉ LAVAL

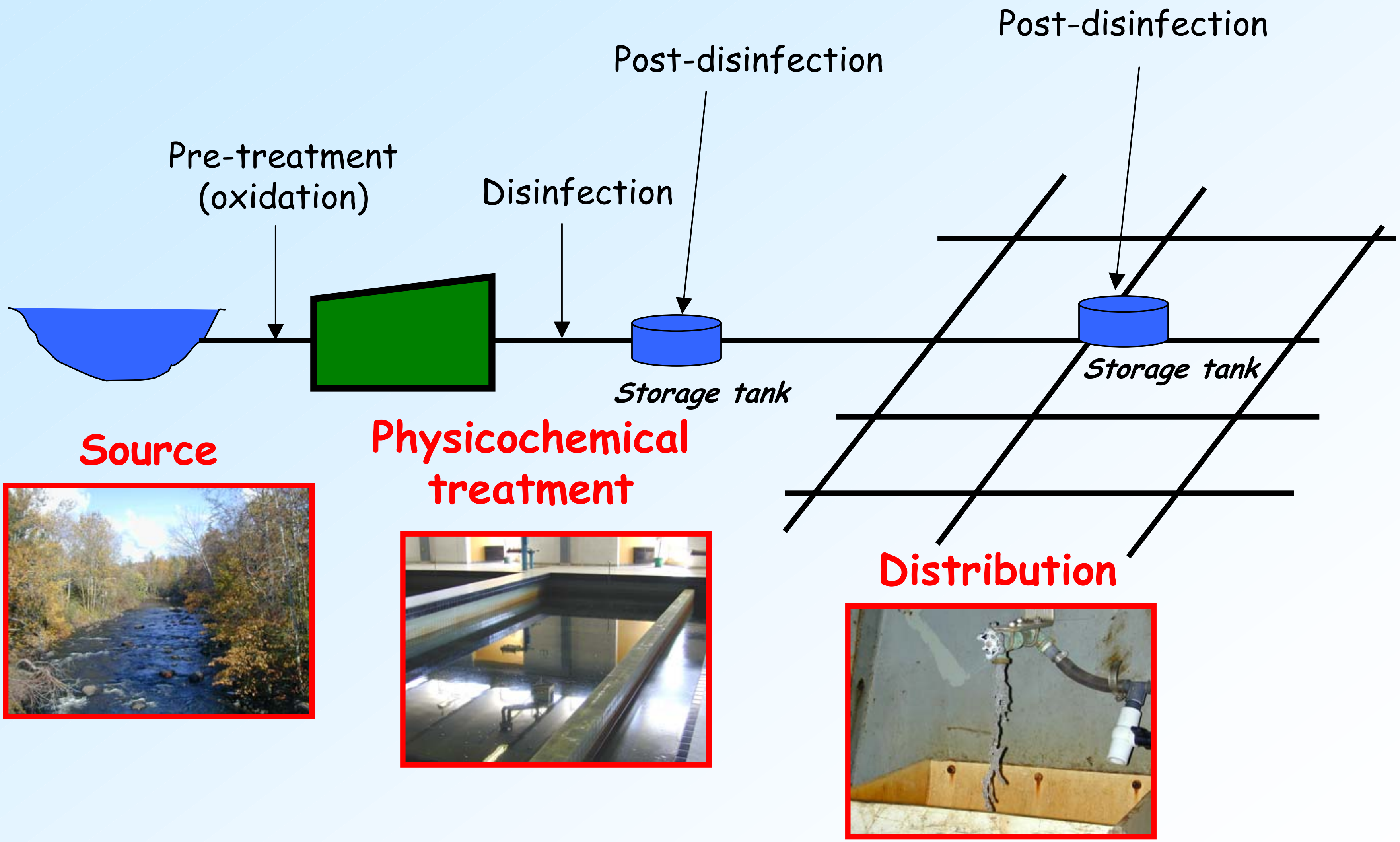
Variability of chlorinated DBPs in distribution systems: Challenges for regulatory compliance

Manuel J. Rodriguez

UNIVERSITÉ LAVAL
Quebec City, CANADA

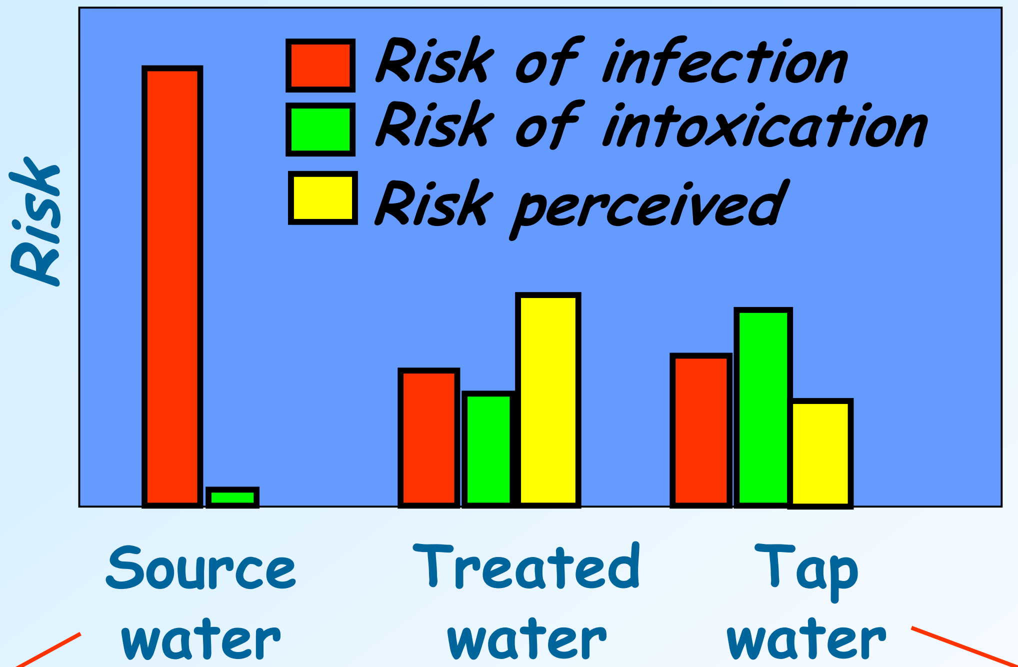
Presented at the:

6th ANNUAL CLEAN AND SAFE DRINKING WATER WORKSHOP
Gander (NF), March 20-22 2007


Pre-treatment
(oxidation)
Disinfection
Post-disinfection
Post-disinfection
Storage tank
Storage tank
Source
Physicochemical
treatment
Distribution

UNIVERSITÉ LAVAL

Risk management for drinking water



Source water protection

Treatment performance

Water quality management during distribution

UNIVERSITÉ LAVAL

DIVERSE TYPES OF DISINFECTANTS and DBPs:

- Chlorine: trihalomethanes, haloacetics
- Chloramines: trihalomethanes
- Chlorine dioxide: chlorite, chlorate
- Ozone: bromate
- UV (?)

UNIVERSITÉ LAVAL

Chlorine
+
Natural organic matter (NOM)
+
Bromide

↓

Chlorination by-products (CBPs)

Trihalomethanes (THM)
- Chloroform
- Bromodichloromethane
- Dibromochloromethane
- Bromoform

Haloacetic acids (HAA)
- Dichloroacetic
- Trichloroacetic
- Bromochloroacetic
- Dibromoacetic
- Bromodichloroacetic

Haloacetonitriles
Halopicrin
Chloral Hydrate

Others

UNIVERSITÉ LAVAL

Possible adverse health effects of exposure to CBPs in drinking water

- Potential carcinogenic and mutagenic (long term)
- Possible reproductive and developmental effects (short term)

UNIVERSITÉ LAVAL

Chronological portrait of CBP standards

(THMs and HAAs)

	Canada (guidelines)	Quebec (regulations)	U.S. (regulations)
1978	350 µg/L		
1979			100 µg/L
1984		350 µg/L	
1996	100 µg/L		
1998			80 µg/L 60 µg/L
2001		80 µg/L	
2005			Second stage DBP rule
2007	80 µg/L		

UNIVERSITÉ LAVAL

The temporal variations of chlorinated DBPs in distribution systems are related to the fluctuations of raw water quality and to the variability of treatment conditions

UNIVERSITÉ LAVAL

BACKGROUND

Factors responsible for CBP formation and evolution in drinking water

They are related to source, treatment and distribution:

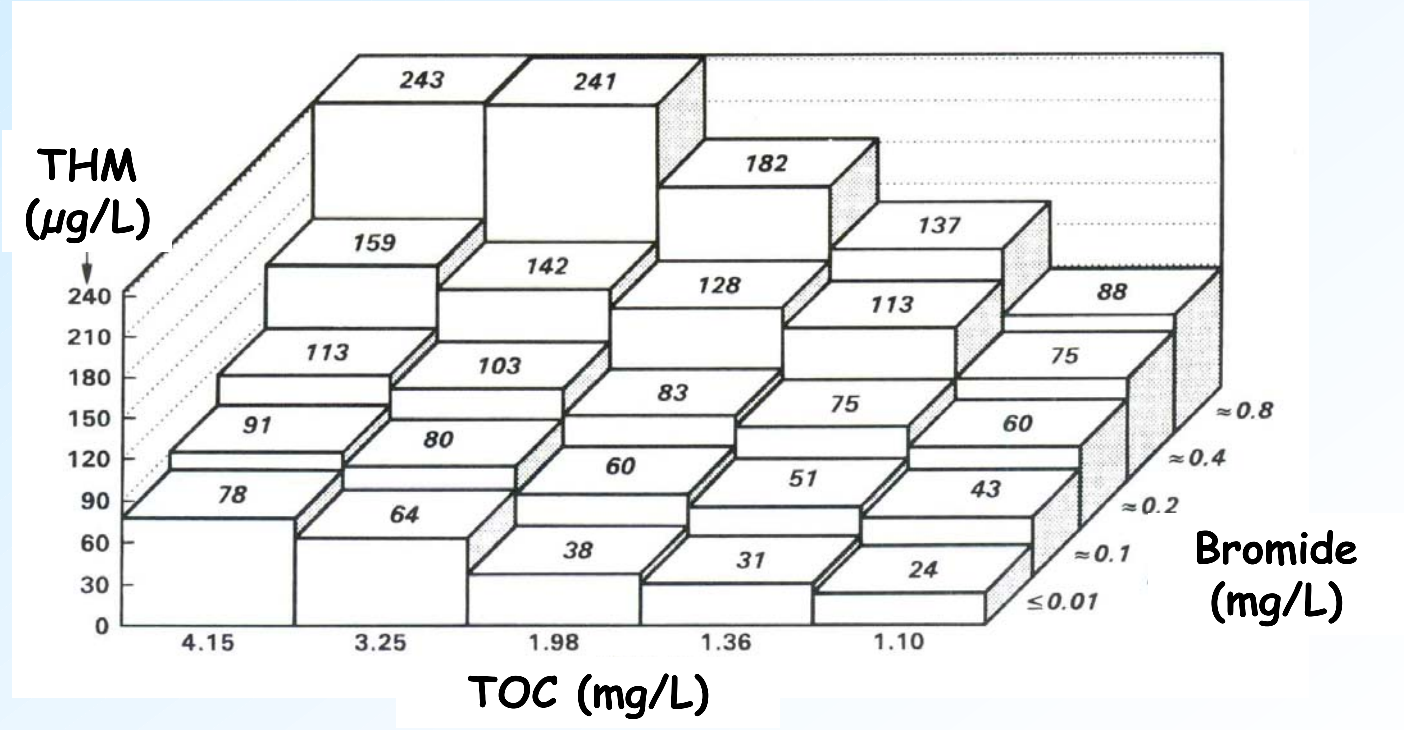
- Water quality at the source
- Environmental conditions
- Modification of source water quality by treatment
- Disinfection strategy
- Water distribution characteristics

Factors responsible ...

Water quality at the source

***Effect of TOC and bromide** (adapted from de Krasner et al., 1996)*

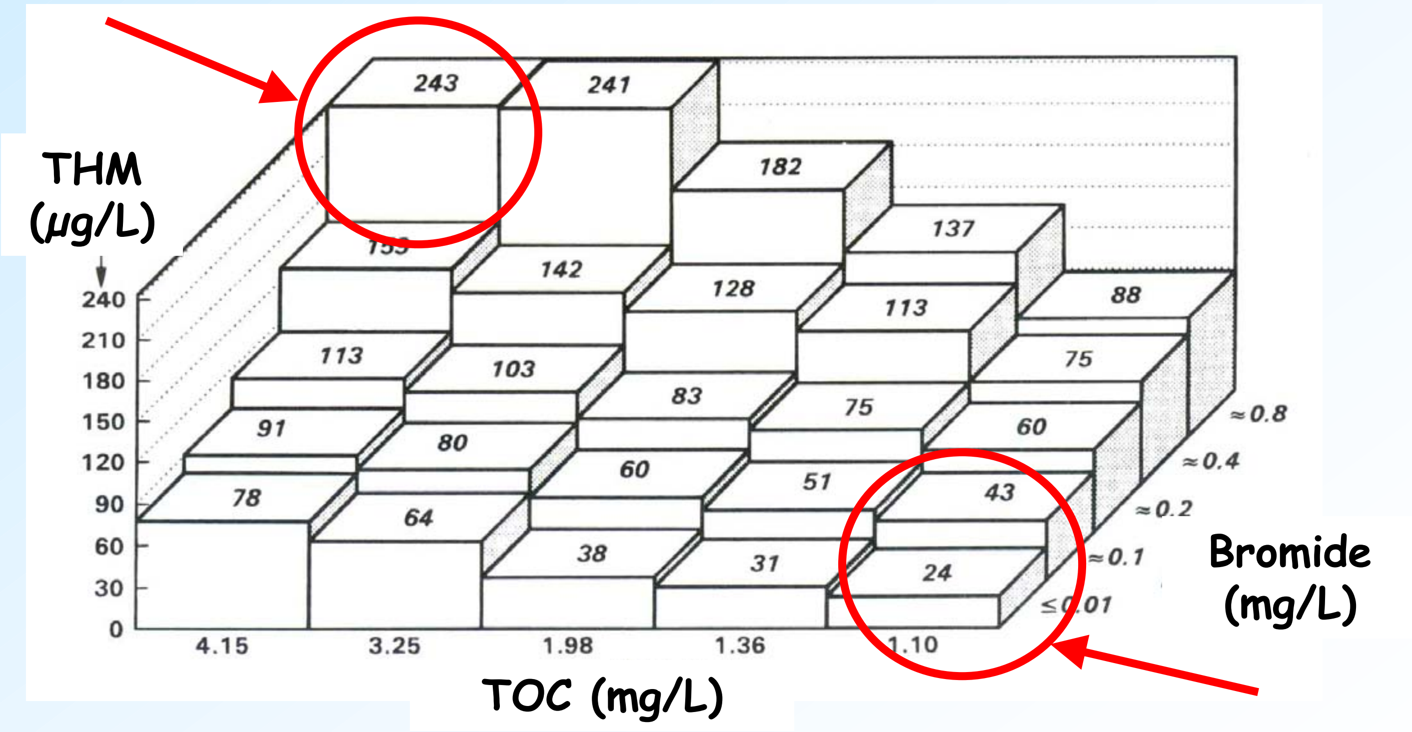
(Surface and groundwaters, chlorinated with dose= 5 mg/L, temperature= 25°C, pH = 8.2, Contact time = 3h)



Factors responsible ...

Water quality at the source

Effect of TOC and bromide *(adapted from de Krasner et al., 1996)*
(Surface and groundwaters, chlorinated with dose= 5 mg/L, temperature= 25°C, pH = 8.2, Contact time = 3h)



UNIVERSITÉ LAVAL

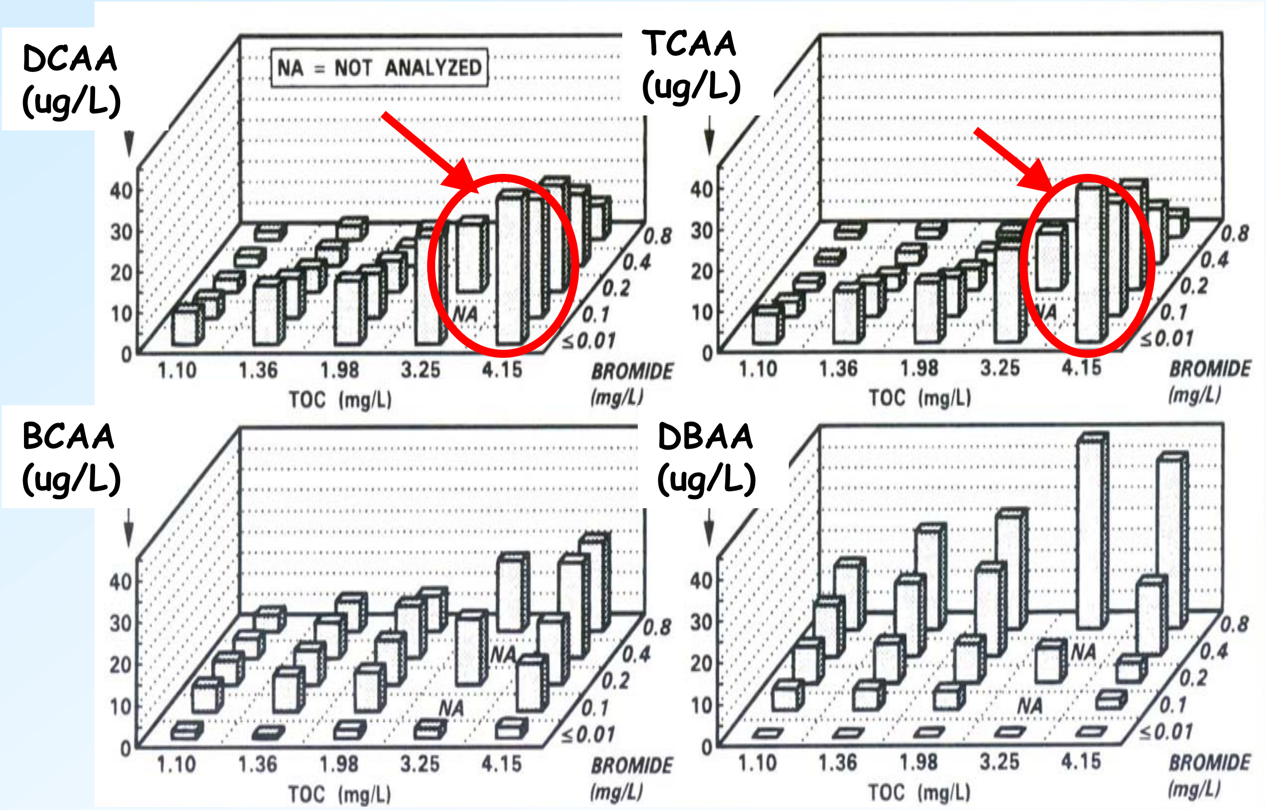
Factors responsible ...

Water quality at the source

***Effect of TOC and bromide** (adapted from de Krasner et al., 1996)*

(Surface and groundwaters, chlorinated with dose= 5 mg/L, temperature= 25°C, pH = 8.2, Contact time = 3h)

HAAs (μg/L)

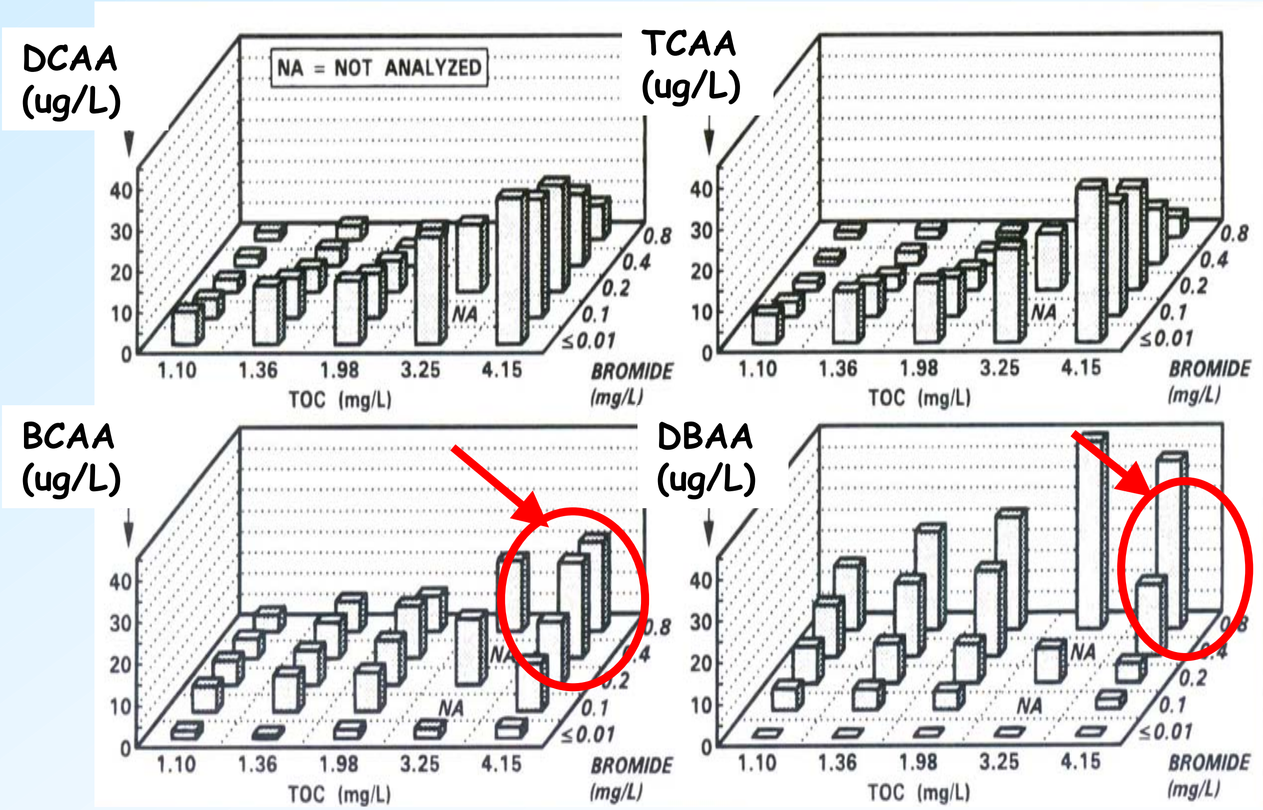


Factors responsible ...

Water quality at the source

Effect of TOC and bromide (adapted from de Krasner et al., 1996)
(Surface and groundwaters, chlorinated with dose= 5 mg/L, temperature= 25°C, pH = 8.2, Contact time = 3h)

HAAs (µg/L)



UNIVERSITÉ LAVAL

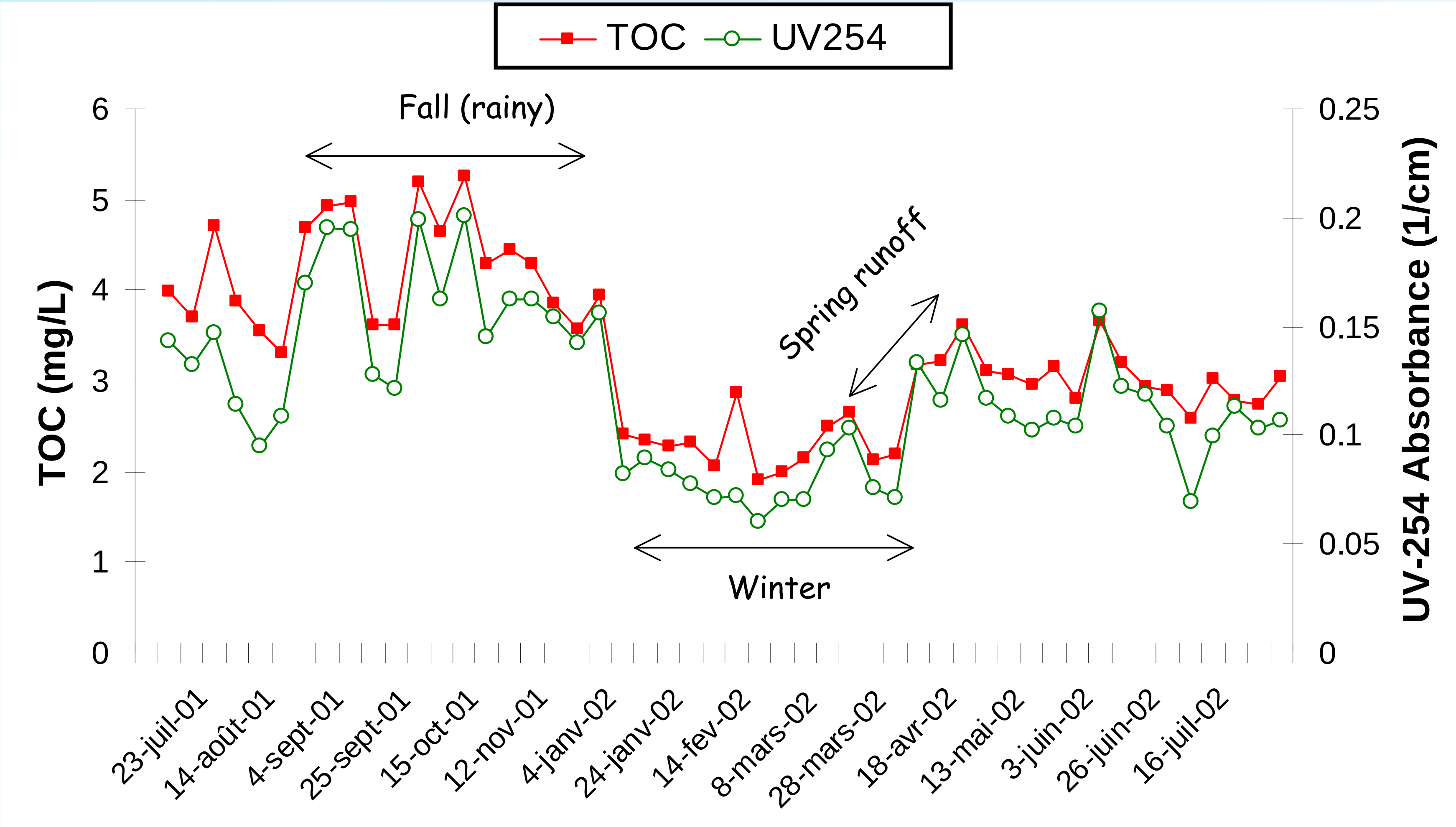
Factors responsible ...

Environmental conditions

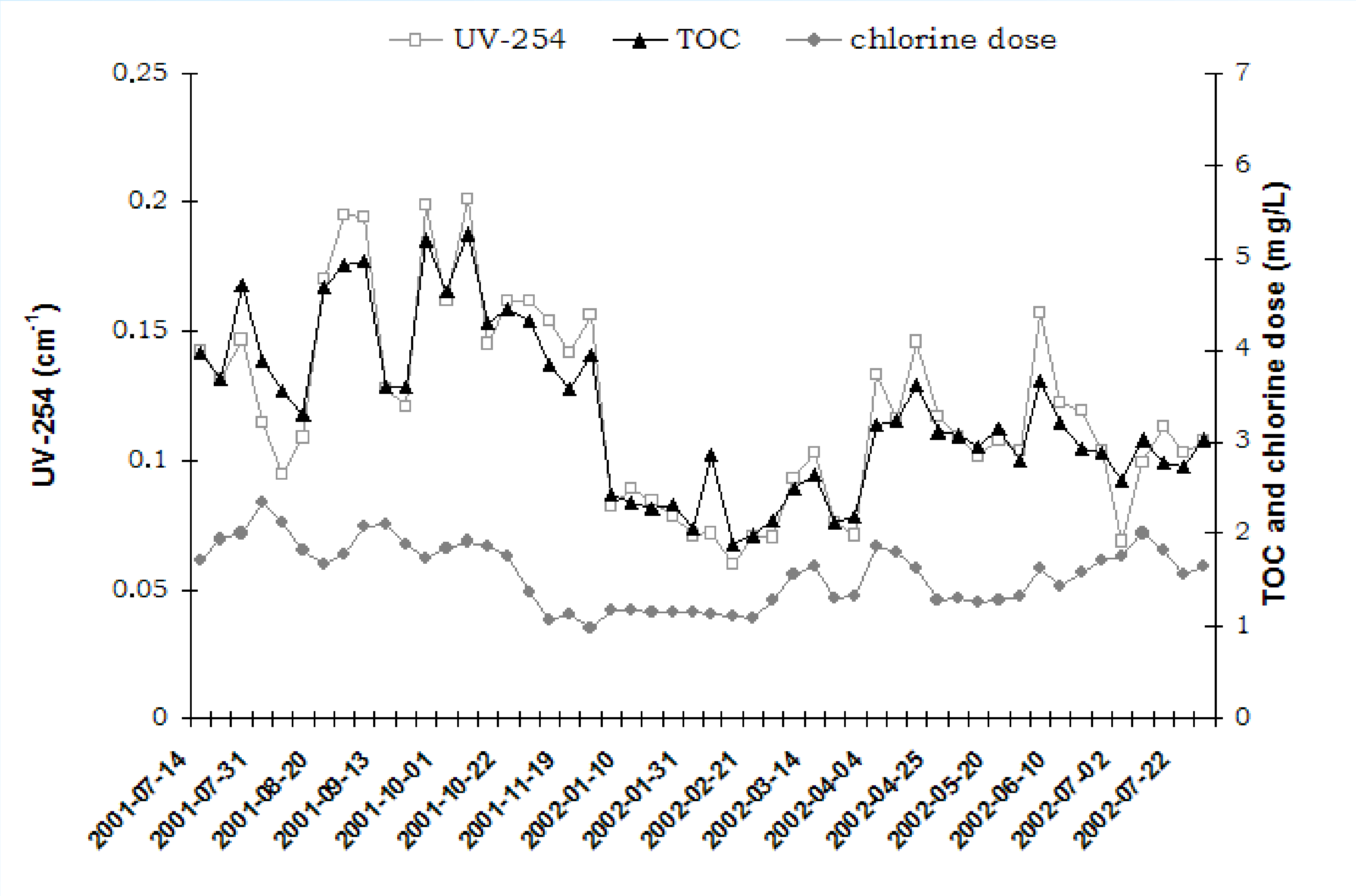
- water temperature
- seasonal characteristics and variations
- climatological conditions

UNIVERSITÉ LAVAL

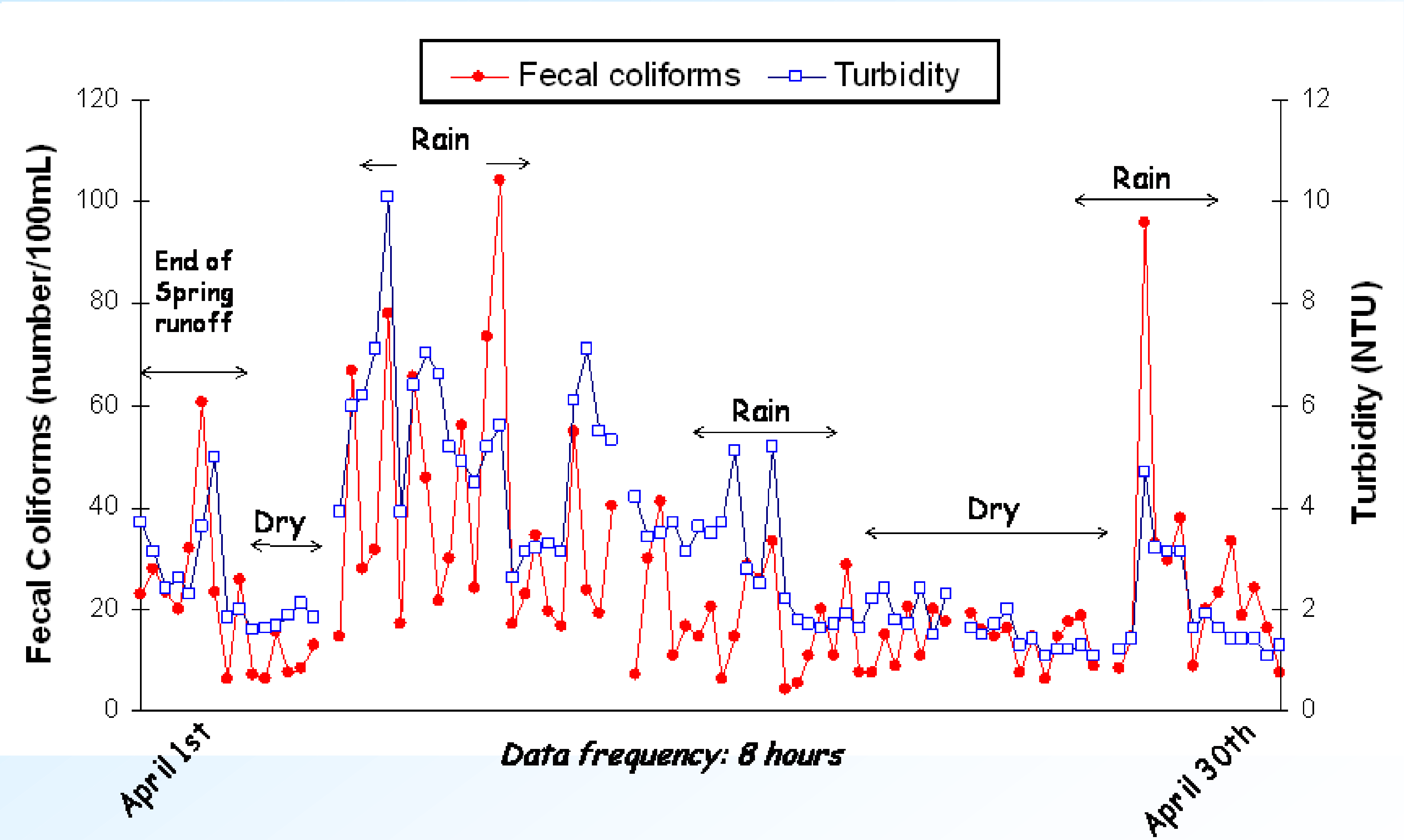
Weekly variation of CPB precursor indicators at the Quebec City water source



DBP precursors indicators in Quebec City raw water and pre-chlorination dose

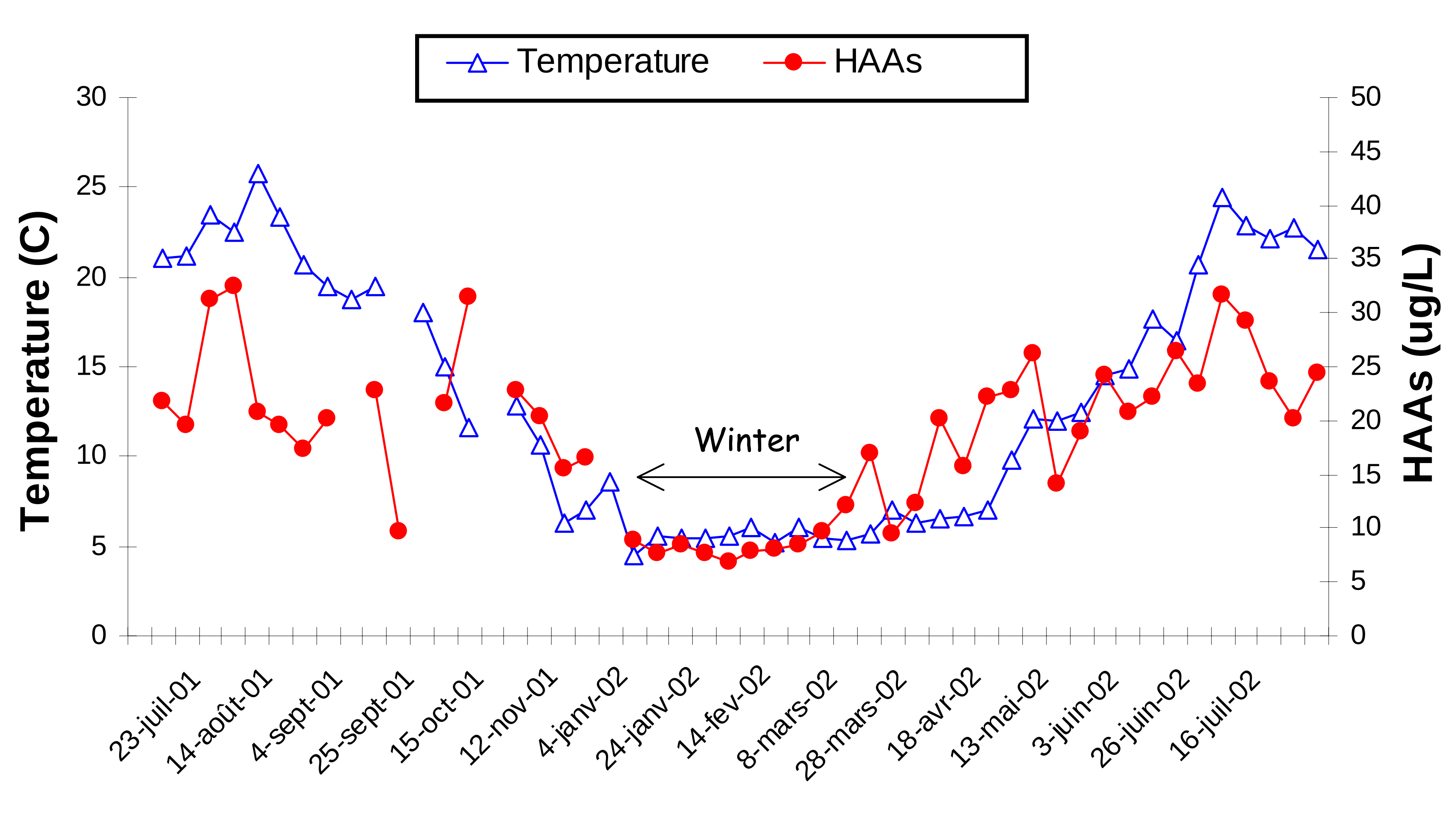


Short term variation of water quality at the Quebec City source (April 2003)



UNIVERSITÉ LAVAL

Relationship between water temperature and HAA formation following pre-chlorination of Quebec City water source



Factors responsible...

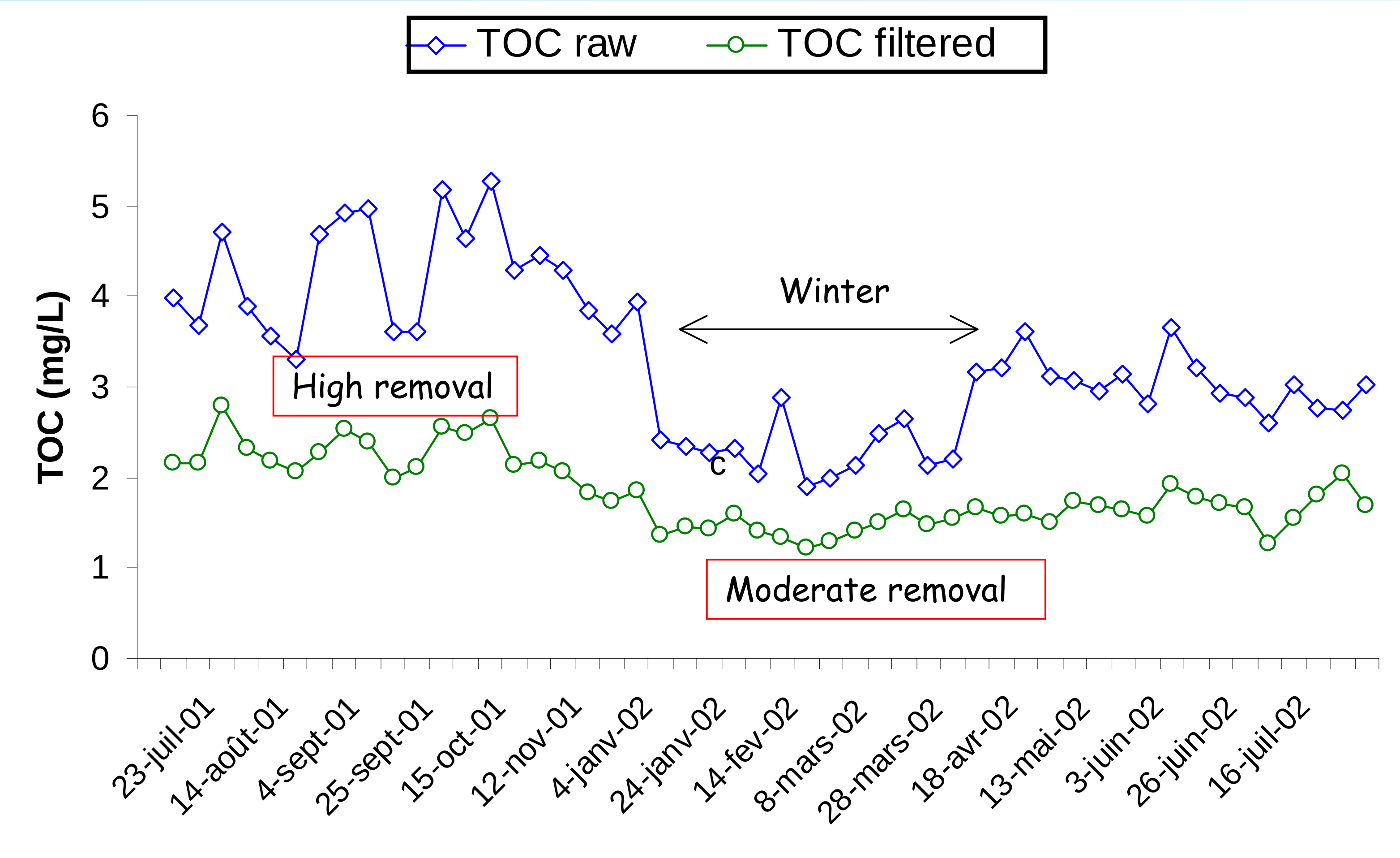
Modification of source water quality by treatment

Removal of NOM by diverse processes:

- *conventional treatment (coagulation- floculation-sedimentation)*
- *use of granular activated carbon,*
- *membrane filtration (nano,micro,ultra) and others*

UNIVERSITÉ LAVAL

TOC removal by the Quebec City water plant



UNIVERSITÉ LAVAL

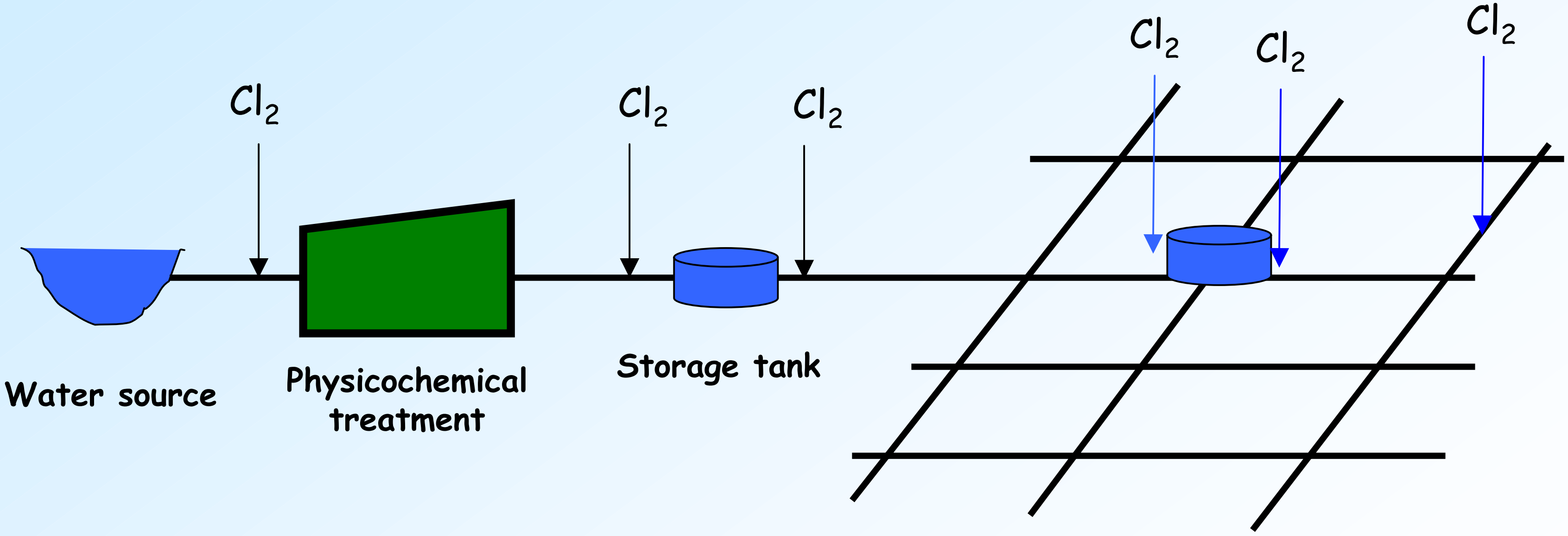
Factors responsible ...

Disinfection strategy

- disinfectant type
- point of application
- applied dose

UNIVERSITÉ LAVAL

Impact of chlorine application point



UNIVERSITÉ LAVAL

Many data concerning precursor removal and THM formation during water treatment

Considerably less data and knowledge about the fluctuations of CBPs and their precursors as well as the implications of such fluctuations

UNIVERSITÉ LAVAL

RESEARCH PROGRAM OBJECTIVES

Document, understand and model the spatio-temporal variations of CBPs in drinking water

UNIVERSITÉ LAVAL

Methodologies to investigate spatio-temporal fluctuations of chlorinated DBPs

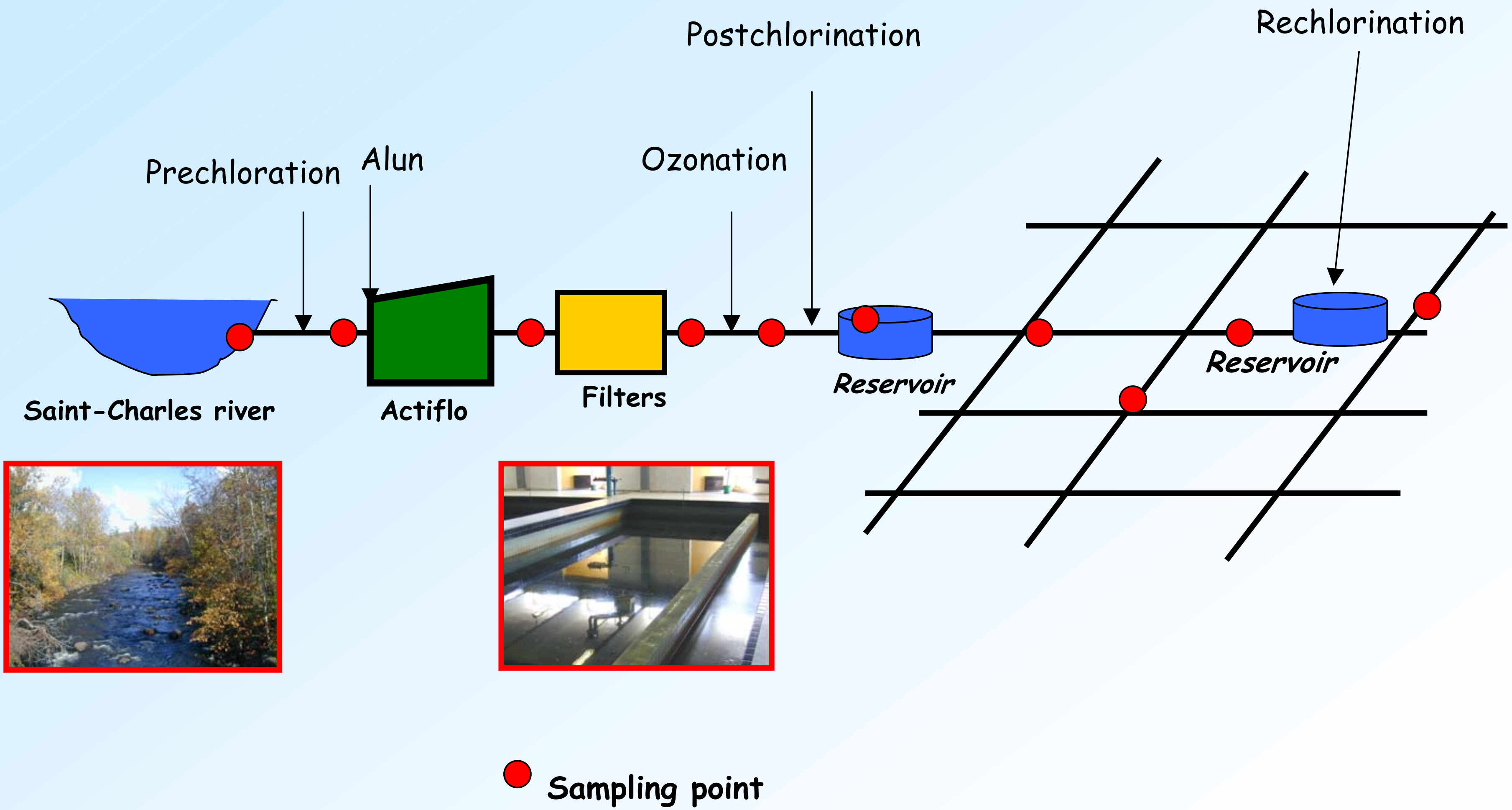
Data generation approach

Time scale

Spatial scale

Utility size

UNIVERSITÉ LAVAL



UNIVERSITÉ LAVAL

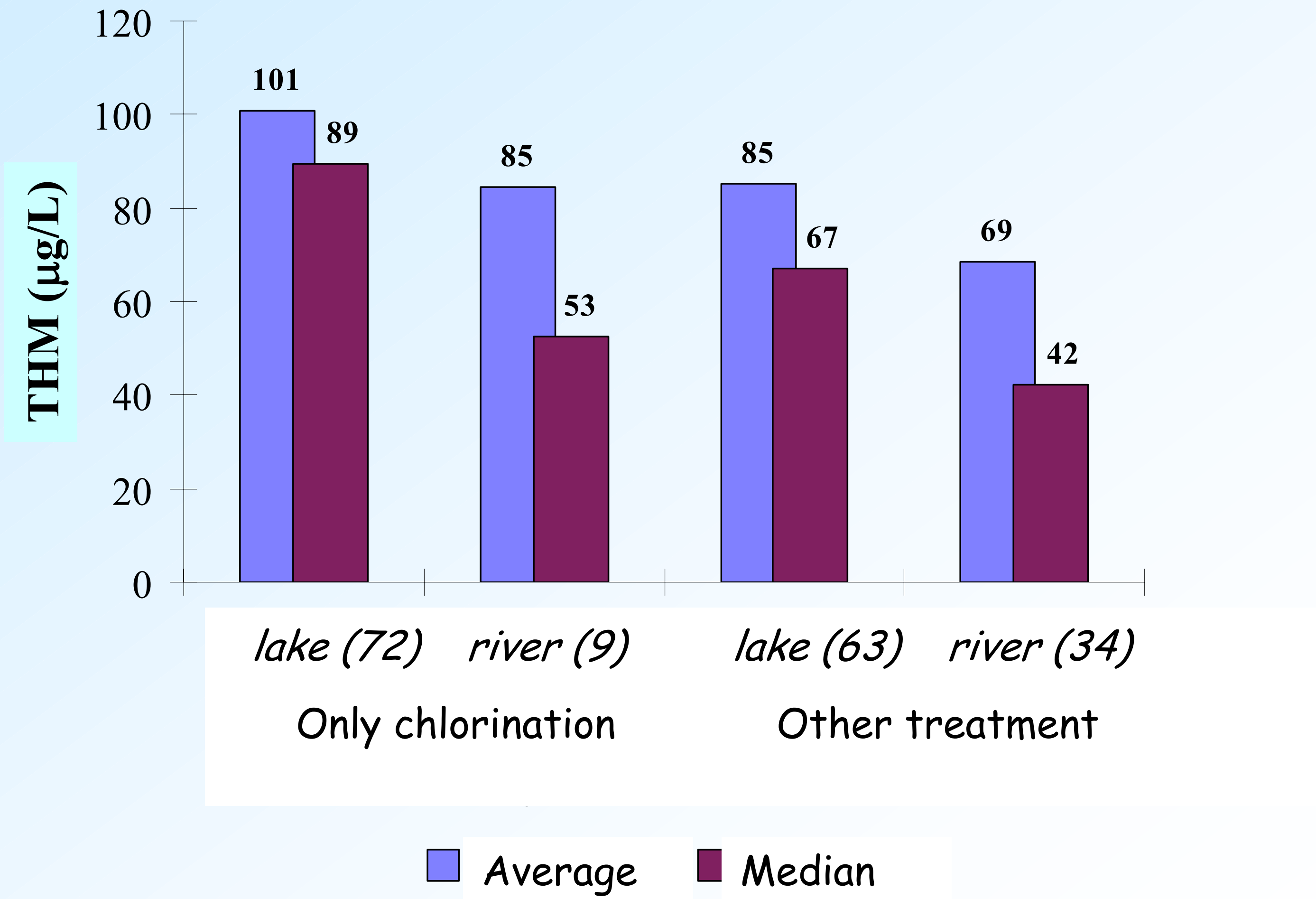
EXAMPLES OF FLUCTUATIONS

1. Regional variations
2. Fluctuations within the treatment plant
3. Fluctuations in the distribution system
4. Short term fluctuations
5. Indoor exposure to chlorinated DBPs

1. Regional variations

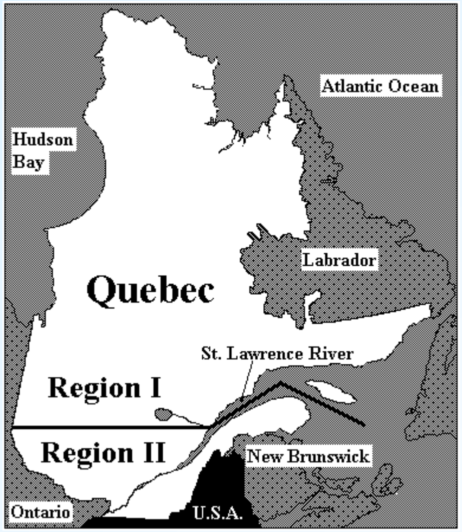
UNIVERSITÉ LAVAL

THM data from 170 distribution systems of Quebec (small and medium systems) (8 years)

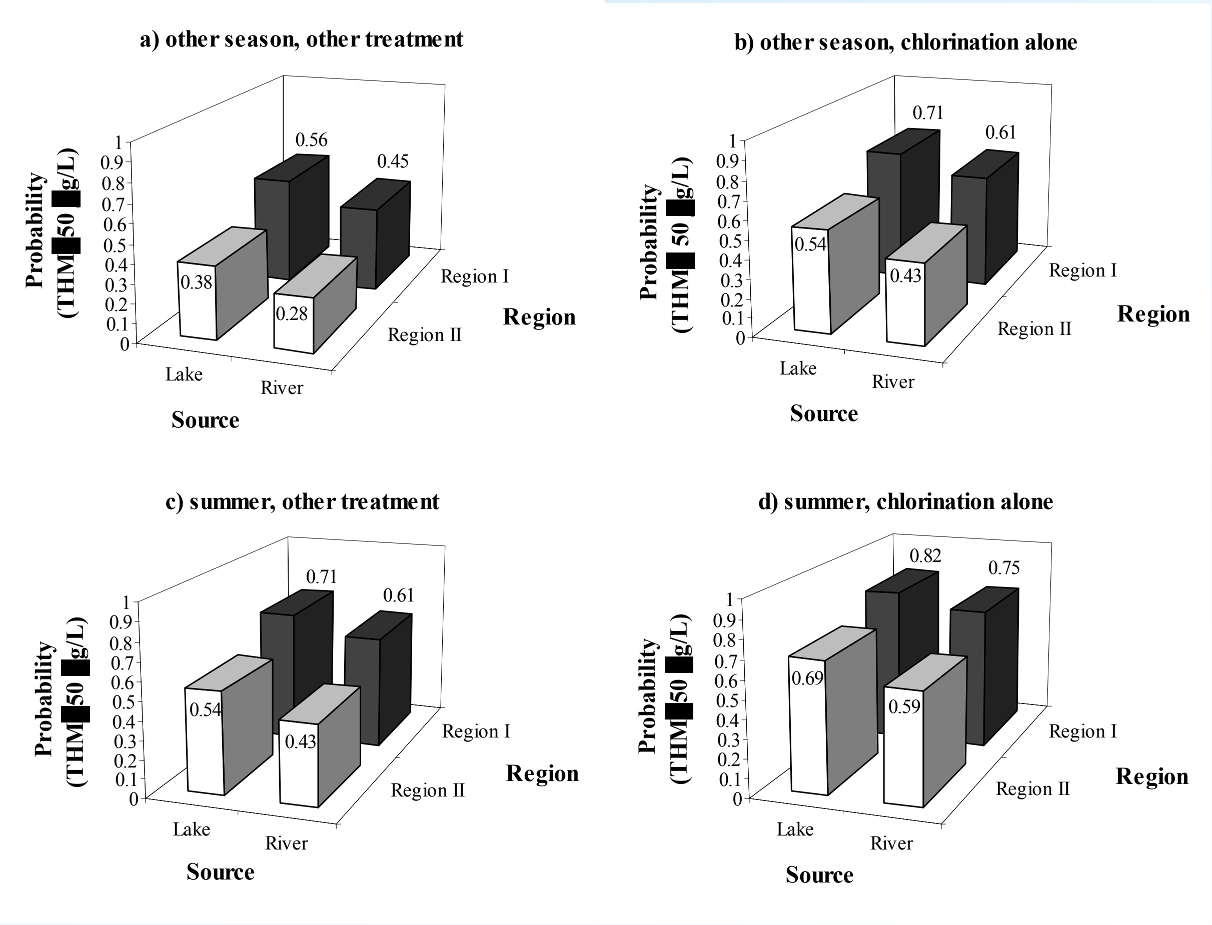


UNIVERSITÉ LAVAL

THM data from 170 distribution systems of Quebec (small and medium systems) (8 years)



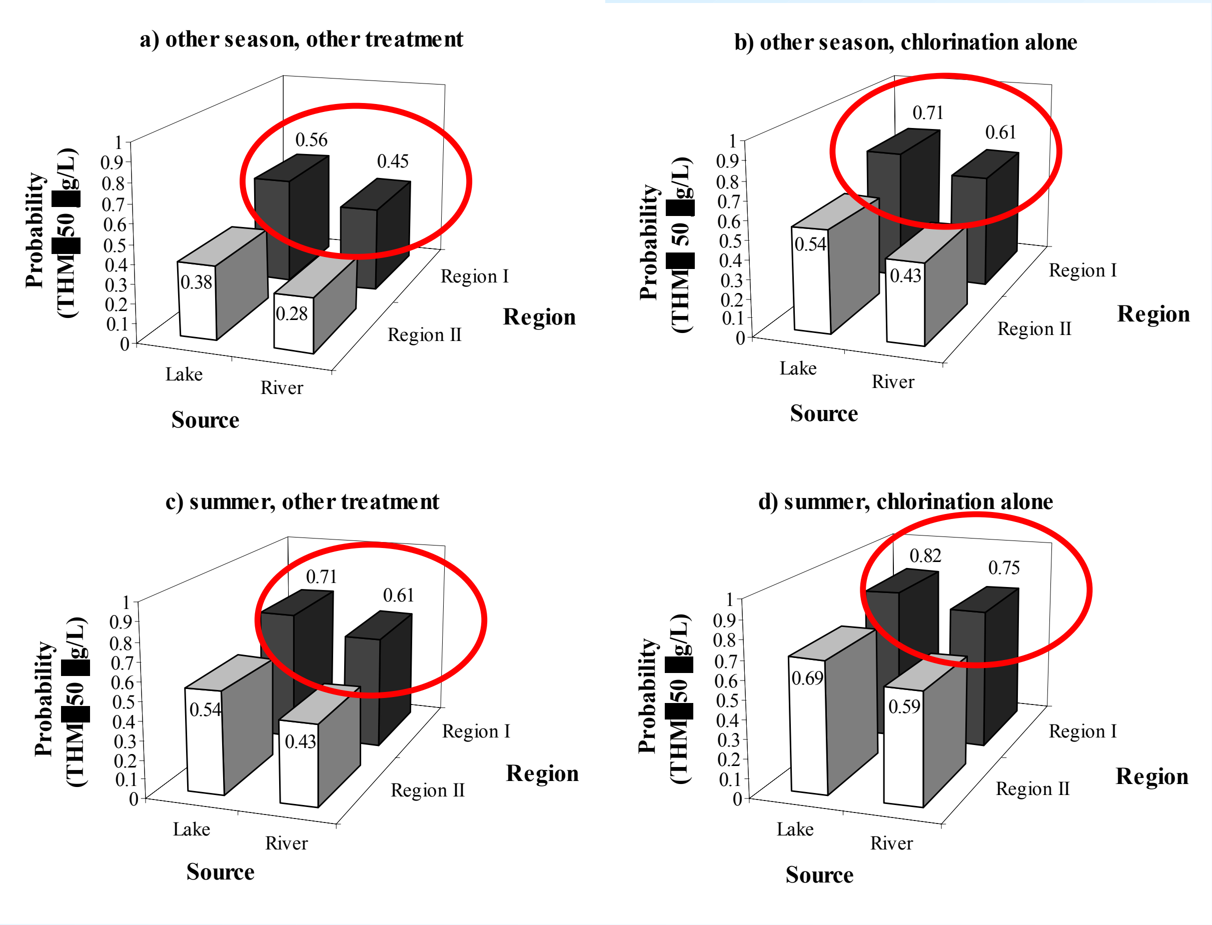
Model for THM occurrence

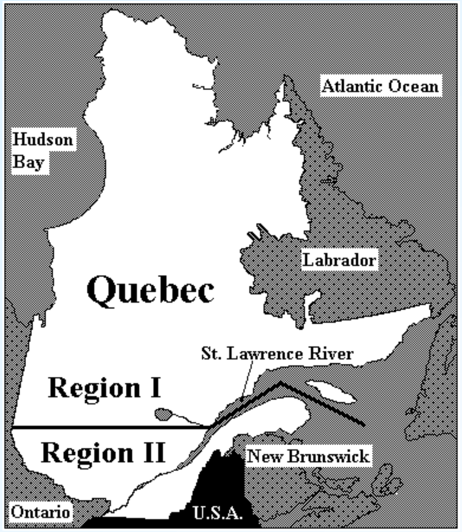


UNIVERSITÉ LAVAL

THM data from 170 distribution systems of Quebec (small and medium systems) (8 years)

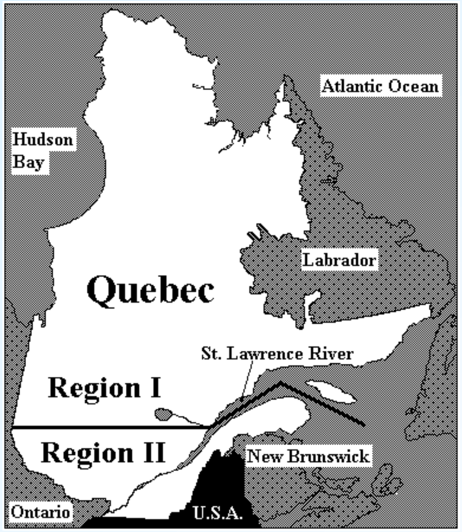
Model for THM occurrence



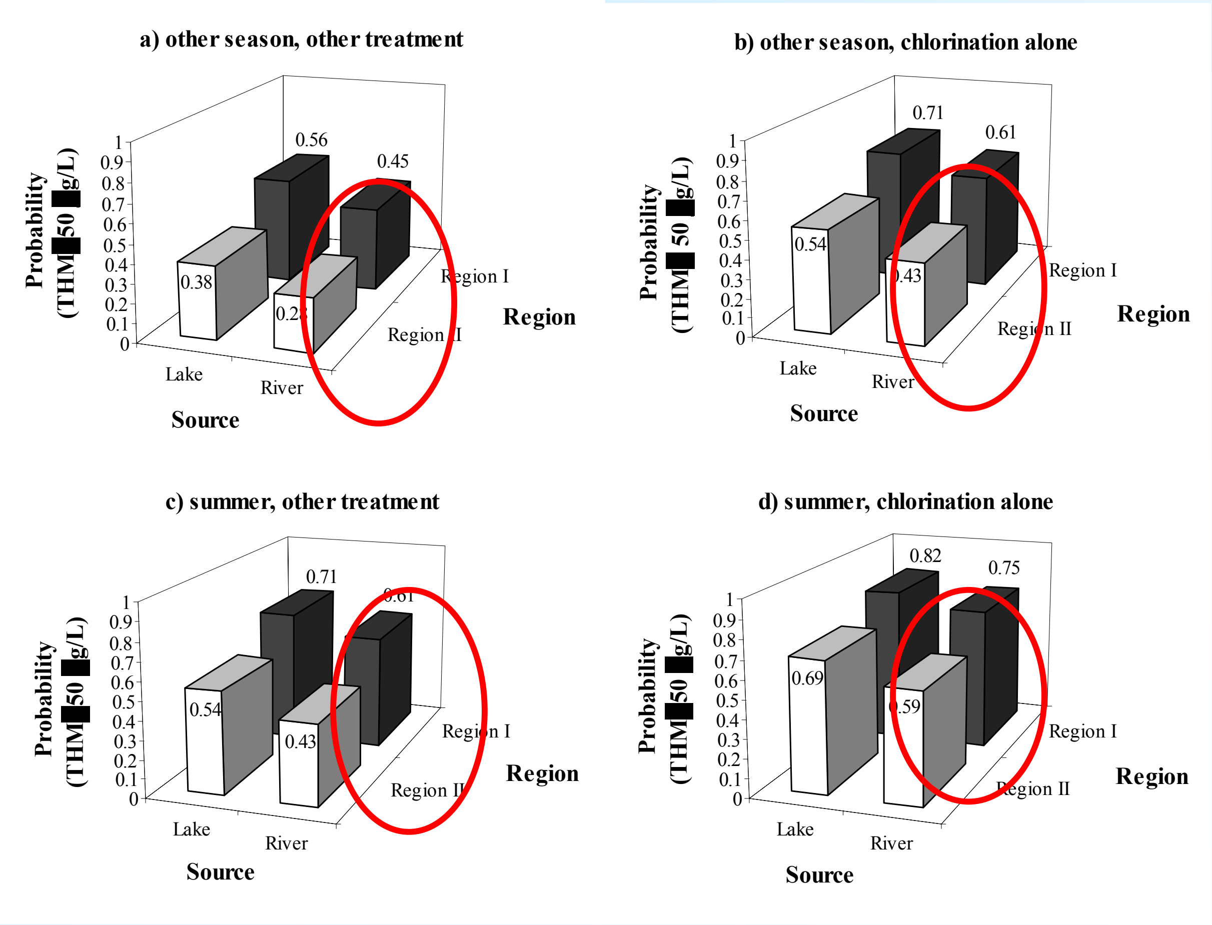


UNIVERSITÉ LAVAL

THM data from 170 distribution systems of Quebec (small and medium systems) (8 years)



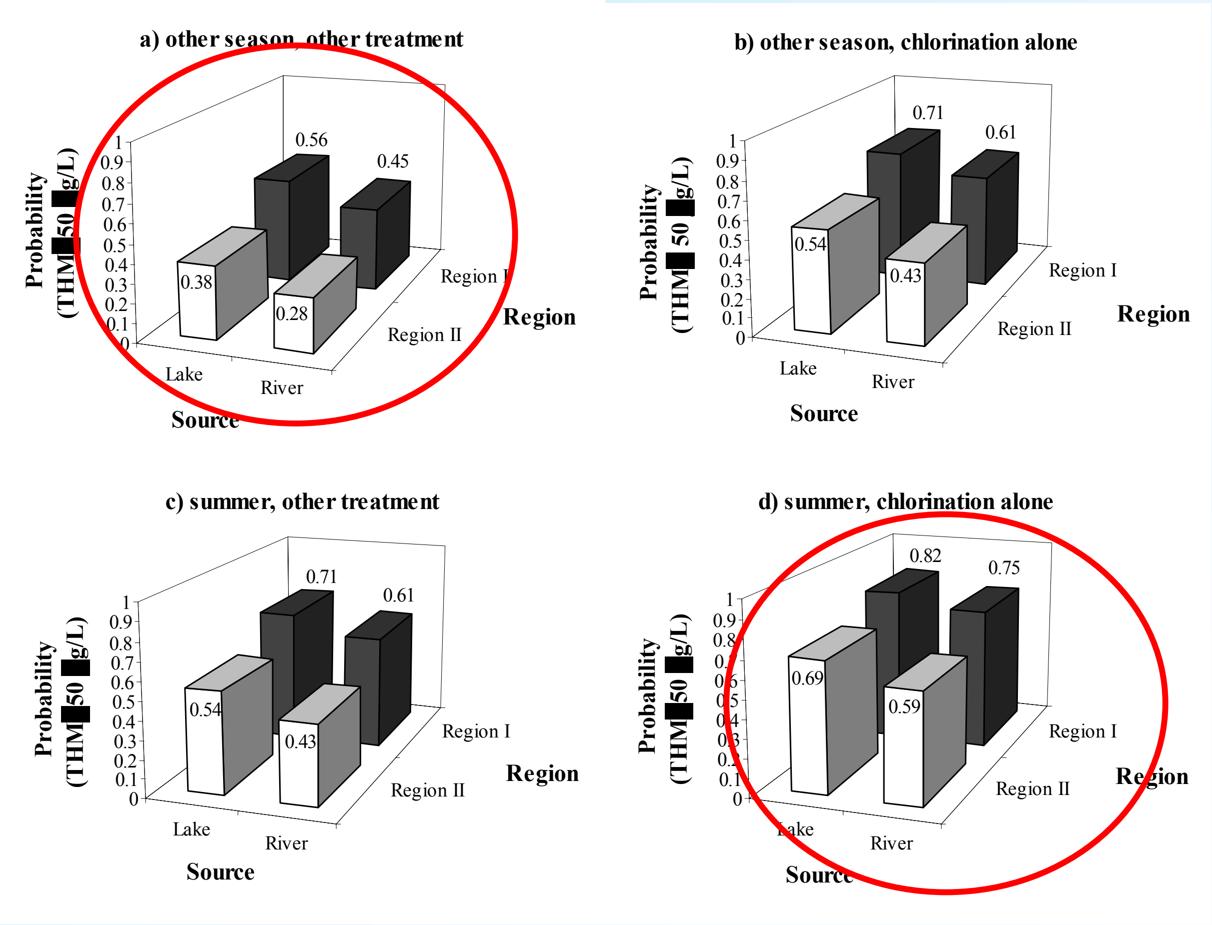
Model for THM occurrence

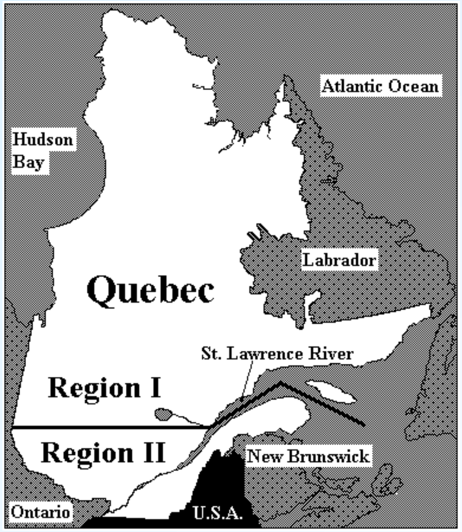


UNIVERSITÉ LAVAL

THM data from 170 distribution systems of Quebec (small and medium systems) (8 years)

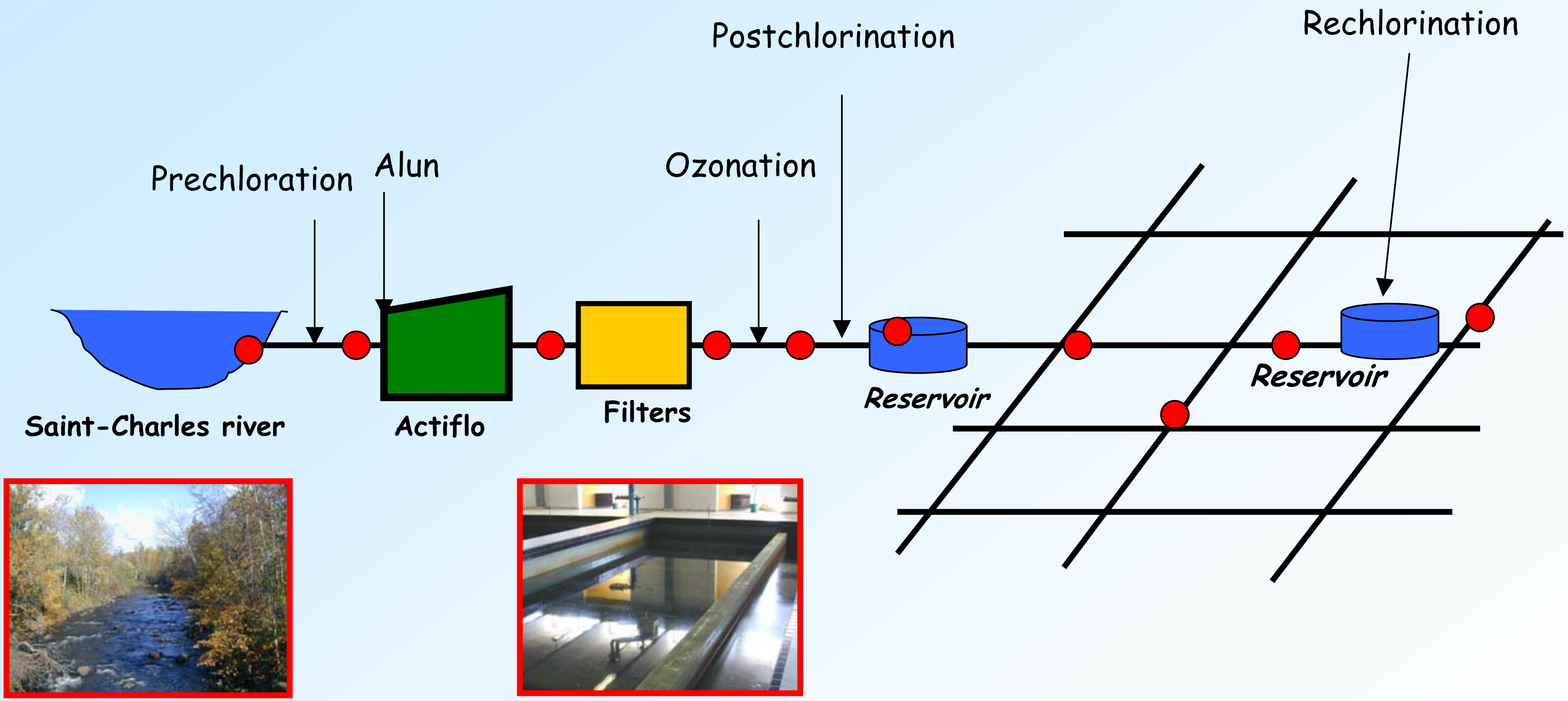
Model for THM occurrence





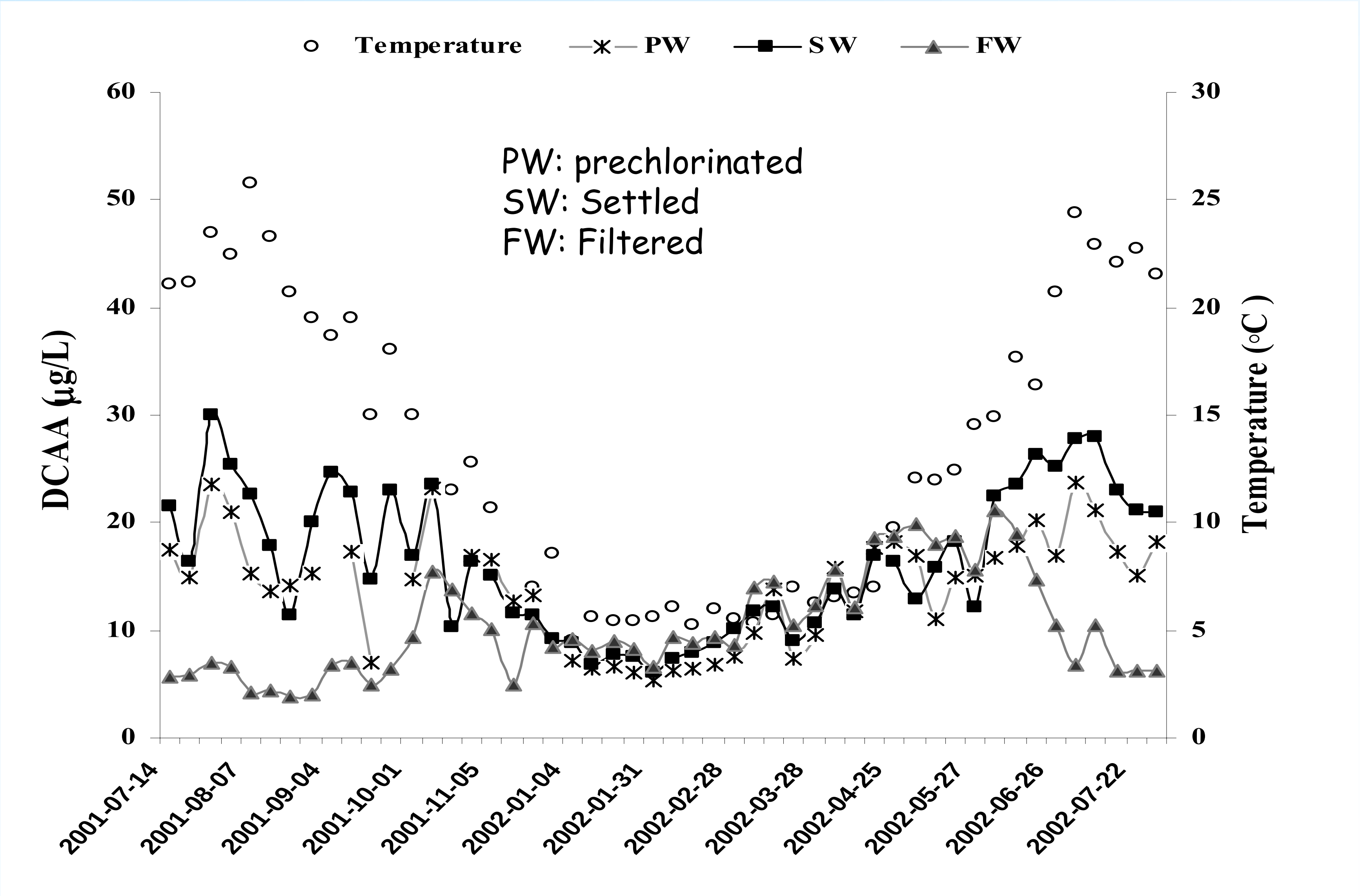
2. Fluctuations within the treatment plant

UNIVERSITÉ LAVAL

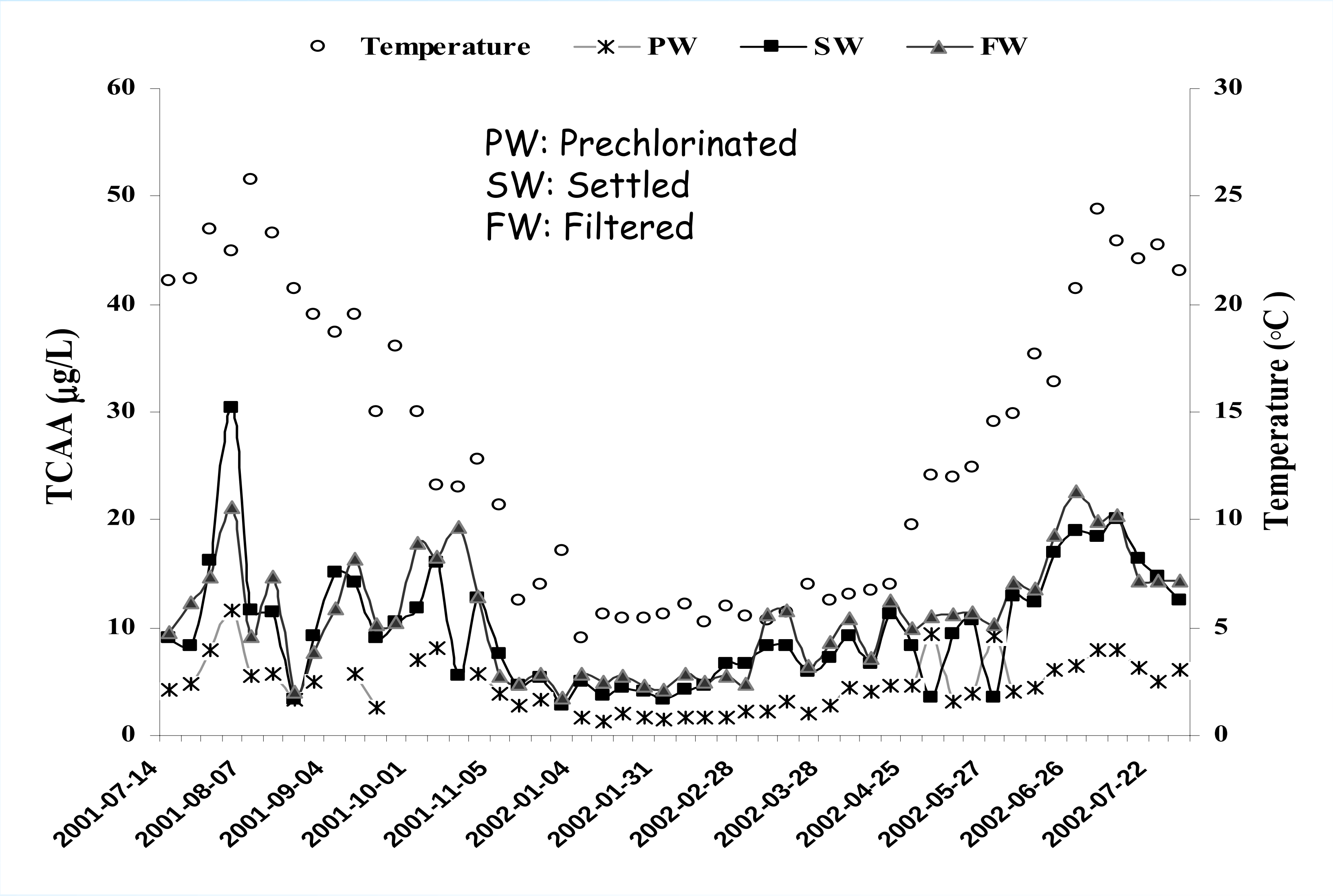


Sampling point

Fluctuations of HAAs within the plant



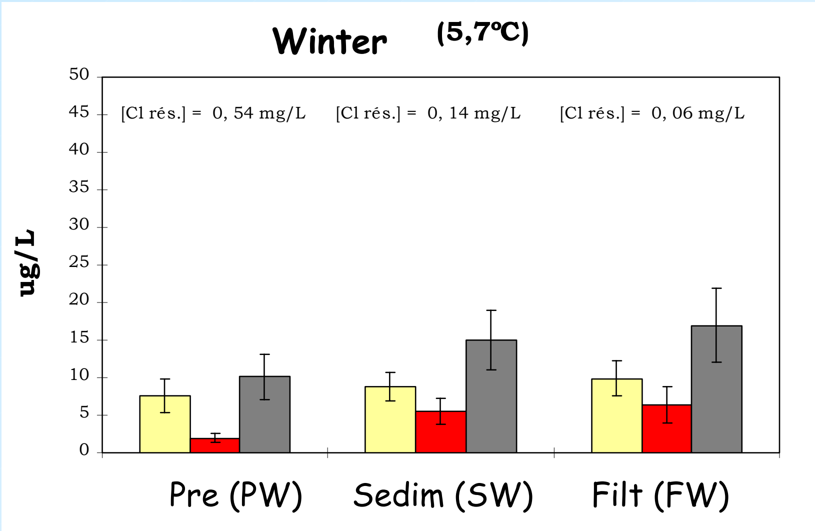
Fluctuations of HAAs within the plant

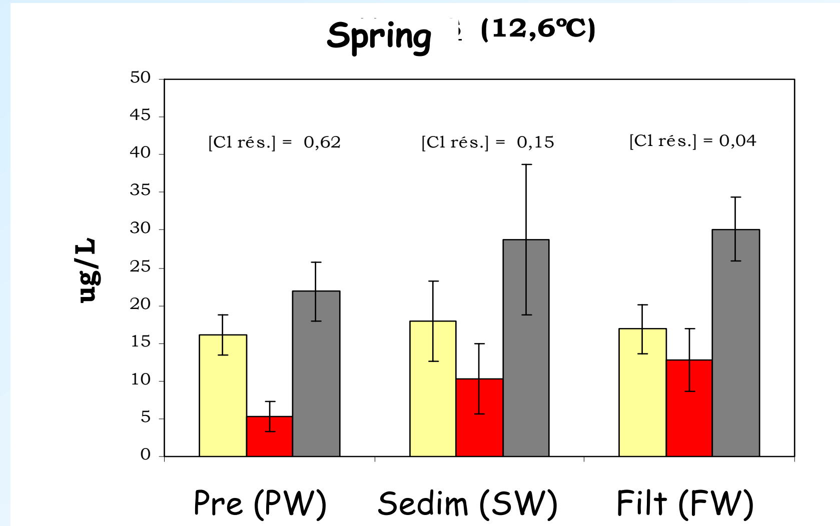


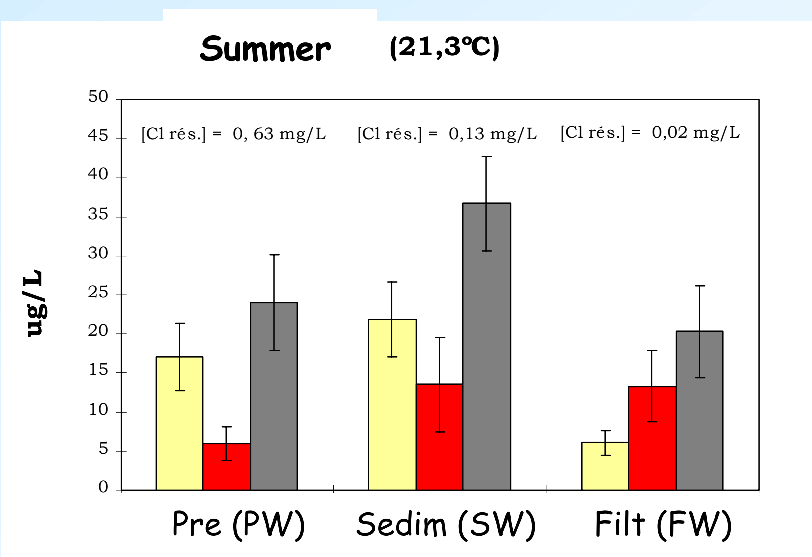
UNIVERSITÉ LAVAL

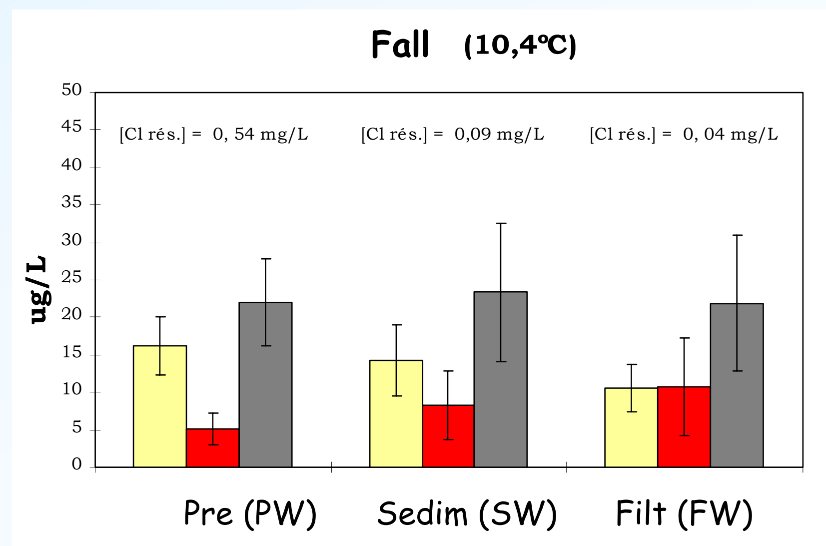
Fluctuations of HAAs within the plant

Dichloroacic (DCAA) | Trichloroacetic (TCAA) | HAAs



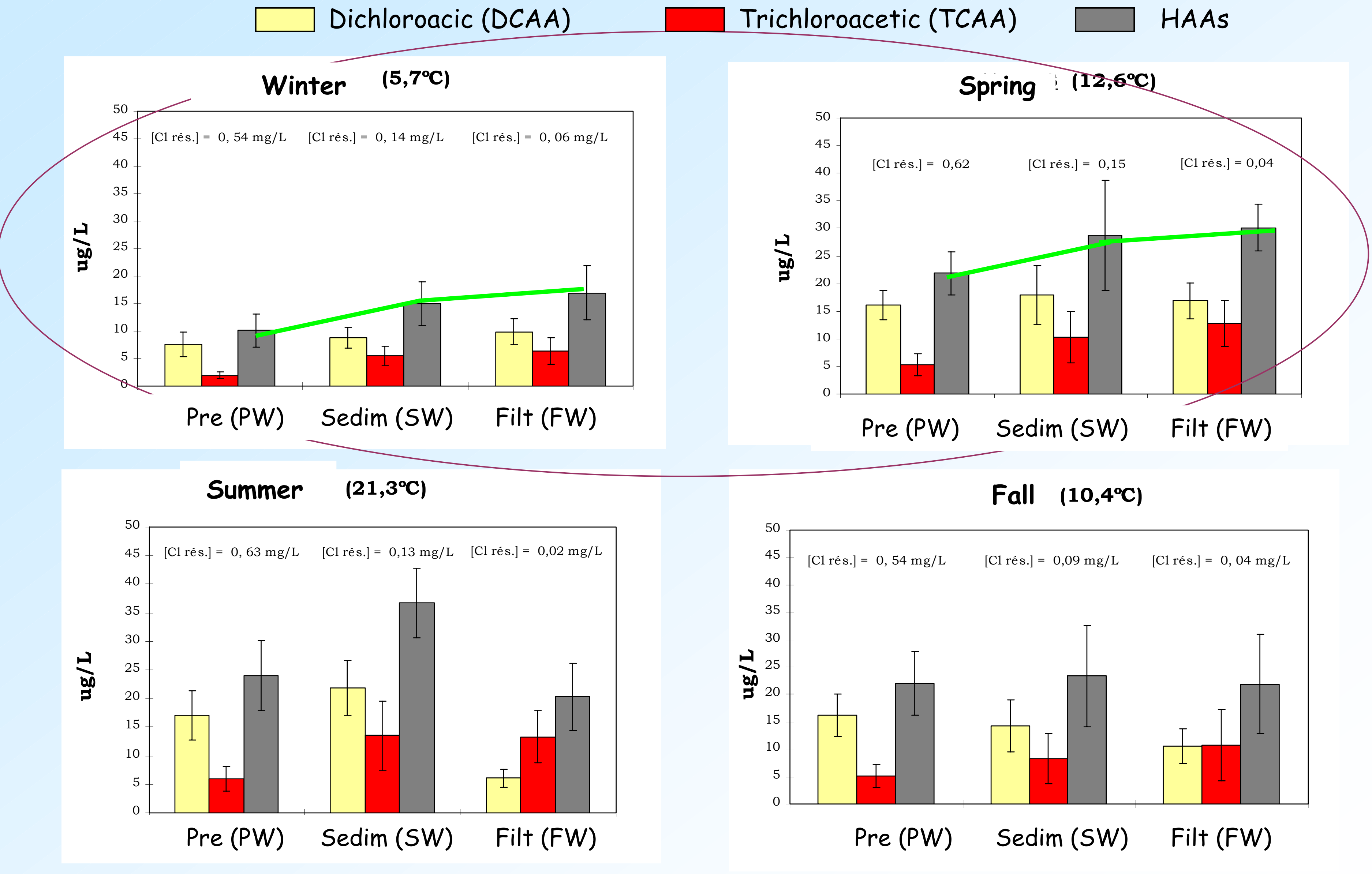






UNIVERSITÉ LAVAL

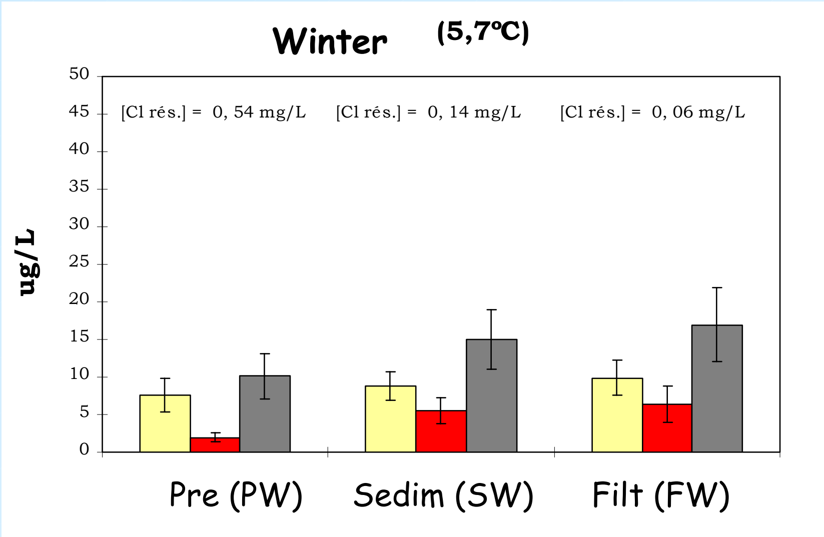
Fluctuations of HAAs within the plant

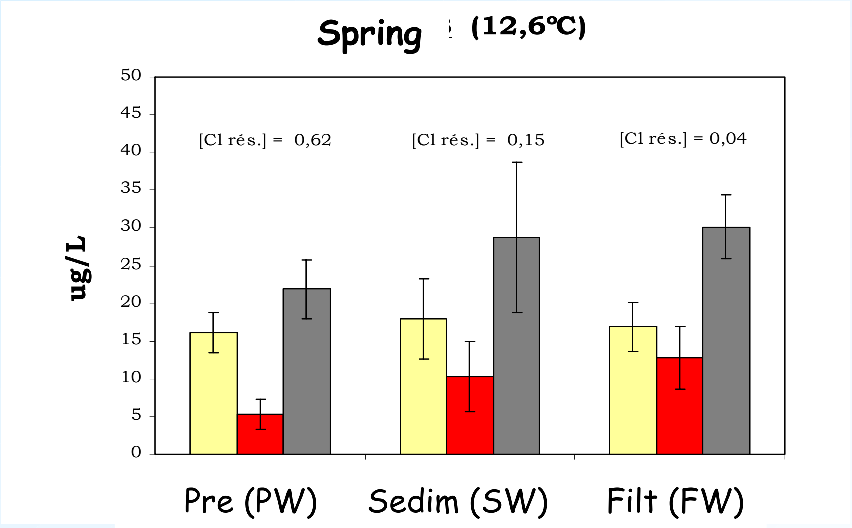


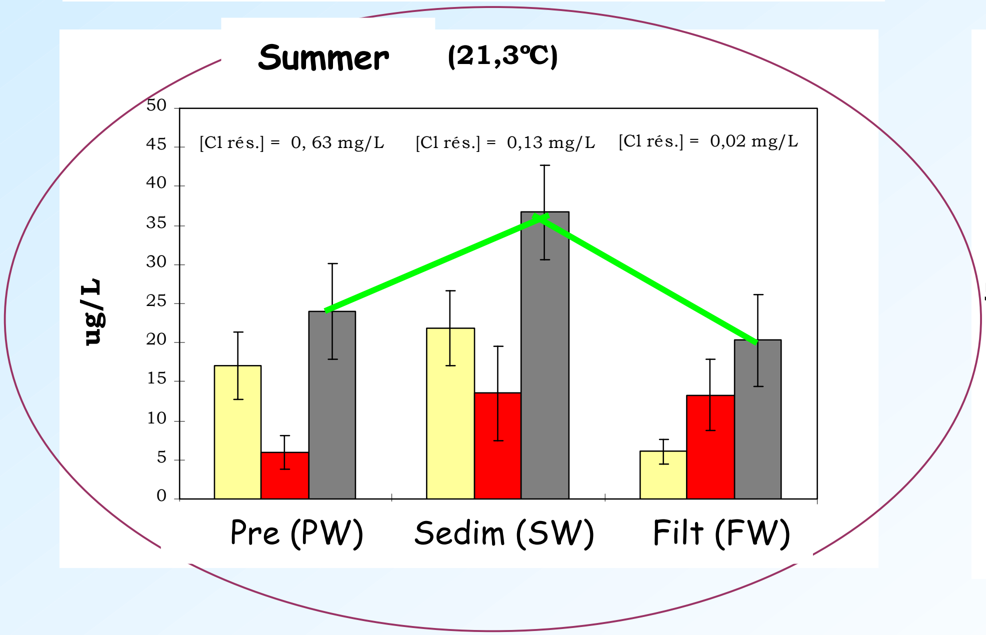
UNIVERSITÉ LAVAL

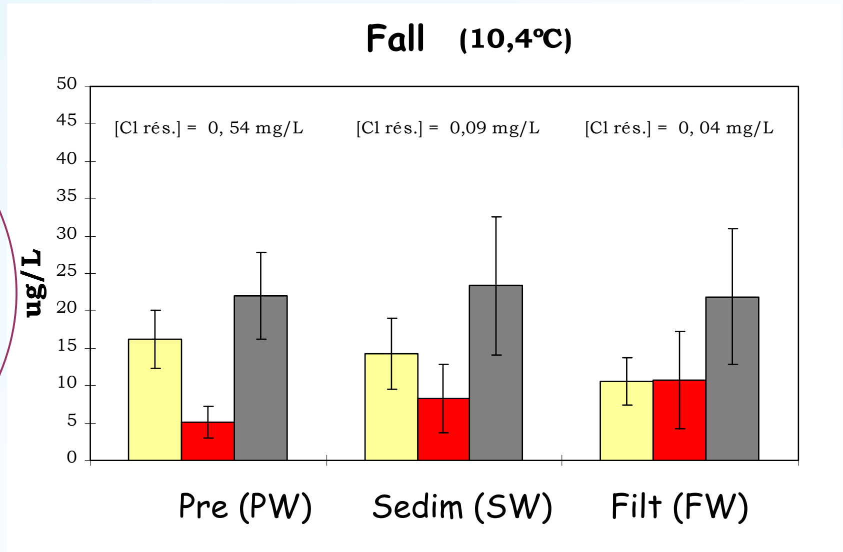
Fluctuations of HAAs within the plant

Dichloroacic (DCAA) | Trichloroacetic (TCAA) | HAAs

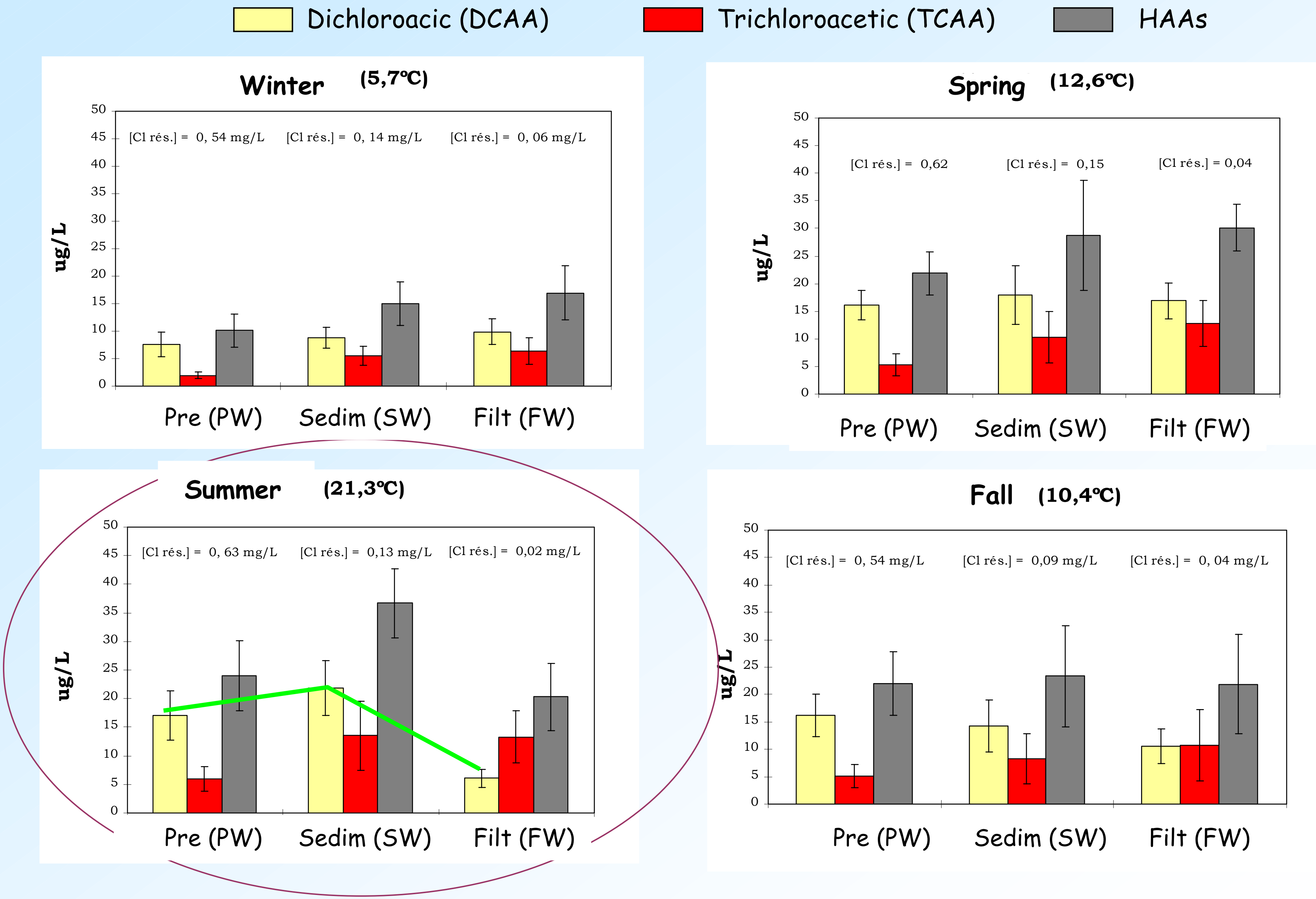






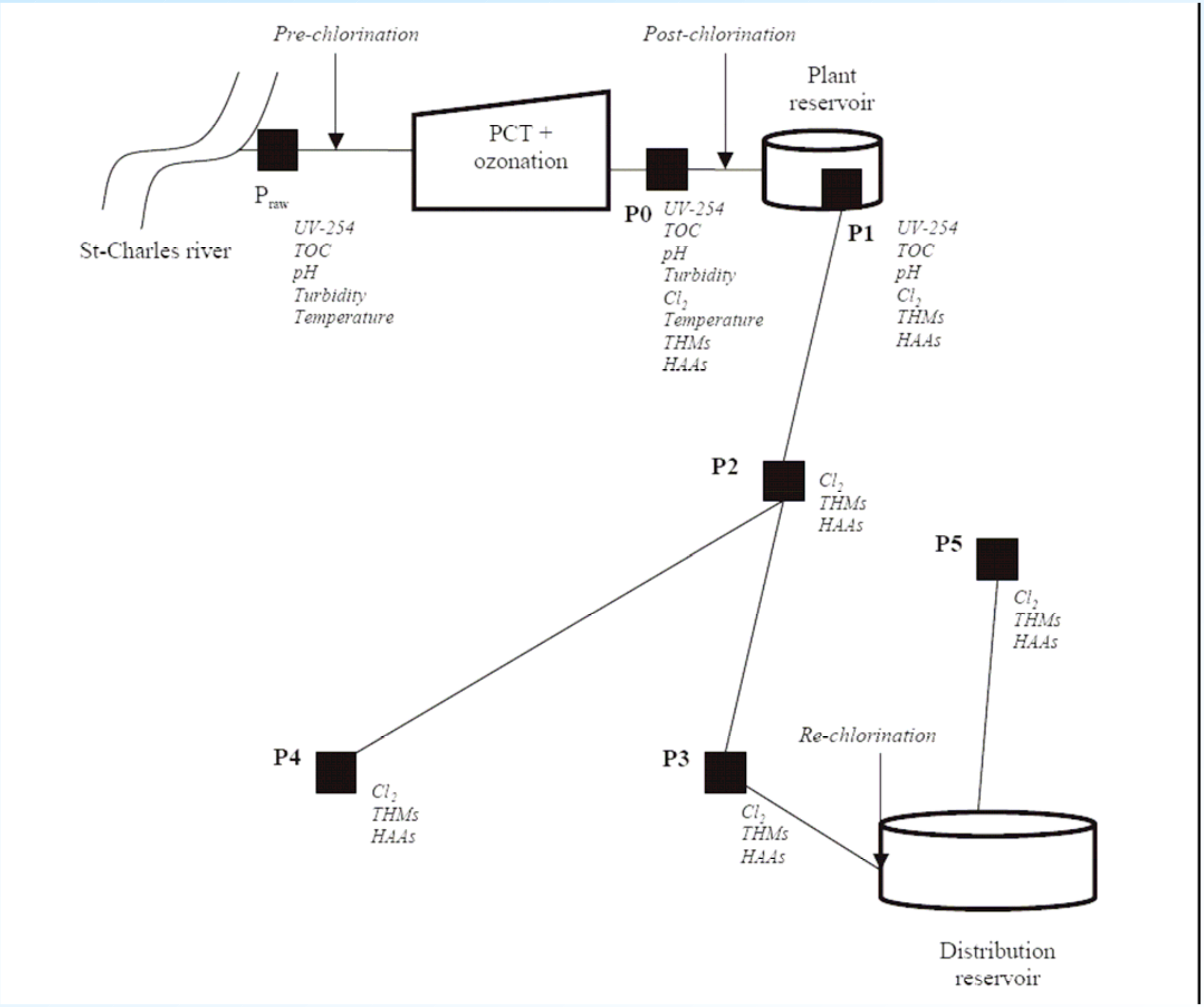


Fluctuations of HAAs within the plant

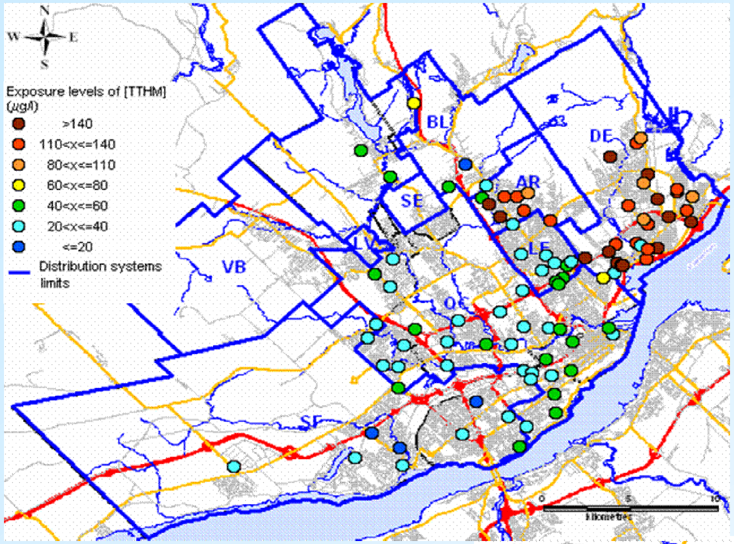


3. Fluctuations in the distribution system

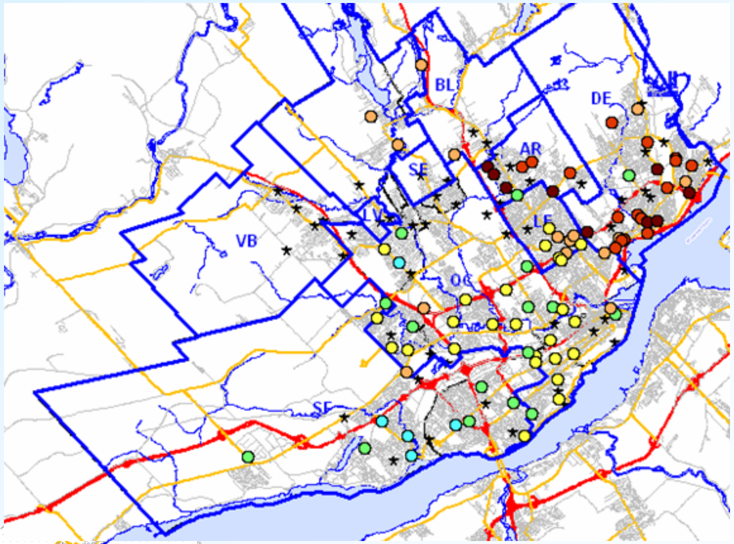
Sampling strategy



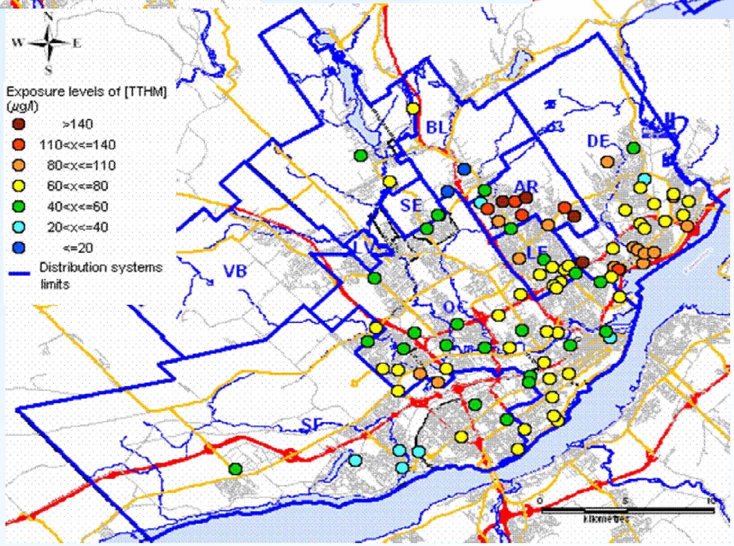
Spatial and temporal variations of THMs *(Quebec City)*



Spring 2005

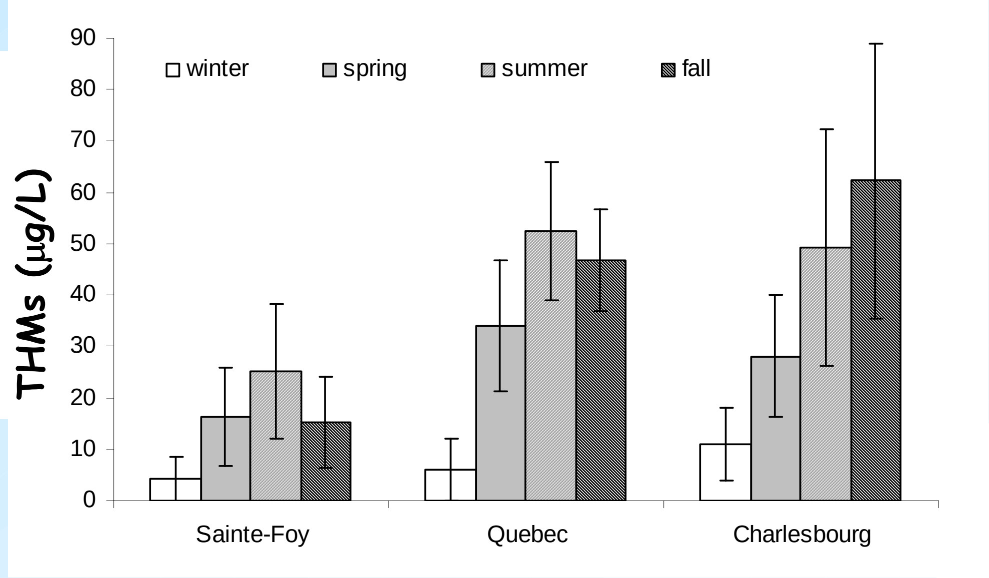


Summer 2005

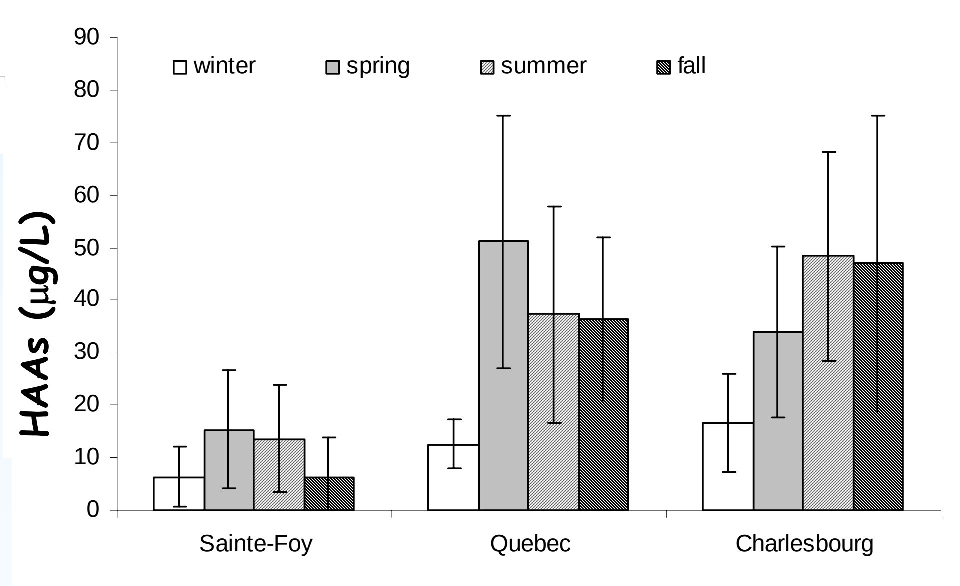


Fall 2005

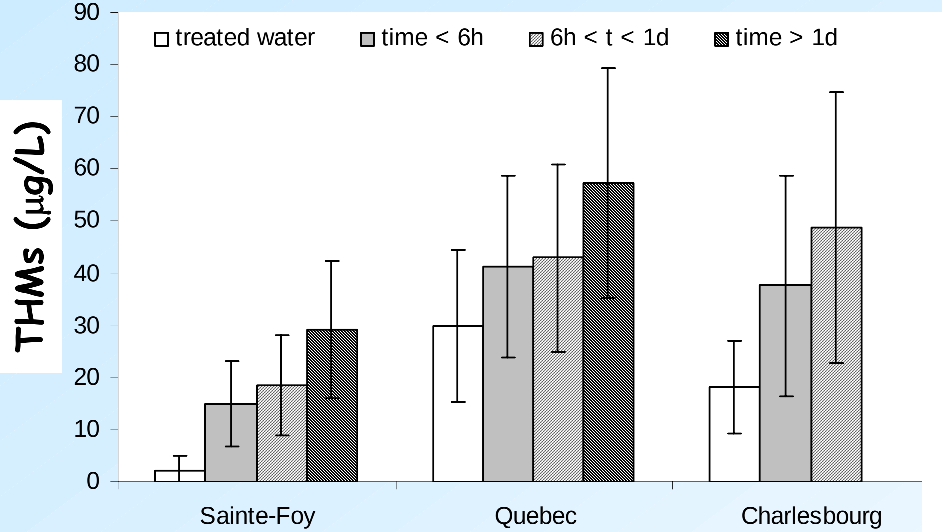
Spatial and temporal fluctuations in the DS



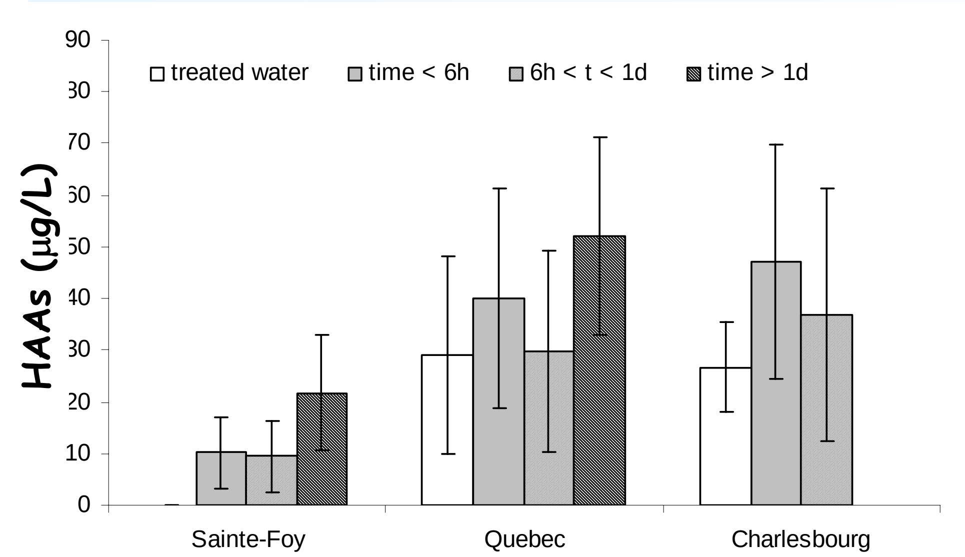
Seasonal variations



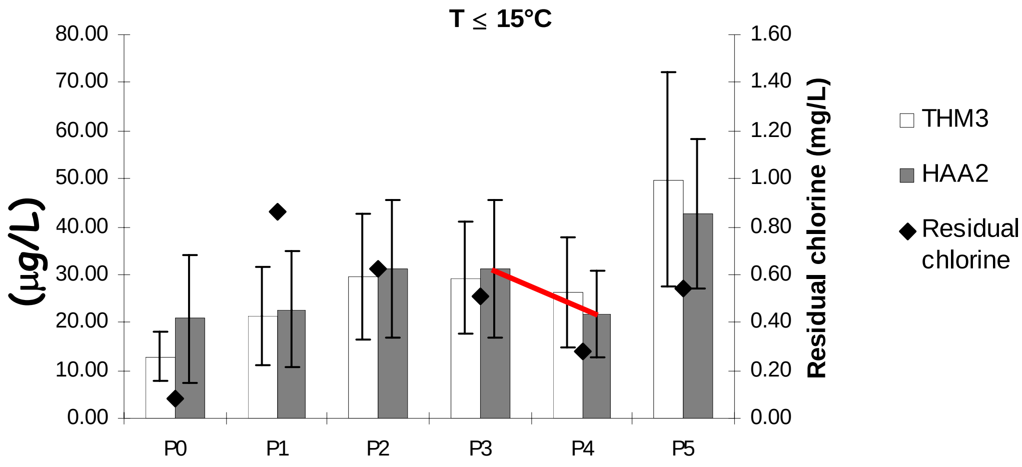
Spatial and temporal fluctuations in the DS



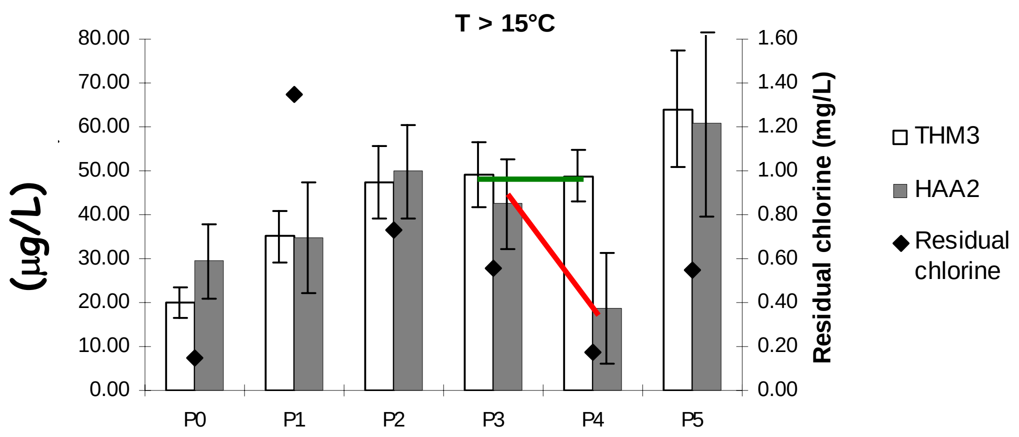
Impact of the residence time



Spatial and temporal fluctuations in the DS



Cold water vs Warm water

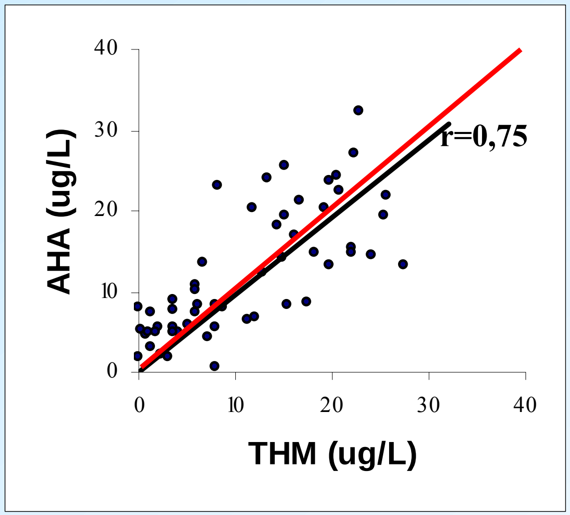


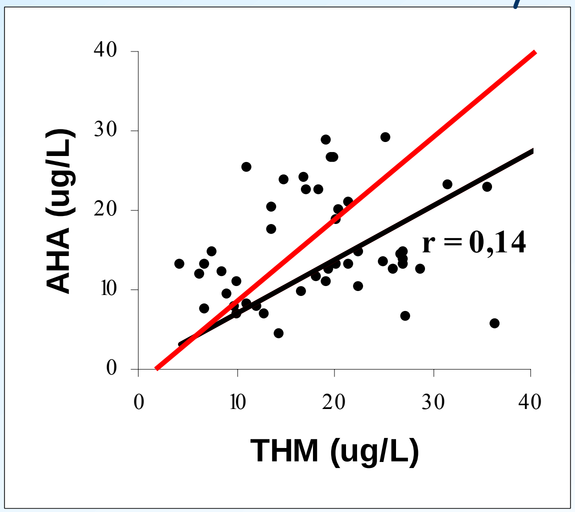
UNIVERSITÉ LAVAL

Preponderance of CBPs according to DS location (Summer)

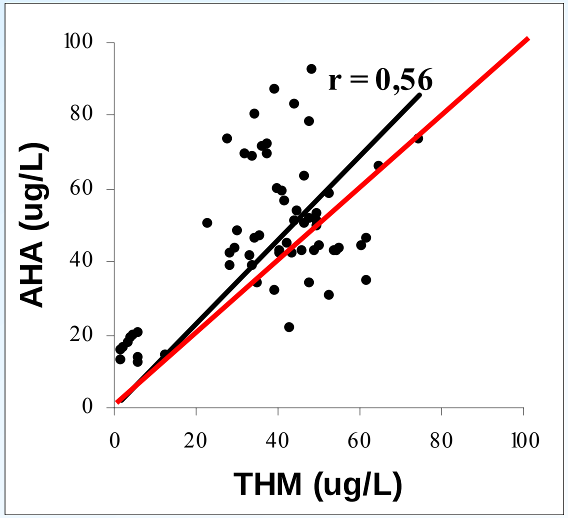
Distribution entrance | Distribution extremity

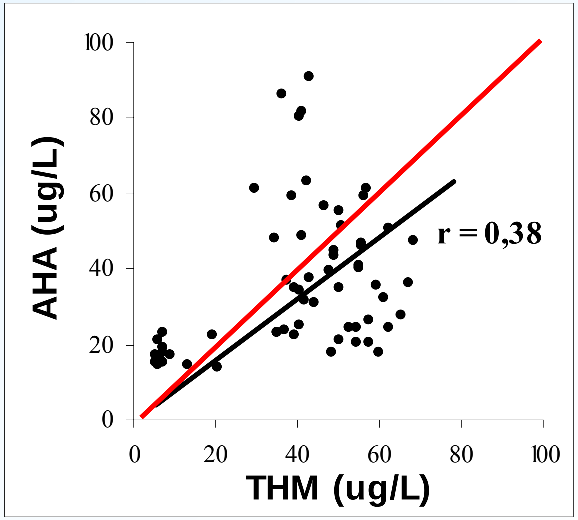
Sainte-Foy





Quebec





UNIVERSITÉ LAVAL

Impact of fluctuations on the regulatory compliance

CDBP	Point	1st First quarter (Fall)		2nd Second quarter (Winter)		3rd Third quarter (Spring)		4rd Fourth quarter (Summer)		Annual average
		Sample	Conc*. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Conc. (µg/L)
THM3	P4	L	35.2	L	5.1	L	29.0	L	37.6	26.7
		H	48.7	H	20.3	H	46.8	H	57.6	43.3
	P5	L	56.4	L	7.1	L	39.7	L	53.5	39.1
		H	64.3	H	24.4	H	42.1	H	101.1	58.0
HAA2	P2	L	37.1	L	9.0	L	56.3	L	34.5	34.2
		H	55.3	H	15.9	H	77.9	H	65.8	53.7
	P4	L	14.7	L	6.3	L	46.1	L	32.3	24.9
		H	19.2	H	11.8	H	51.8	H	37.0	29.9
	P5	L	53.6	L	19.1	L	45.3	L	28.3	36.6
		H	66.3	H	25.5	H	106.8	H	96.4	73.8

Quebec standard on total THMs

« Annual average of four quarterly samples (extremity); Delay of samples at least 2 months »

UNIVERSITÉ LAVAL

Impact of fluctuations on the regulatory compliance

		1st		2nd		3rd		4rd		
CDBP	Point	First quarter (Fall)		Second quarter (Winter)		Third quarter (Spring)		Fourth quarter (Summer)		Annual average
		Sample	Conc*. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Conc. (µg/L)
THM3	P4	L	35.2	L	5.1	L	29.0	L	37.6	26.7
		H	48.7	H	20.3	H	46.8	H	57.6	43.3
	P5	L	56.4	L	7.1	L	39.7	L	53.5	39.1
		H	64.3	H	24.4	H	42.1	H	101.1	58.0
HAA2	P2	L	37.1	L	9.0	L	56.3	L	34.5	34.2
		H	55.3	H	15.9	H	77.9	H	65.8	53.7
	P4	L	14.7	L	6.3	L	46.1	L	32.3	24.9
		H	19.2	H	11.8	H	51.8	H	37.0	29.9
	P5	L	53.6	L	19.1	L	45.3	L	28.3	36.6
		H	66.3	H	25.5	H	106.8	H	96.4	73.8

Quebec standard on total THMs

« Annual average of four quarterly samples (extremity);
Delay of samples at least 2 months »

UNIVERSITÉ LAVAL

Impact of fluctuations on the regulatory compliance

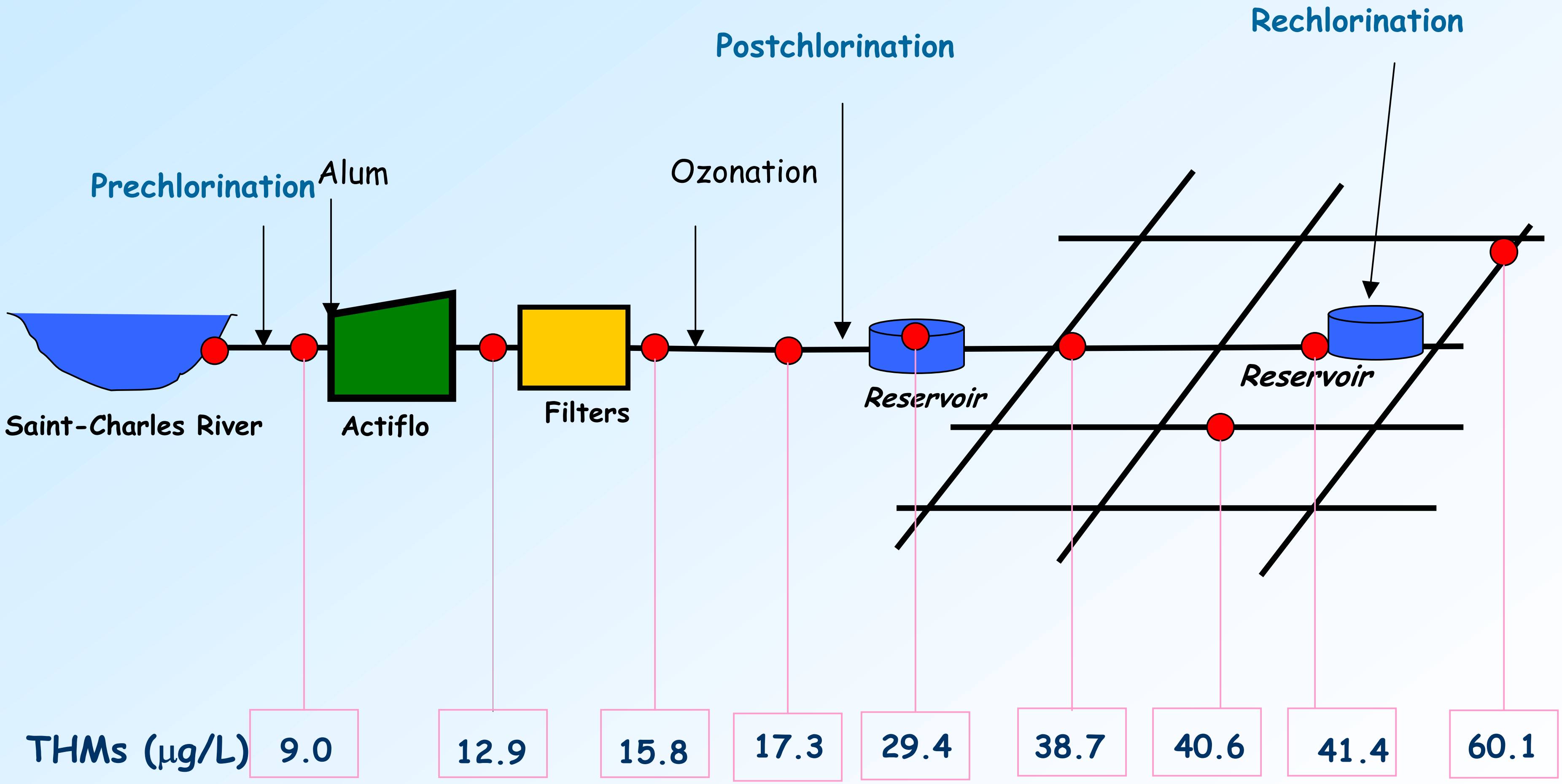
CDBP	Point	First quarter (Fall) 1st		Second quarter (Winter) 2nd		Third quarter (Spring) 3rd		Fourth quarter (Summer) 4rd		Annual average
		Sample	Conc*. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Sample	Conc. (µg/L)	Conc. (µg/L)
THM3	P4	L	35.2	L	5.1	L	29.0	L	37.6	26.7
		H	48.7	H	20.3	H	46.8	H	57.6	43.3
	P5	L	56.4	L	7.1	L	39.7	L	53.5	39.1
		H	64.3	H	24.4	H	42.1	H	101.1	58.0
HAA2	P2	L	37.1	L	9.0	L	56.3	L	34.5	34.2
		H	55.3	H	15.9	H	77.9	H	65.8	53.7
	P4	L	14.7	L	6.3	L	46.1	L	32.3	24.9
		H	19.2	H	11.8	H	51.8	H	37.0	29.9
	P5	L	53.6	L	19.1	L	45.3	L	28.3	36.6
		H	66.3	H	25.5	H	106.8	H	96.4	73.8

Quebec standard on total THMs

« Annual average of four quarterly samples (extremity);
Delay of samples at least 2 months »

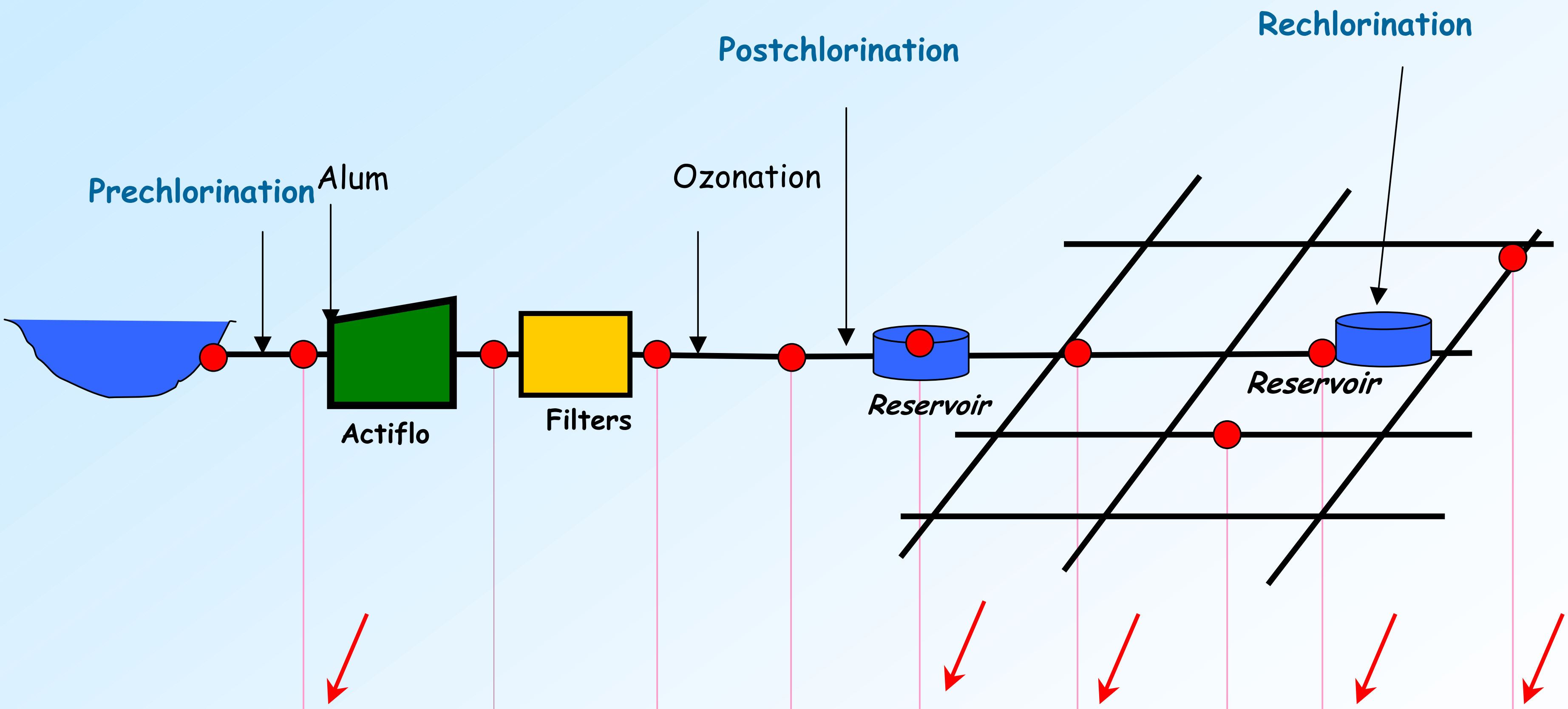
UNIVERSITÉ LAVAL

Summary of spatial fluctuations



UNIVERSITÉ LAVAL

Summary of spatial fluctuations



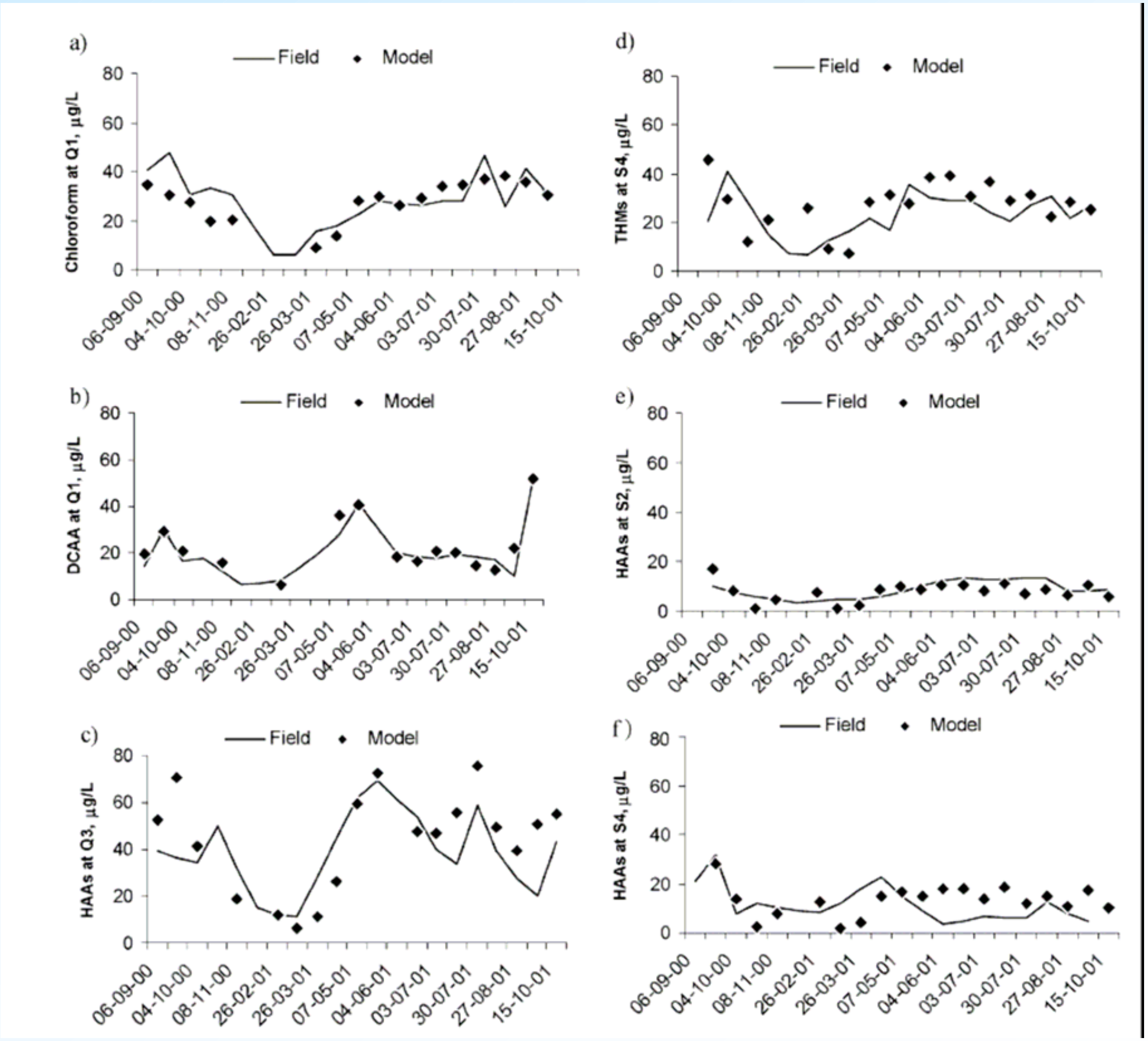
THMs (µg/L)	9.0	12.9	15.8	17.3	29.4	38.7	40.6	41.4	60.1
HAAs (µg/L)	19.3	27.1	22.1	25.4	28.4	39.9	35.4	20.4	58.2

Modelling THMs and HAAs in DS

Chloroform

DCAA

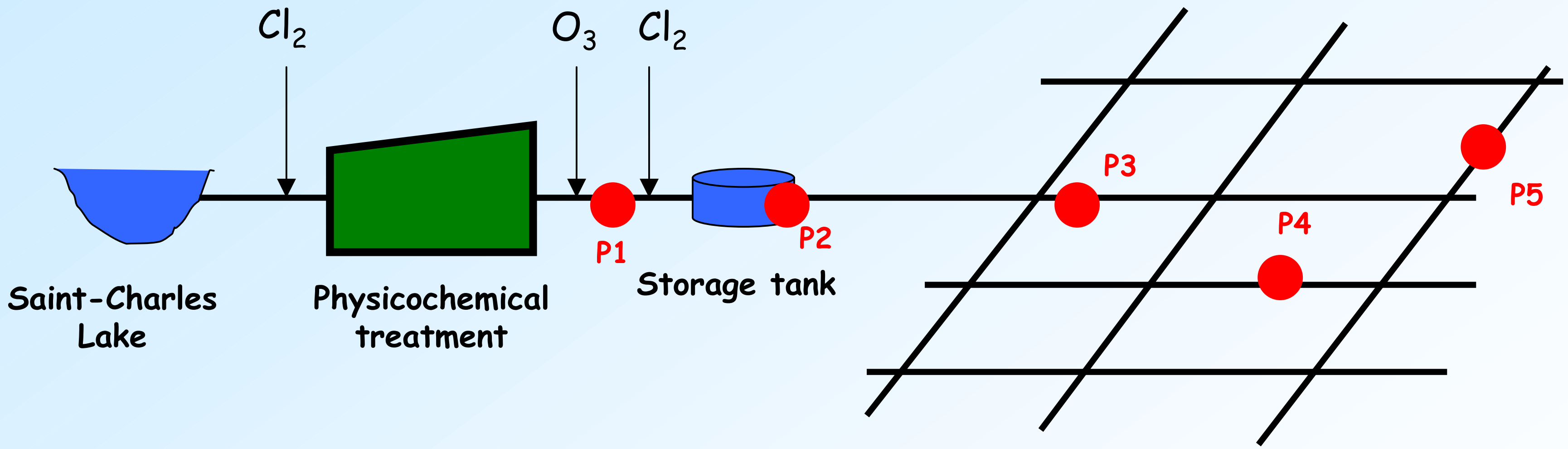
HAA



4. Short term fluctuations

UNIVERSITÉ LAVAL

Short term variations of THMs

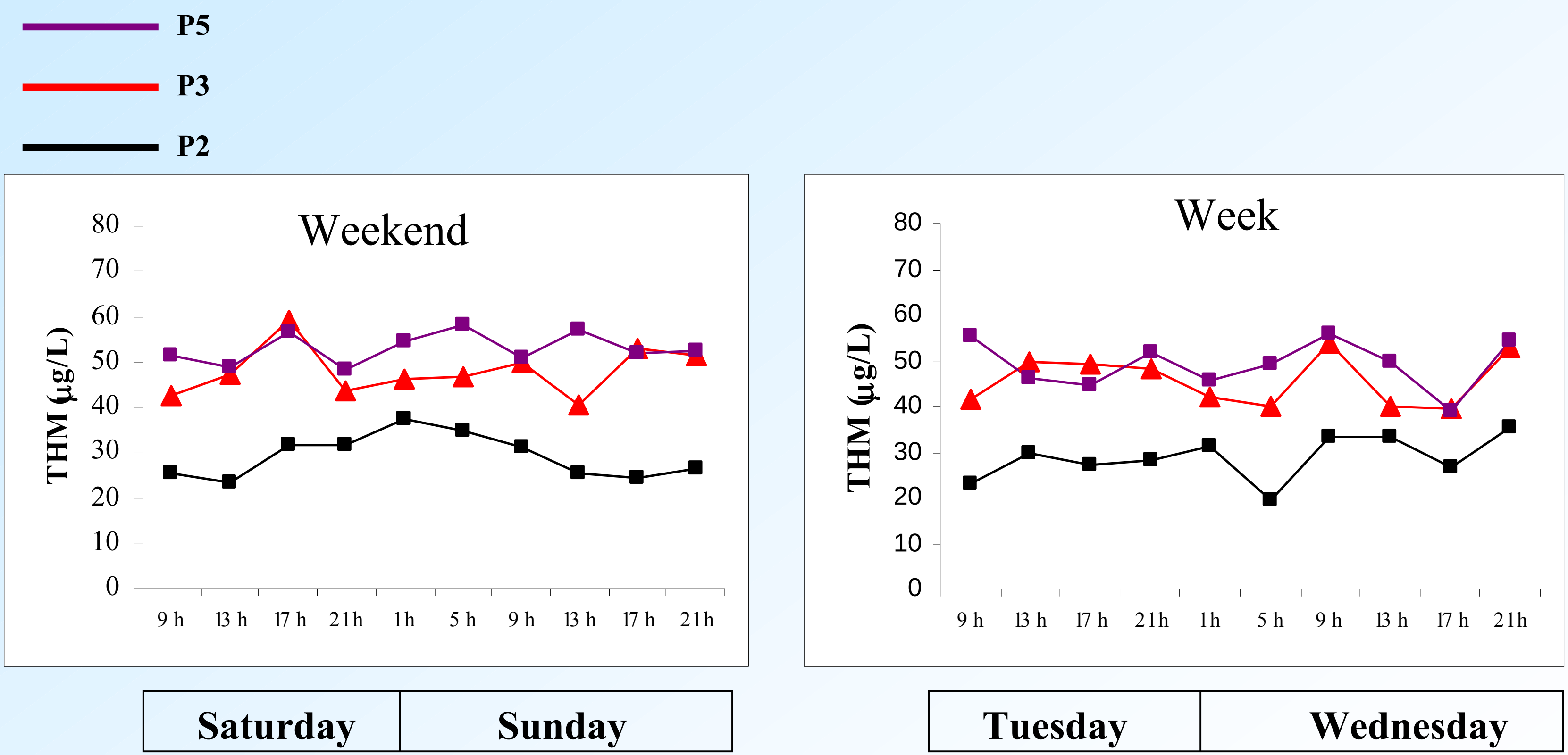


Water residence time

P2 ≈ 1 h
P3 ≈ 5 h
P4 ≈ 8 h
P5 ≈ 18 h

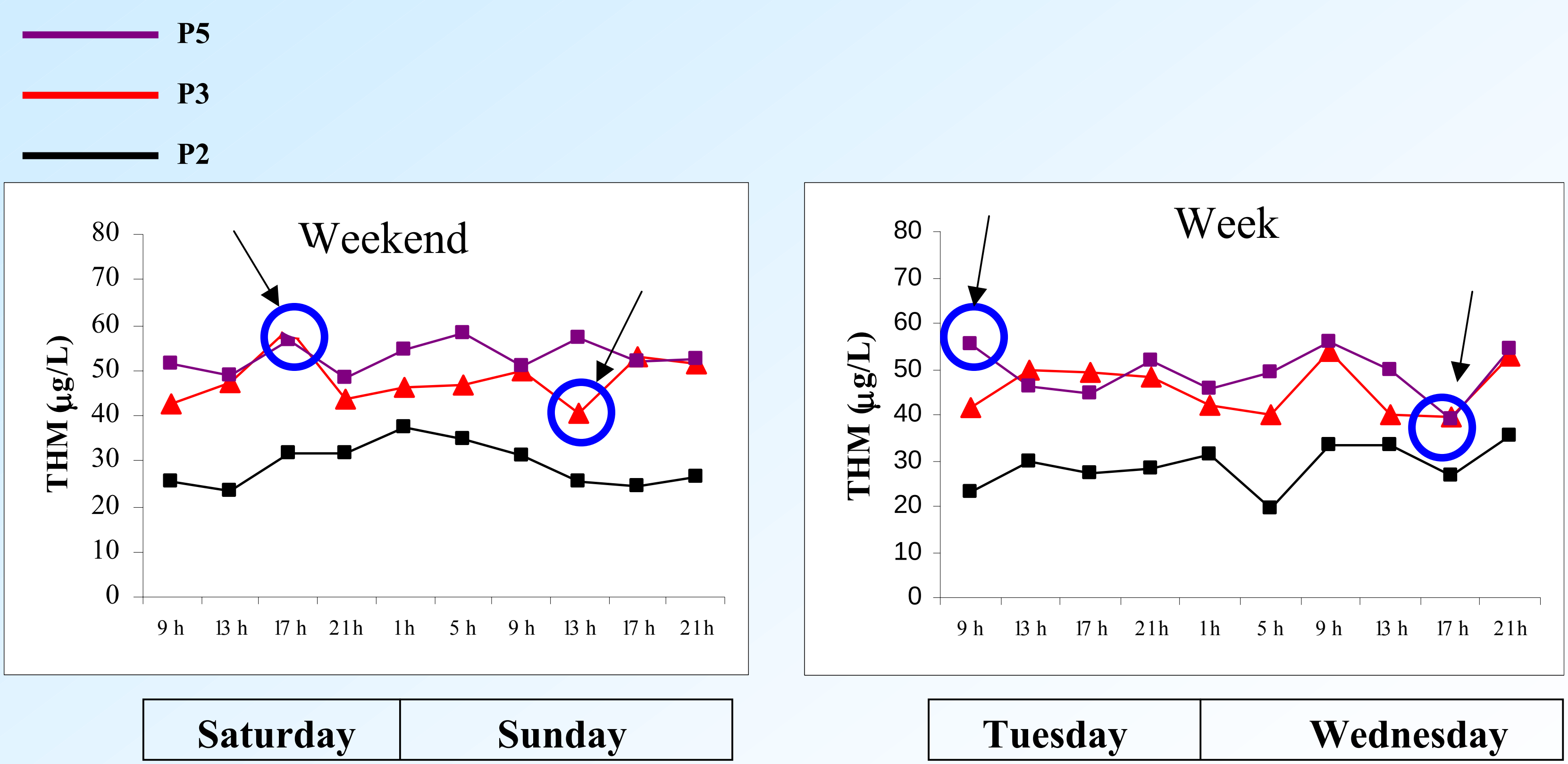
- 5 intensive sampling programs (7 days)
- sampling frequency of 4 hours

Hourly and spatial variations of THMs in 3 selected points of Quebec City distribution system

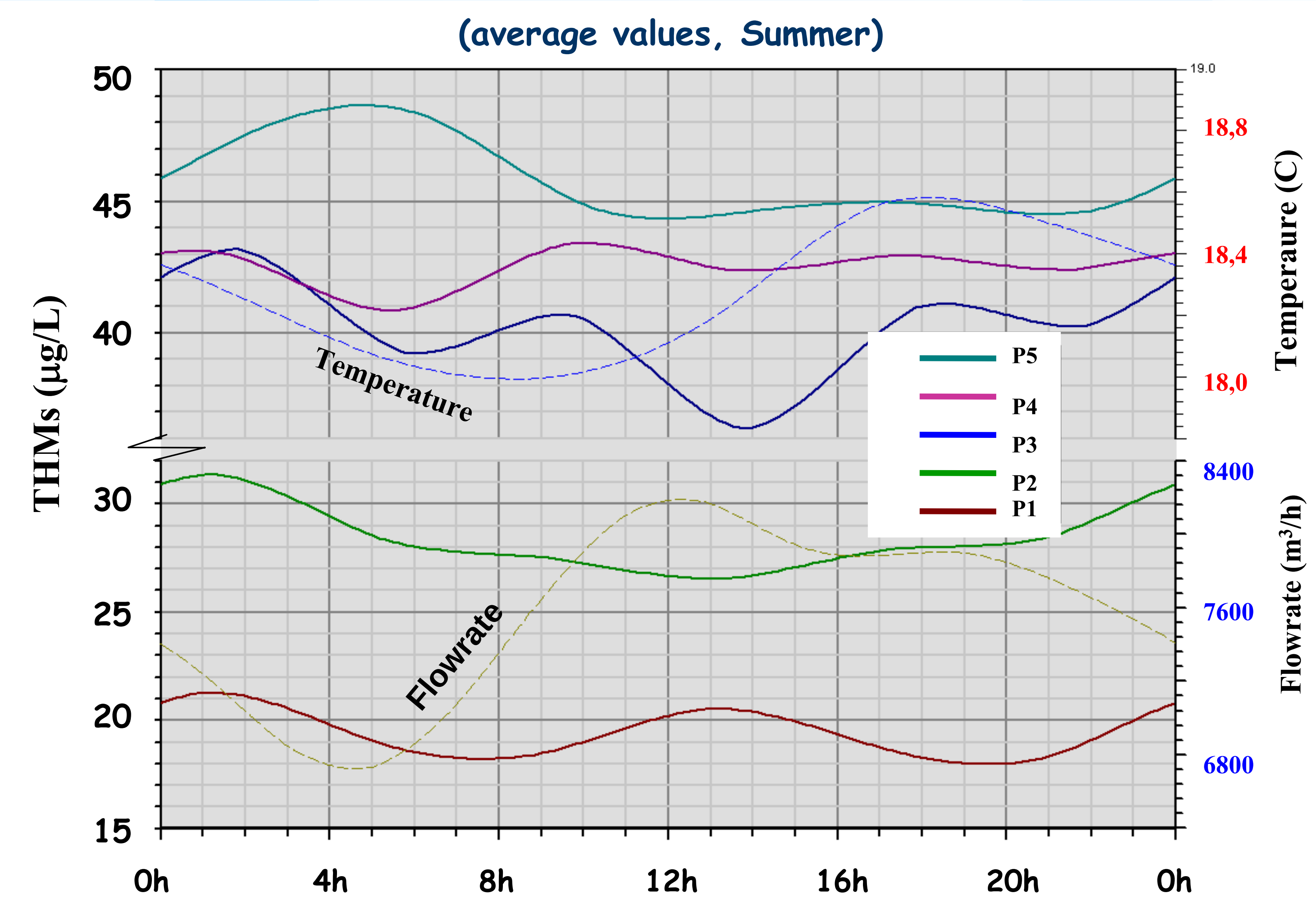


UNIVERSITÉ LAVAL

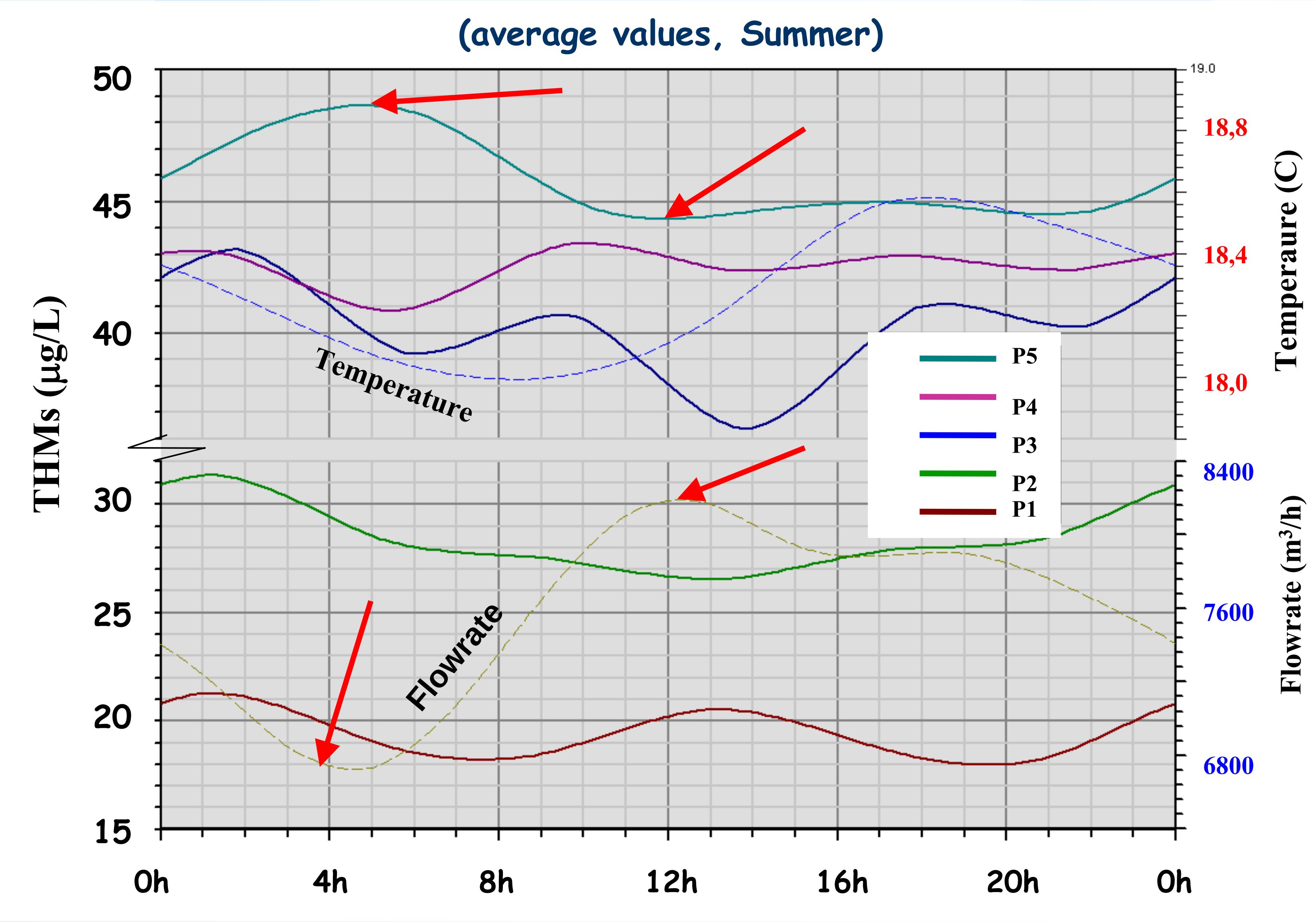
Hourly and spatial variations of THMs in 3 selected points of Quebec distribution system



Hourly et spatial variations of THMs in Quebec distribution system



Hourly et spatial variations of THMs in Quebec distribution system

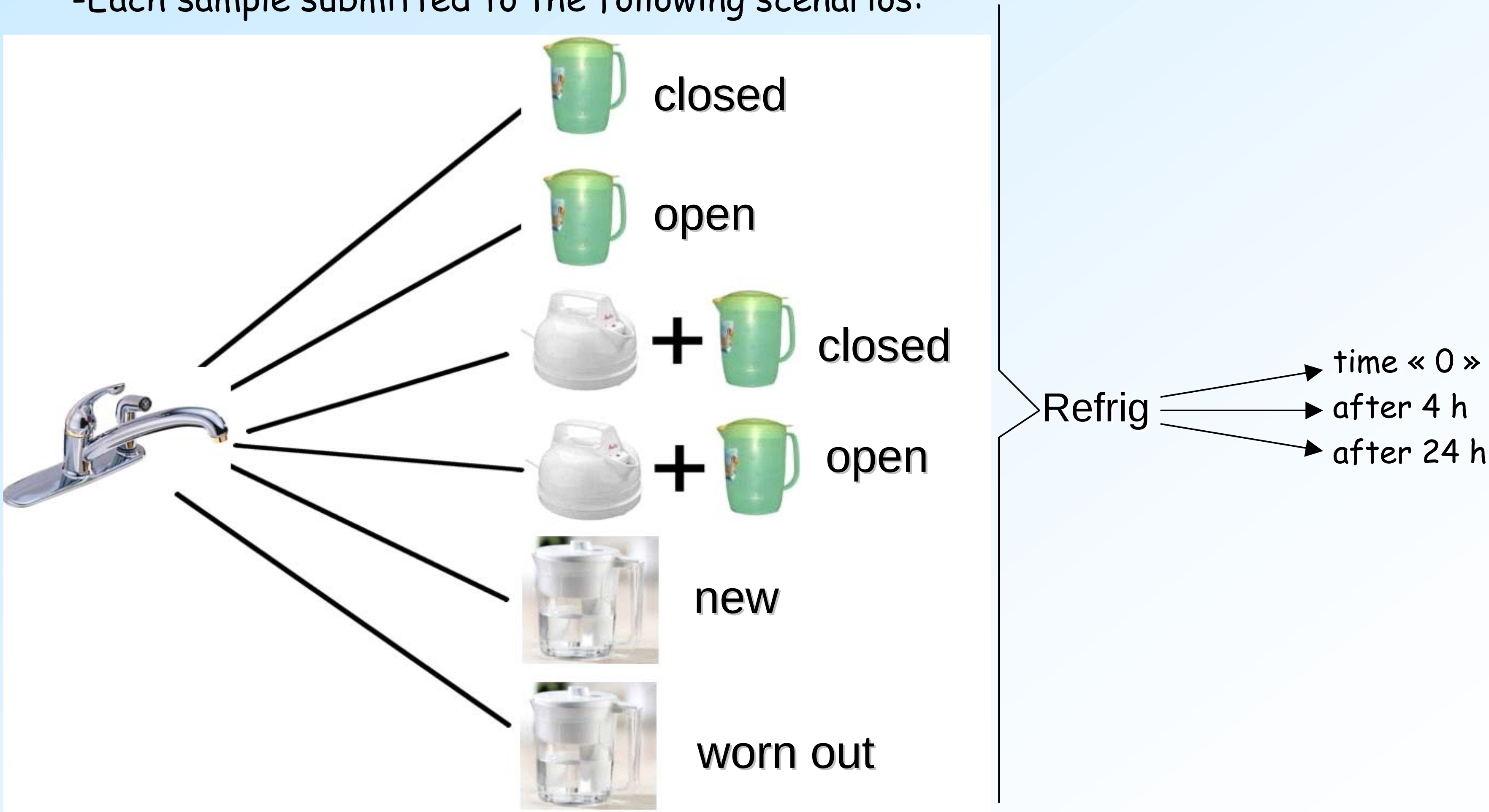


5. Indoor exposure to chlorinated DBPs

UNIVERSITÉ LAVAL

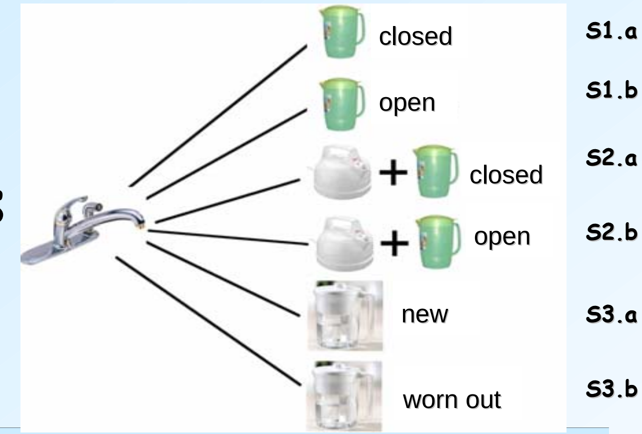
Indoor exposure to chlorinated DBPs

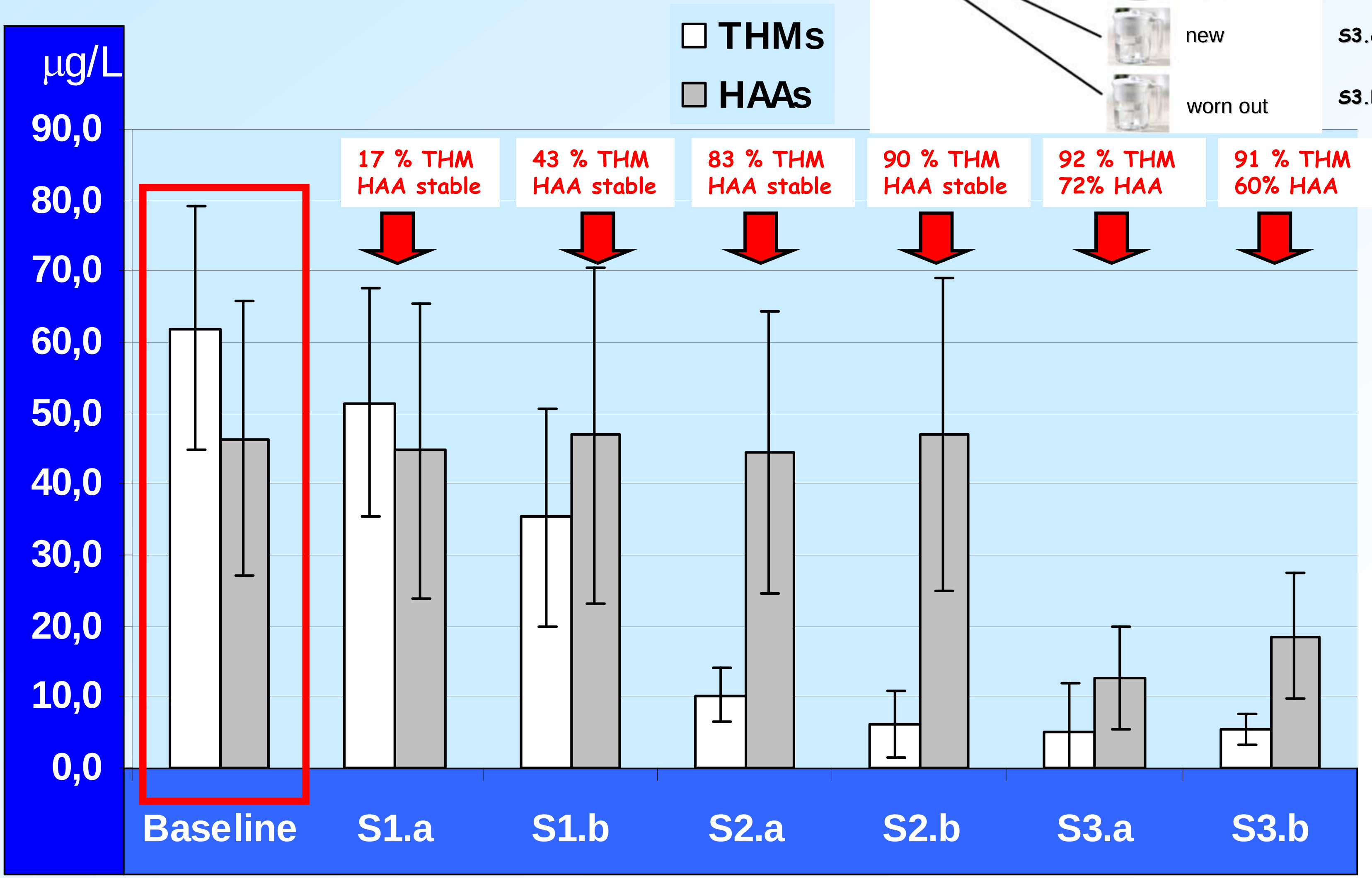
-Samples taken at three points of the distribution system
-Five samples per point (taken from June to August)
-Each sample submitted to the following scenarios:



UNIVERSITÉ LAVAL

Indoor exposure to chlorinated DBPs

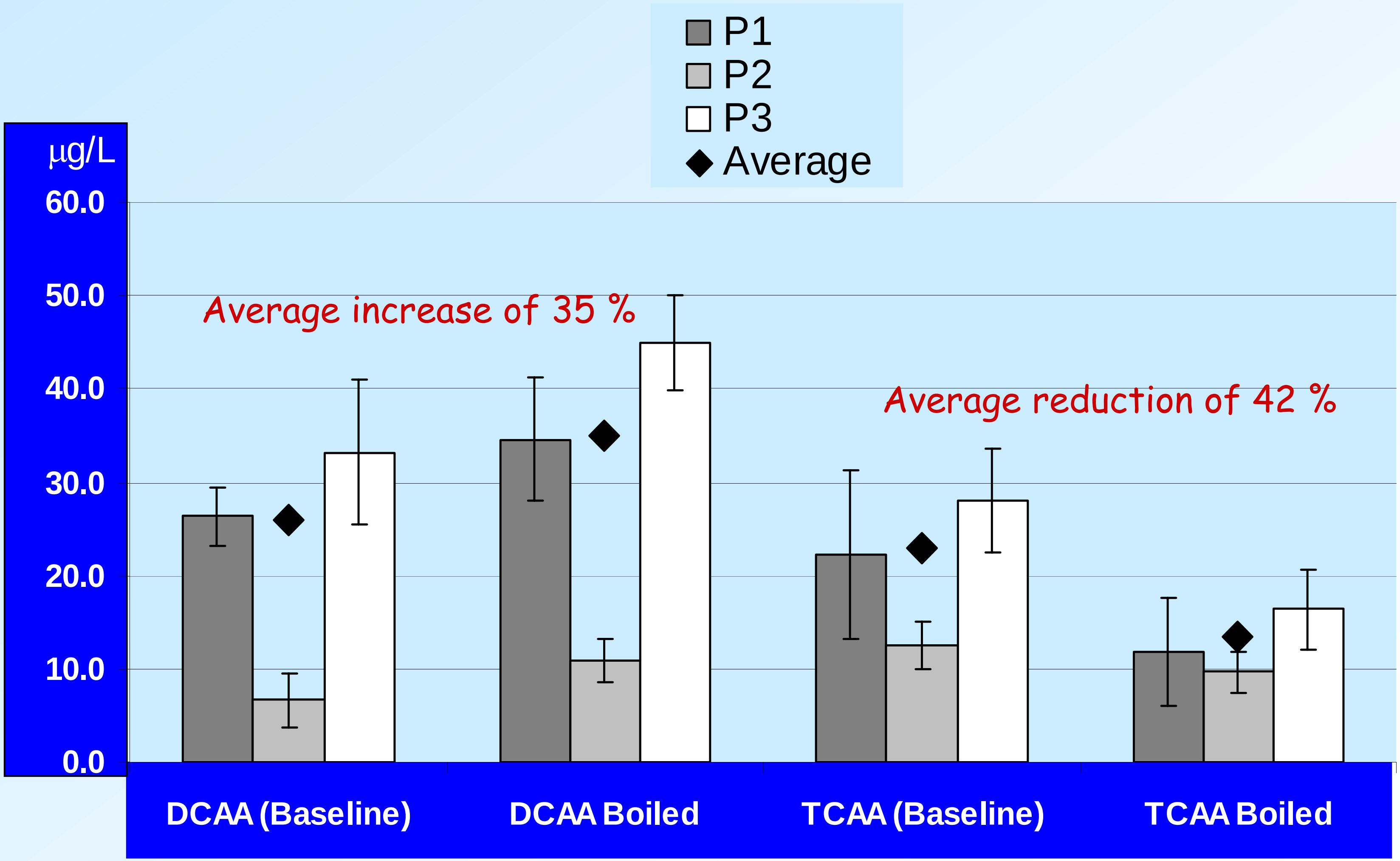




UNIVERSITÉ LAVAL

Indoor exposure to chlorinated DBPs

Effect of boiling on HAAs



UNIVERSITÉ LAVAL

CWN project: DBP vs Pathogens in small systems

METHODOLOGY

Small systems between 300 and 3000 people, focus only in surface source water: Project with three phases

PHASE 1

- Development of a robust retrospective DBP and pathogen occurrence database for small water systems in Canada
- Conduction of a survey of Canadian small municipal systems to collect information on practices, in particular those related to DBP occurrence and microbial occurrence and inactivation

UNIVERSITÉ LAVAL

CWN project: DBP vs Pathogens in small systems

PHASE 2

- One-year field-scale study for the occurrence of DBPs (from source-to-tap) and pathogens/indicators (source) on a spatio-temporal basis in representative systems of 4 or 5 Canadian Provinces (approx.8-10 per province)
- Field-scale survey/visit with the utility manager and observations of the system operations
- Development of a model that associates the occurrence of the various DBPs with the water quality and operational characteristics, and watershed features

UNIVERSITÉ LAVAL

CWN project: DBP vs Pathogens in small systems

PHASE 3

- Controlled-condition experiments to evaluate the impact on primary and/or secondary disinfection changes on DBP levels: representative systems (5-10) in which balancing of DBPs and microbial risks appeared difficult according to empirical data and modelling results

- Identification of cost-effective strategies to efficiently minimize DBP levels without compromising microbial inactivation

UNIVERSITÉ LAVAL

THANK YOU

CONTACTS:

www.crad.ulaval.ca/grepul

manuel.rodriguez@esad.ulaval.ca

grepul@crad.ulaval.ca