Hydraulic calibration of wastewater treatment plants as a key tool for the evaluation and comparison of the removal efficiencies of contaminants of emerging concern

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Controlling Contaminants of Concern

McGill

Contents

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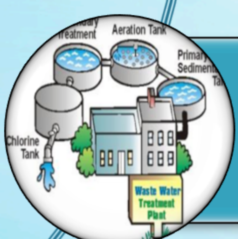
Background

Several contaminants of emerging concern (CECs) are detected in surface water

These contaminants are discharged to the environment from wastewater treatment plants (WWTPs)



It is essential to understand the removal of CECs during wastewater

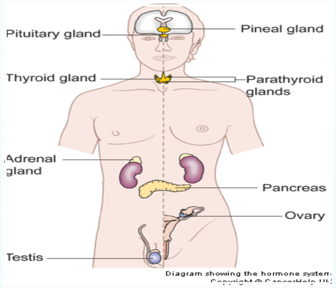
Contaminants of Emerging Concern (CECs)

Persistent organic pollutants

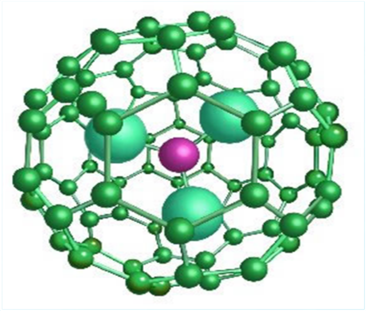
Pharmaceuticals and illicit drugs

Personal Care products

Veterinary medicines



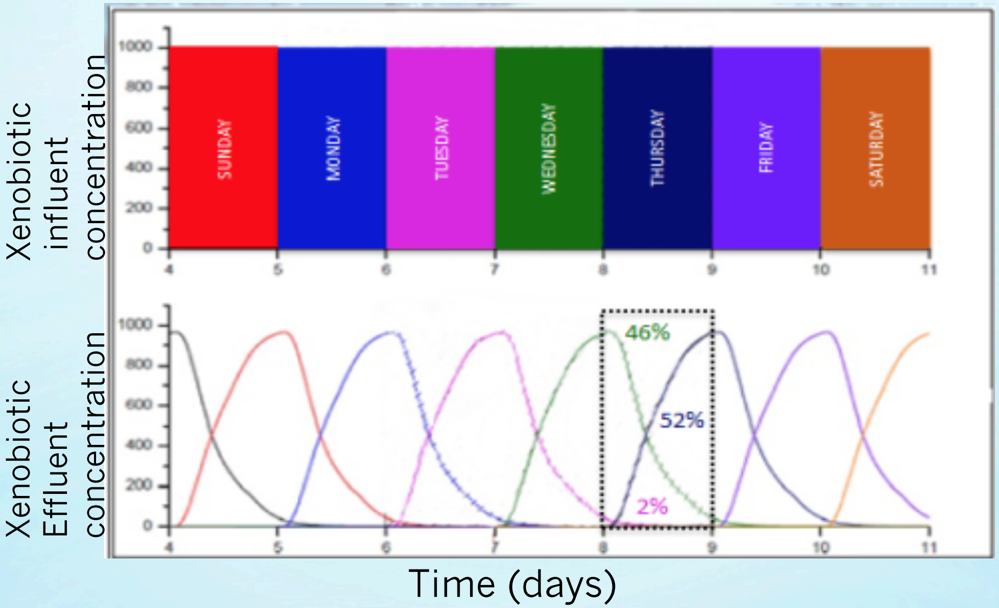
Endocrine disrupting compounds (EDCs)



Nanomaterials

Problem statement

- **The conventional way to determine removal of CECs compares influent and effluent loads on the same day**
  - **→ might lead to unreliable and even negative removals due to mismatch of loads**
- **The effluent on a certain day contains influent load from several past day due to residence time distribution (RTD)**



Calculation of removal efficiency

✧ Conventional approach

$$E = \frac{L_{inf} - L_{eff}}{L_{eff}} \; x \, 100 \; \%$$

✧ Proposed approach taking RTD into consideration

$$E = \frac{L_{ref} - L_{eff}}{L_{eff}} \; x \, 100 \; \%$$

Leff : Output measured load on one day

E : *R*emoval efficiency

$$L_{ref} = \sum_{i=1}^{n} f_n L_n$$

Lref: The output load considering the RTD and without any removal

fn: Load fraction of each day

Ln: Measured load from each day

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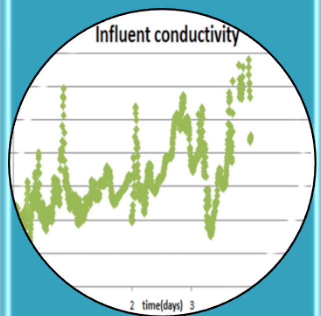
Objectives

- Use hydraulic calibrations for selected WWTPs to understand the differences in the hydraulic behavior and its impact on the calculation of CECs removals

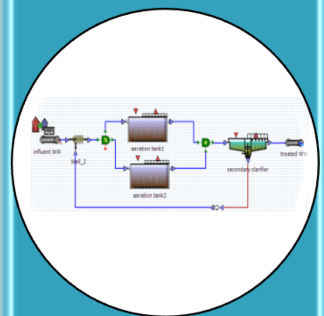
Ville de Granby Québec	• Population of 54,000 • Treats around 50,260 m^3/day
City of Peterborough Ontario	• Population of 78,700 • Treats around 43,000 m^3/day
City of Guelph Ontario	• Population of 120,000 • Treats around 60,000 m^3/day

Methodology

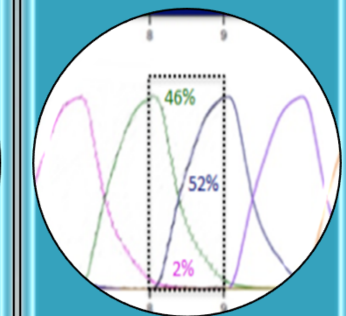
Deploy electroconductivity (EC) probes and collect composite samples around the activated sludge unit of the 3 WWTPs



Use EC as a tracer as a indicator of the residence time distribution



Model the aeration tank as different number and arrangement of aeration tanks using WEST software

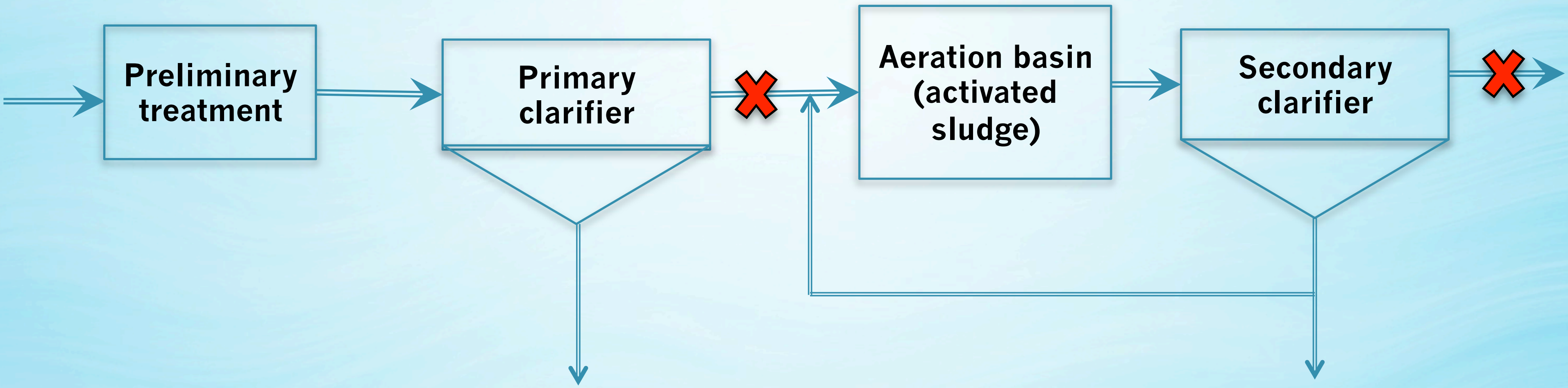


Use the model to find effluent load fractions from past days

Use load fractions and chemical analysis (LC-MS/MS) to find the removal of CECs by activated sludge unit

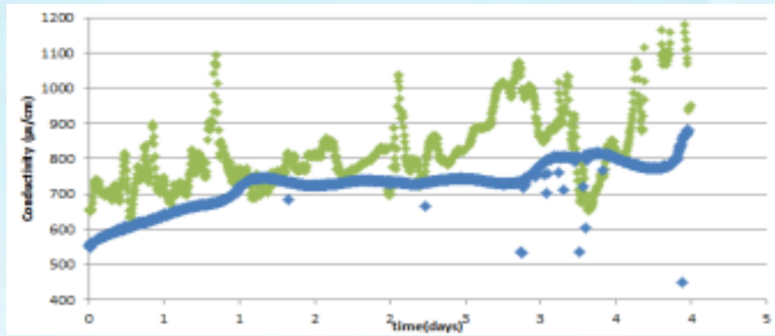
Electroconductivity as a tracer

- It is not practical to inject an inert in the water of multiple WWTPs to model their RTD
- Conductivity changes between influent and effluent of activated sludge unit, or other units, is then used to trace the hydraulic behavior

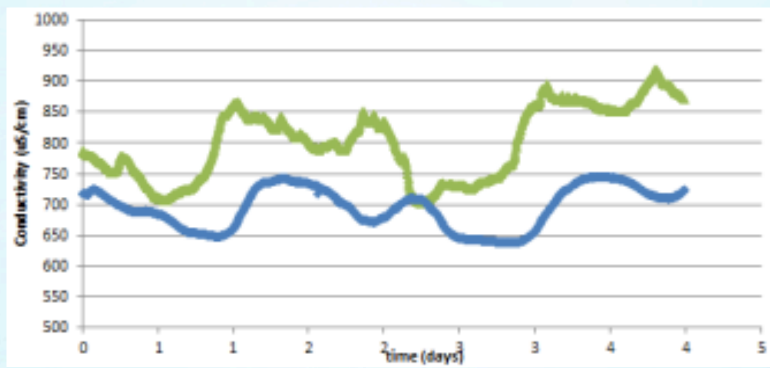


Collected conductivity trends

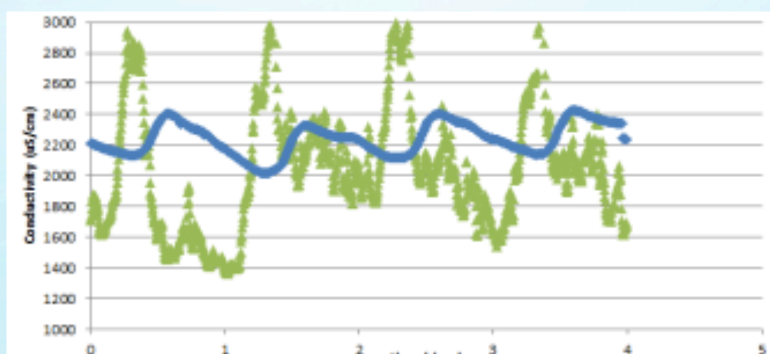
- **Granby**

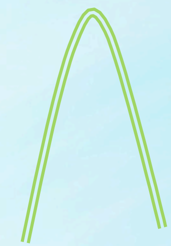


- **Peterborough**



- **Guelph**





Influent
Sharp signal

Effluent distributed and shifted response

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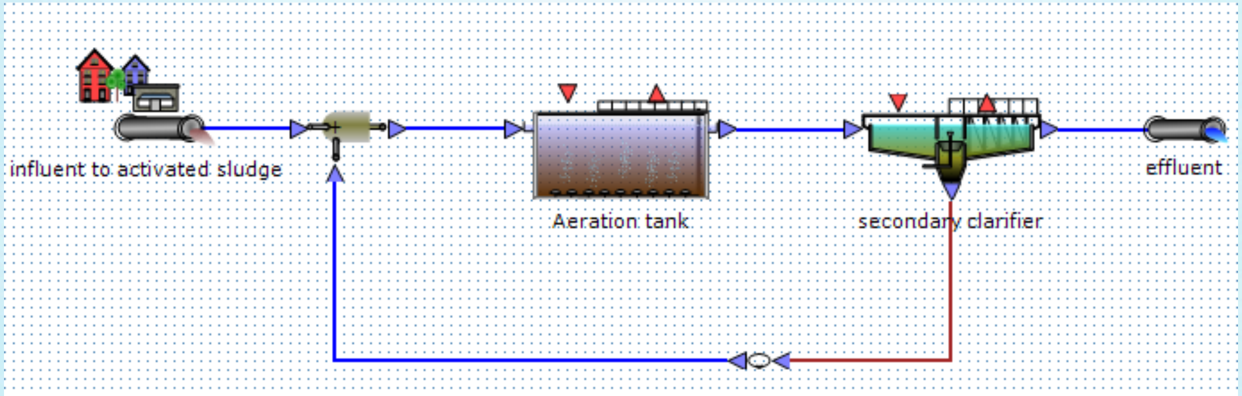
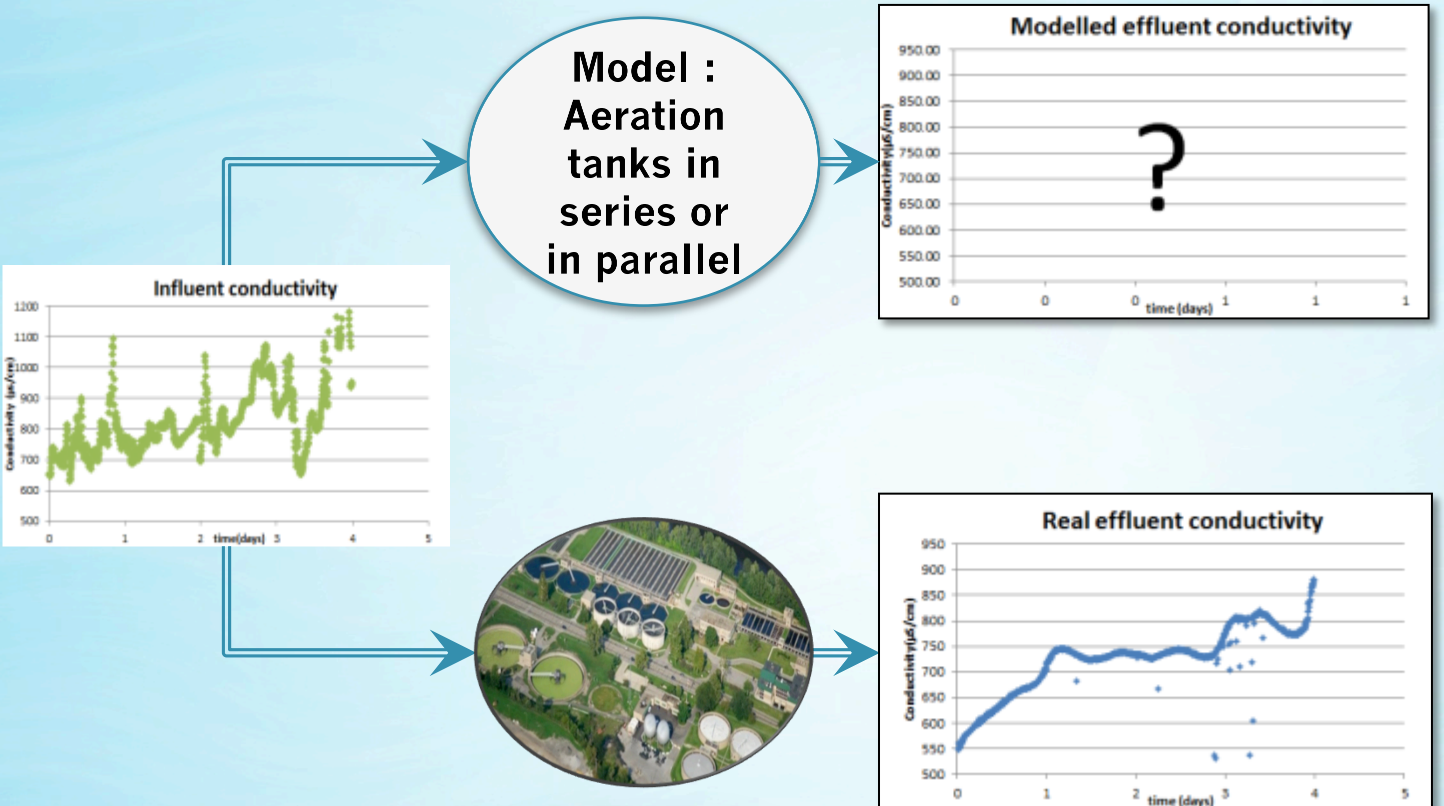
Modelling using WEST

- Real influent data are inputted to the model
- The base case consists of one aeration tank and one secondary clarifier, both with the same actual total volume



- Aeration tanks are added in series or parallel, to create various RTD models but the total volume of aeration tanks is kept the same
- Dynamic simulation is carried out on 4 days (same as EC probes deployment period)

Choose the best RTD model



Chi-square test: minimize

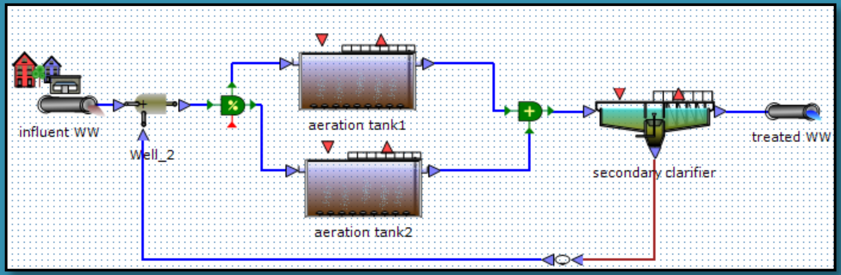
$$X^2 = \sum \frac{(modelled - real)^2}{modelled}$$

- **The different models tested represent different residence time distribution (RTD) patterns**

Results for the best models

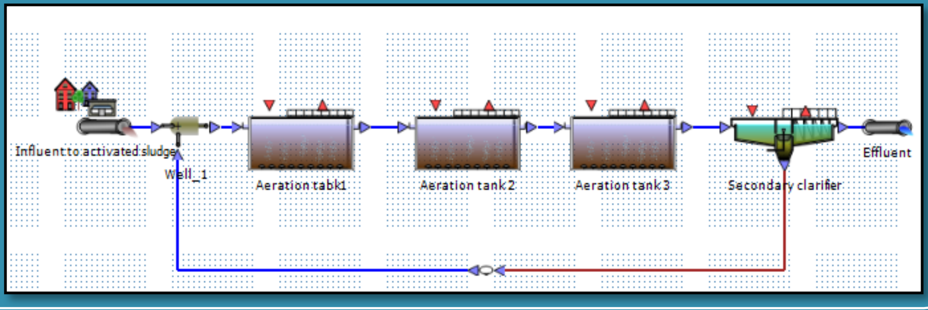
Granby

- Two aeration tanks in parallel



Guelph

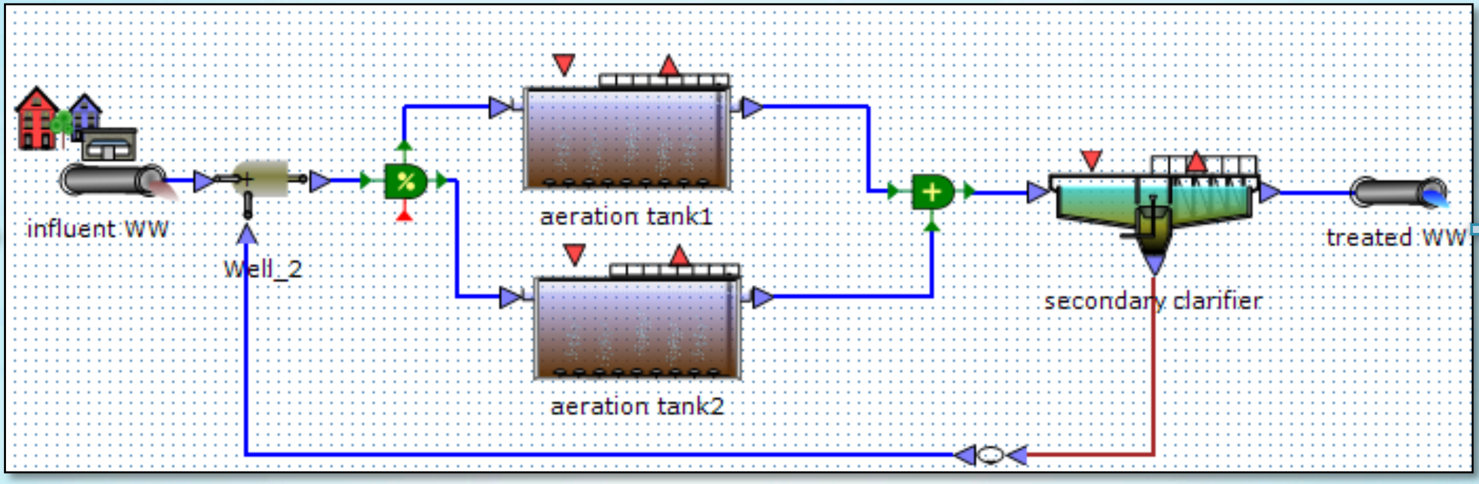
- Three aeration tanks in series

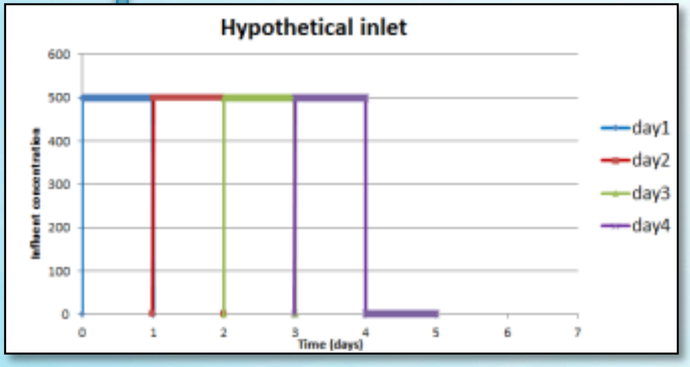


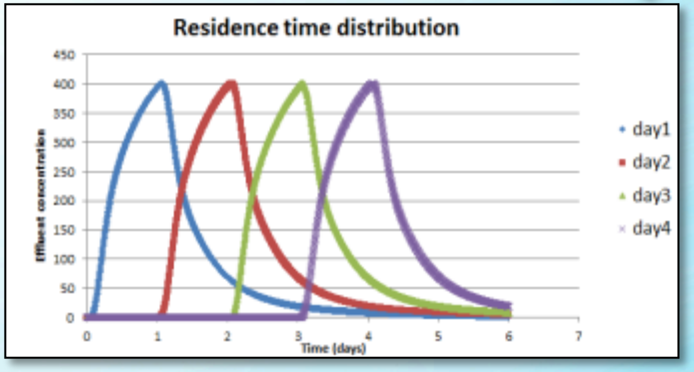
Peterborough

- Infinite aeration tanks in series or PFR because effluent is only time shift of influent

Obtaining load fractions – Granby







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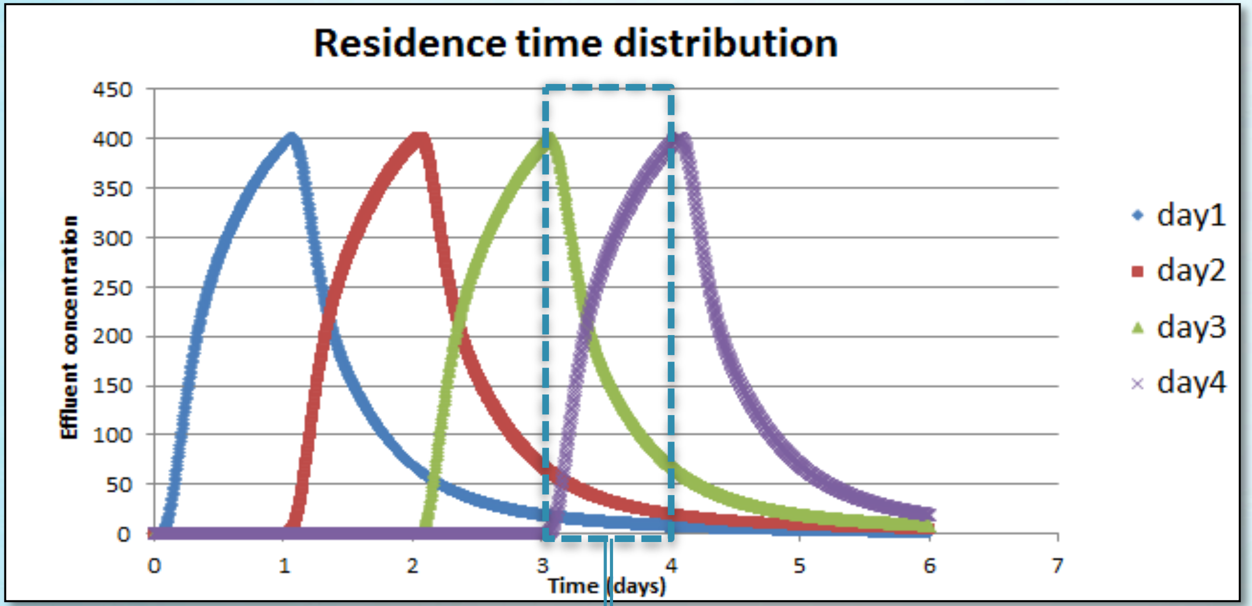
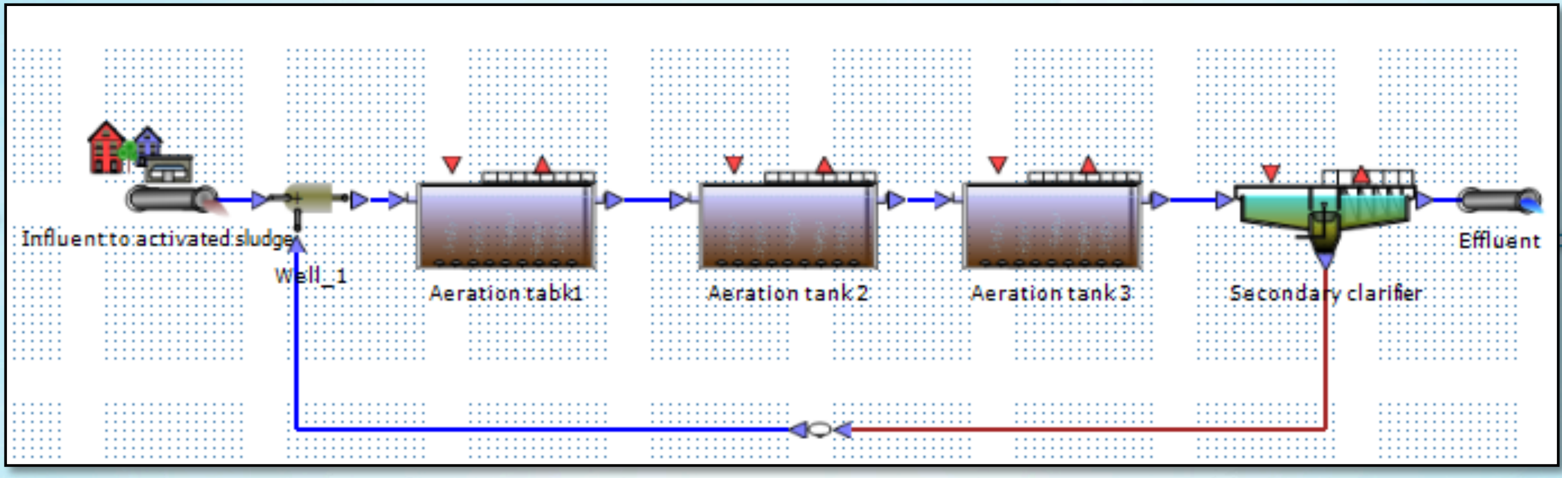
Obtaining load fractions – Granby

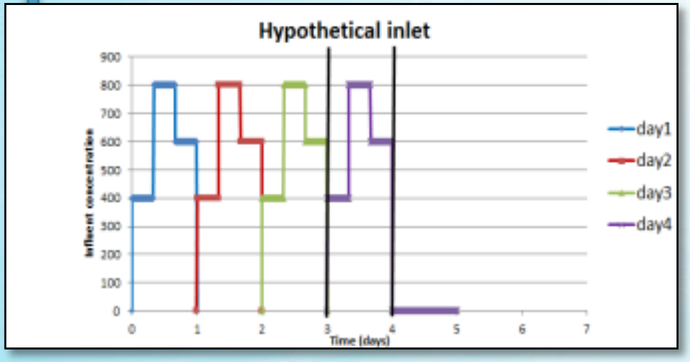
- **The fractions are found as the fraction of the area under each curve in the box of a given day**

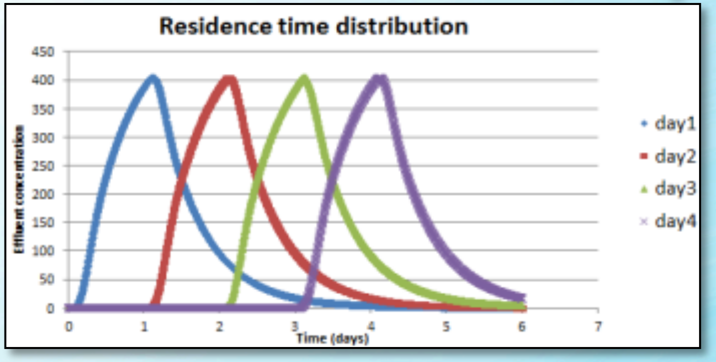


Indicates that the effluent on day 4 is composed of: **49% day 4 (same day)**
41% day 3
8% day 2
3% day 1

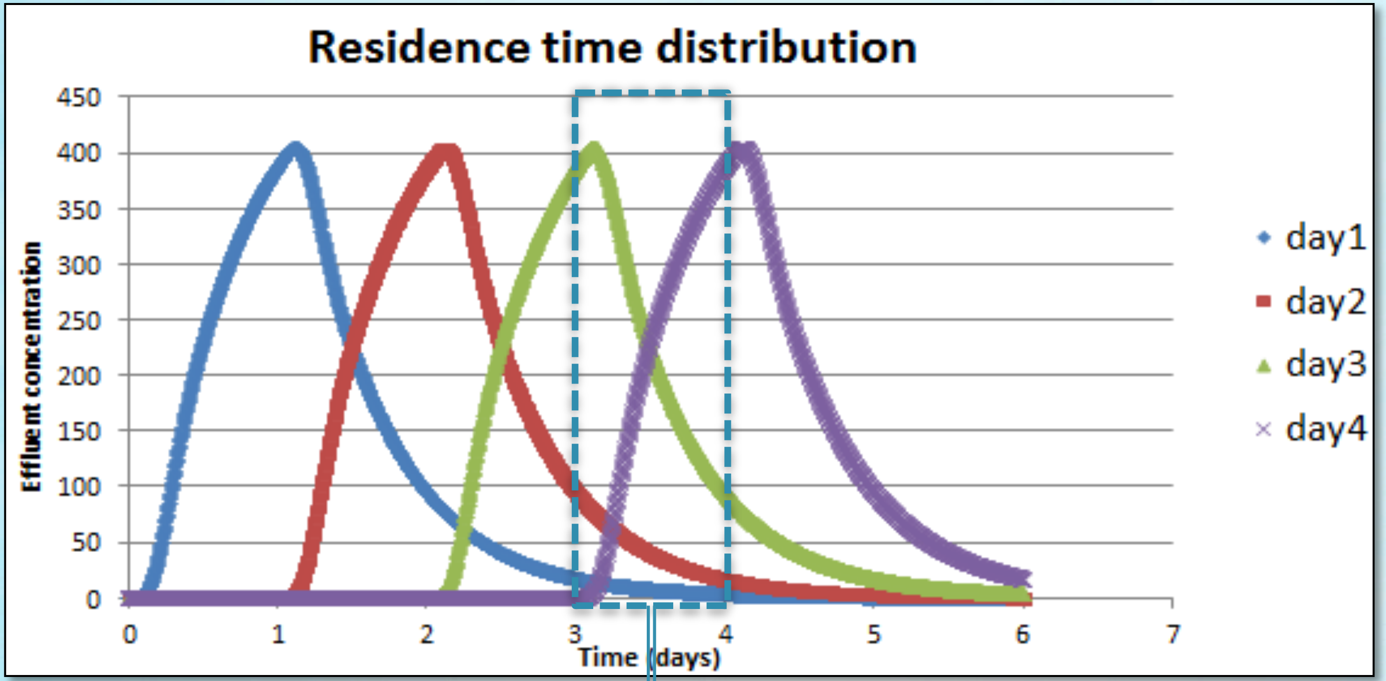
Obtaining load fractions – Guelph







Obtaining load fractions – Guelph



Indicates that the effluent on day 4 is composed of: **40% day 4 (same day)**
49% day 3
9% day 2
2% day 1

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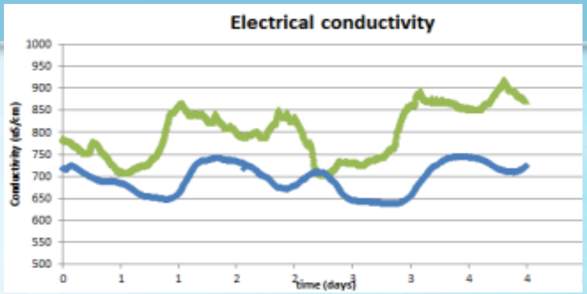
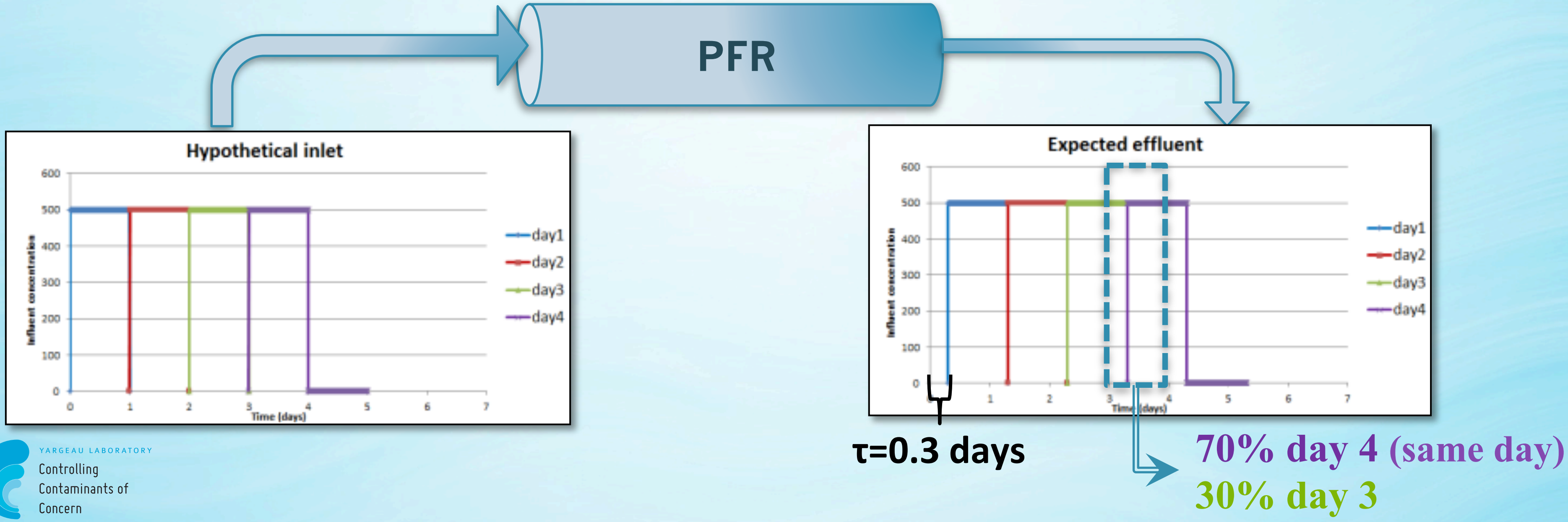
Obtaining load fractions - Peterborough



- Due to the absence of RTD as plug flow reactor (PFR) → WEST not needed
- The effluent on one day contains load from only one past day and the fractions depend on the time constant of the activated sludge unit



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Calculations of removal

✧ Example of Granby

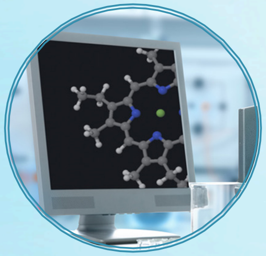
- Concentrations were determined by LC-MS\MS
- Removal efficiencies were using the conventional method and the time-shifted approach

Location	Day	Ephedrine (ng/L)	Methadone (ng/L)
Influent	1	558	9
	2	982	23
	3	1019	16
	4	946	21
Effluent	1	87	12
	2	93	10
	3	103	10
	4	139	11

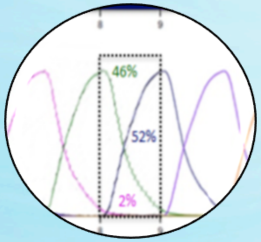
Compound	Day	Day-by-day removal (%)	Time-shifted removal (%)
Ephedrine	1	85%	86%
	2	91%	
	3	90%	
	4	85%	
Methadone	1	-29%	42%
	2	55%	
	3	37%	
	4	48%	

Conclusions and further steps

- The three activated sludge plants proved to have different mixing regimes, which significantly affect the transport of contaminants in the activated sludge unit.
- The residence time distribution is critical in properly evaluating the removal of contaminants



Chemical analysis



Hydraulic calibration

Reliable CECs removal data

Model to predict CECs removal as a design tool

Acknowledgements

- Prof. Viviane Yargeau
- Laval University for training on WEST Software
- 3Cs group
- McGill Engineering Doctoral Award (MEDA)
- NSERC Strategic Projects Program for funding

Questions

Summary of results

- Granby
  - Best model is 2 tanks in parallel
  - Effluent is composed of 49% day-4 (same day), 41% day-3, 8% day-2, 3% day-1
- Peterborough
  - Best model is PFR
  - Effluent is composed of 70% day-4 (same day), 30% day-3
- Guelph
  - Best model is 3 tanks in series
  - Effluent is composed of 40% day-4 (same day), 49% day-3, 9% day-2, 3% day-1