SPATIAL EVOLUTION OF PHARMACEUTICALS IN SUSPENDED PARTICULATE MATTERS AND BED-LOAD SEDIMENTS OF A PERI-URBAN STREAM

L. LEDIEU[1], A. SIMONNEAU[1], T. THIEBAULT[2], L. FOUGERE[3], E. DESTANDAU[3], O. CERDAN[4], F. LAGGOUN[1]

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HS9.5: Transfer of sediments and contaminants in catchments, rivers systems and lakes

[1]Univ. Orléans, CNRS, BRGM, ISTO, UMR 7327, F-45071, Orléans, France (lauriane.ledieu@cnrs-orleans.fr,anaelle.simonneau@univ-orleans.fr)
[2] EPHE, PSL University, UMR 7619 METIS (SU, CNRS, EPHE), 4 Place Jussieu, F-75005, Paris, France
[3]Univ Orleans, CNRS, ICOA, UMR 7311, 45067 Orleans, France
[4] BRGM, 3 avenue Claude Guillemin, 45060 Orléans, France

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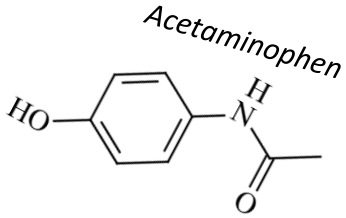
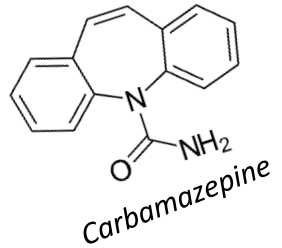
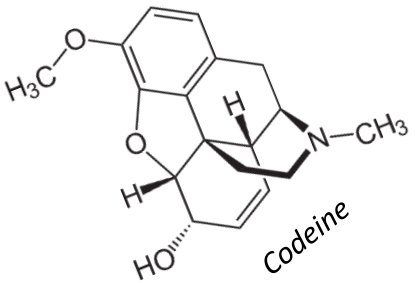
Context

Global issue





Pharmaceutical products constitute an **emerging environmental concern** for several reasons :



A hospital sewage effluent

- Being **worldwide** consumed *(Jjemba, 2004)*
- Being **continuously** emitted at low concentrations *(Loos et al., 2009)*
- Being released as **complex assemblages** *(Petrie et al., 2015)*
- Having **biological effects** *(Halling-Sørensen et al., 1998)*
- Including a **wide variety** of compounds with **various properties** *(Zhou and Broodbank, 2014)*

Main sources are the partial removal of the compounds in **sewage treatment plants** *(Munoz, 2009)*

Medical institutions wastewaters released **strong levels** *(Verlicchi et al., 2010)*

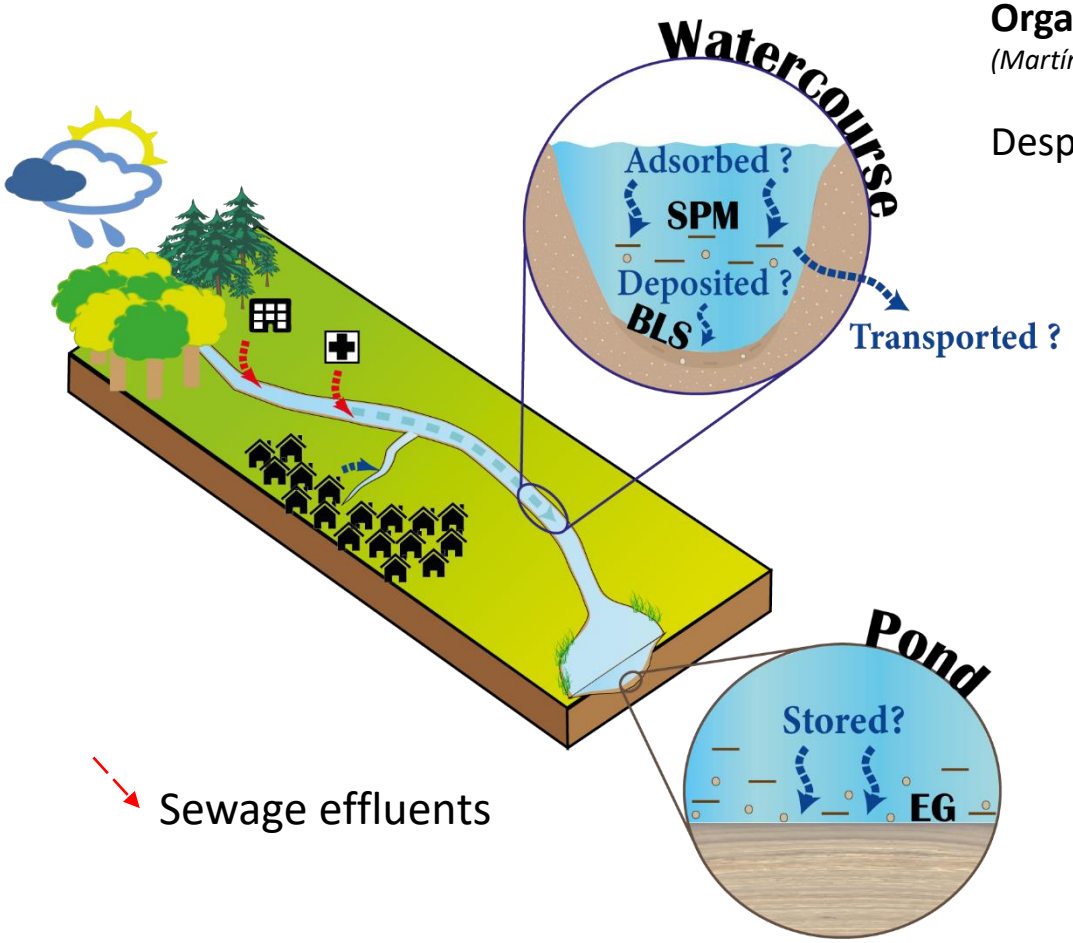
France is one of the **higher** drugs **consumer** in the European Union *(Bouvier et al., 2010)*

Among the hydrological systems of the Loire Bretagne basin, the **Loire River** show the **larger contamination levels**

(Amalric et al., 2011)

Context

Scientific purposes: Who ? Where ? How ?



Organic and mineral particles of solid matrices can **adsorb** pharmaceutical products *(Martínez-Hernández et al., 2014; Svahn and Bjorklund, 2015)*

Despite that, **particulate material** analyses are **neglected** *(Munoz, 2009)*

Understanding sorption processes and compounds dynamics is however needed to manage environmental contaminations *(Dobor et al., 2012; Martínez-Hernández et al., 2014; Petrie et al., 2015)*

Sorption processes were mostly evaluated by batch experiments *(Scheytt et al., 2005; Stein et al., 2008; Yamamoto et al., 2008)*

Suspended particulate matter is rarely evaluated *(Maskaoui and Zhou, 2010)*

Comparison between different compartments are poorly investigated *(Da Silva et al., 2011)*

Spatial-temporal evolution is even more unclear *(Fairbairn et al., 2015)*

How occur drugs adsorption and spatial evolution into different compartments of the particulate phase at a catchment scale ?

Study site

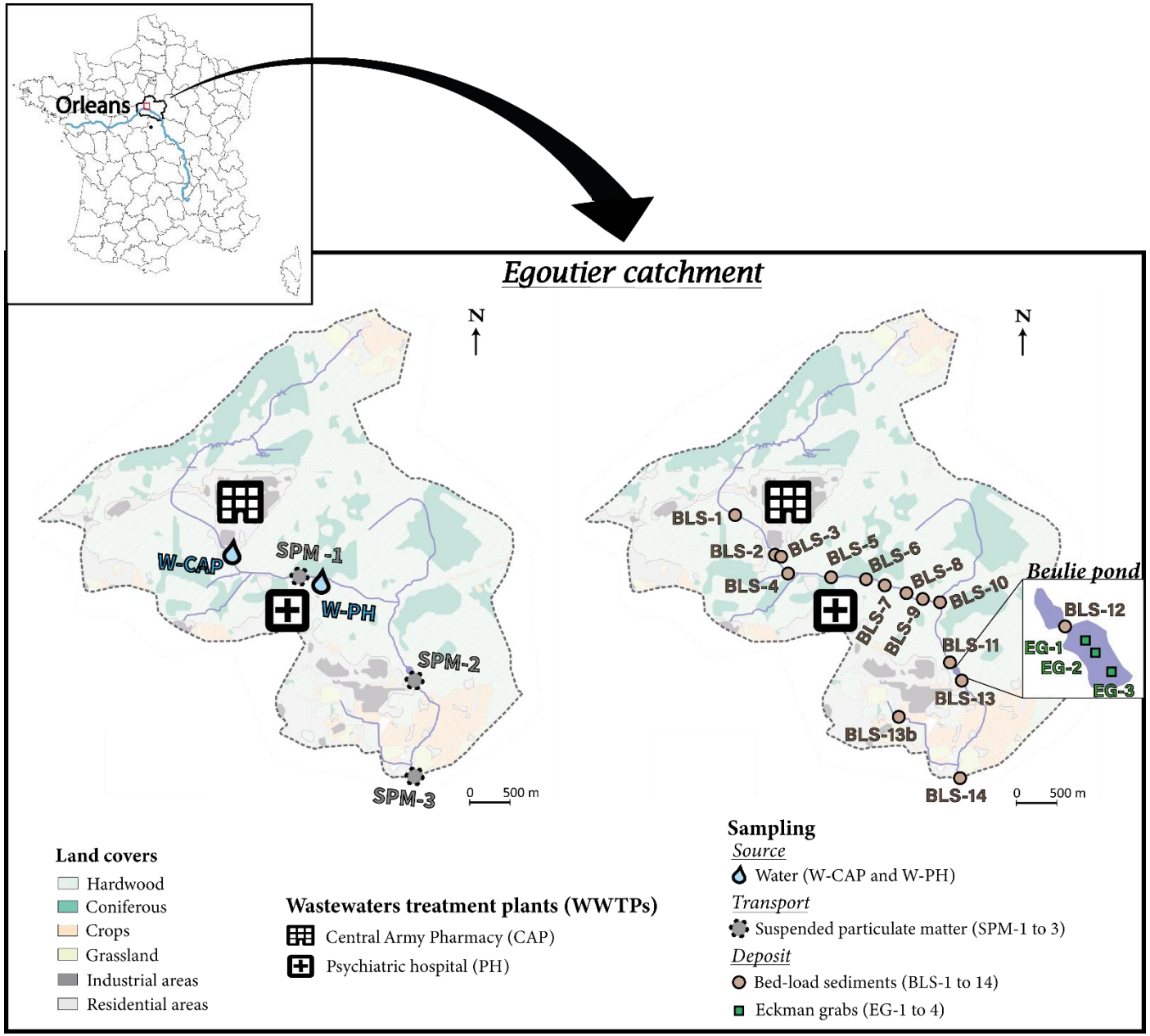
Egoutier stream :

Tributary of the **Loire River** flowing on **hydromorphic subsoils** *(Soucémarianadin and Verbèque, 2007)* developped on **Sologne sands and clays** and **Orleanais sands** *(Berger and Desprez, 1969)*

Collects two sewage effluents :

- ✓ One from a Central Army Pharmacy (CAP) with continuous releases
- ✓ One from a psychiatric hospital (PH) with periodical releases

Discharge into **a pond** (the Beulie pond) in its central part



(Land cover: Inglada et al., 2017)

Sampling

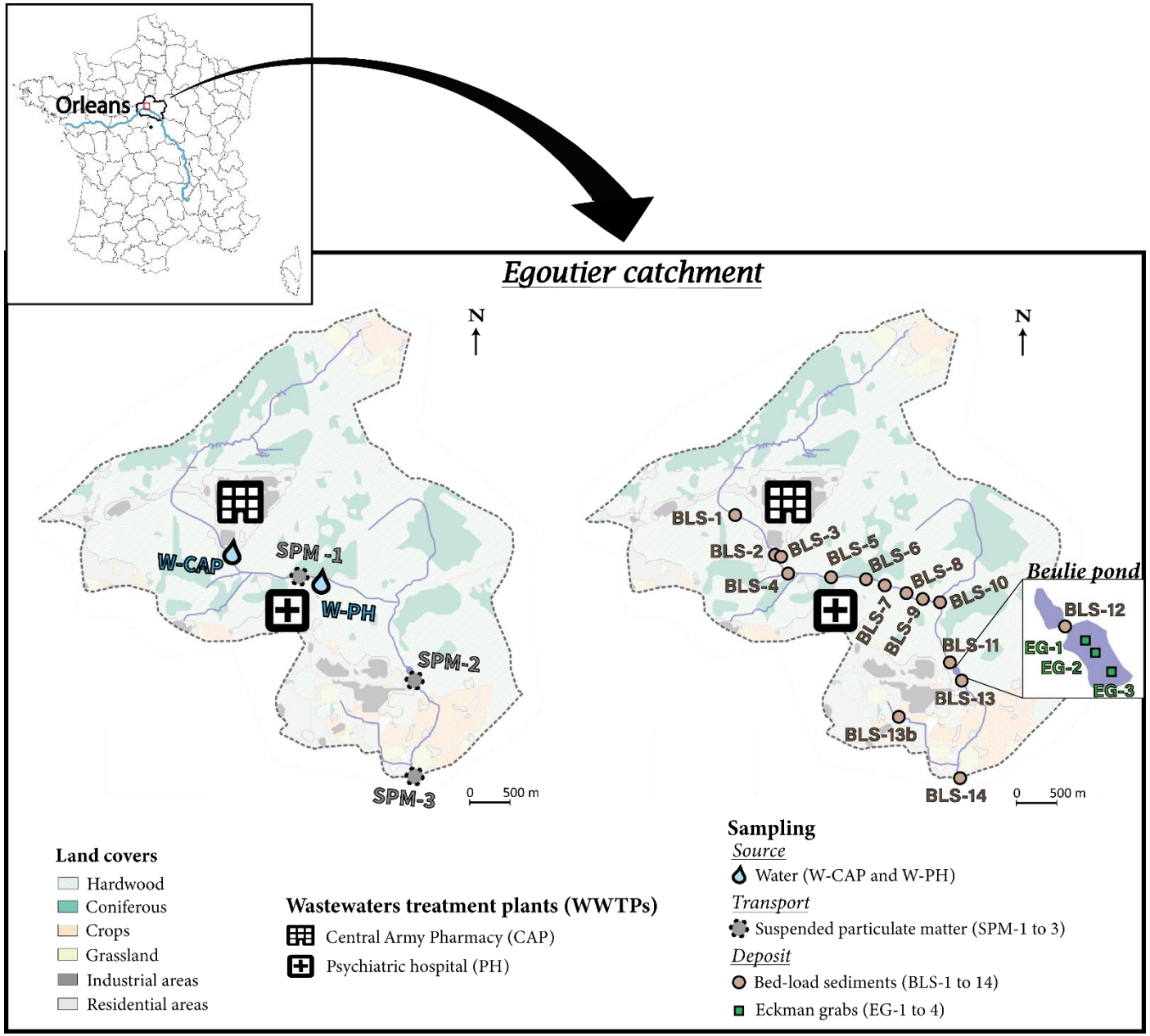
4 compartments analysed :

- **The two water sources (W)**
  -> Once with plastic bottles

- **Three locations of suspended particulate matter (SPM)**
  -> 3 periods of 2 months with GEACOS
  (Simonneau et al., 2020)

- **15 samples of bed-load sediments (BLS) along the watercourse**
  -> 4 sets in spring and summer of two years with Flacon tubes

- **A transect of the pond interface sediments (EG)**
  -> 3 eckman grabs collected once



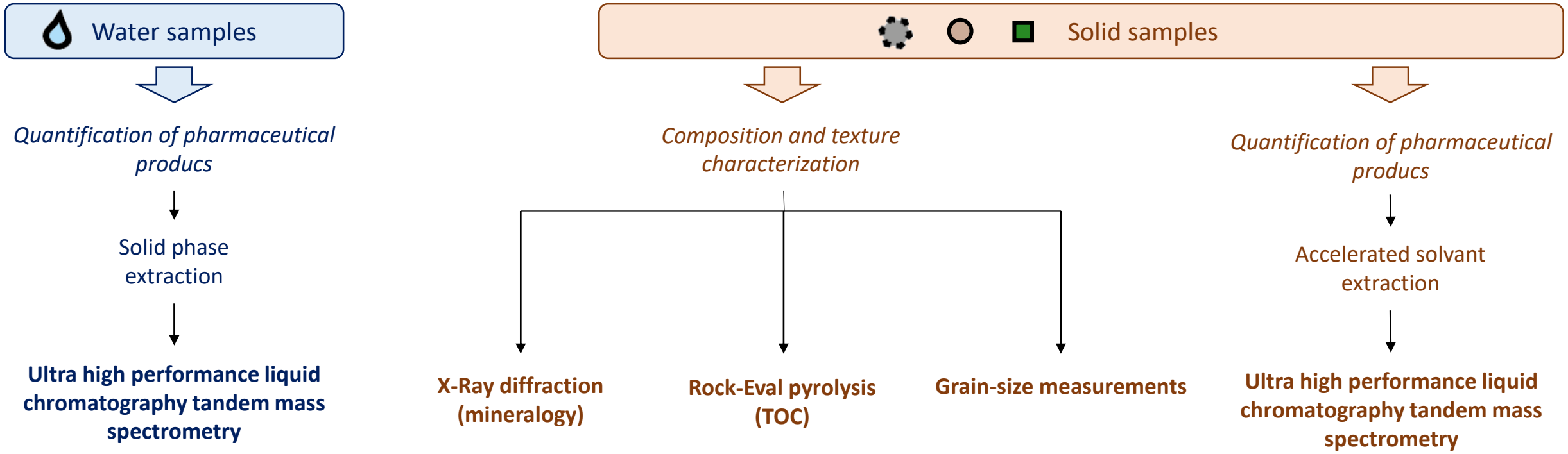
(Land cover: Inglada et al., 2017)

Methods

Quantification of different groups of drugs with different properties :

- Cationic compounds : *atenolol (ATE), codeine (COD), tramadol (TRA), trimethoprim (TRI)*
- Neutral compounds : *acetaminophen (ACM), carbamazepine (CBZ), diazepam (DIA), oxazepam (OXA)*
- Anionic compounds : *diclofenac (DIC), salicylic acid (SCA)*

And their influencing factors



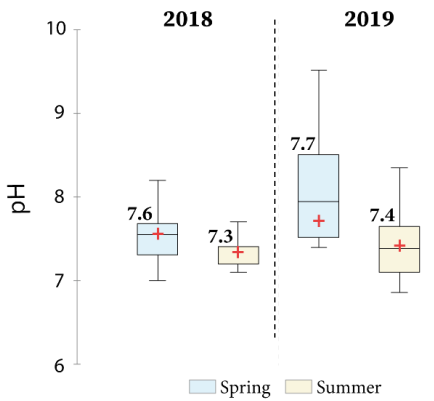
+ Field pH measurements with a portable pH meter

Results

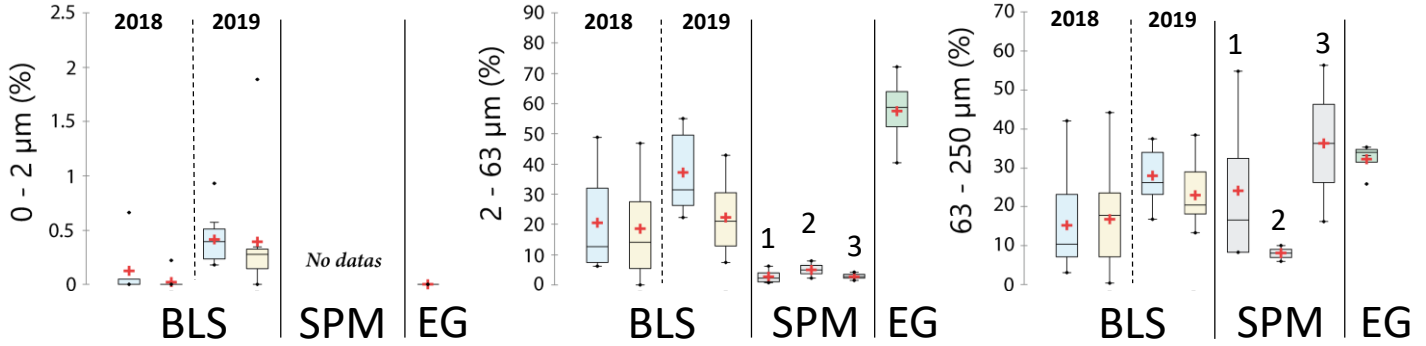
Environmental and solid materials parameters

➢ **Minerals :** *Quartz (dominant), calcite, albite, orthoclase, smectite (except downstream the pond), pyrite (only in the pond)*

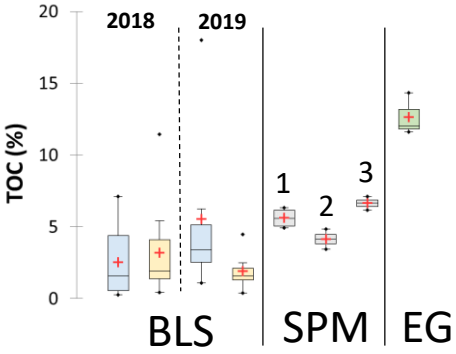
Physical-chemical conditions



Grain sizes of the particulate material



Organic content



➢ **Physical-chemical conditions :**

- Around **neutrality**
- On average **higher** in **spring**
- Slightly **variable** at **catchment scale** in summer

(the only molecule influenced by such variations is TRI, passing from a cationic form to a neutral one)

➢ **Grain-sizes** :

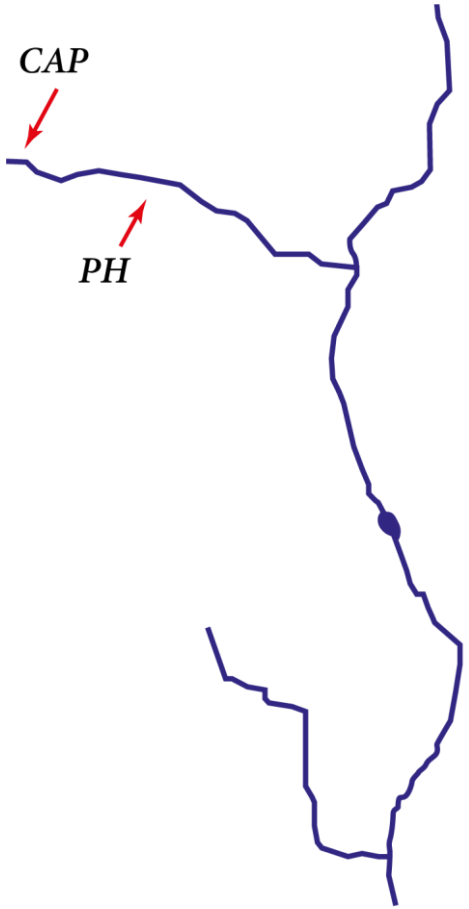
- **BLS** were **coarse** and seasonally **homogeneous** in 2018, **finer** in **2019**, mostly in **spring**
- **SPM** have similar proportions in **2 – 63 µm fraction**
- The presence of the pond only **decrease** intermediate grain-size particles (**63 – 250 µm**) in **SPM**
- **Beulie pond** sediments are mainly composed of fine grain-size particles **(2 – 63 µm)**

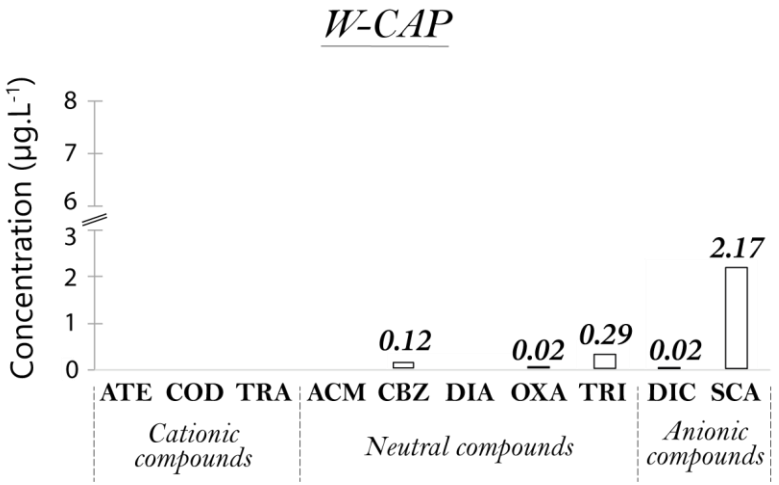
➢ **TOC :**

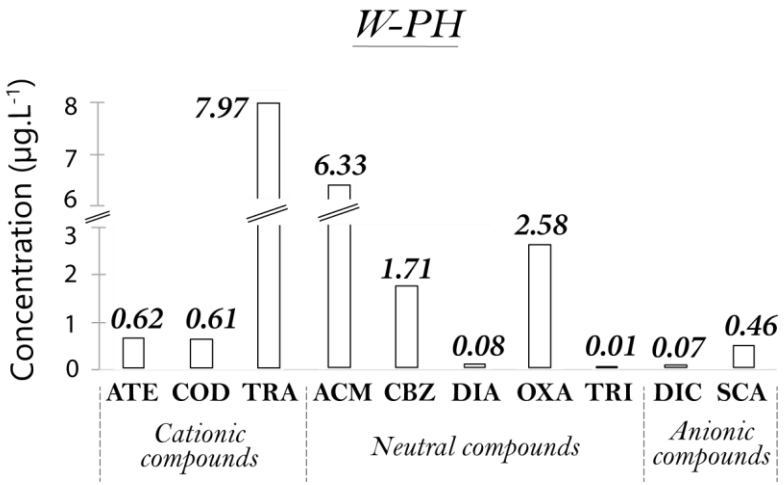
- Moderate, the **pond** present the **higher** amonts
- **Low variations** in **BLS** from 2018 and in **SPM**
- **Seasonal dissimalirities** were higher in **BLS** from **2019**

Results

Sources (sewage waters effluents)



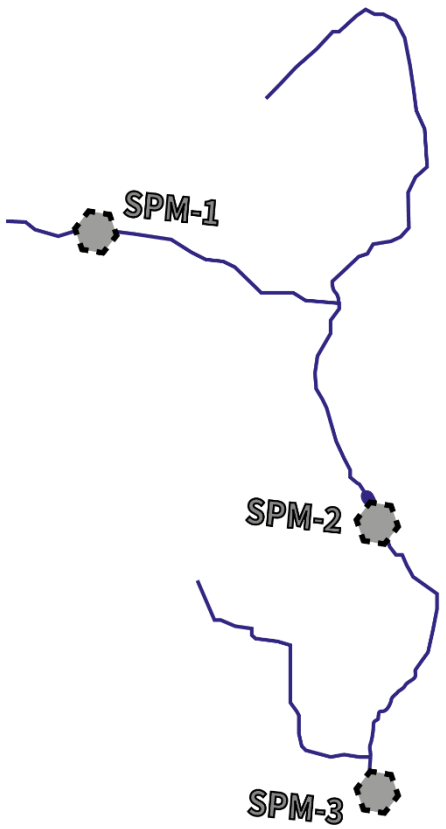


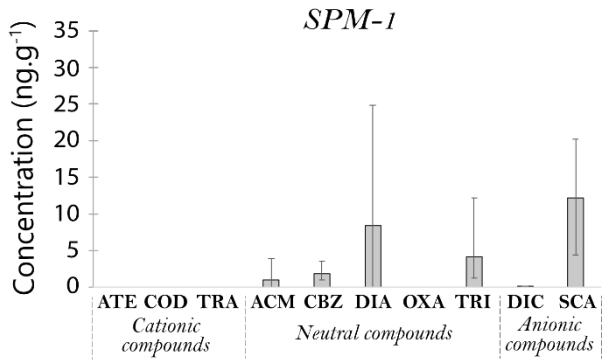


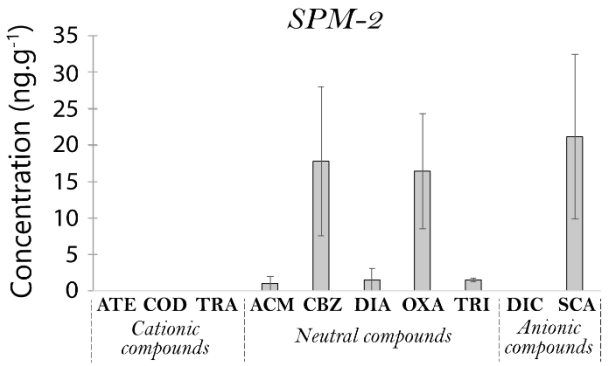
- The **PH** consume a **higher variety** of pharmaceutical products than the CAP
- The **CAP** treatment plant seems **more efficient** than the PH one, exhibiting much lower amounts of compounds. Despite that, **TRI and SCA** are released in **higher rates**
- The **PH** sewage effluent released **high levels** of compounds, with **TRA, ACM, CBZ** and **OXA** in several µg.L^{-1}.

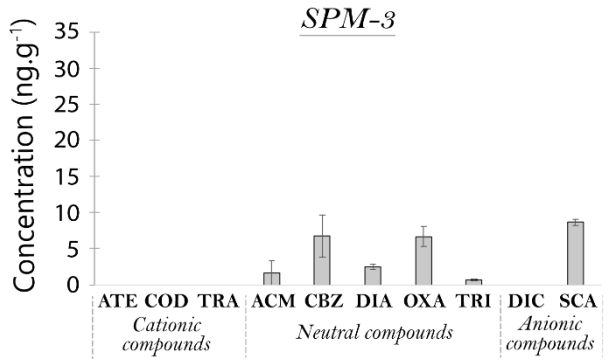
Results

Transported rates (suspended particulate matter)









- **Only 6 compounds quantified**

- Except the **apparition** and the **disparition** of **OXA and DIC**, respectively, **adsorbed compounds were the same**

- **Amounts** between the different compounds were **variable** :

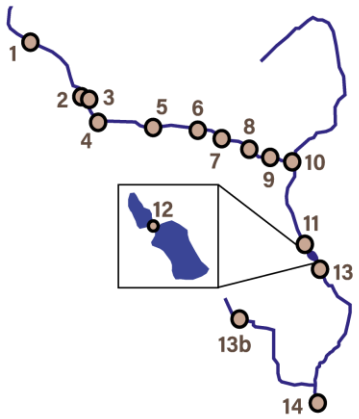
  - **CBZ, OXA** and **SCA** presented the **highest** mean concentrations
  - **ACM, DIA, TRI** and **DIC** the **lowest**

- Amounts **fluctuated** at catchment scale :

  - **CBZ, OXA** and **SCA** are on average **higher downstream the pond** and **decreased towards the outlet**
  - **DIA** exhibited **higher** amounts **upstream the pond**
  - **ACM, TRI** and **DIC** were only **slightly variable**

Results

Accumulated rates (bed-load sediments)



	Cationic compounds									*Neutral compounds*													*Anionic compounds*					
	ATE			COD			TRA			ACM			CBZ			DIA			OXA			TRI			DIC			SCA		
	M	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*	*M*	*SD*	*DF*
1	0	/	*0/2*	0	/	*0/2*	0	/	*0/2*	0	/	*0/2*	**0.2**	/	*1/2*	0	/	*0/2*	0	/	*0/2*	**4.2**	0	*1/2*	0	/	*0/2*	**8.3**	±0.1	*2/2*
2	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**0.6**	±0.2	*2/4*	**7.0**	±7.0	*3/4*	0	/	*0/4*	**3.6**	±2.0	*2/4*	**0.1**	/	*1/4*	**8.6**	±11.5	*3/4*
3	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**2.3**	±2.8	*2/4*	**3.4**	±2.1	*2/4*	**0.8**	/	*1/4*	**3.1**	±2.7	*2/4*	0	/	*0/4*	**18.5**	±28.1	*4/4*
4	0	/	*0/4*	0	/	*0/4*	**41.9**	/	*1/4*	0	/	*0/4*	**0.6**	±0.6	*2/4*	**1.9**	/	*1/4*	0	/	*0/4*	**1.5**	±0.4	*3/4*	**0.4**	/	*1/4*	**8.9**	±10.6	*3/4*
5	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**0.6**	/	*1/4*	**0.6**	±0.4	*3/4*	**3.7**	±0.4	*2/4*	**0.1**	/	*1/4*	**2.8**	±1.2	*2/4*	0	/	*0/4*	**7.6**	±11.1	*3/4*
6	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**0.3**	±0.1	*3/4*	**4.9**	±1.8	*2/4*	0	/	*0/4*	**1.0**	±0.5	*3/4*	**0.1**	/	*1/4*	**8.1**	±10.3	*3/4*
7	**3.4**	±4.4	*2/4*	**12.3**	/	*1/4*	0	/	*0/4*	**3.5**	/	*1/4*	**51.1**	±53.1	*4/4*	0	/	*0/4*	**33.2**	±22.9	*4/4*	**7.1**	0	*1/4*	**0.4**	/	*1/4*	**26.2**	±25.1	*4/4*
8	**3.8**	/	*1/4*	**8.1**	/	*1/4*	0	/	*0/4*	**2.5**	/	*1/4*	**4.7**	±3.0	*4/4*	**1.3**	±0.6	*2/4*	**6.3**	±5.3	*4/4*	**1.5**	±1.2	*3/4*	0	/	*0/4*	**26.6**	±34.0	*3/4*
9	**3.0**	±3.2	*2/4*	**17.3**	±4.3	*2/4*	**5812**	/	*1/4*	**10.1**	/	*1/4*	**30.1**	±6.3	*4/4*	**9.1**	±3.8	*4/4*	**30.9**	±13.2	*4/4*	**6.8**	±7.9	*4/4*	**3.7**	±4.2	*2/4*	**29.0**	±25.4	*2/4*
10	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**1.2**	/	*1/4*	**3.7**	±3.5	*4/4*	**2.5**	±1.4	*3/4*	**5.8**	±4.6	*4/4*	**1.4**	±0.4	*2/4*	**0.2**	/	*1/4*	**37.3**	±47.0	*4/4*
11	0	/	*0/2*	**4.2**	±5.9	*1/2*	0	/	*0/2*	**16.9**	/	*1/2*	**1.3**	±1.8	*1/2*	**39.6**	/	*1/2*	**141.4**	/	*1/2*	**4.5**	±2.6	*2/2*	**4.9**	/	*1/2*	**1.7**	/	*1/2*
12	0	/	*0/2*	0	/	*0/2*	0	/	*0/2*	**0.7**	/	*1/2*	**6.0**	±5.1	*2/2*	**2.4**	±2.0	*2/2*	**10.8**	±11.2	*2/2*	0	0	*0/2*	**0.2**	±0.3	*2/2*	**57.9**	/	*1/2*
13	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**1.6**	±0.9	*4/4*	0	/	*0/4*	**2.0**	±1.1	*4/4*	**2.5**	±2.1	*2/4*	**0.1**	/	*1/4*	**11.4**	±13.0	*4/4*
13b	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**1.4**	/	*1/4*	**4.7**	/	*1/4*	0	/	*0/4*	**11.2**	0	*1/4*	**0.1**	/	*1/4*	**30.5**	±17.7	*2/4*
14	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	0	/	*0/4*	**2.1**	±1.1	*2/4*	**2.2**	/	*1/4*	**2.1**	±1.9	*3/4*	**15.3**	±17.2	*2/4*	0	/	*0/4*	**49.0**	±81.0	*4/4*

All compounds quantified

Detection frequencies :

- **CBZ, TRI** and **SCA** were **ubiquitous**, already present before CAP sewage effluent
- **DIA** and **OXA** also **frequent**
- **ATE** and **COD local** presence in **some** sample **sets**
- **ACM and DIC rare** and in **variable** locations
- **TRA** even **more rare**

Variability and rates :

TRA > OXA > SCA > CBZ > DIA > ACM > TRI > COD > DIC > ATE

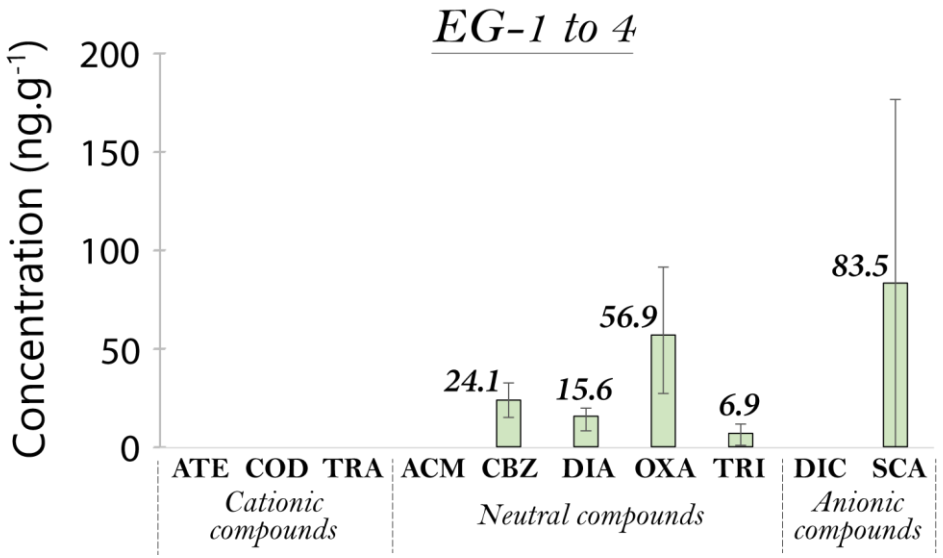
Most contaminated samples :

BLS-9 > BLS-11 > BLS-7

Surprinsingly, samples collected at storm waters discharges (BLS-2 and 13b) presented concentrations in CBZ, DIA, DIC, TRI and SCA

Results

Stored rates (the Beulie pond interface sediments)



- **Only 5 compounds quantified**
- **SCA** was the **more concentrated** with an increasing concentration towards the pond outlet
- **OXA** presented **high levels**
- **CBZ** and **DIA** had **intermediate concentrations**
- **TRI** was the compound with **lowest amounts**

Discussion

Effect of compounds degradation

Therapeutic group	Coumpound	Log K_{ow}	Persistence	Major degradation processes
Analgesics	ACM	0.46	Low [q,w]	BT [q,w]
	SCA	2.26	Low [j]	Both [j]
Antibiotic	TRI	0.91	High [k,q]	Debated [j,q]
Anti-inflammatory	DIC	4.98	Low [i]	PH [m,p]
B-blocker	ATE	0.16	Moderate [k,u]	BT [s,u,v]
Opioids	COD	1.19	High [o]	PH [r]
	TRA	1.34	High [l]	None [l]
Psychotropics	CBZ	2.45	High [k,q]	PH [q]
	DIA	2.63	High [t]	PH [m,n]
	OXA	2.24	Moderate [t]	BT [n]

References www.drugbank.ca

[i]Ashton et al., 2004
[j]Baena-Nogueras et al., 2017
[k]Bendz et al., 2005
[l]Bergheim et al., 2011
[m]Boreen et al., 2003
[n]Calisto and Esteves, 2009
[o]Fekadu et al., 2019
[p]Koumaki et al., 2015
[q]Lam et al., 2004
[r]Lin et al., 2014
[s]Liu et Williams, 2007
[t]Löffler et al., 2005
[u]Ramil et al., 2010
[v]Yamamoto et al., 2008
[w]Yu et al., 2006

- **ACM, SCA and DIC are known to have low persistencies :**

  ACM and **DIC scarcity** in every particulate compartments is **consitent**

  SCA has an **ubiquitous** presence, probably because of a **low solubility** (logK_{ow}) and **high releasing rates**

- **CBZ and TRI ubiquity is congruent with their high peristence in spite of not being the stronger emitted compounds**

- **OXA** is **moderatly** submitted to **biotransformation** but **high releasing rates** and being **DIA** main **metabolite** *(Klaminder et al., 2015)* explain its **high levels** and **presence**

- **DIA intermediate concentrations** despite **low amounts** in the **dissolved** phase correspond to a **high persistence**

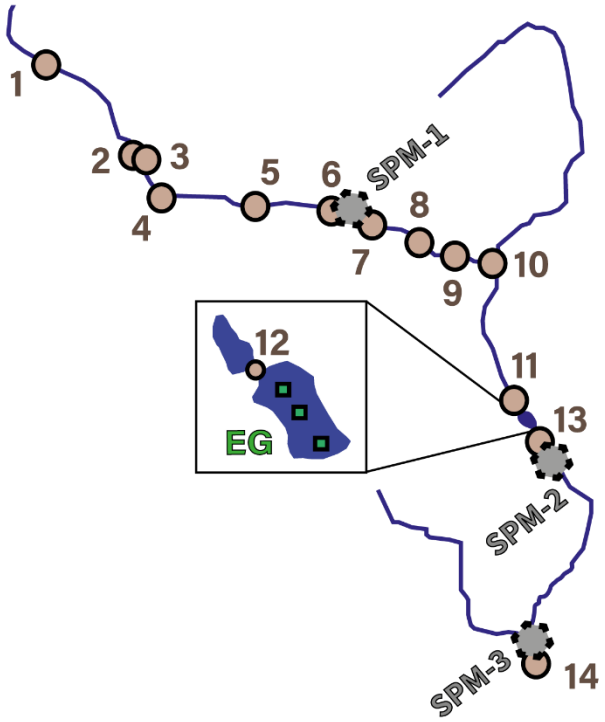
- **ATE** and **COD** have **local presence** even if they are **moderatly** to **highly persistent**, probably due to their **solubility** and **suggesting other driving factors**

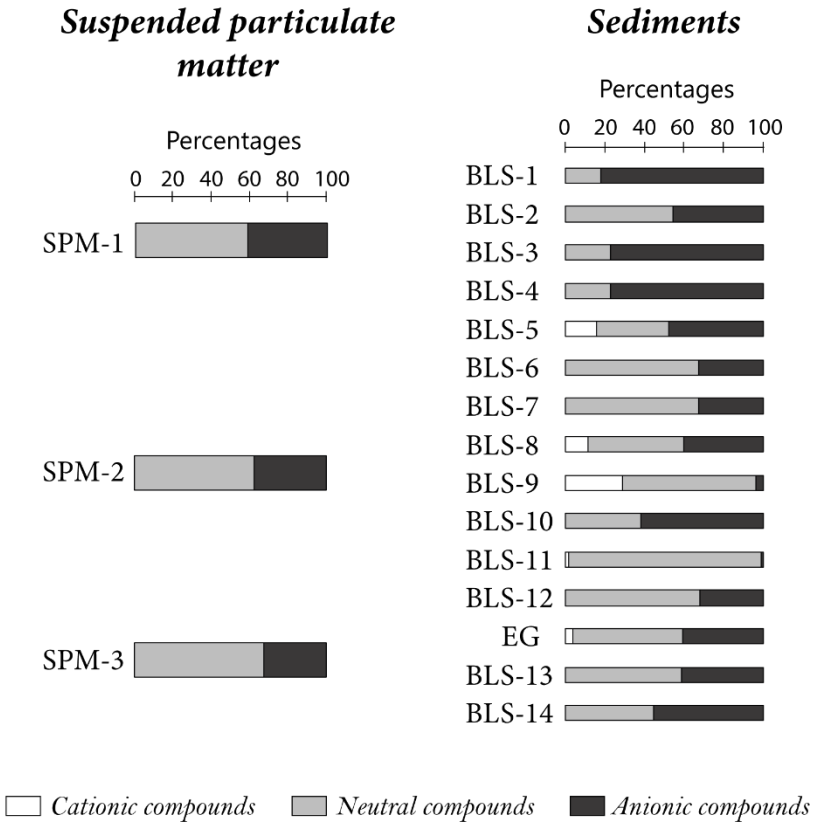
- **TRA** is the **more discharged** compound and is **highly persistent**, in accordance with the **high concentrations** observed in BLS but can be **desorbed** *(Stein et al., 2008)* which can explain its **general absence**

Compounds abundance depends on their resistance to degradation but that is not the main process explaining their levels

Discussion

Effect of compounds charges





Neutral compounds are **predominant** in **SPM** and in the Beulie **pond sediments**

Neutral compounds are also **mostly prevalent** in **BLS**

Resulting from **three factors** :

- High **releasing rates**
- High **persistence**
- High **hydrophobic interactions** with **organic matter** as solid matrices have **low contents** of **clay minerals**

Thus compounds rates were mostly driven by their lipophilicities

Few **exceptions** because of **SCA** presence **upstream** sewage effluents (**BLS-1**), SCA **higher releasing rates** at CAP wastewaters dicharges (**BLS-3**) and **high sorption rates** of neutral componds at the **accumulation zone** (**BLS-9**) with an **important level** of **organic matter** (8,5 %)

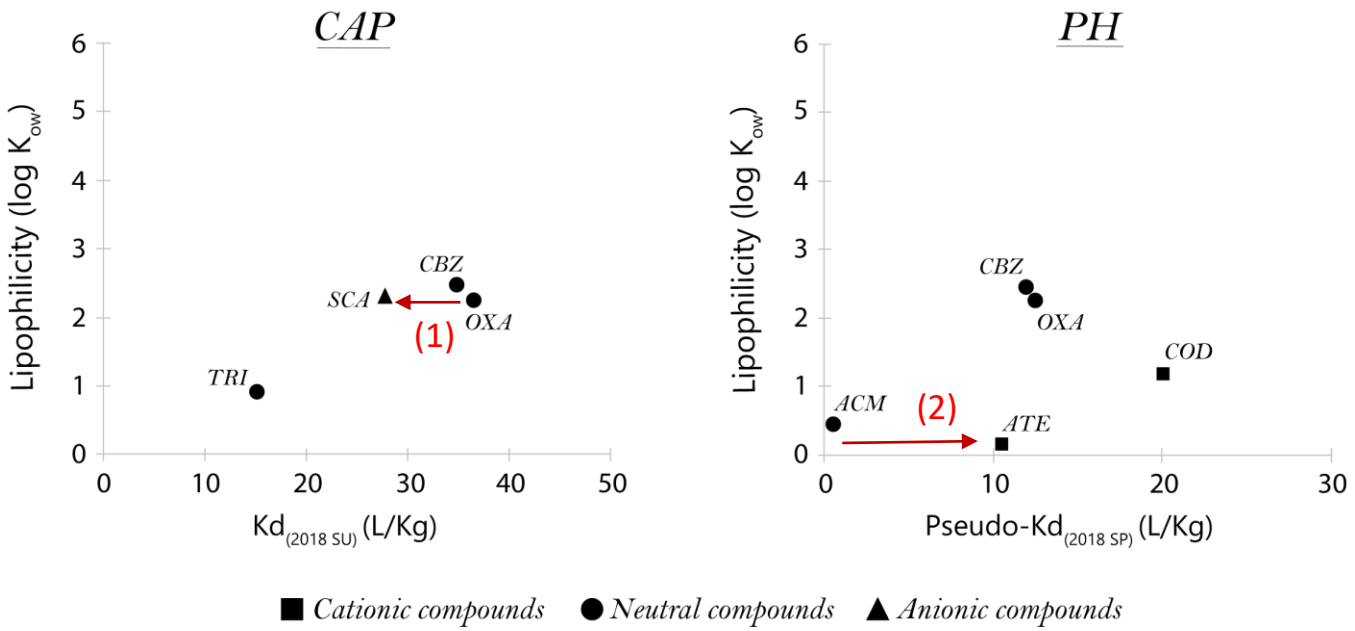
Neutral compounds have the better affinity with particulate phases because of their persistence and low contents of clay grain sizes limiting potential ionic interactions

Discussion

Effect of compounds lipophilicity

Sorption coefficient : $Kd = [X]_{PP}/[X]_{DP}$ *(Williams et al., 2009)*

(A pseudo-Kd for the PH because water and sediments were not sampled together)



(1) Hydrophobic interactions are less important for anionic compounds with a similar lipophilicity ?

(2) Sorption of cationic compounds does not only occur through hydrophobic interactions ?

*Kd values could not be calculated for **TRA, DIA** and **DIC** because of their absence in the dissolved or particulate phase*

Calculated Kd values were in the same ranges than those observed in others studies

Few exceptions were observed mainly because of different contents in organic matter

Sorption coefficients increased with increasing lipophilicity (log K_{ow})

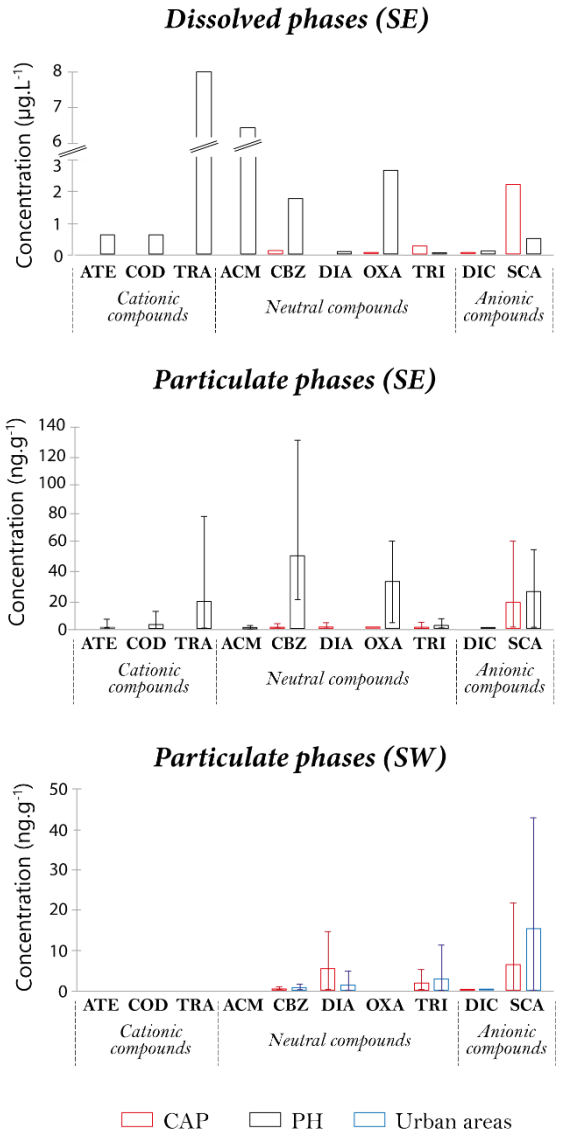
TRI and SCA exhibited extreme pseudo-Kd for PH sewage effluent, probably because of variable consumption levels

Kd coefficients were different between anionic, cationic and neutral compounds with similar lopophilicities

Effect of the less interactions or contributions of ionic bounding ?

Discussion

Different sources of pharmaceutical products



Compounds have thus a good affinity with particulate phases

Assemblages founded in BLS samples collected at CAP and PH sewage effluents were the same than in the dissolved phase

Only DIA and DIC presented dissimilarities but these compounds were released in the lower amounts

It can also be consider that mixtures observed at storm waters releasing reflect others sources linked to leaks of domestic wastewaters

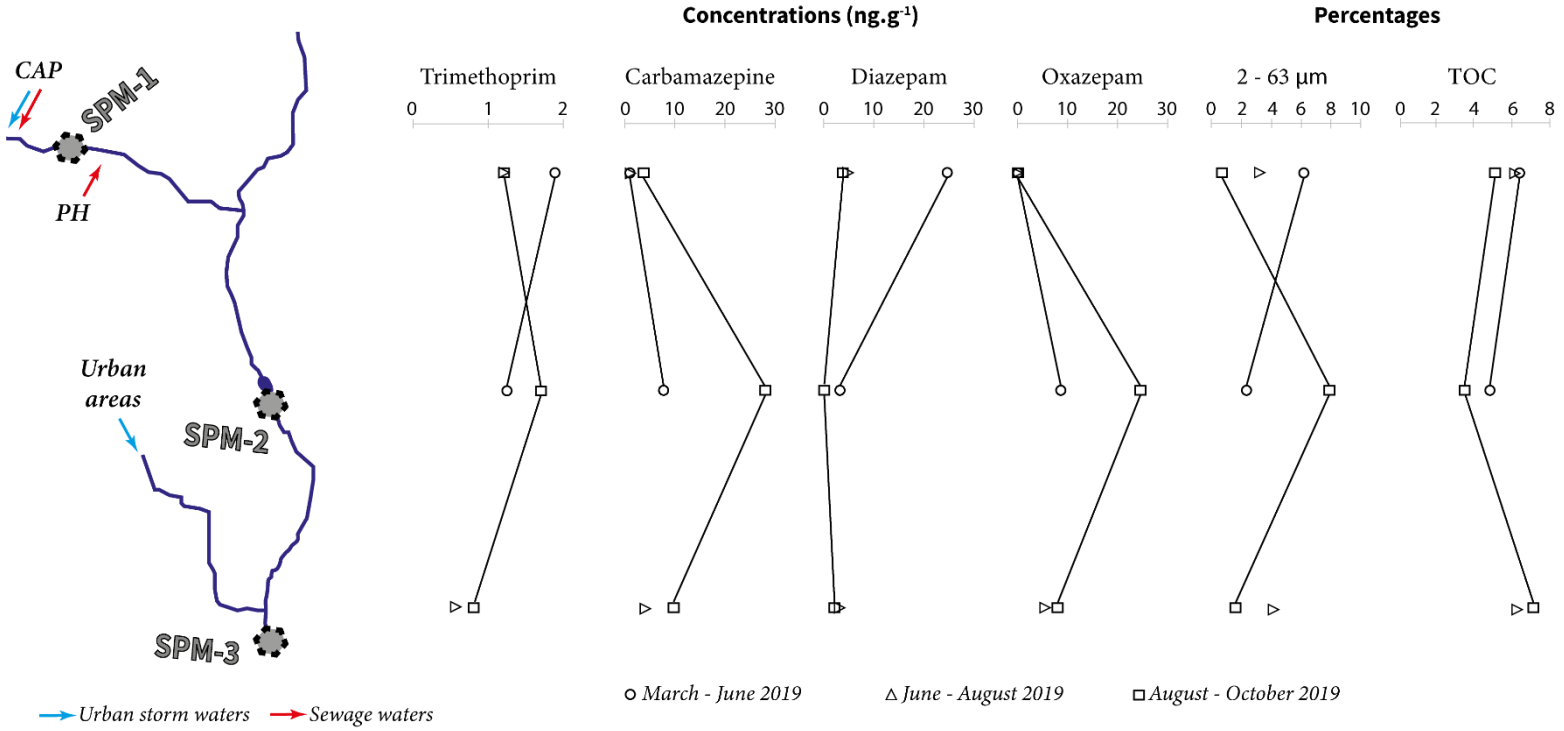
In this way, households consumption mostly emitted CBZ, DIA, TRI, DIC and SCA

Which is also consistent because both CAP and urban areas storm waters presented the same mixture

Discussion

Spatial evolution of suspended particulate matter contamination levels

Resistant to degradation processes, 4 neutral compounds with different sources were represented : TRI mostly from the CAP sewage effluent, CBZ and OXA mostly from the PH one and DIA mostly from domestic wastewaters



- With the lowest lipophilicity and low releasing rates, **TRI** exhibited a **low variability** at catchment scale, slightly following the 2 – 63 µm grain – size fraction

- **CBZ and OXA increased downstream** the pond and **decreased toward the outlet** :

-> Because of the **adding contribution of the PH** effluent
-> **High amounts** are **transported** at catchment scale despite the presence of the pond
-> Amounts do not reach the outlet because of the presence of an accumulation zone between SPM-2 and SPM-3

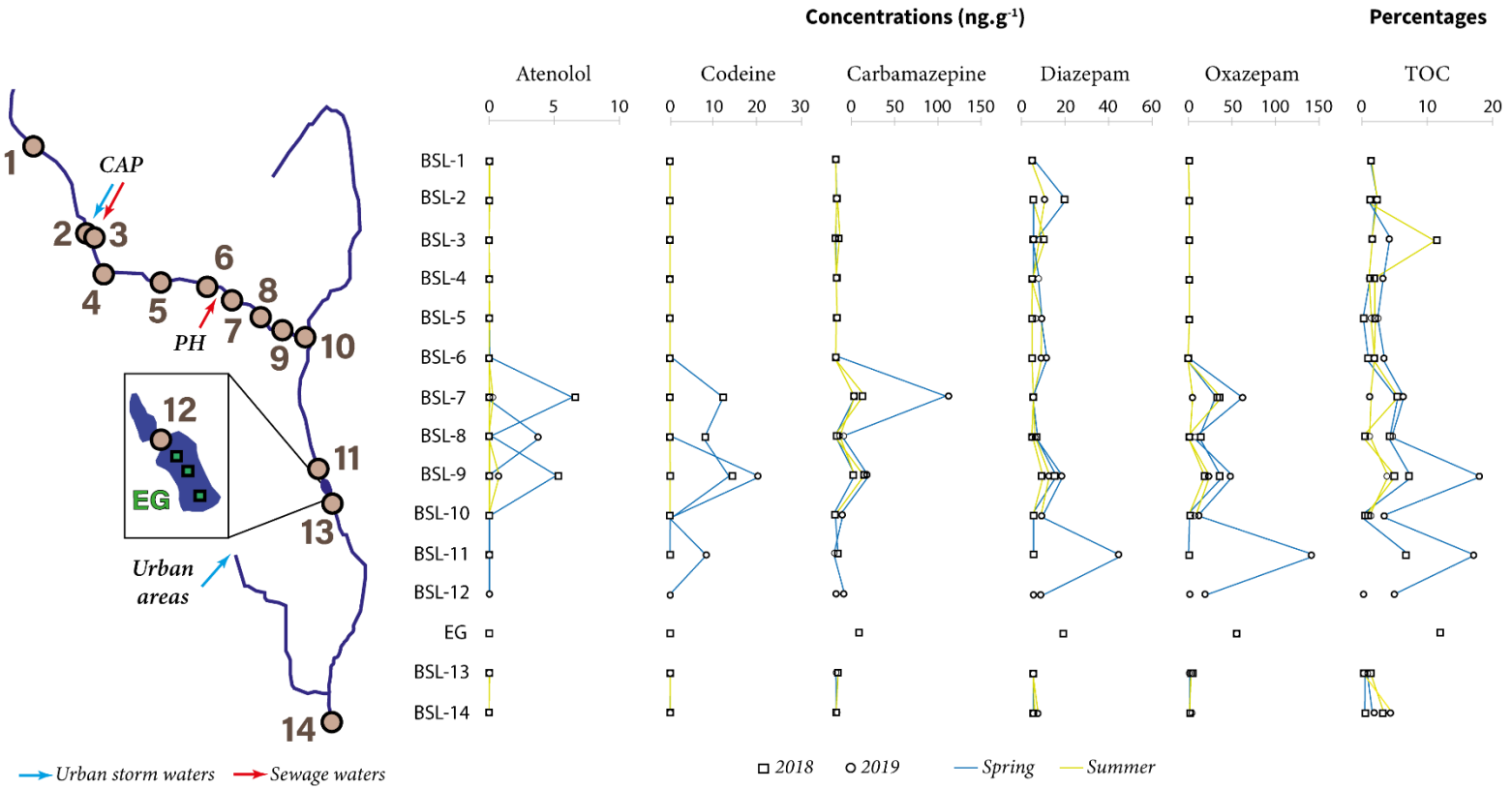
In SPM, compounds with low concentrations tend to have low variations following their bearing phases, but amounts mainly reflect sources contributions independently of bearing phases levels

- **DIA** is the **lowest released** compound and **slightly followed the TOC** contents

Discussion

Spatial evolution of sediments contamination levels

Resistant to degradation processes, 5 cationic and neutral compounds with different properties and some already used as tracers were represented (OXA, Maskaoui and Zhou, 2010; CBZ, Amalric et al., 2011)

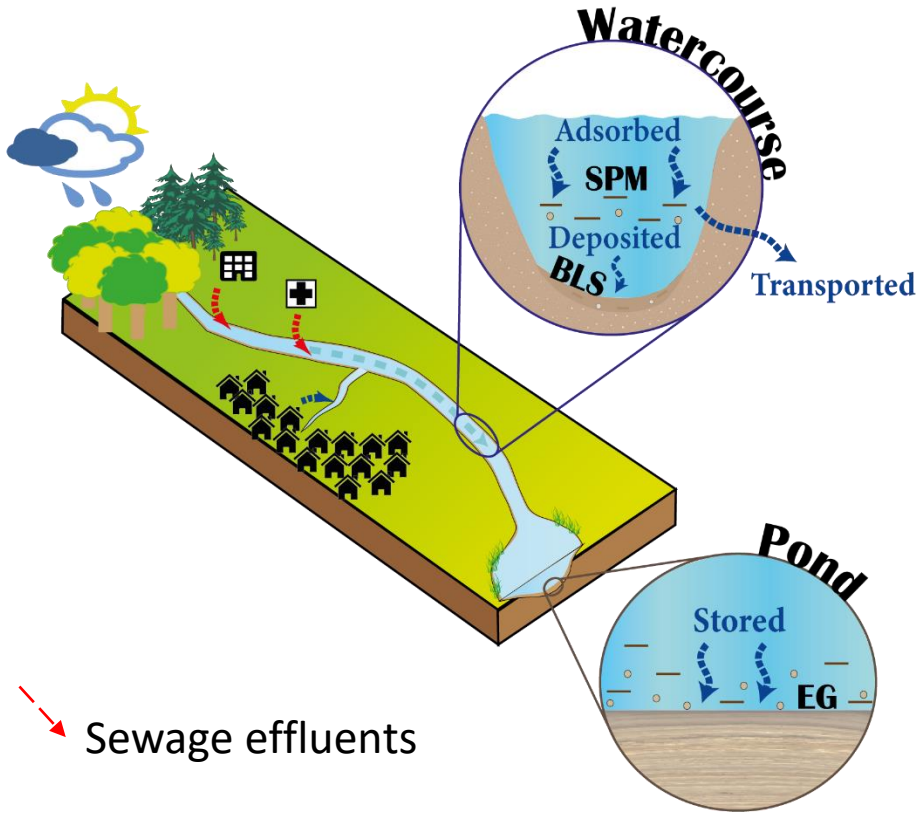


In sediments, spatial distribution of compounds mainly reflect discharging sites and the sedimentary dynamic of the stream
Seasonal variations linked to the degradation processes efficiency appear too

- Pharmaceutical products are **concentrated at discharging sites** and where **organic matter** levels are the highest
- In BLS downstream the pond, contamination levels were very low evidencing the **strong storage capacity of the pond** and the limited presence of accumulation zones demonstrated by lower fine grain-size particles (2 – 63 µm)
- Higher levels are observed in **spring** probably because of **lower degradation processes efficiency** resulting from **higher flow rates** *(Amalric et al., 2011)*, a **colder weather** *(Kim and Carlson, 2007)* and **higher organic matter inputs**

Conclusions

- ✓ **All investigated compounds presented an affinity with the particulate phase and mixture observed in bed-load sediments collected at discharging sites reflected the dissolved phase content**



- ✓ **Degradation processes play a role in compounds abundance but releasing rates and compounds solubilities were the major factors driving compounds sorption**
- ✓ **Neutral compounds were predominant because of higher releasing rates and persistence**
- ✓ **Organic matter is the main bearing phase as clay grain sizes were very low, promoting hydrophic interactions**
- ✓ **Hydrophobic interactions seem lower for anionic compounds and in addition to ionic ones for cationic compounds**
- ✓ **Spatial distribution in suspended particulate matter mainly reflect sources contributions but this fraction have a good transportation capacity at a catchment scale**
- ✓ **Spatial distribution in sediments is linked to discharging site and the sedimentary dynamic of the watercourse depending on compounds bearing phases**

Perspectives / suggestions

- ✓ **Further investigations will be needed to demonstrate :**

  - If sorption processes are different between a dynamic environment like in suspended particulate matter and a stagnant one like in bed-load sediments

  - If the Kd coefficient can highlight different kinds of interactions contributing to compounds sorption

- ✓ **The Egoutier stream can be a good opportunity to observe the particulate content and evolution for other groups of compounds**

- ✓ **The Beulie pond can be a perfect candidate to investigate the archive of contamination levels temporal evolution as it is present since centuries**

References

Amalric, L., Togola, A., & Lopez, B. (2011). Suivi des résidus de substances pharmaceutiques dans les systèmes aquatiques du bassin Loire-Bretagne. Rapport final. BRGM/RP-59371-FR.

Berger, G., Desprez, N. (1969). Carte de France (1/50 000), "Orléans (363)". BRGM, Orléans.

Bouvier, M., Durand, F., & Guillet, R. (2010). Médicament et environnement: La régulation du médicament vis-à-vis du risque environnemental. Conseil général de l'Environnement et du Développement durable, 007058-01.

Da Silva, B. F., Jelic, A., López-Serna, R., Mozeto, A. A., Petrovic, M., & Barceló, D. (2011). Occurrence and distribution of pharmaceuticals in surface water, suspended solids and sediments of the Ebro river basin, Spain. Chemosphere, 85(8), 1331-1339.

Dobor, J., Varga, M., & Záray, G. (2012). Biofilm controlled sorption of selected acidic drugs on river sediments characterized by different organic carbon content. Chemosphere, 87(2), 105-110.

Fairbairn, D. J., Karpuzcu, M. E., Arnold, W. A., Barber, B. L., Kaufenberg, E. F., Koskinen, W. C., Novak, P. J., Rice, P. J., & Swackhamer, D. L. (2015). Sediment–water distribution of contaminants of emerging concern in a mixed use watershed. Science of the total environment, 505, 896-904.

Halling-Sørensen, B. N. N. S., Nielsen, S. N., Lanzky, P. F., Ingerslev, F., Lützhøft, H. H., & Jørgensen, S. (1998). Occurrence, fate and effects of pharmaceutical substances in the environment-A review. Chemosphere, 36(2), 357-393.

Inglada, J., Vincent, A., Thierion, V. (2017). Theia OSO Land Cover Map 2106 [Data set]. Zenodo.

Jjemba, P. K. (2006). Excretion and ecotoxicity of pharmaceutical and personal care products in the environment. Ecotoxicology and environmental safety, 63(1), 113-130.

Kim, S. C., & Carlson, K. (2007). Temporal and spatial trends in the occurrence of human and veterinary antibiotics in aqueous and river sediment matrices. Environmental science & technology, 41(1), 50-57.

Klaminder, J., Brodin, T., Sundelin, A., Anderson, N. J., Fahlman, J., Jonsson, M., & Fick, J. (2015). Long-term persistence of an anxiolytic drug (oxazepam) in a large freshwater lake. Environmental Science & Technology, 49(17), 10406-10412.

Loos, R., Gawlik, B. M., Locoro, G., Rimaviciute, E., Contini, S., & Bidoglio, G. (2009). EU-wide survey of polar organic persistent pollutants in European river waters. Environmental pollution, 157(2), 561-568.

Martínez-Hernández, V., Meffe, R., Herrera, S., Arranz, E., & de Bustamante, I. (2014). Sorption/desorption of non-hydrophobic and ionisable pharmaceutical and personal care products from reclaimed water onto/from a natural sediment. Science of the total environment, 472, 273-281.

Maskaoui, K., & Zhou, J. L. (2010). Colloids as a sink for certain pharmaceuticals in the aquatic environment. Environmental Science and Pollution Research, 17(4), 898-907.

Munoz, J. F. (2009). Résidus de médicaments dans les milieux aquatiques: besoins et outils pour la surveillance, évaluation des risques. Rapport Onema.

Petrie, B., Barden, R., & Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. Water research, 72, 3-27.

Scheytt, T., Mersmann, P., Lindstädt, R., & Heberer, T. (2005). Determination of sorption coefficients of pharmaceutically active substances carbamazepine, diclofenac, and ibuprofen, in sandy sediments. Chemosphere, 60(2), 245-253.

Simonneau, A., Simonneau, J., Hatton, M. (2020) GranulomEtric pAssive Capture of dissOlved matter & Sediment (GEACOS), Zenodo.

Soucémarianadin L., Verbèque, B. (2007). Notice explicative de la carte des sols de Orléans (1/50 000). Chambre d'argriculture du Loiret, Orléans.

Stein, K., Ramil, M., Fink, G., Sander, M., & Ternes, T. A. (2008). Analysis and sorption of psychoactive drugs onto sediment. Environmental science & technology, 42(17), 6415-6423.

Svahn, O., & Björklund, E. (2015). Describing sorption of pharmaceuticals to lake and river sediments, and sewage sludge from UNESCO Biosphere Reserve Kristianstads Vattenrike by chromatographic asymmetry factors and recovery measurements. Journal of chromatography A, 1415, 73-82.

Verlicchi, P., Galletti, A., Petrovic, M., & Barceló, D. (2010). Hospital effluents as a source of emerging pollutants: an overview of micropollutants and sustainable treatment options. Journal of Hydrology, 389(3-4), 416-428.

Yamamoto, H., Nakamura, Y., Moriguchi, S., Nakamura, Y., Honda, Y., Tamura, I., Hirate, Y., **Hayashi**, A., & Sekizawa, J. (2009). Persistence and partitioning of eight selected pharmaceuticals in the aquatic environment: laboratory photolysis, biodegradation, and sorption experiments. Water research, 43(2), 351-362.

Zhou, J., & Broodbank, N. (2014). Sediment-water interactions of pharmaceutical residues in the river environment. Water research, 48, 61-70.