The fate of non-conventional stormwater pollutants in bioretention systems: microplastics, benzotriazole and more

Jennifer Drake[1] & Elodie Passeport[1,2]

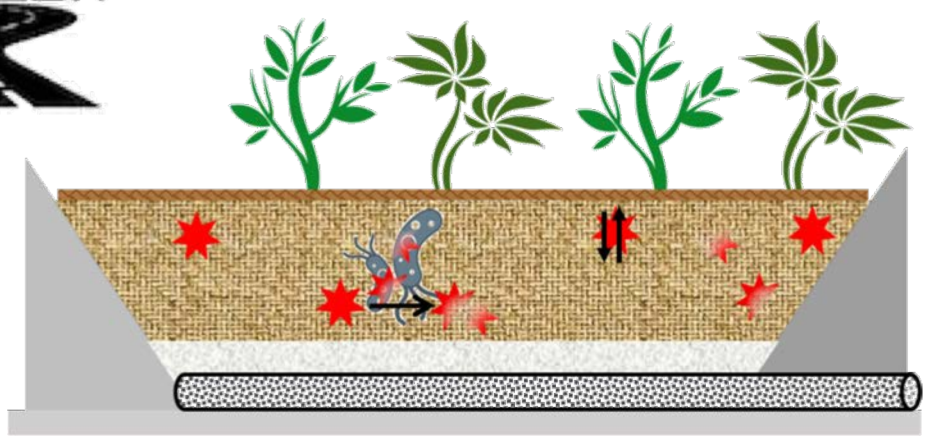
[1] Civil & Mineral Engineering

[2] Chemical Engineering & Applied Chemistry

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Introduction

BIORETENTION CELLS



CONTAMINANTS

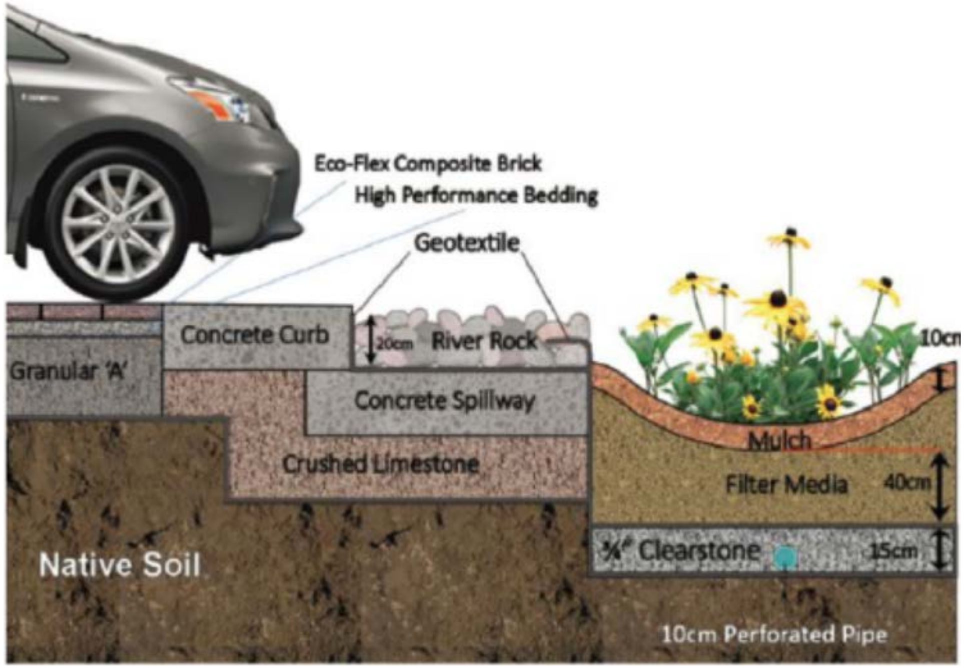
Conventional

- N, P, TSS
- Heavy metals, PAHs

Unconventional

- Trace polar organic contaminants
- Microplastics

Bioretention cell site



- Kortright Centre for Conservation, Vaughan, ON
- Started operation in 2013
- Drainage Area (parking lot) = **265 m²**
- Infiltration Surface Area = **30 m²**

Toronto and Region Conservation for The Living City

Spraakman et al. (2020) *Ecol. Eng.*

Field-scale performance

Ecological Engineering 158 (2020) 106036

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

ELSEVIER

How has it changed? A comparative field evaluation of bioretention infiltration and treatment performance post-construction and at maturity

Sylvie Spraakman[a], Tim Van Seters[b], Jennifer Drake[a], Elodie Passeport[a,c,*]

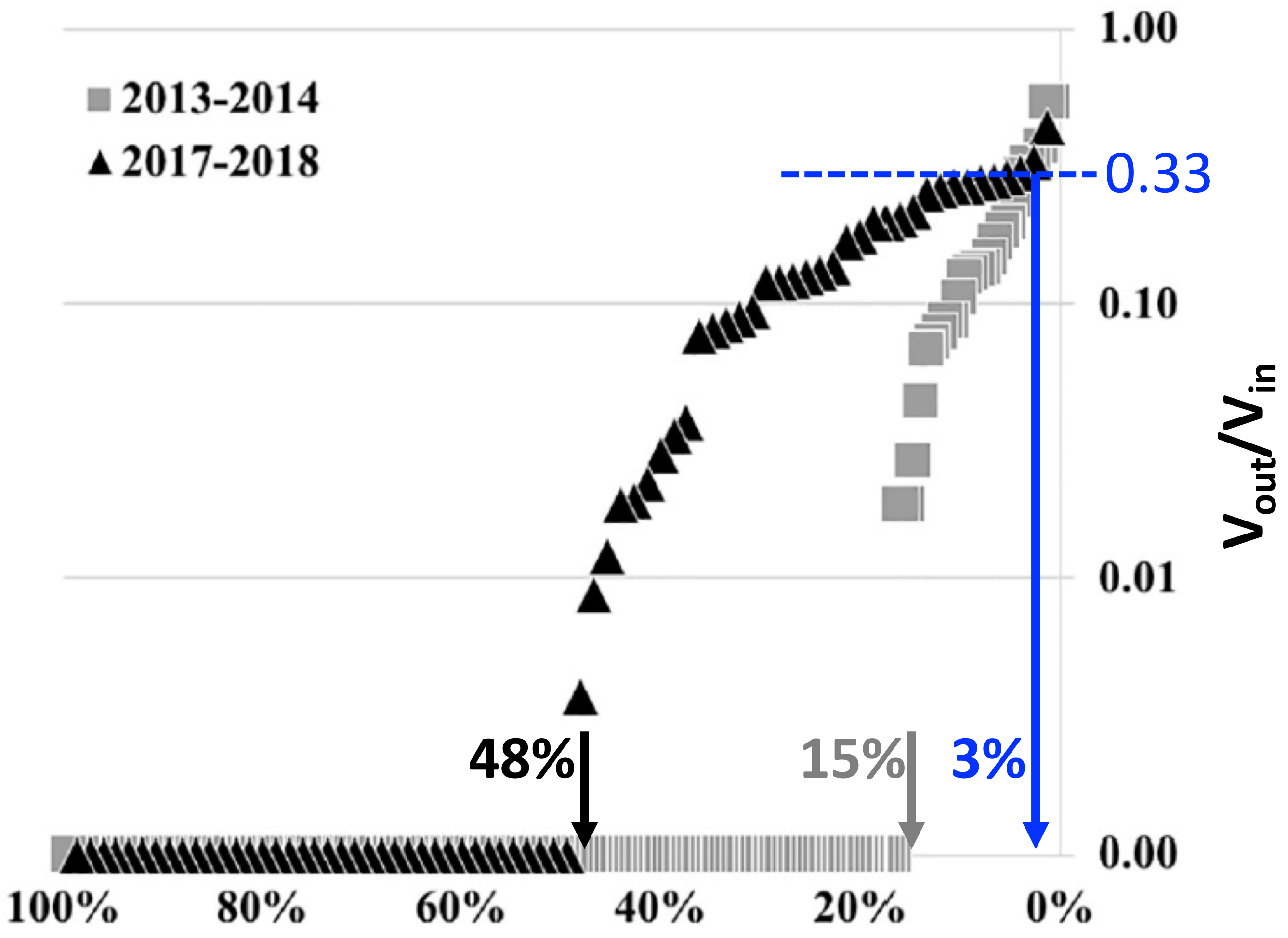
[a] Civil and Mineral Engineering, University of Toronto, 35 St George Street, Toronto, ON M5S 1A4, Canada
[b] Toronto and Region Conservation Authority, Sustainable Technologies Evaluation Program, 101 Exchange Avenue, Vaughan, ON L4K 5R6, Canada
[c] Chemical Engineering and Applied Chemistry, University of Toronto, 200 College Street, Toronto, ON M5S 3E5, Canada

Inlet vs outlet performance 2017-2018

Spraakman et al. (2020) *Ecol. Eng.*

Field-scale performance

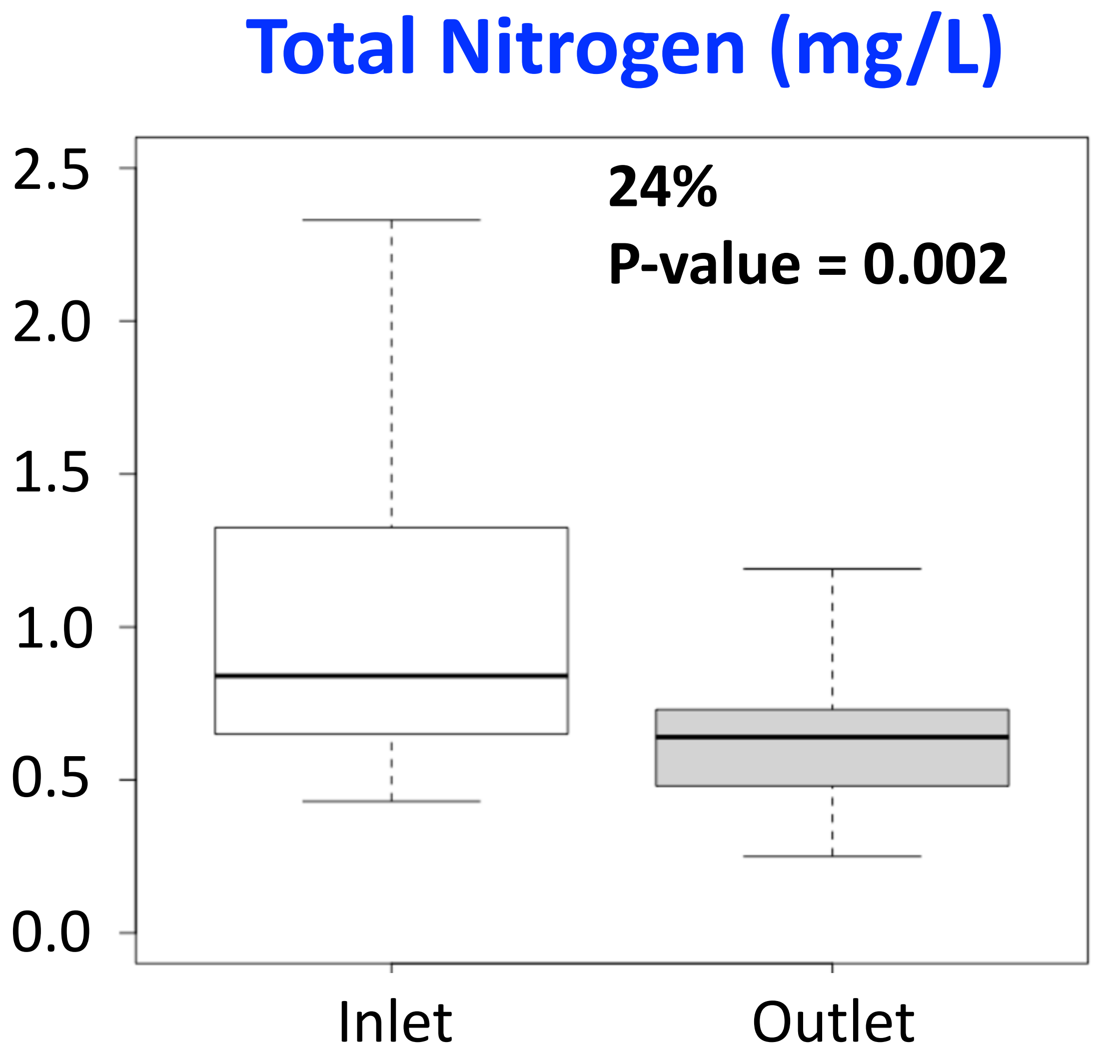
Hydrology

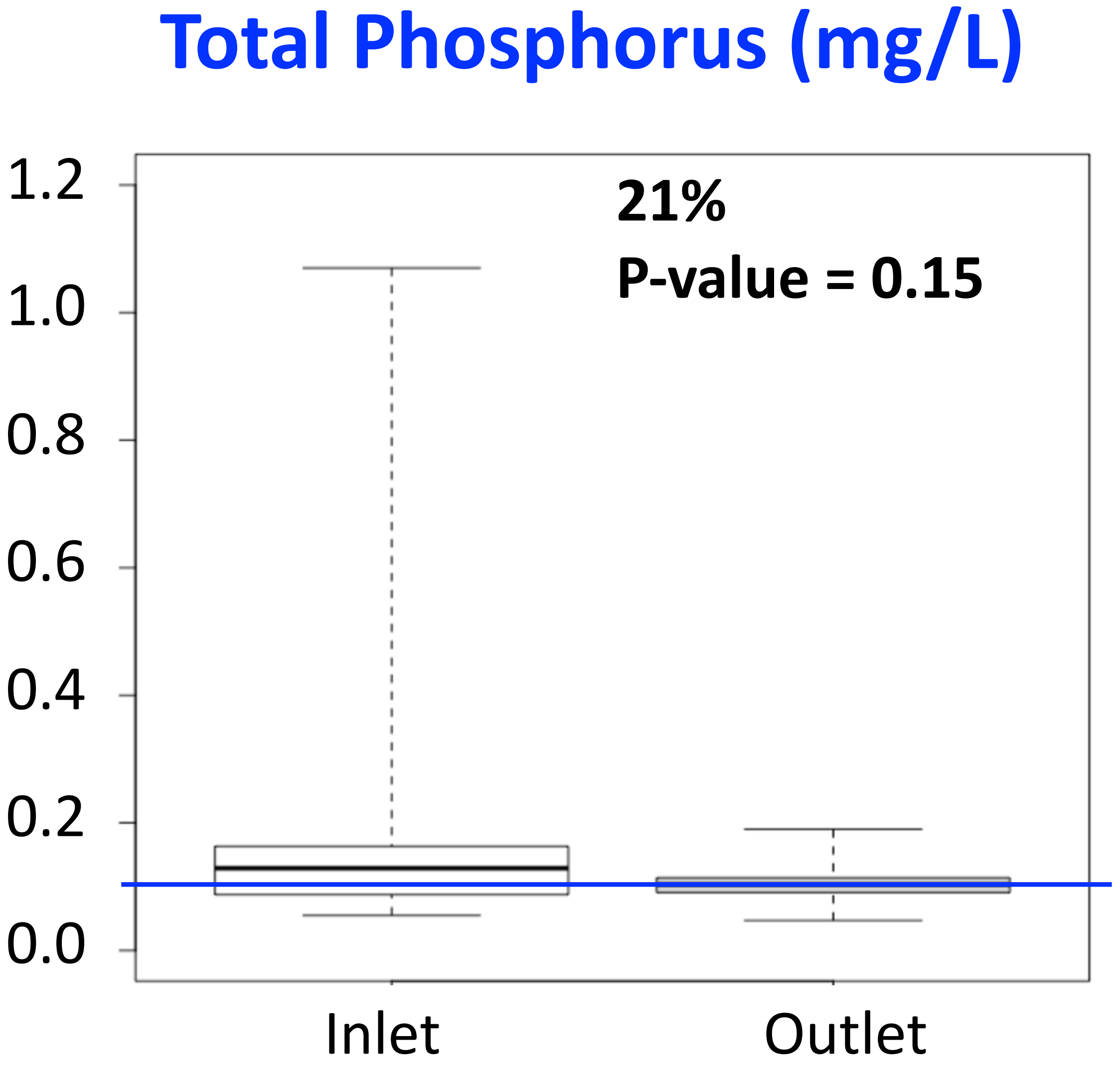


- Good hydrology performance over years
- High water volume reduction
- High contaminant mass reduction

Spraakman et al. (2020) *Ecol. Eng.*

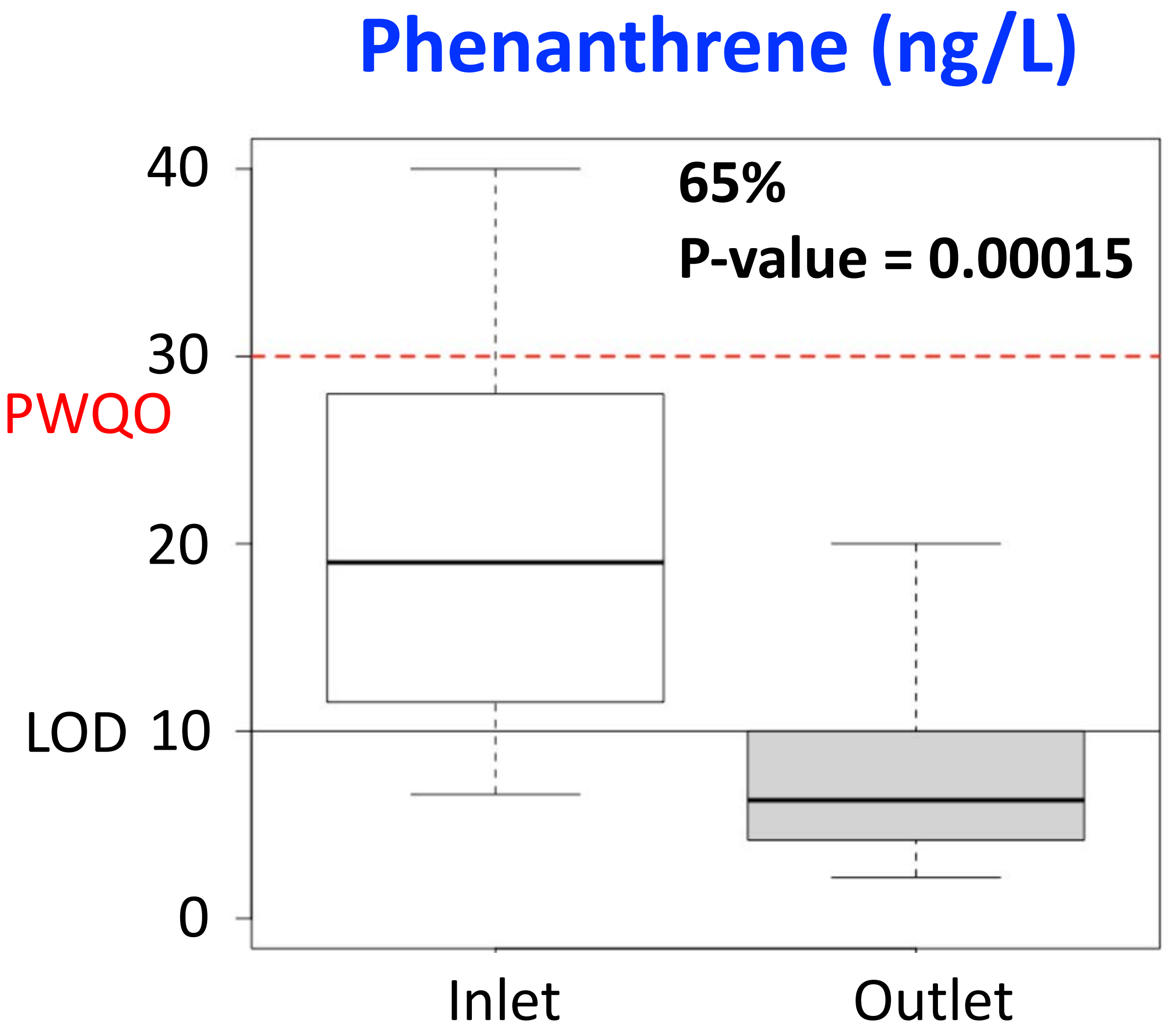
Field-scale performance

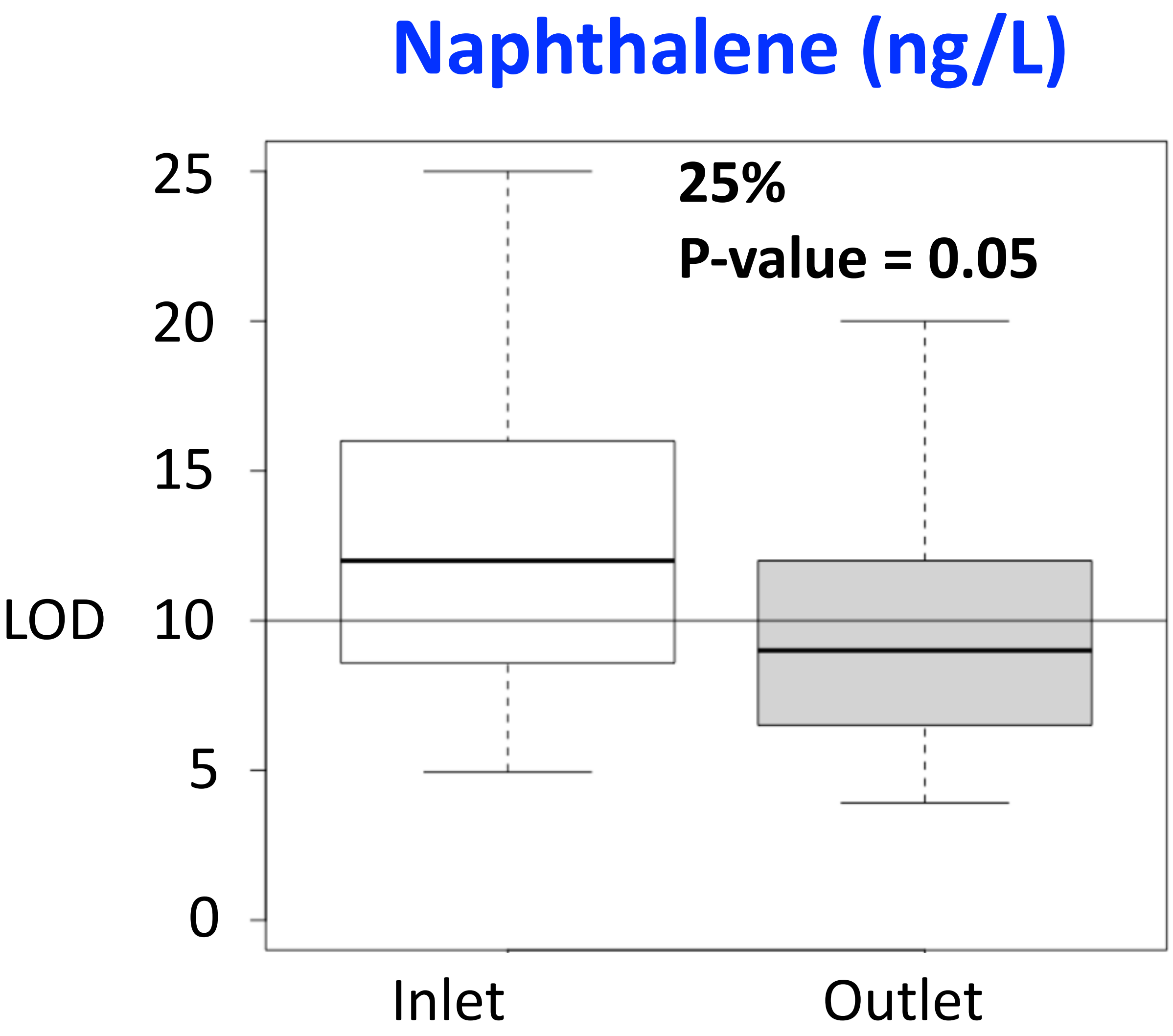




Spraakman et al. (2020) *Ecol. Eng.*

Field-scale performance





Spraakman et al. (2020) *Ecol. Eng.*

Field-scale performance

Take-home messages

- **Very high volume and load reductions**

- **Low efficiency for nutrient concentration reduction**

→Needs design/operation optimization

- **Working well for PAHs: apolar trace organic contaminants**

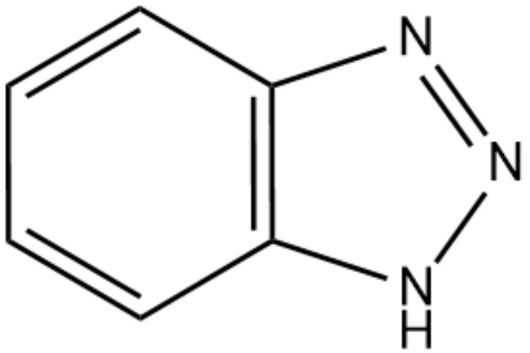
→How about polar trace organic contaminants?

Example: Benzotriazole

Spraakman et al. (2020) *Ecol. Eng.*

Benzotriazole

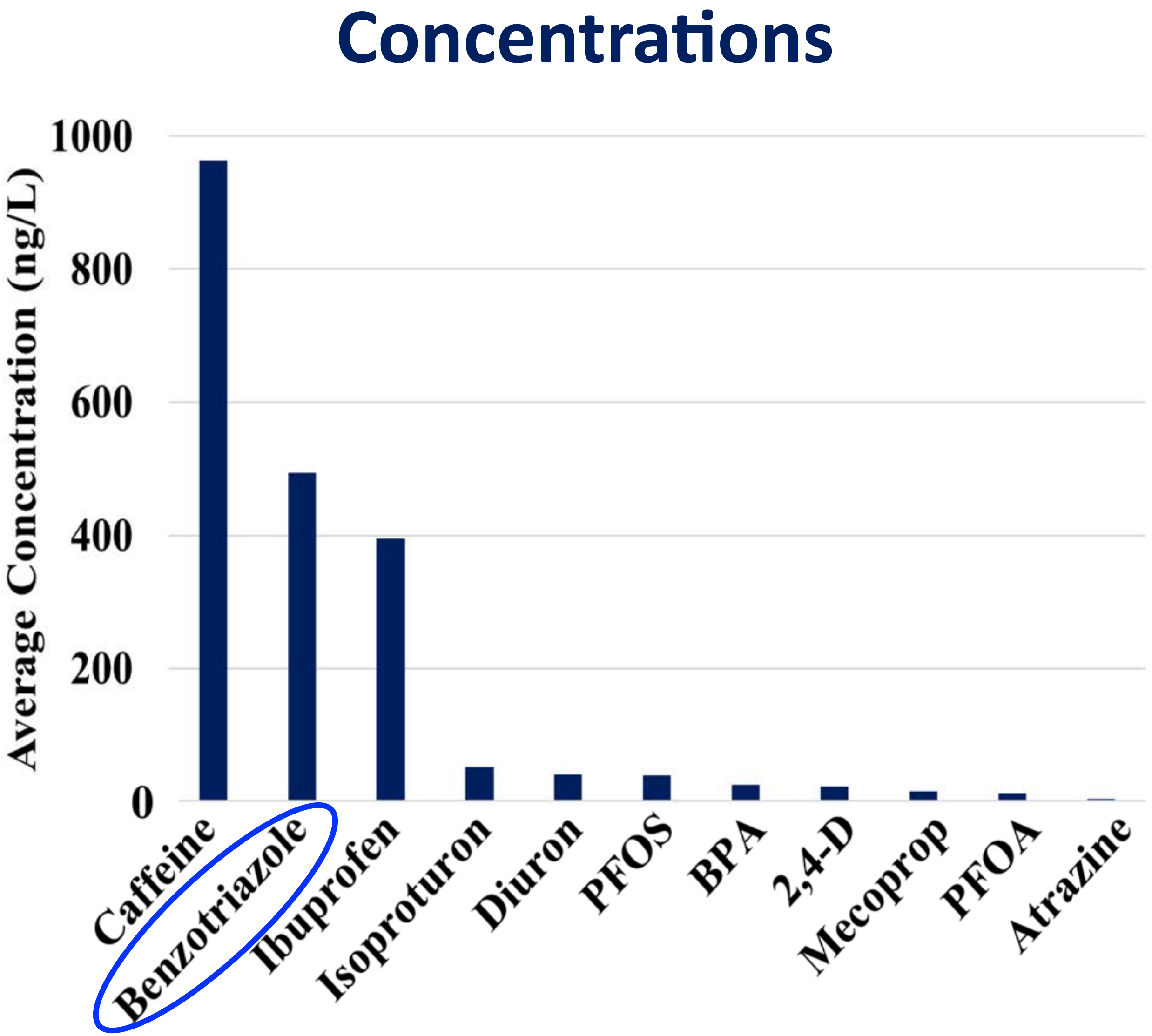
- **Corrosion inhibitor**
  - Antifreeze liquids
  - De-icer fluids
  - Dishwashing detergents

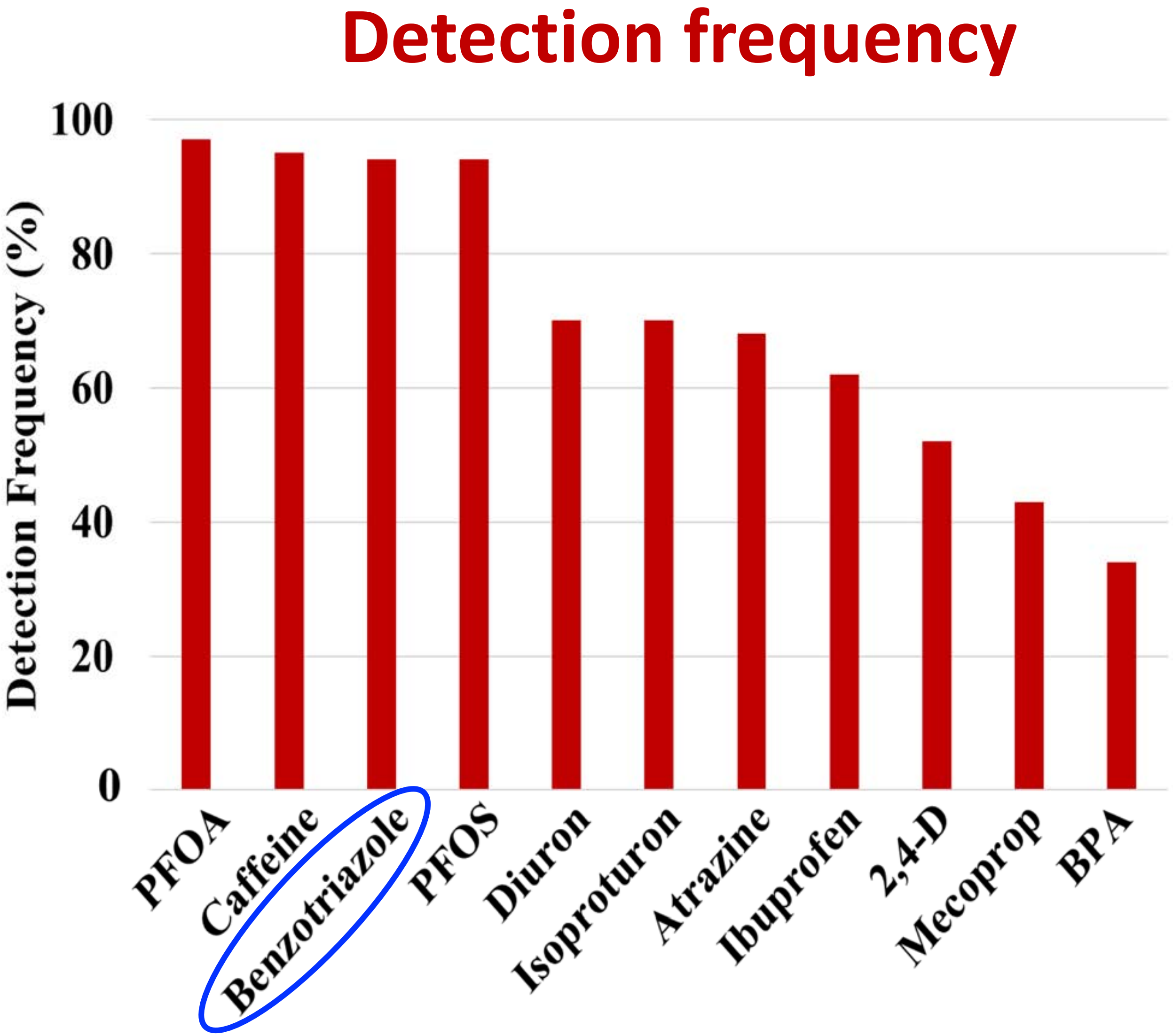


Solubility = 20 g/L
pKa = 8.4
log Kow = 1.2-1.4

W. Giger et al. (2006). *Environ. Sci. Technol., 40*(23), 7186–7192.

Benzotriazole in European Rivers





R. Loos et al. (2009). *Environ. Pollut.*, *157*, 561–568.

Benzotriazole

- **Toxicity**
  - Acutely toxic at low mg/L levels
  - Suspect human carcinogen (NH)
  - Affects physiological responses
- **Environmental persistence**
  - Low removal in WWTPs
  - Slow biodegradation
  - Weak adsorption properties

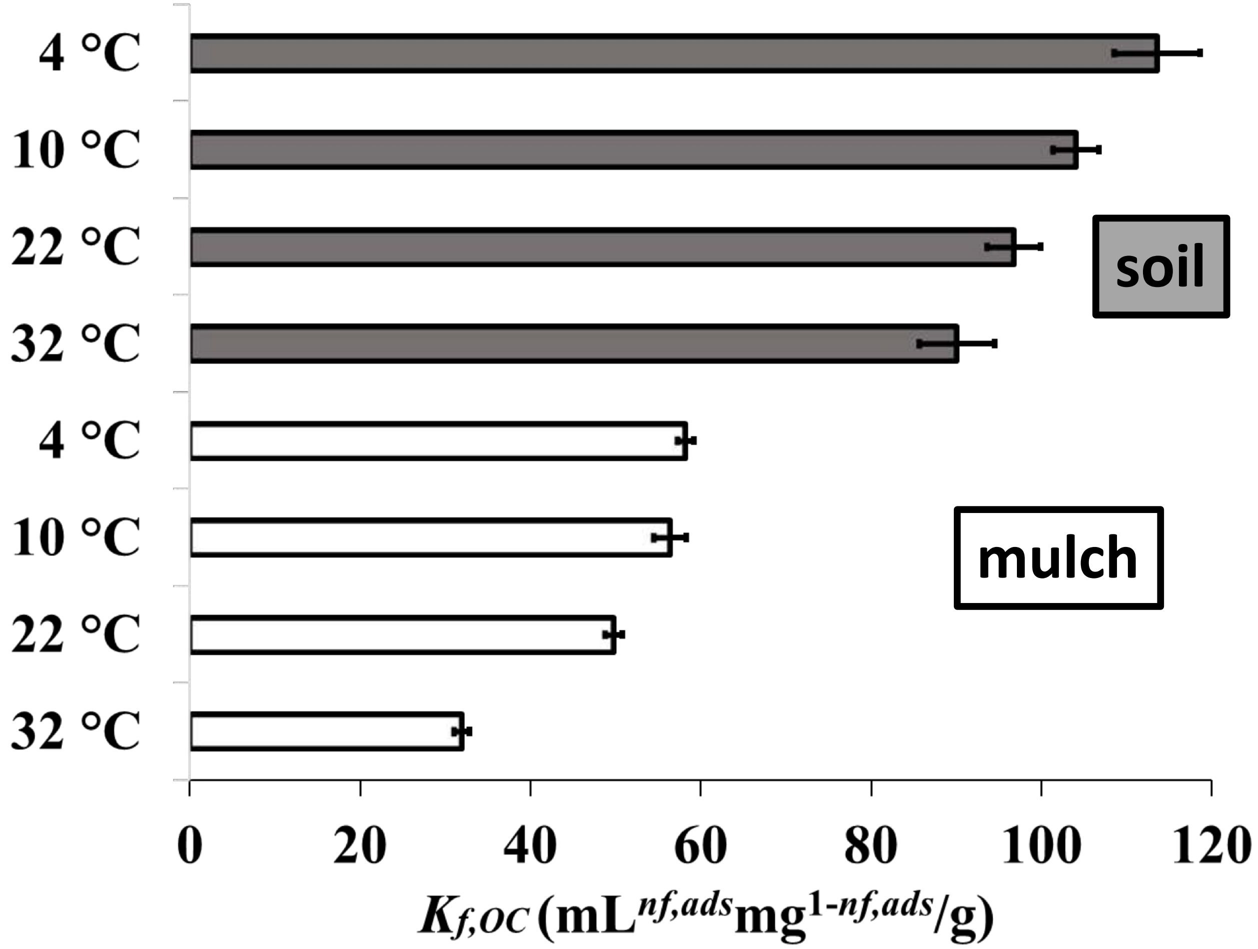
Alters molting in D. magna at 2 µg/L

Liver hypertrophy after 30 d at 600 µg/L

A. Seeland et al. (2012). *Environ. Sci. Pollut. Res., 19*(5), 1781-1790; SRC Inc.: http://esc.syrres.com/fatepointer/search.asp; Duan et al. (2017). *Environ. Poll.*, 224:706-713

Benzotriazole adsorption and desorption

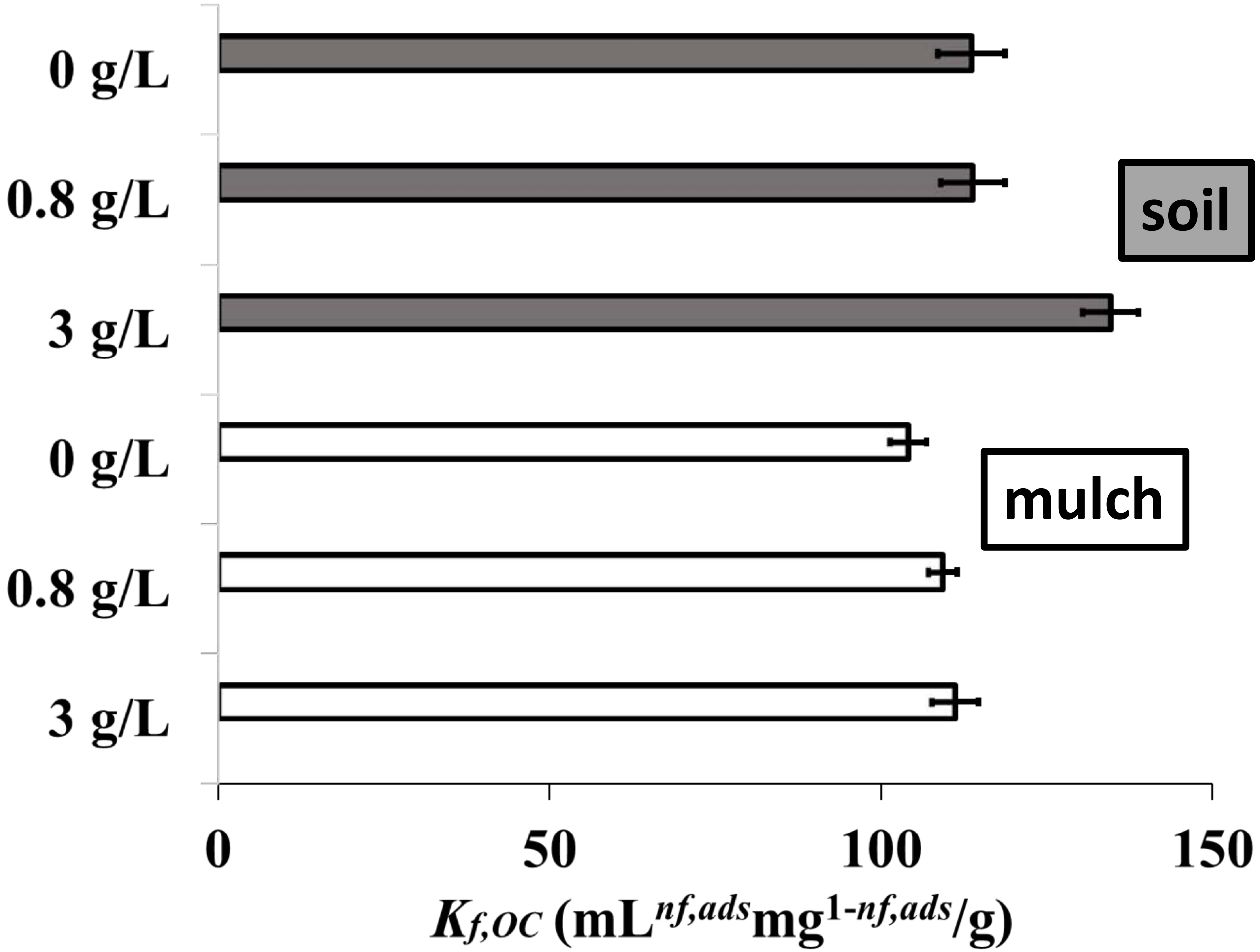
- **Temperature**
  - Adsorption soil > mulch
  - Adsorption ↗ when temperature ↘



Rhodes Dicker and Passeport (2019) *Ecol. Eng.*

Benzotriazole adsorption and desorption

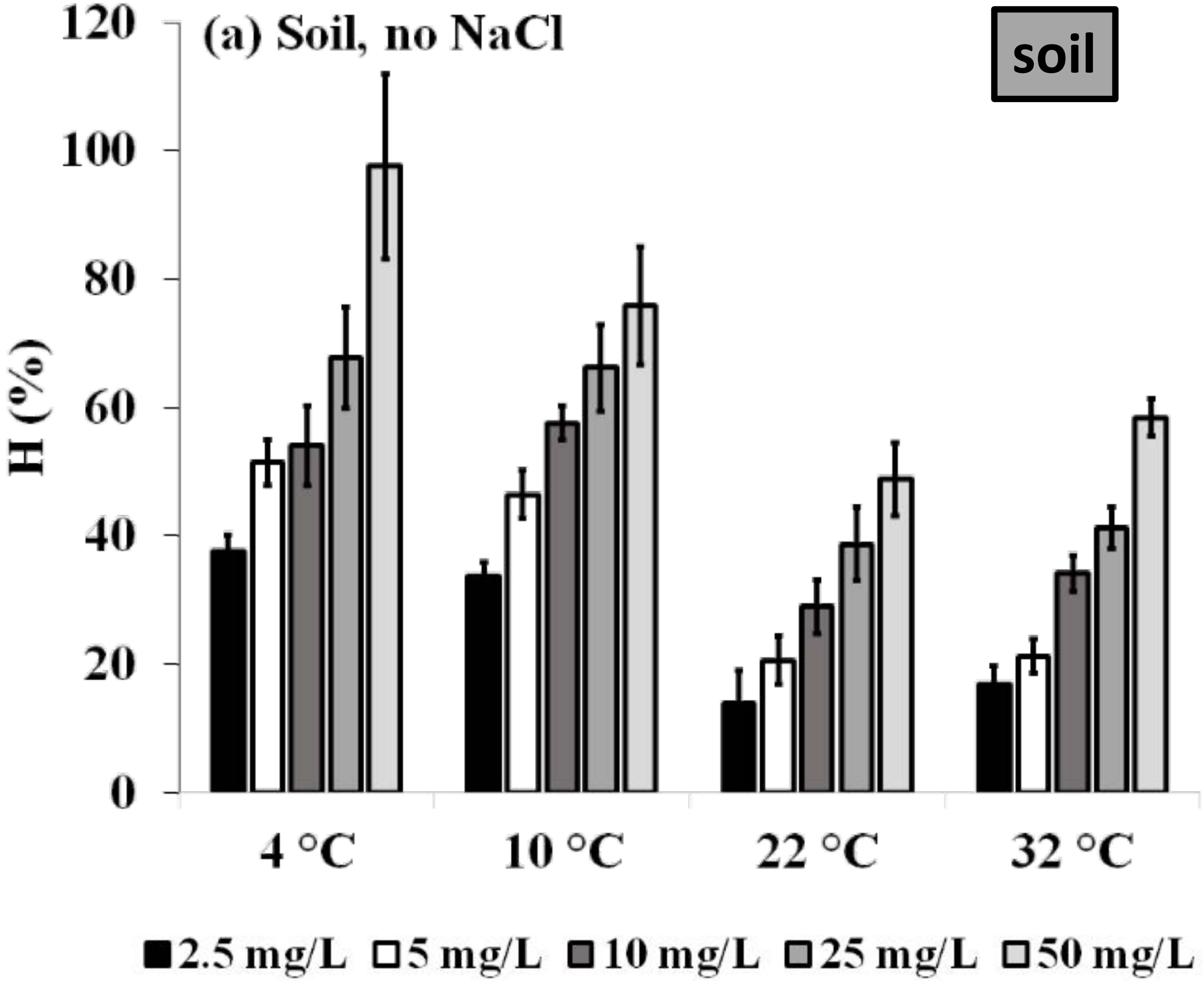
- **Temperature**
  - Adsorption soil > mulch
  - Adsorption ↗ when temperature ↘
- **Salinity**
  - Adsorption slightly ↗ with salt



Rhodes Dicker and Passeport (2019) *Ecol. Eng.*

Benzotriazole adsorption and desorption

- **Temperature**
  - Adsorption soil > mulch
  - Adsorption ↗ when temperature ↘
- **Salinity**
  - Adsorption slightly ↗ with salt
- **Concentration**
  - Less desorption at low concentration



Rhodes Dicker and Passeport (2019) *Ecol. Eng.*

Benzotriazole adsorption and desorption

Take-home messages

- **At environmentally-relevant concentrations:**

→Benzotriazole can adsorb more strongly under cold climate conditions

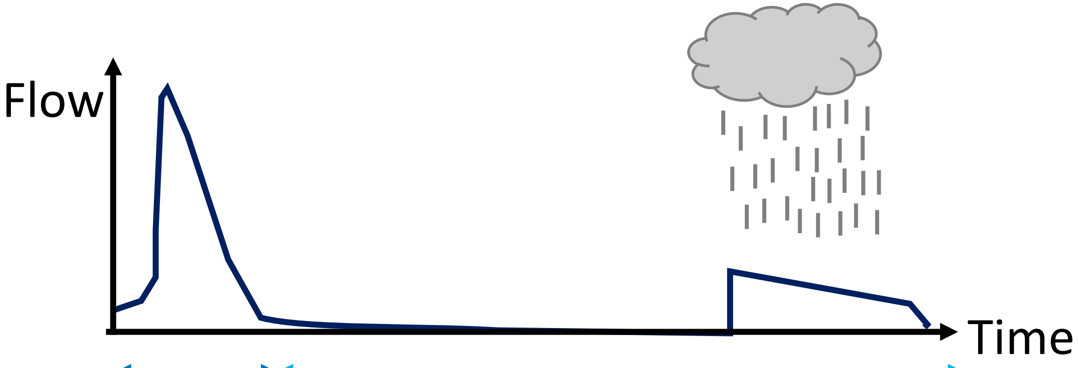
- **Bioretention cells**

→Can retain benzotriazole

→Could retain it even more with amendments

Rhodes Dicker and Passeport (2019) *Ecol. Eng.*

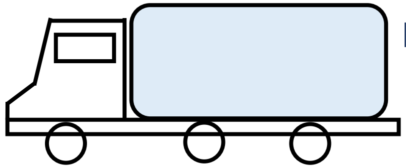
Contaminants’ fate in full-scale bioretention

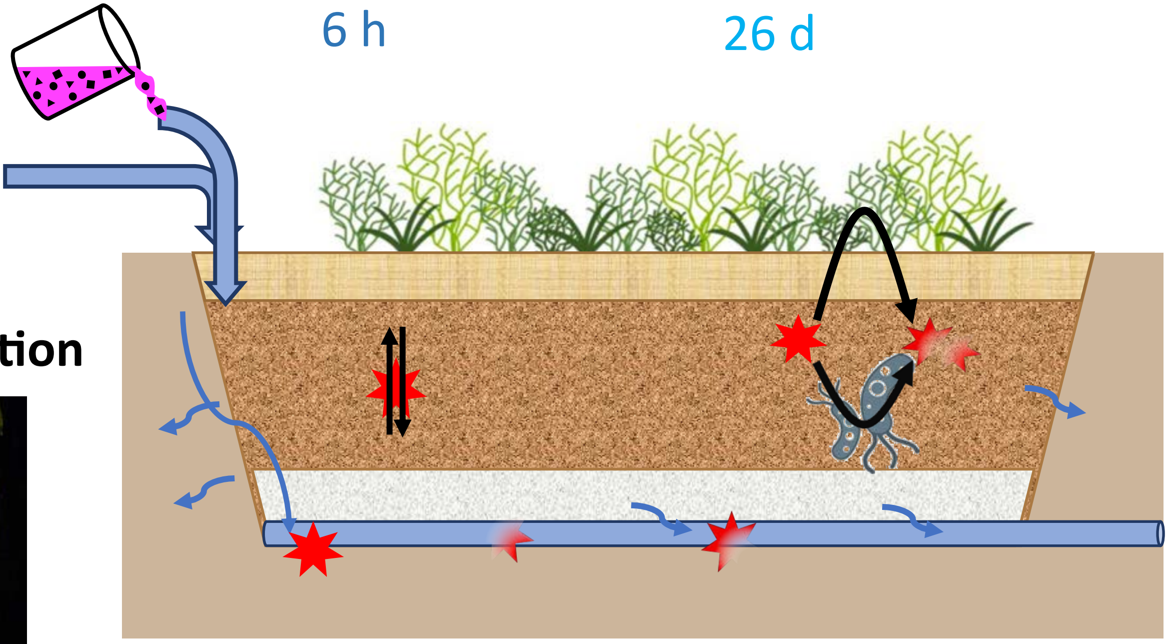


During event	In-between events
6 h	26 d

② **Pulse injection of tracer mixture**

- Br, N, P, OPEs
- Rhodamine WT
- Benzotriazole

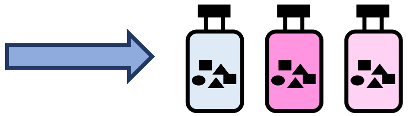




① **Continuous water injection**

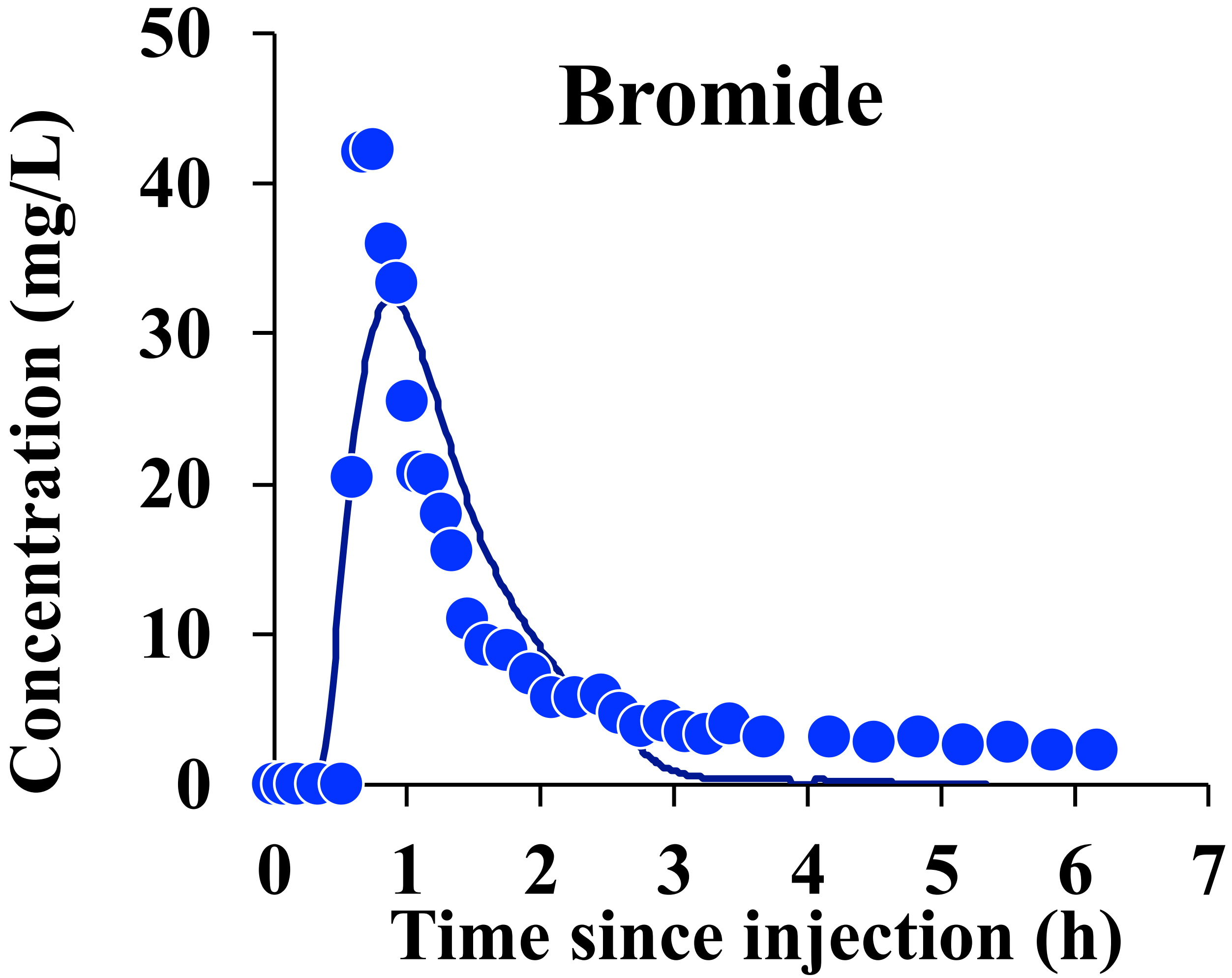
③ **Sample collection of the outflow**

every 5 to 30 min



Parent & Transformation products

Contaminants’ fate in full-scale bioretention



Recovery: 81 – 96%

Retention time: 1.8 h

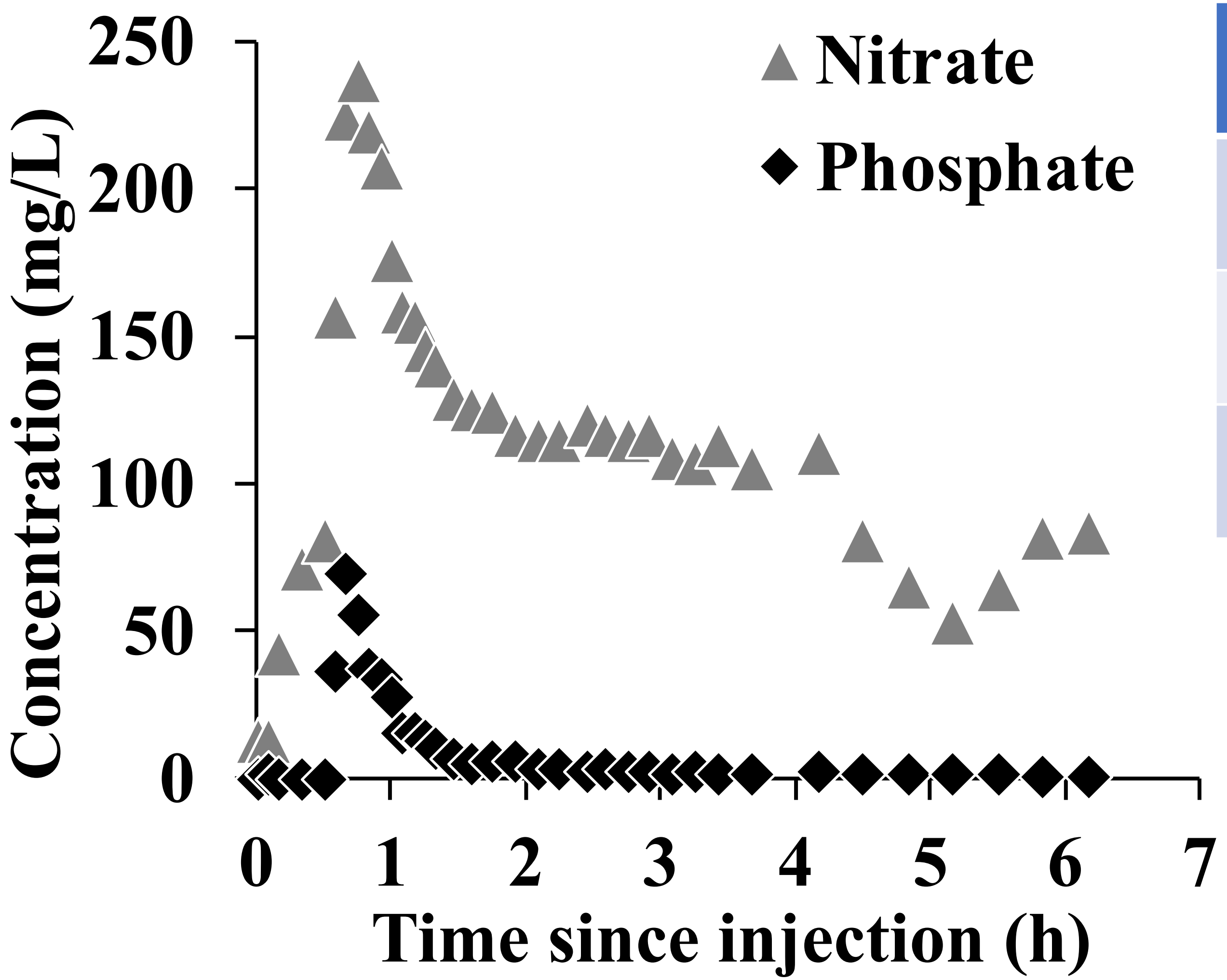
Effective volume ratio: 0.3

Fast infiltration

Dead volumes

Gu et al. (Revisions submitted) *ES&T*

Contaminants' fate in full-scale bioretention



	NO_3^-	PO_4^{3-}
Recovery	62%	52%
Retention time	2.5h	1.5 h
Composition	68% of TN	All of TP

➔ Moderate losses

➔ Organic N + NH_4^+

➔ 40% P adsorption

Gu et al. (Revisions submitted) *ES&T*

Nutrients' fate in full-scale bioretention

Take-home messages

- **Pathways**

→Moderate P adsorption

→Microbial transformation of N

→Plant uptake

- **Need strategies to optimize treatment**

→Hydraulics

→Keep plants

→Amendments

→Soil with low organic N content

→Anoxic conditions & bioavailable C

State-of-the-Art Review

Check for updates

ASCE

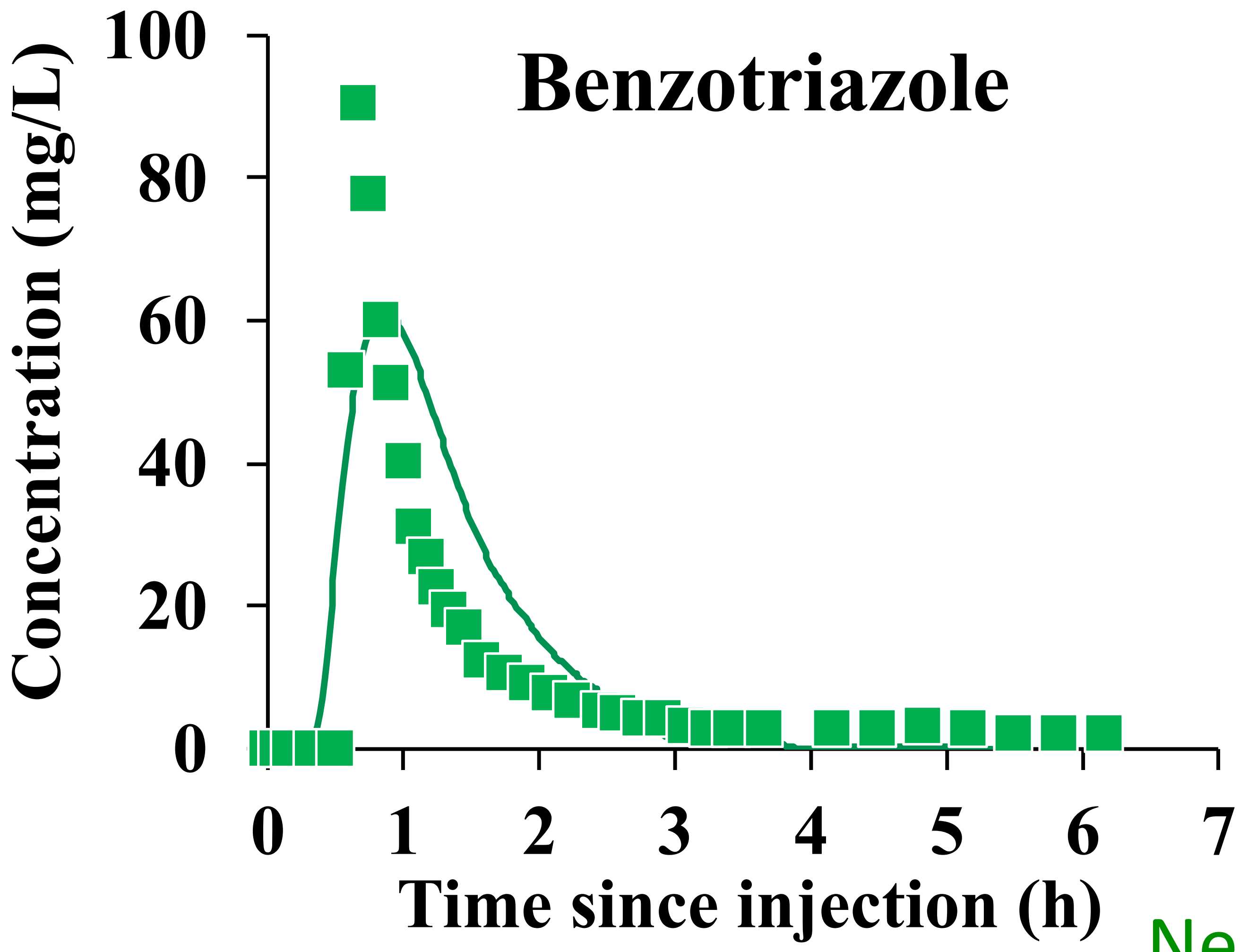
State-of-the-Art Review of Phosphorus Sorption Amendments in Bioretention Media: A Systematic Literature Review

Jeffrey T. Marvin[1]; Elodie Passeport[2]; and Jennifer Drake, M.ASCE[3]

Abstract: The ability of bioretention systems to treat phosphorus heavily depends on the filter media composition. Dissolved phosphorus is primarily removed from influent stormwater runoff through sorption processes, although the organic material contained within bioretention media can also leach phosphorus. Amendments containing sorptive metals such as aluminum, iron, and calcium have been introduced in recent years to increase the phosphorus sorption capacities and rates of bioretention media. This study is a state-of-the-art review that uses a systematic literature review process to identify, integrate, and critically evaluate the findings of all published column, mesocosm, and field studies identified from two database platforms that have provided quantitative analyses of phosphorus sorption amendments for bioretention systems. These amendment materials were grouped into four categories: (1) waste products, (2) natural materials, (3) processed materials, and (4) proprietary products. A total of 51 amendment materials or material combinations were evaluated across 59 studies, of which only four have been evaluated within a field setting (expanded slate, fly ash, Sorbtive Media, and aluminum-based water treatment residuals) and only one (fly ash) has been evaluated within an aged system. This study provides a detailed discussion on the performance, applicability, constructability, and operational challenges of phosphorus sorption amendments used in bioretention systems. Recommendations for amendment selection and installation methods are provided to support both engineering practice and future research on the topic. **DOI: 10.1061/JSWBAY.0000893.** *© 2019 American Society of Civil Engineers.*

Gu et al. (Revisions submitted) *ES&T;* Marvin, Passeport, Drake (2020) *J. Sustainable Water Built Environ.*

Benzotriazole's fate in full-scale bioretention



Recovery: 71 – 75%

Benzotriazole distribution

Soil: ~8.8%

Exfiltration: 16%

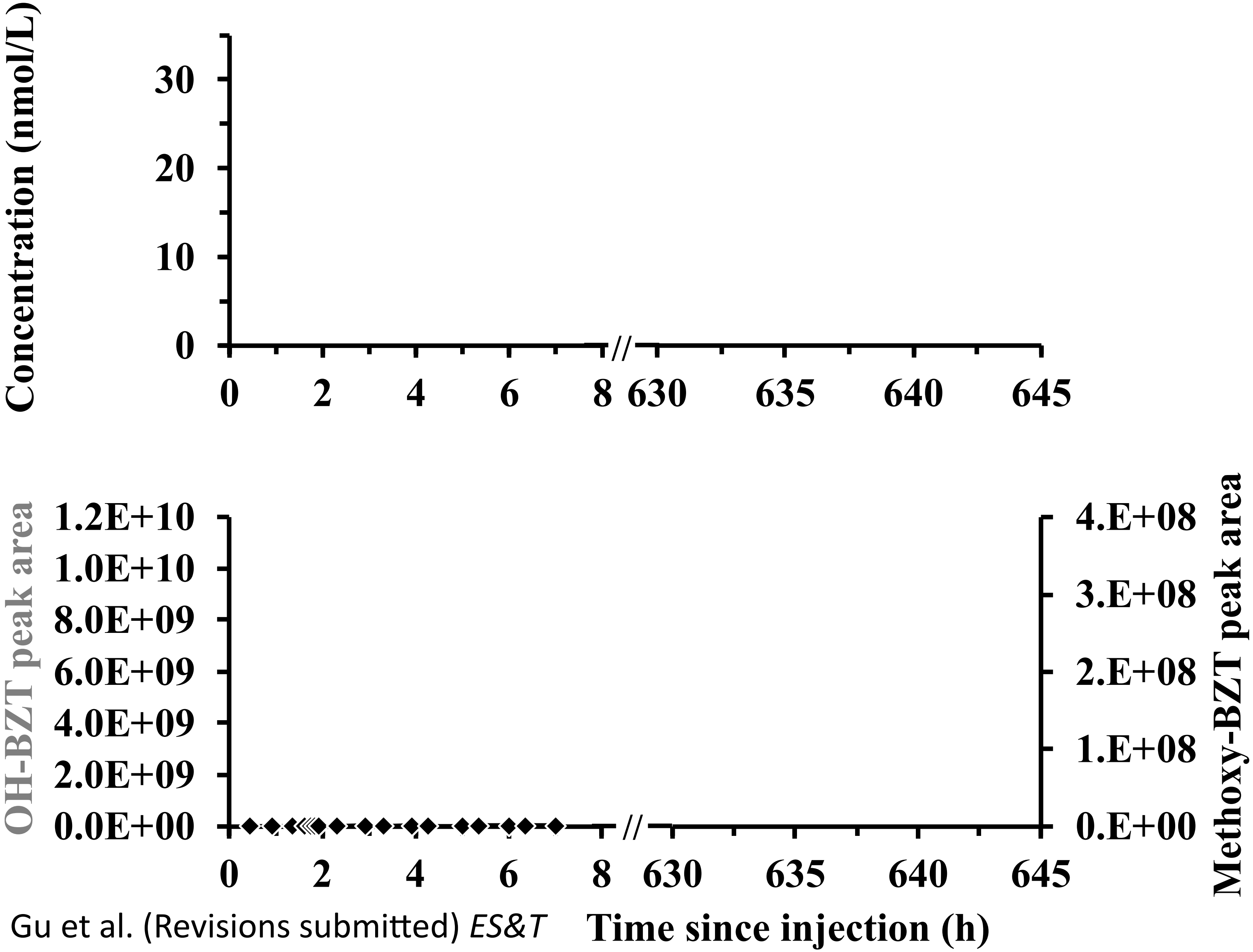
Transformation: 1%

Moderate sorption

Negligible transformation during test

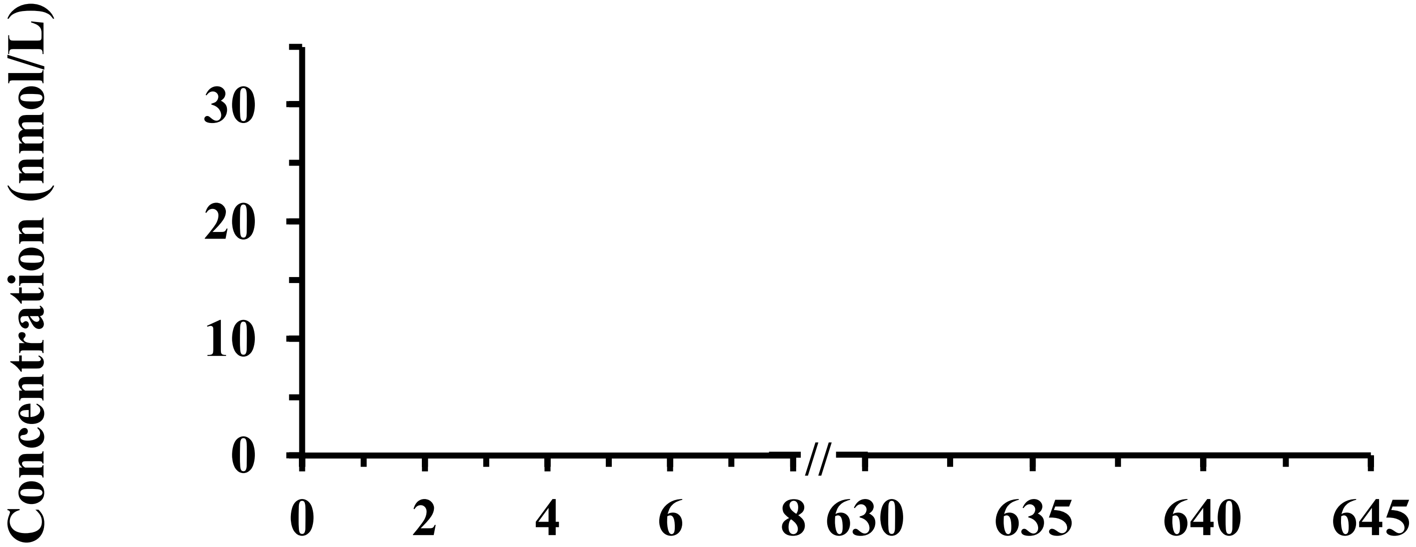
Gu et al. (Revisions submitted) *ES&T*

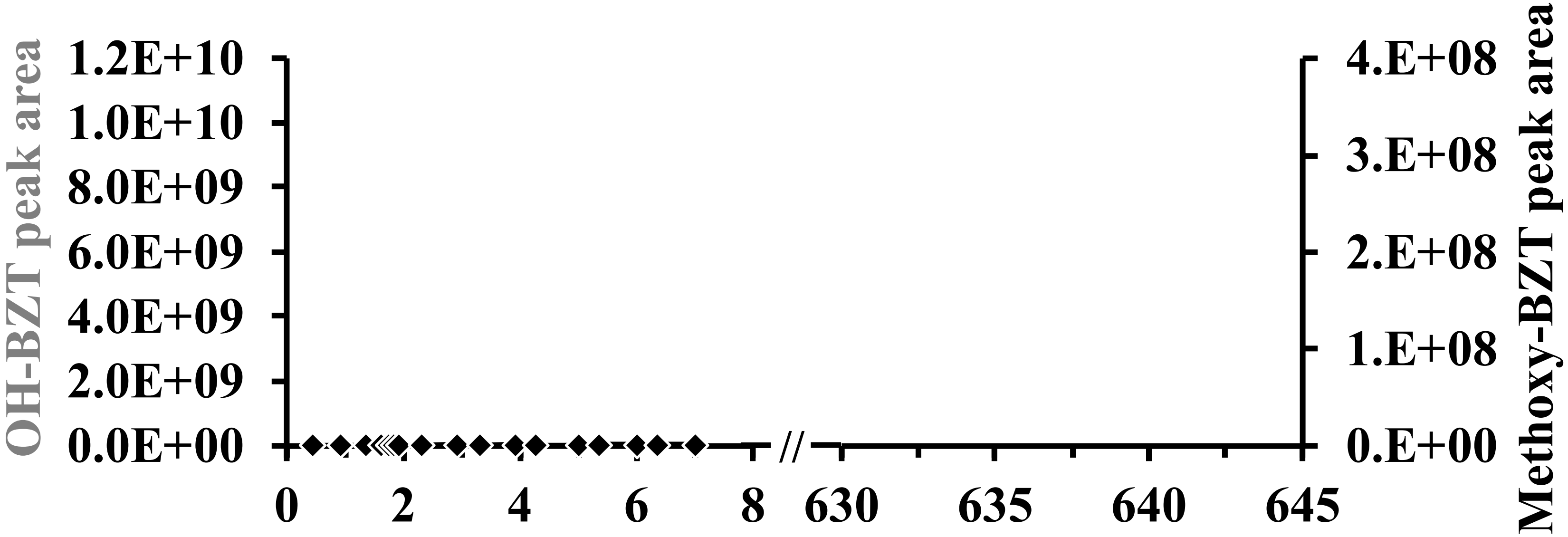
Benzotriazole's fate in full-scale bioretention



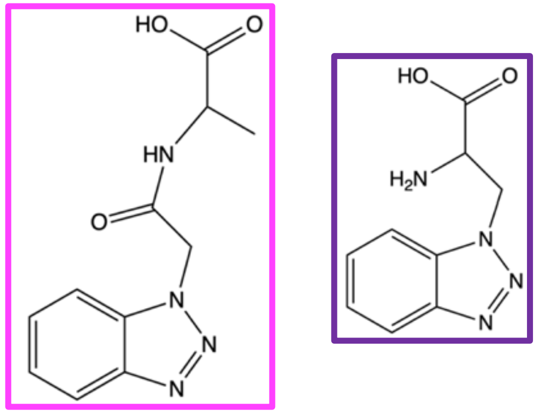
Gu et al. (Revisions submitted) *ES&T*

Benzotriazole's fate in full-scale bioretention

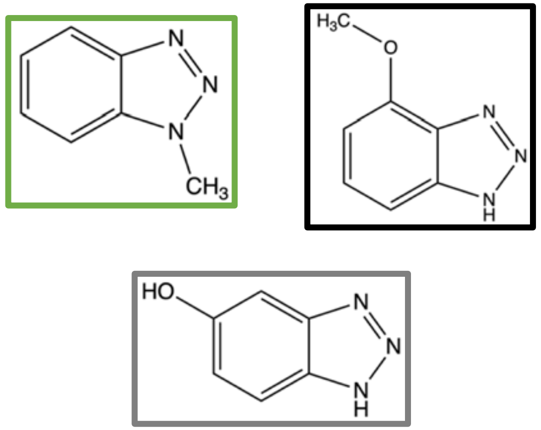




Phytotransformation

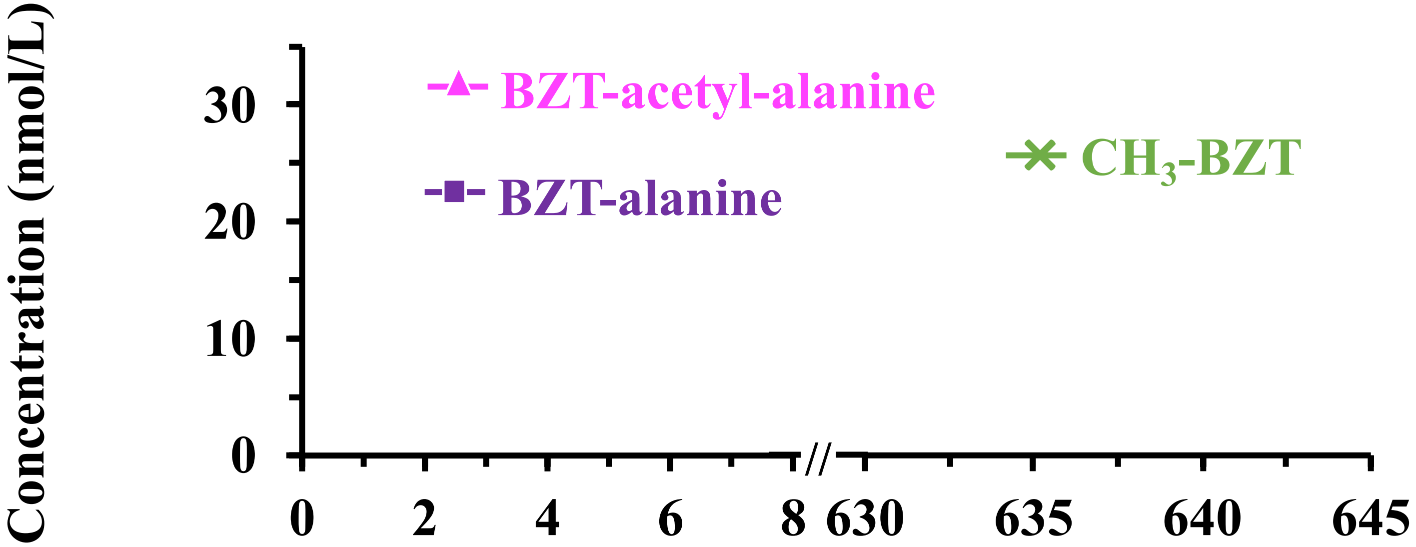


Microbial transformation

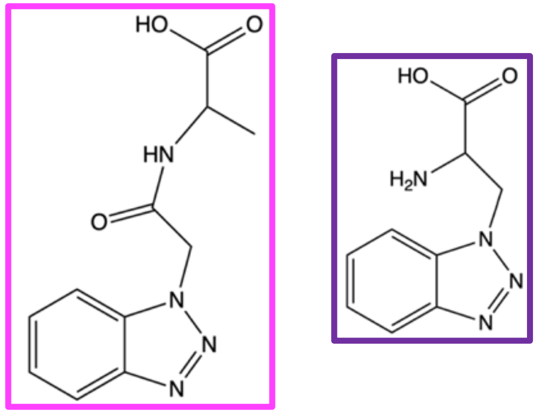


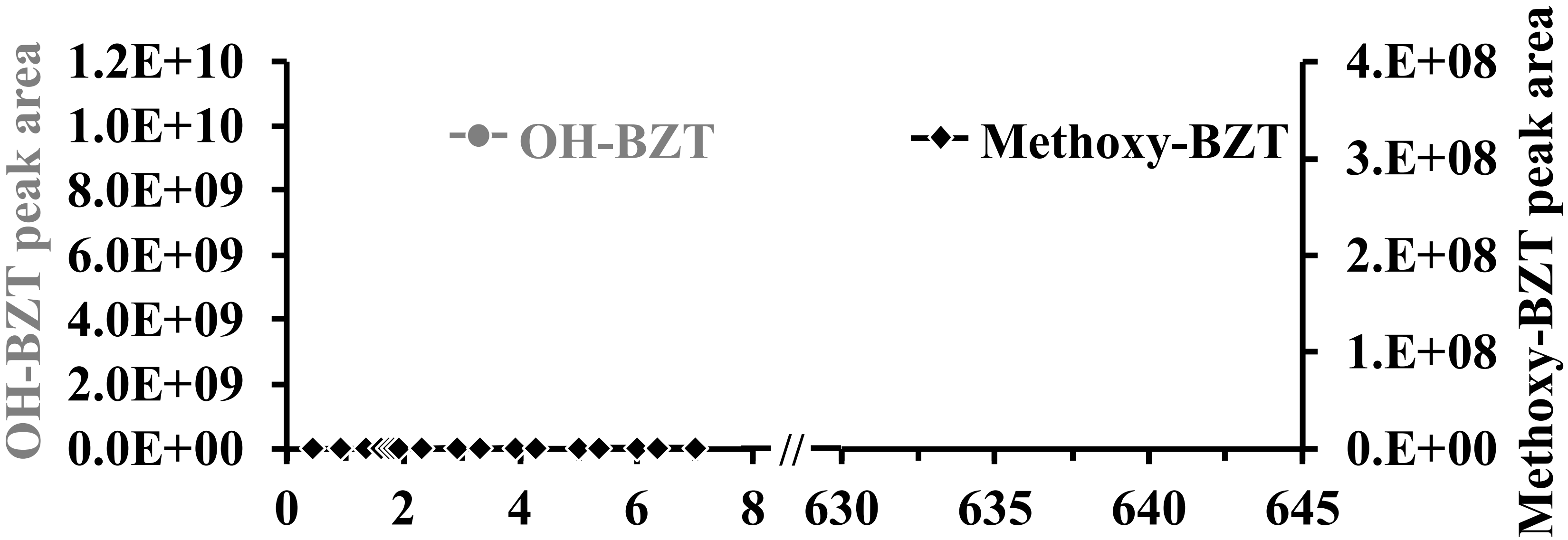
Gu et al. (Revisions submitted) *ES&T*

Benzotriazole's fate in full-scale bioretention

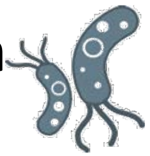


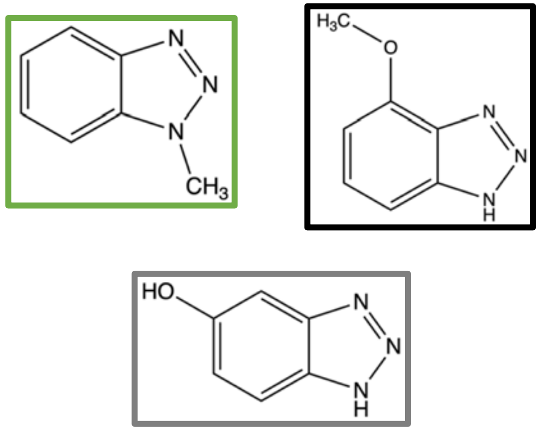
Phytotransformation





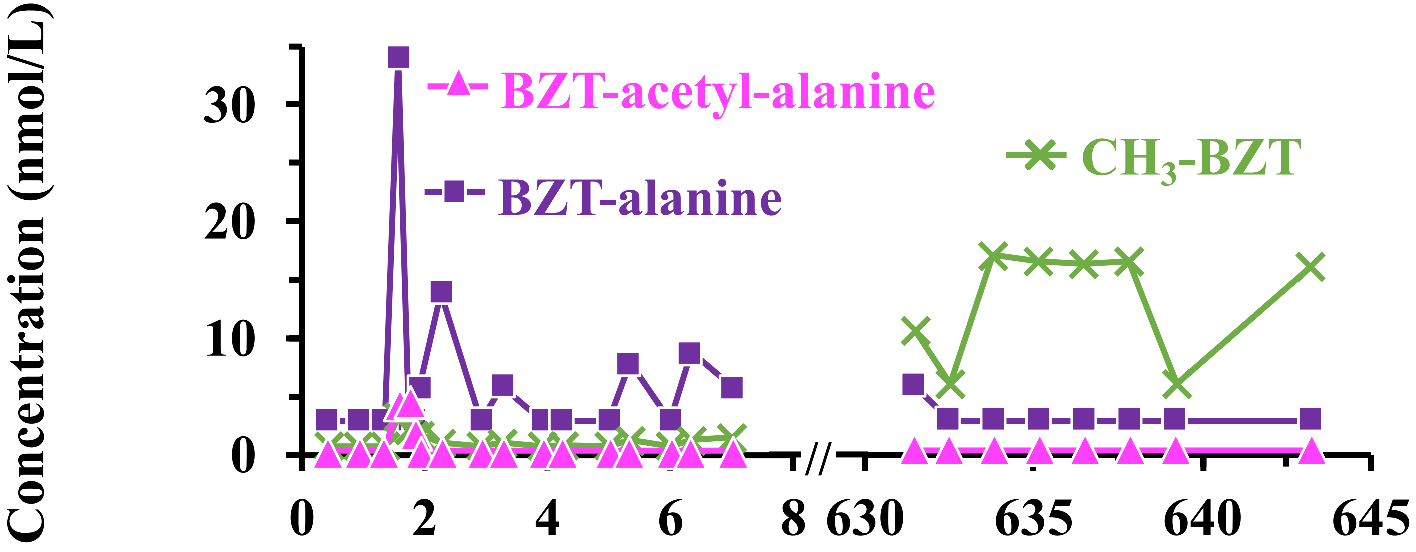
Microbial transformation

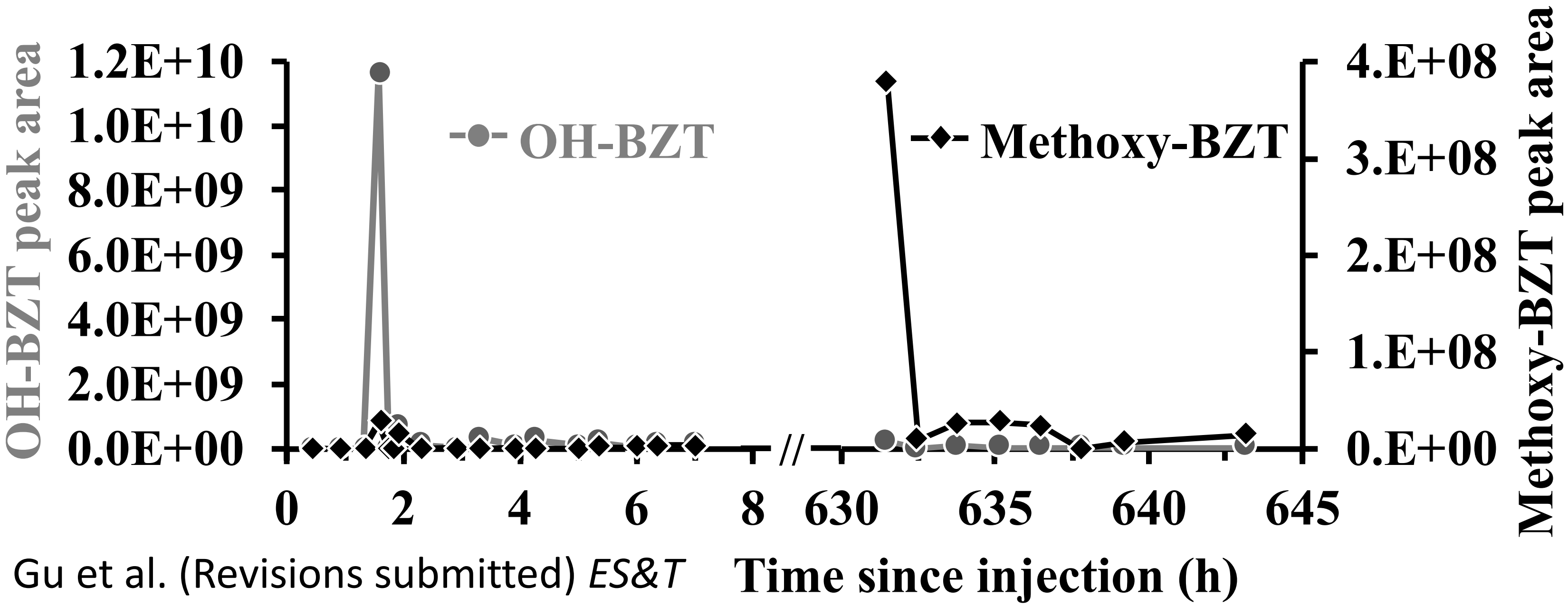




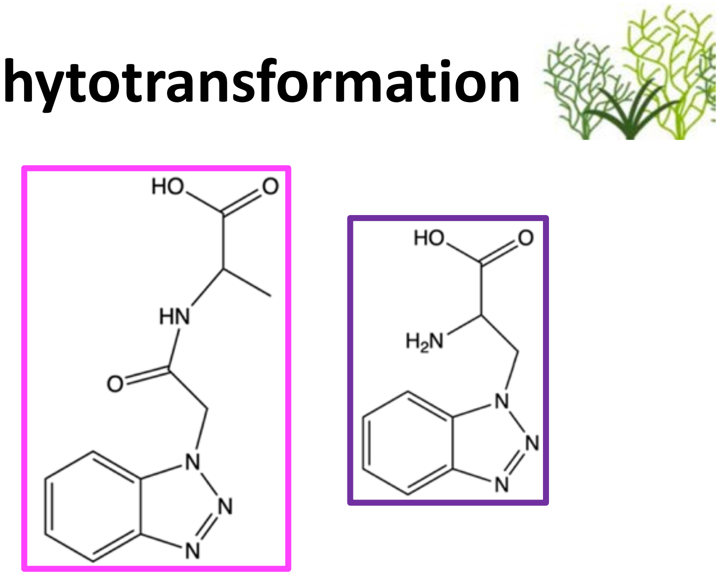
Gu et al. (Revisions submitted) *ES&T*

Benzotriazole's fate in full-scale bioretention

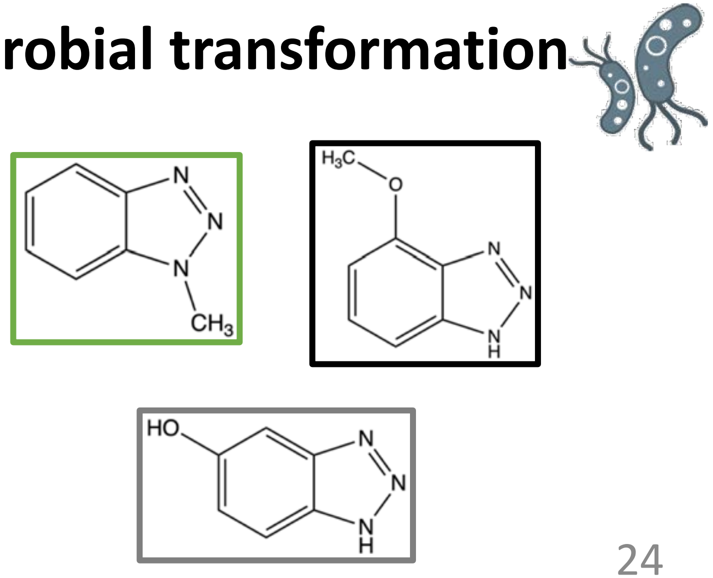




Phytotransformation



Microbial transformation



Gu et al. (Revisions submitted) *ES&T*

Benzotriazole's fate in full-scale bioretention

Take-home messages

- **Benzotriazole undergoes**

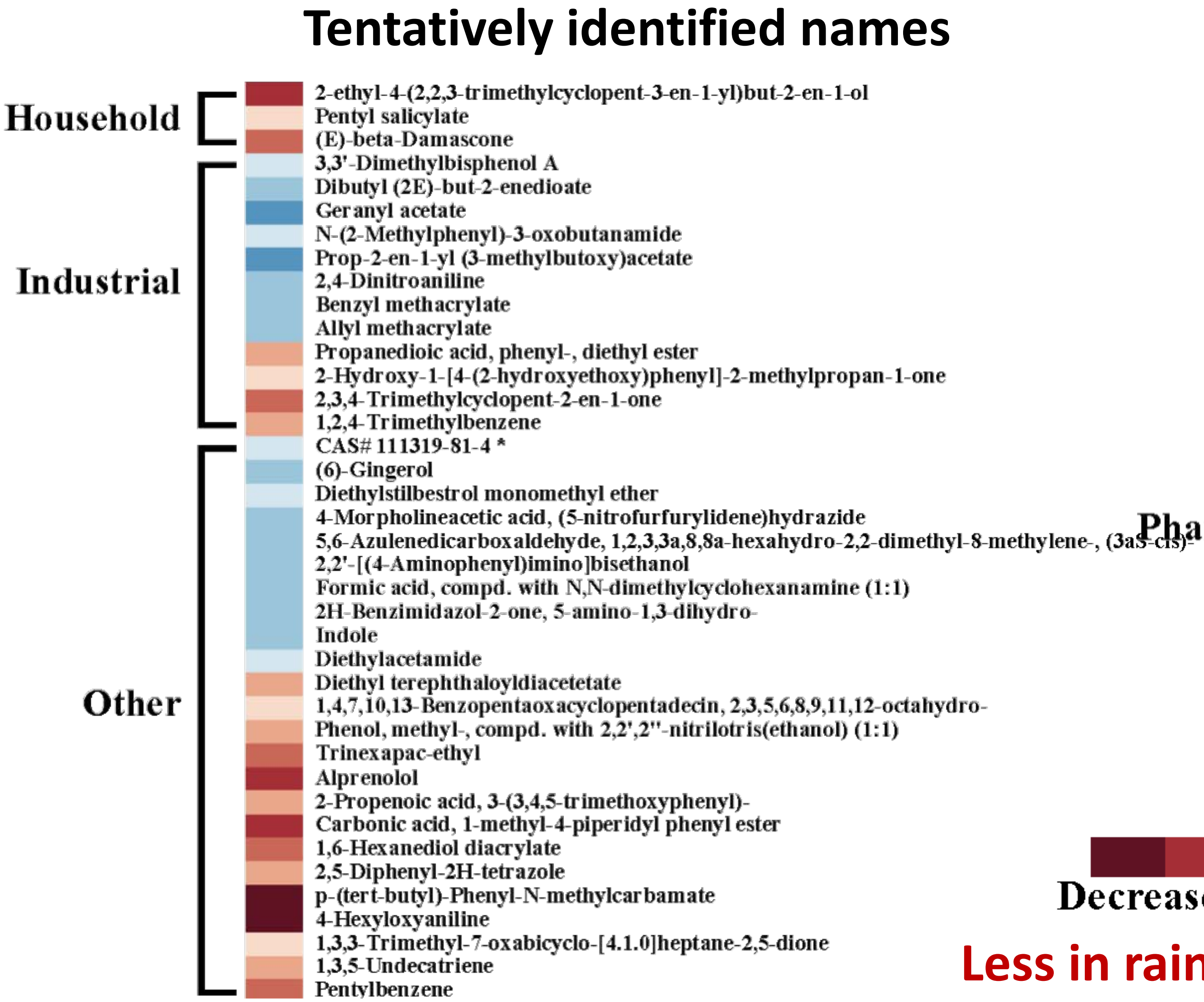
→Moderate adsorption
→Microbial transformation
→Fast phytotransformation

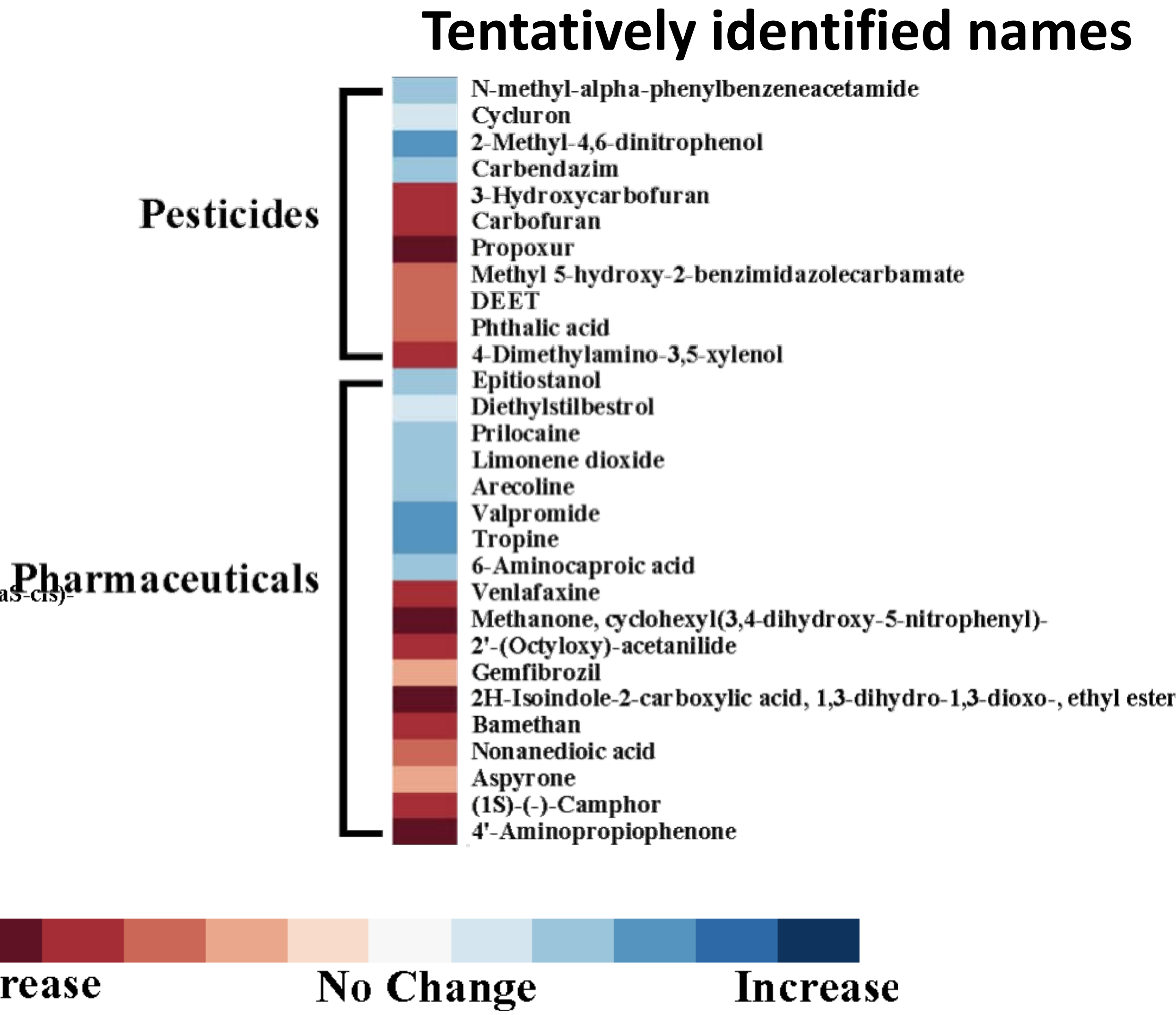
- **Need strategies to optimize treatment**

→Hydraulics
→Keep plants
→Amendments

Gu et al. (Revisions submitted) *ES&T*

Other trace organics from non-target analysis





Less in rain event 26 days after tracer test

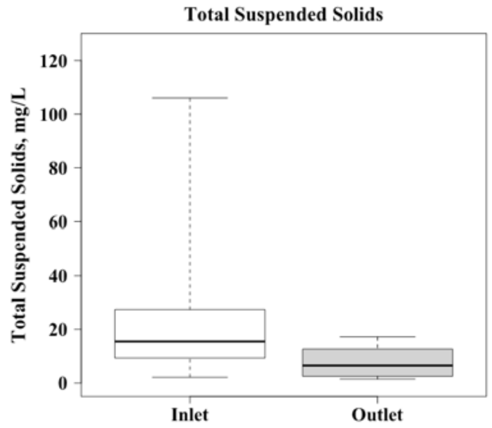
More in rain event 26 days after tracer test

Gu et al. (Revisions Submitted) *ES&T*

Microplastics

- Hypothesis: MP will be filtered out like TSS

Spraakman et al. (2020) *Ecol. Eng.*



Smyth et al. (2021) *Water Research*

Microplastics

- Plastic particles < 5 mm
- Health impacts
- Suggested entry point: Stormwater

Water Research 191 (2021) 116785

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

ELSEVIER

WATER RESEARCH

Bioretention cells remove microplastics from urban stormwater

Kelsey Smyth[a], Jennifer Drake[a], Yourong Li[b], Chelsea Rochman[c], Tim Van Seters[d], Elodie Passeport[a,b,*]

[a] Department of Civil and Mineral Engineering, University of Toronto, 35St. George Street, Toronto ON M5S 1A4, Canada
[b] Department of Chemical Engineering and Applied Chemistry, University of Toronto, 200 College Street, Toronto ON M5S 3E5, Canada
[c] Department of Ecology and Evolutionary Biology, University of Toronto, 25 Willcocks Street, Toronto ON M5S 3B2, Canada
[d] Toronto Region Conservation Authority, 101 Exchange Avenue, Concord ON L4K 5R6, Canada

ARTICLE INFO

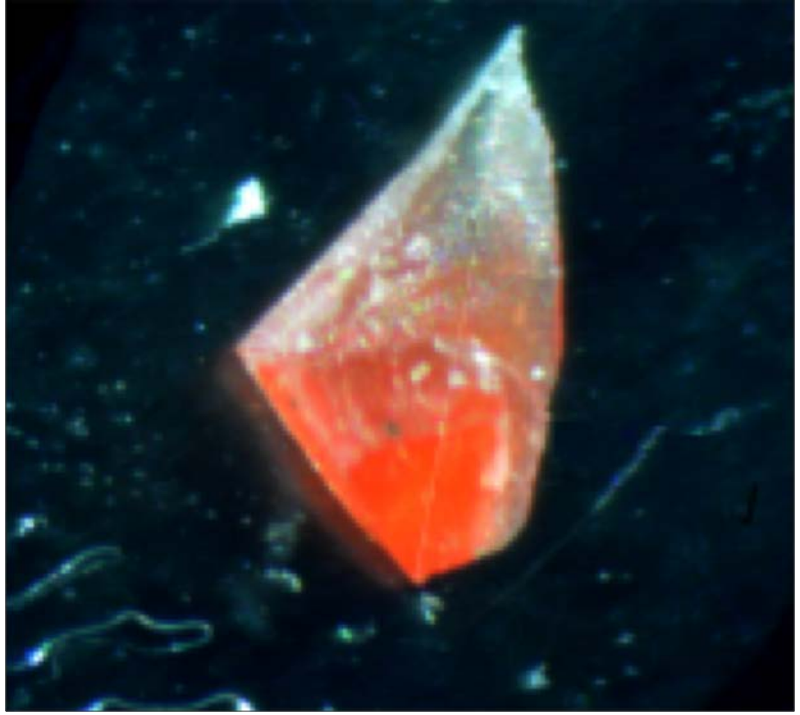
Article history:
Received 28 October 2020
Revised 8 December 2020
Accepted 23 December 2020
Available online 26 December 2020

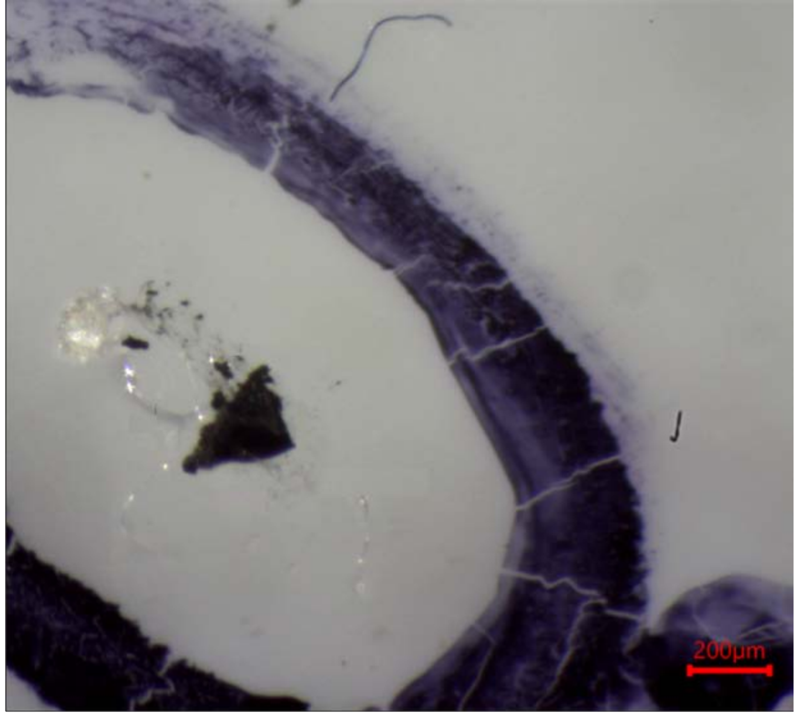
Keywords:
Bioretention
Microplastic
Microfiber
Water quality
Stormwater

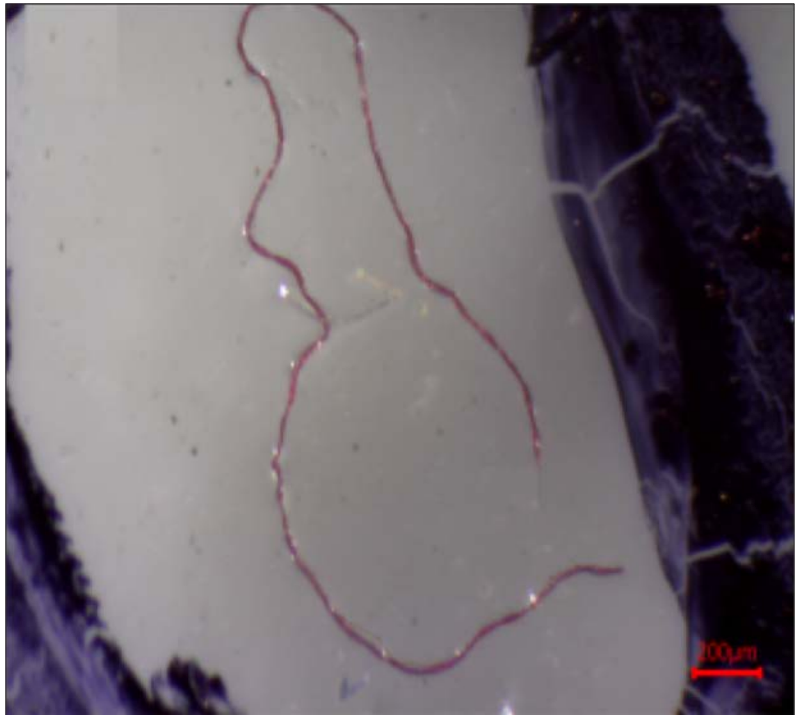
ABSTRACT

Microplastic pathways in the environment must be better understood to help select appropriate mitigation strategies. In this 2-year long field study, microplastics were characterized and quantified in urban stormwater runoff and through a bioretention cell, a type of low impact development infrastructure. Concentrations of microparticles ranged from below the detection limit to 704 microparticles/L and the dominant morphology found were fibers. High rainfall intensity and longer antecedent dry days resulted in larger microparticle concentrations. In addition, atmospheric deposition was a source of microplastics to urban runoff. Overall, these results demonstrate that urban stormwater runoff is a concentrated source of microplastics whose concentrations depend on specific climate variables. The bioretention cell showed an 84% decrease in median microparticle concentration in the 106–5,000 µm range, and thus is effective in filtering out microplastics and preventing their spread to downstream environments. Altogether, these results highlight the large contribution of urban stormwater runoff to microplastic contamination in larger aquatic systems and demonstrate the potential for current infiltration-based low impact development practices to limit the spread of microplastic contamination downstream.

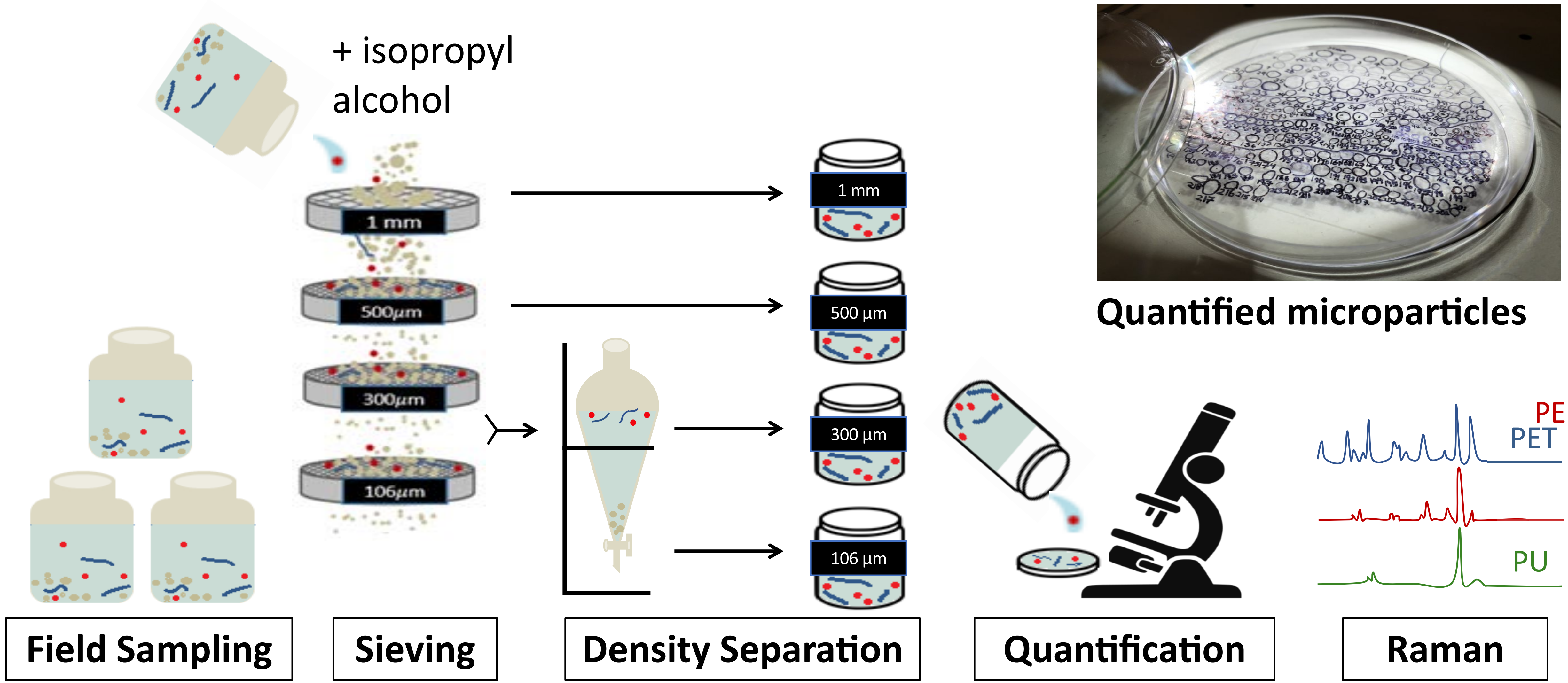
Smyth et al. (2021) *Water Research*





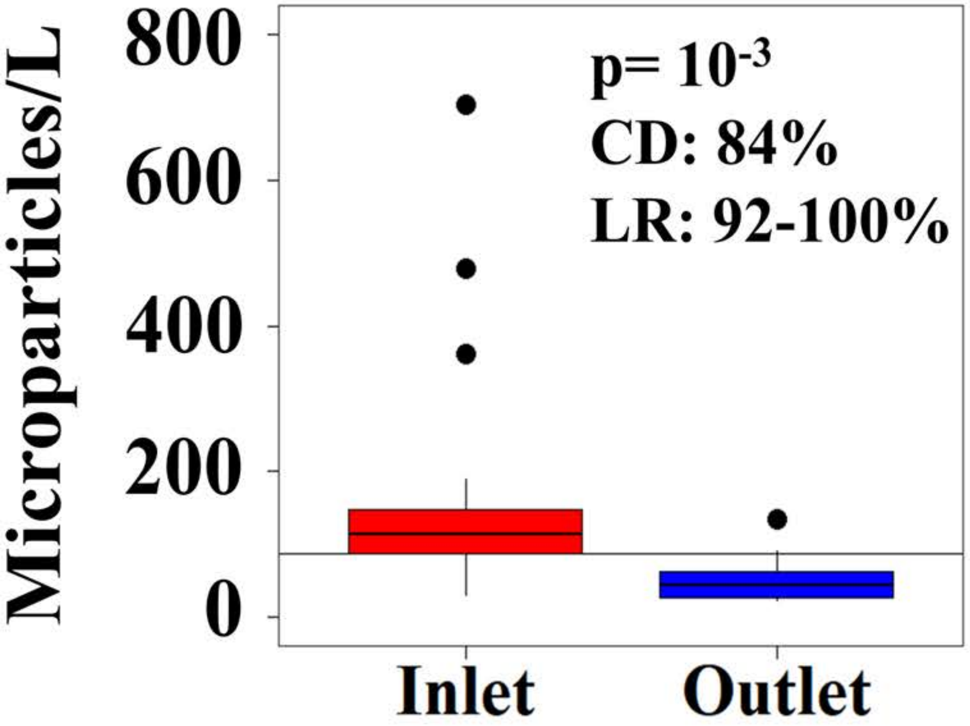


Microplastics



Smyth et al. (2021) *Water Research*

Non-parametric censored data

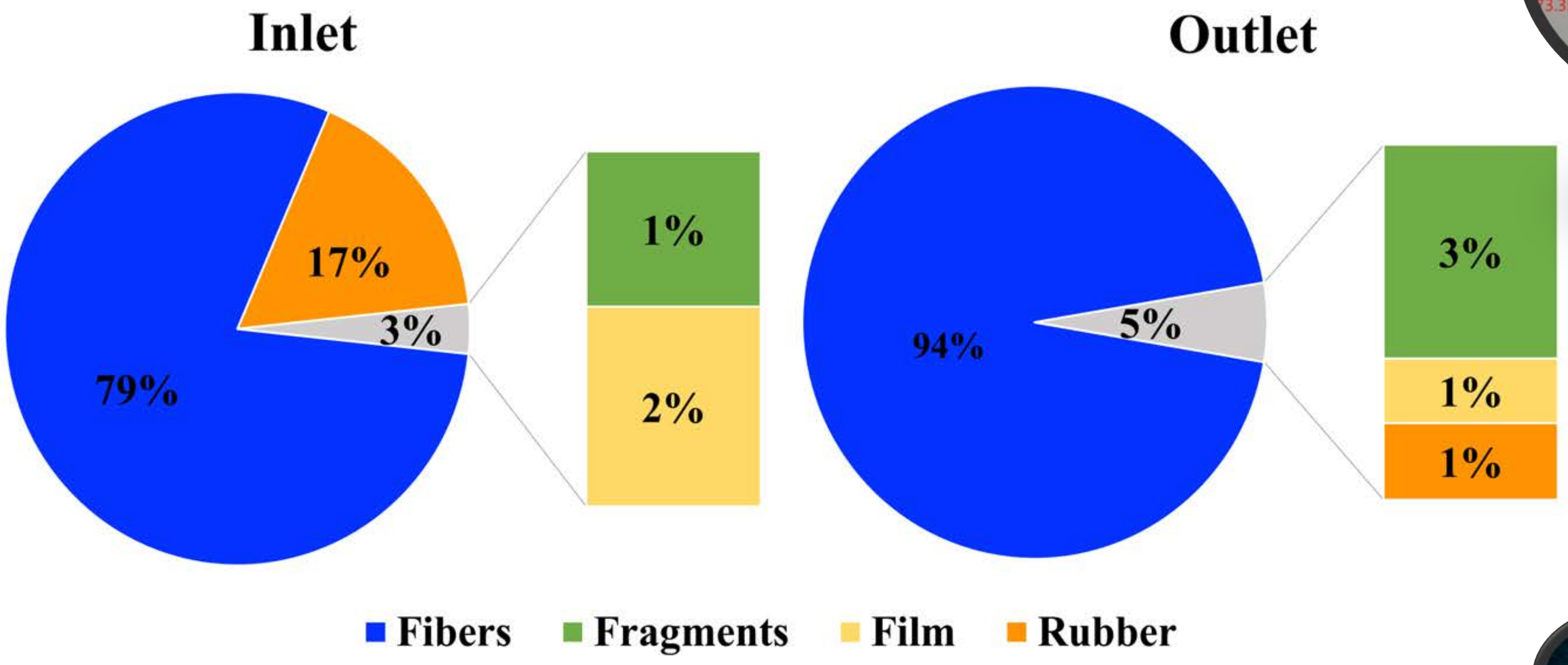


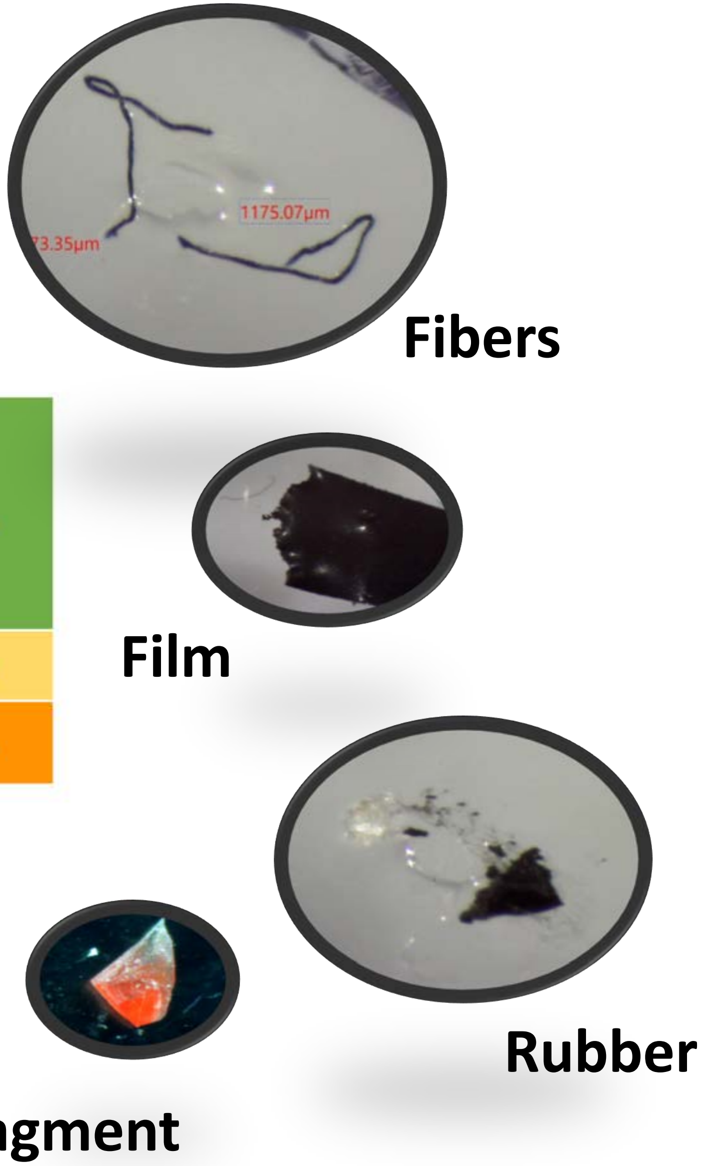
In = 186 and Out = 31 microparticles / L

- Regression on Statistics and Kaplan Meier methods
- Detection limit = field blank concentration

Smyth et al. (2021) *Water Research*

Morphologies

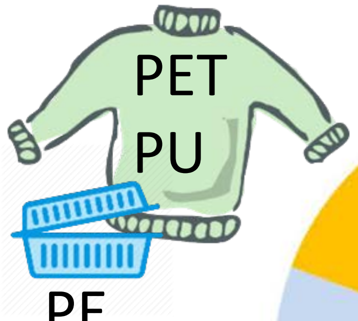


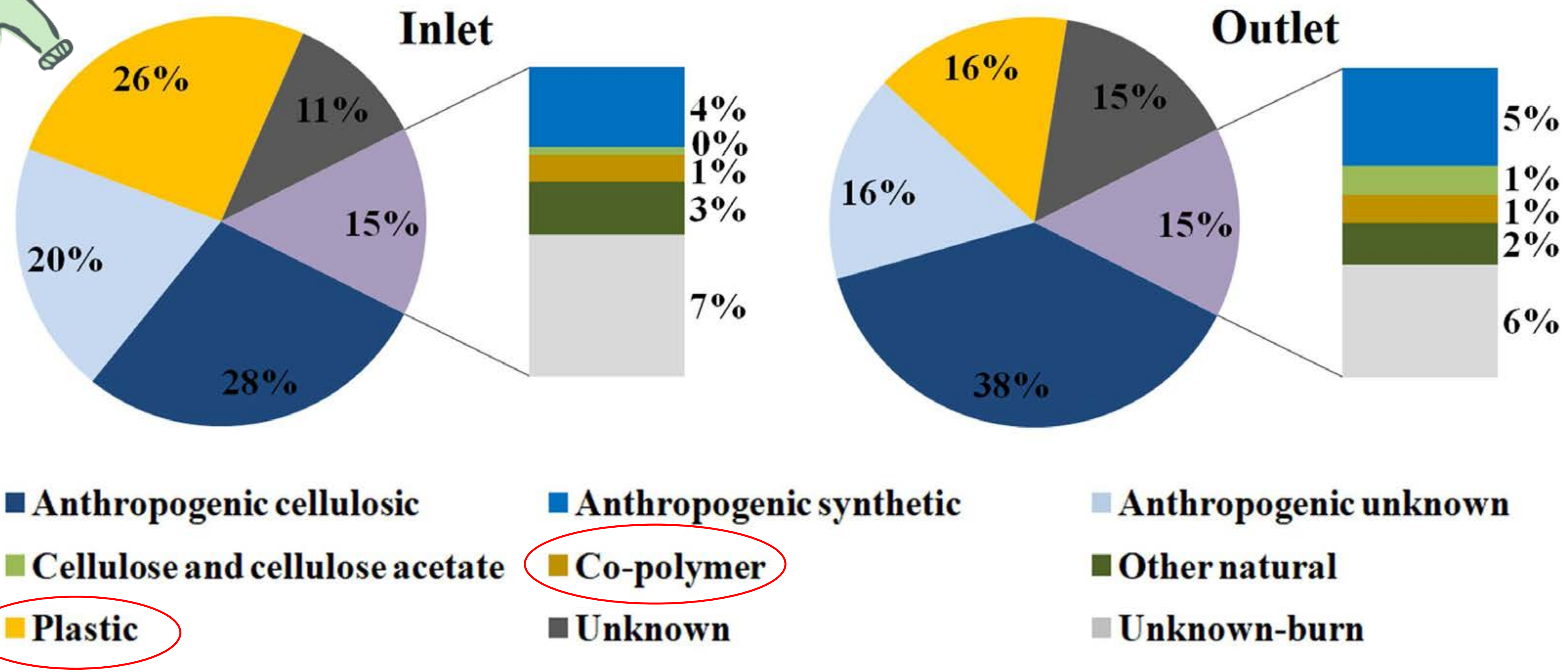


Field blanks: 96% fibers

Smyth et al. (2021) *Water Research*

Particle Characterization

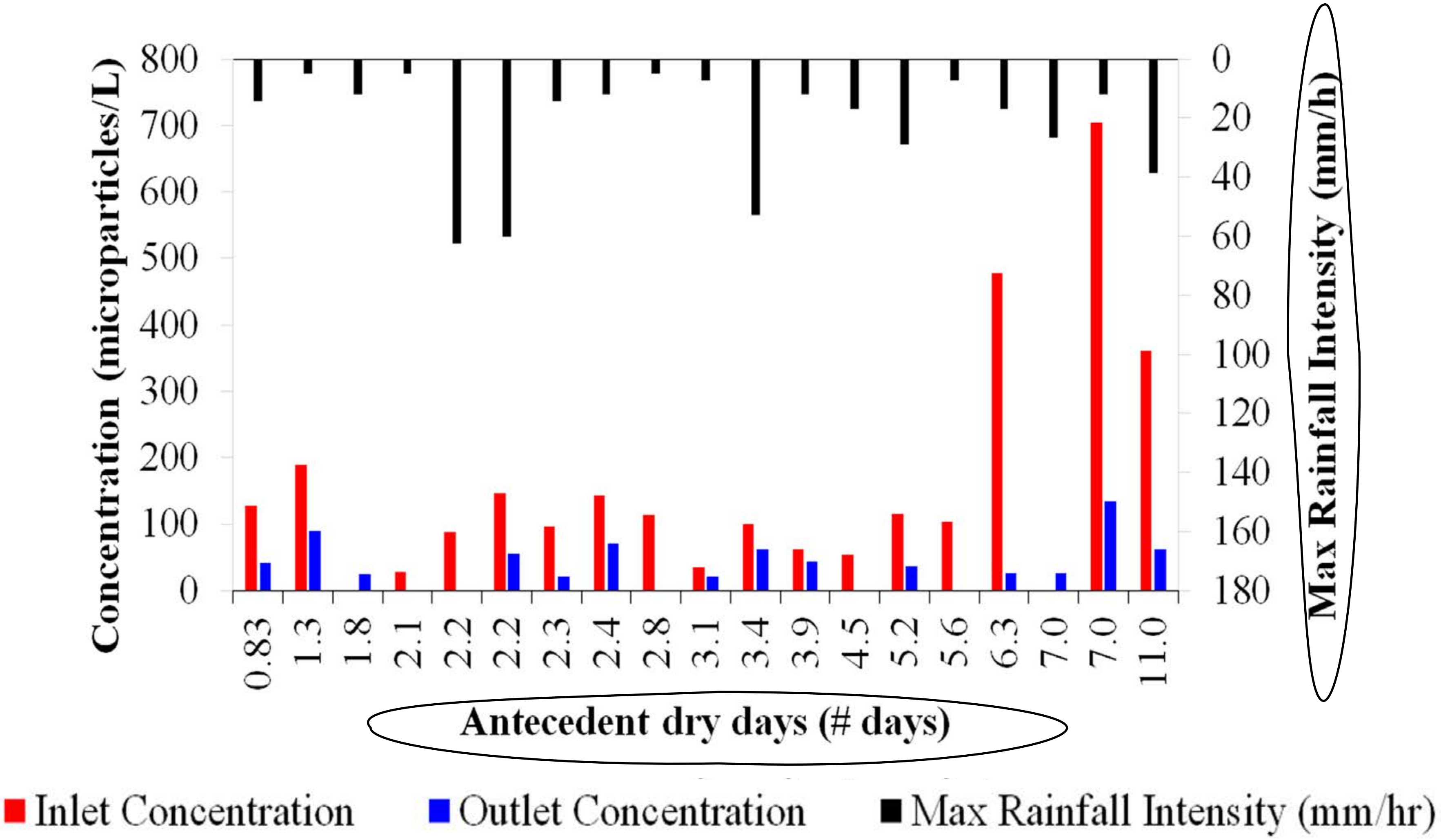




(n = 10 inlet and 10 outlet samples)

Smyth et al. (2021) *Water Research*

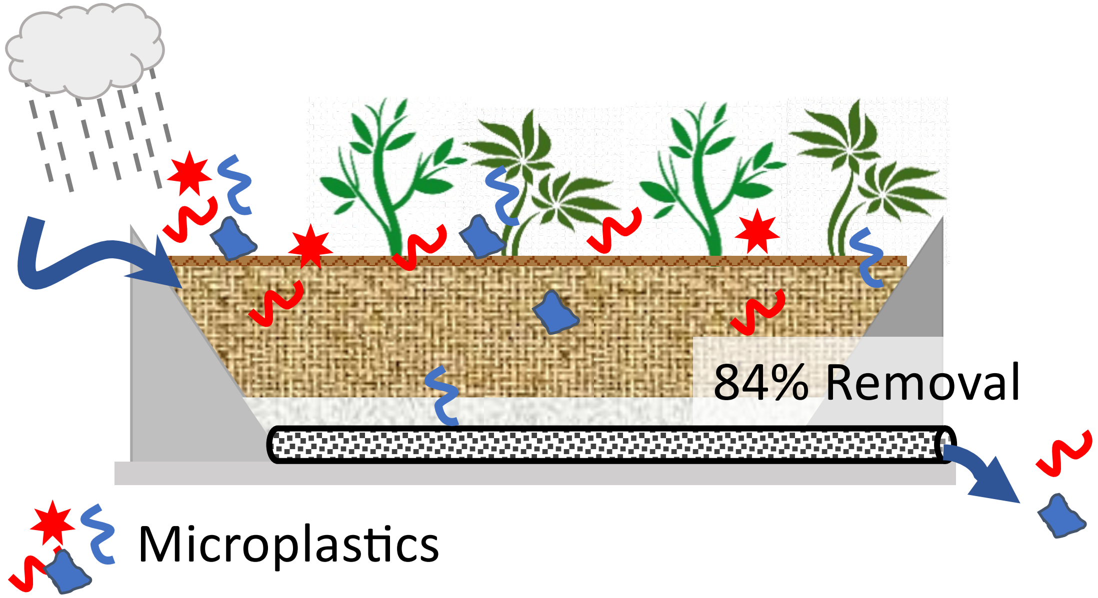
Climate Variables



Smyth et al. (2021) *Water Research*

Conclusions

- Bioretention cell effectively removes microparticles
- High concentrations of microparticles in stormwater
- Supports stormwater as a contributing entry path

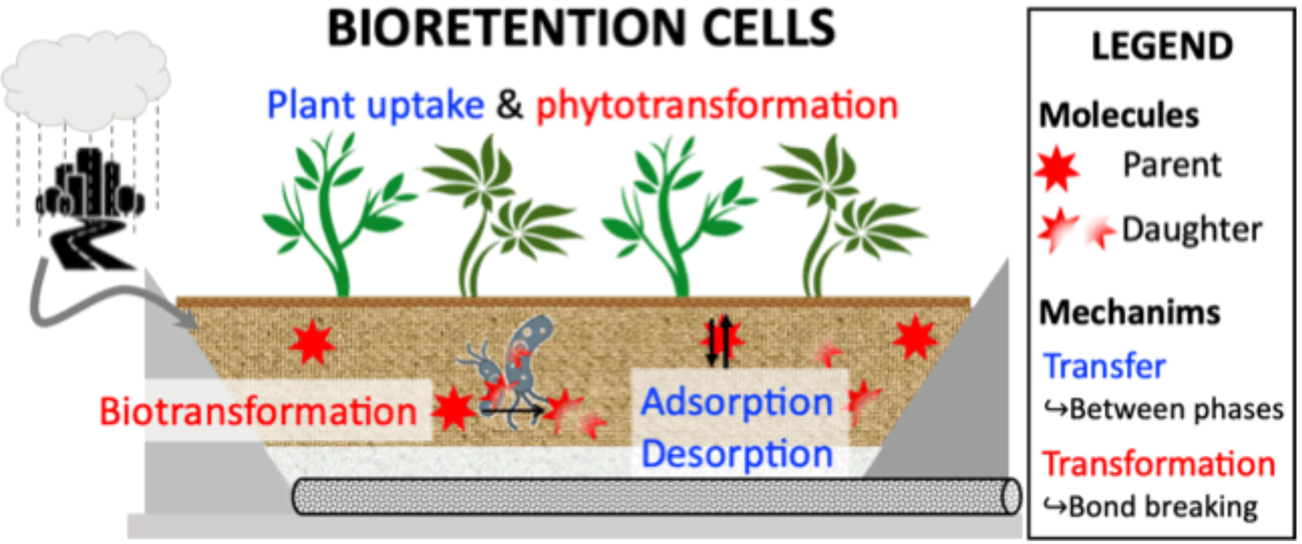


Smyth et al. (2021) *Water Research*

Final thoughts

- Strong potential of green infrastructure for water treatment

- Can be enhanced with detailed knowledge of internal processes



- Bioretention cell effectively remove microparticles

Details in published work

- Gu I., Rodgers, T.F.M., Spraakman, S., Van Seter, T., Flick, R., Diamond, M.L., Drake, J., and Passeport E. **Trace organic contaminant transfer and transformation in bioretention cells: a field tracer test with benzotriazole**. (Revisions submitted on May 28, 2021). Environmental Science and Technology.
- Akdeniz, C., Yu, Z.-H., Passeport E. **Adsorption and desorption of naphthalene in bioretention cells under cold climate conditions.** (In Press). Ecological Engineering.
- Smyth K., Drake J., Li Y., Rochman C., Van Seters T., Passeport E. **Bioretention cells remove microplastics from urban stormwater**. (2021). Water Research. 191:116785.
- Spraakman S., Rodgers T.F.M., Monri-Fung H., Nowicki A., Diamond M.L., Passeport E., Thuna M., Drake J. **A need for standardized reporting: a scoping review of bioretention research 2000-2019**. (2020) Water. 12(11): 3122
- Spraakman S., Van Seters T., Drake J.A, Passeport E. **How has it changed? A comparative field evaluation of bioretention infiltration and treatment performance post-construction and at maturity**. (2020). Ecological Engineering. 158:106036
- Marvin J., Passeport E., Drake J.A. **State-of-the-art review of phosphorus sorption amendments in bioretention media: A systematic literature review**. (2020). Journal of Sustainable Water in the Built Environment. 6(1): 03119001
- Rhodes-Dicker, L., Passeport E. **Effects of cold-climate environmental factors temperature and salinity on benzotriazole adsorption and desorption in bioretention cells**. (2019). Ecological Engineering. 127:58-65
- Ding B., Rezanezhad F., Gharedaghloo B., Van Cappellen P., Passeport E. **Bioretention cells under cold climate conditions: Effects of freezing and thawing on water infiltration, soil structure, and nutrient removal**. (2019). Science of the Total Environment. 649:749-759

Copies available from elodie.passeport@utoronto.ca and jenn.drake@utoronto.ca

Thank you!

Graduate students

Kelsey Smyth
MASc

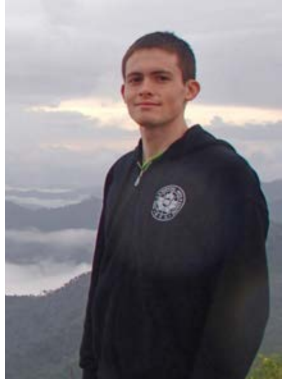
Irene Gu
MASc

Leandra Rhodes-Dicker
MASc

Tim Rodgers
PhD

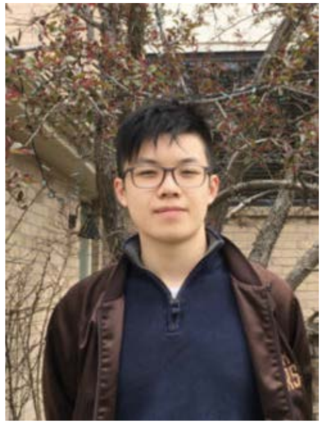
Sylvie Spraakman
PhD

Alwish Gnanaraj
MASc



Jeffrey Marvin
MASc

Summer undergraduate students: Microplastic team



Adam Tam

Amandine Rault

Chaitanya Ahuja

Yourong Li

Judy Xia

Yucong Shi

Aquafor Beech Limited

Jenkins Soil Mixtures

Toronto and Region Conservation Authority

NSERC CRSNG

Chaires de recherche du Canada | Canada Research Chairs

Canada

UNIVERSITY OF TORONTO

Ontario