The influence of spatial and technological parameters on the removal efficiencies of surfactants and fragrances in activated sludge wastewater treatment

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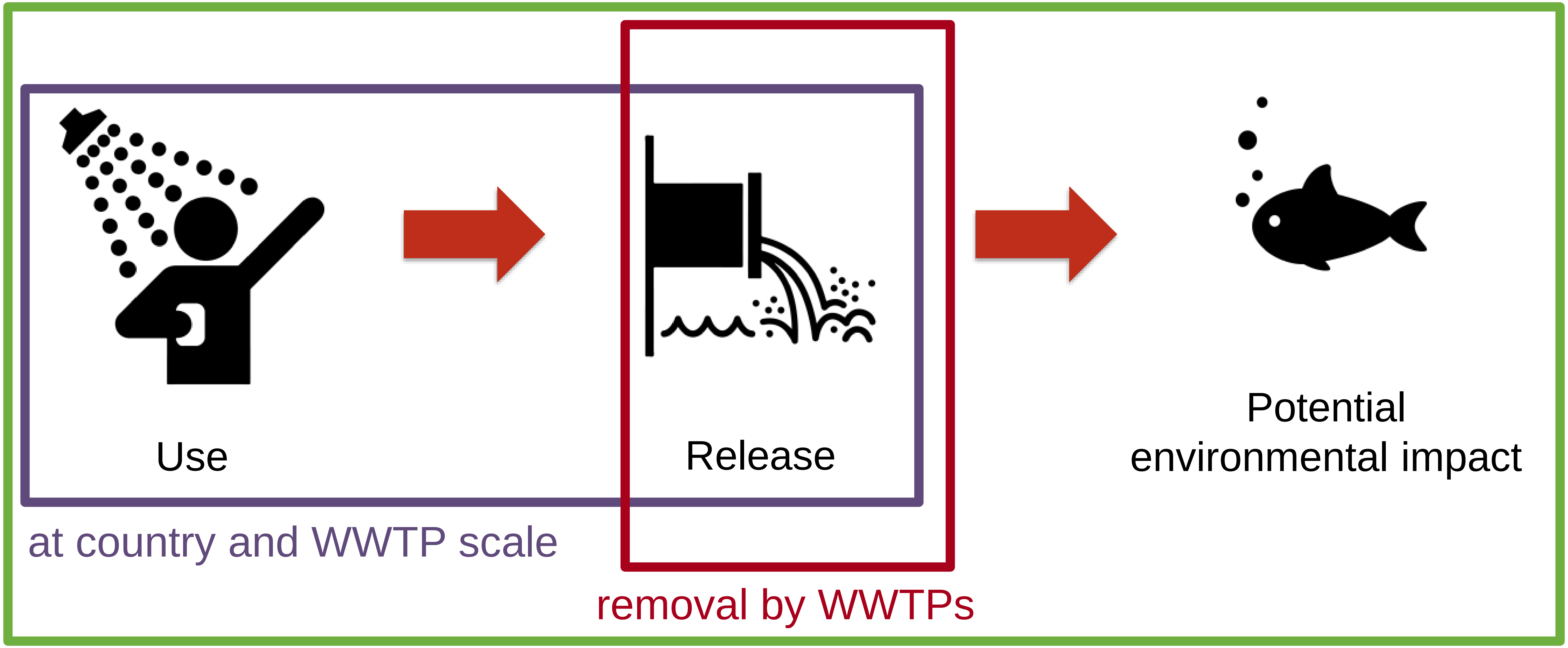
Chemical footprint at individual level



RESEARCH QUESTION

Which spatial and technological parameters explain the observed variability in the removal of surfactants and fragrances in activated sludge WWTPs?

Biological treatment ②

Water release ③

Hydrolysis/Oxidation ④

Thickener ⑤

Digester ⑥

Primary treatment ①

VARIABILITY IN REMOVAL EFFICIENCIES

PHYSICO-CHEMICAL PROPERTIES	SPATIAL	TECHNOLOGICAL
Volatility Adsorption to solid Biodegradability …	Flow rate Population served Temperature …	Sludge retention time (SRT) Hydraulic retention time (HRT) Redox conditions …

METHODS – OVERALL APPROACH

Literature review: studies reporting at least plant location, influent and effluent concentrations of fragrances or surfactants (excluding alkylphenols and their precursors and perfluorinated surfactants)

Collection of **physico-chemical properties** (experimental or estimated with EPISuite and other regression methods)

Database of influent and effluent concentrations of surfactants and fragrances and their properties

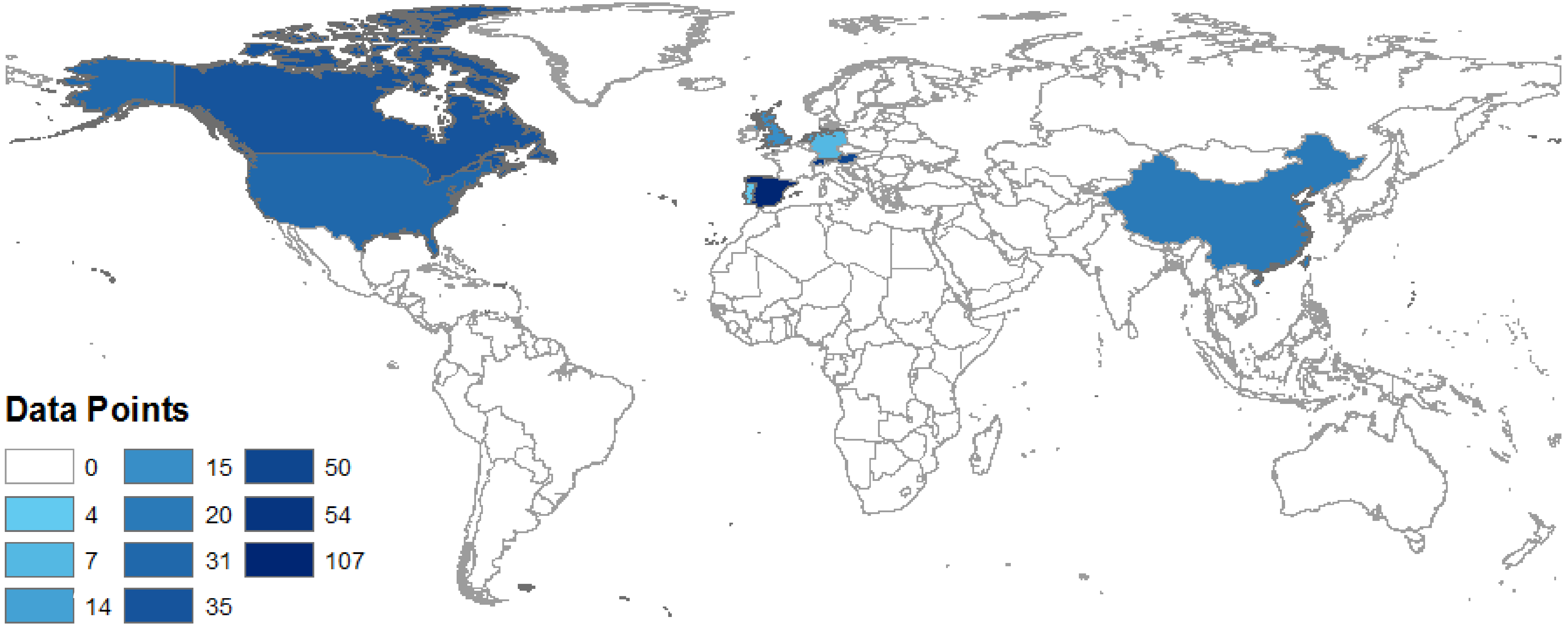
Meta-Analysis

Fitting of **Mixed-Effect Model**

Identification of the **key moderators** of removal efficiency

DATABASE

- 337 data points from 32 studies
- 11 negative removal efficiencies (no correction for influent concentration)
- Spread in removal efficiencies: -2 to >0.99
- 56 different chemicals (35 fragrances, 21 surfactants)
- 67 WWTPs
- Spatial extent



METHODS – META-ANALYSIS

- Summarise studies using a common value (effect size) while accounting for the weights of the different studies (1/sampling variance)

Effect size: Response ratio $\mathrm{RR} = \ln\left(\frac{\overline{\mathrm{C}}_{\mathrm{eff}}}{\overline{\mathrm{C}}_{\mathrm{in}}}\right)$

Sampling variance: $\hat{\sigma}^2(RR) = \frac{\left(SD_{Ceff}\right)^2}{N_{ceff}\bar{X}_{Ceff}^2} + \frac{(SD_{Cin})^2}{N_{Cin}\bar{X}_{Cin}^2}$

Backtransform to removal efficiency $\mathrm{RE} = 1 - \exp\left(\mathrm{RR}\right)$

METHODS – MIXED-EFFECT MODEL

$$\ln\left(\frac{\bar{C}_{\text{eff}}}{\bar{C}_{\text{in}}}\right) = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_p x_{ip} + u_i$$

Fixed part

Moderators

Similar to linear regression models

PHYSICO-CHEMICAL PROPERTIES | SPATIAL | TECHNOLOGICAL

Random part

Amount of residual heterogeneity

Variability between studies (sampling methodology, sample characteristics, one chemical with different RR…)

METHODS – MIXED-EFFECT MODEL

- Potential fixed effects (Continuous / Categorical) (* log transformed)

PHYSICO-CHEMICAL PROPERTIES	SPATIAL	TECHNOLOGICAL
- Organic carbon-water partitioning coefficient (K_{OC}) * - Henry Law constant * - Readily biodegradable	- Flow rate * - Share domestic influent	- Reactor configuration (Plug-flow or other)

- Bayesian information criteria (BIC) to choose best model

- Model averaging over models within 2 BIC of best model

RESULTS – META-ANALYSIS

- Mean weighted removal efficiency 99% (95 CI: 97.0-99.6%)

- Only surfactants
  - Mean weighted removal efficiency 99.8% (95 CI: 98.9-100%)

- Only fragrances
  - Mean weighted removal efficiency 97.3% (95 CI: 91.4-99.1%)

RESULTS – MIXED-EFFECT MODELS

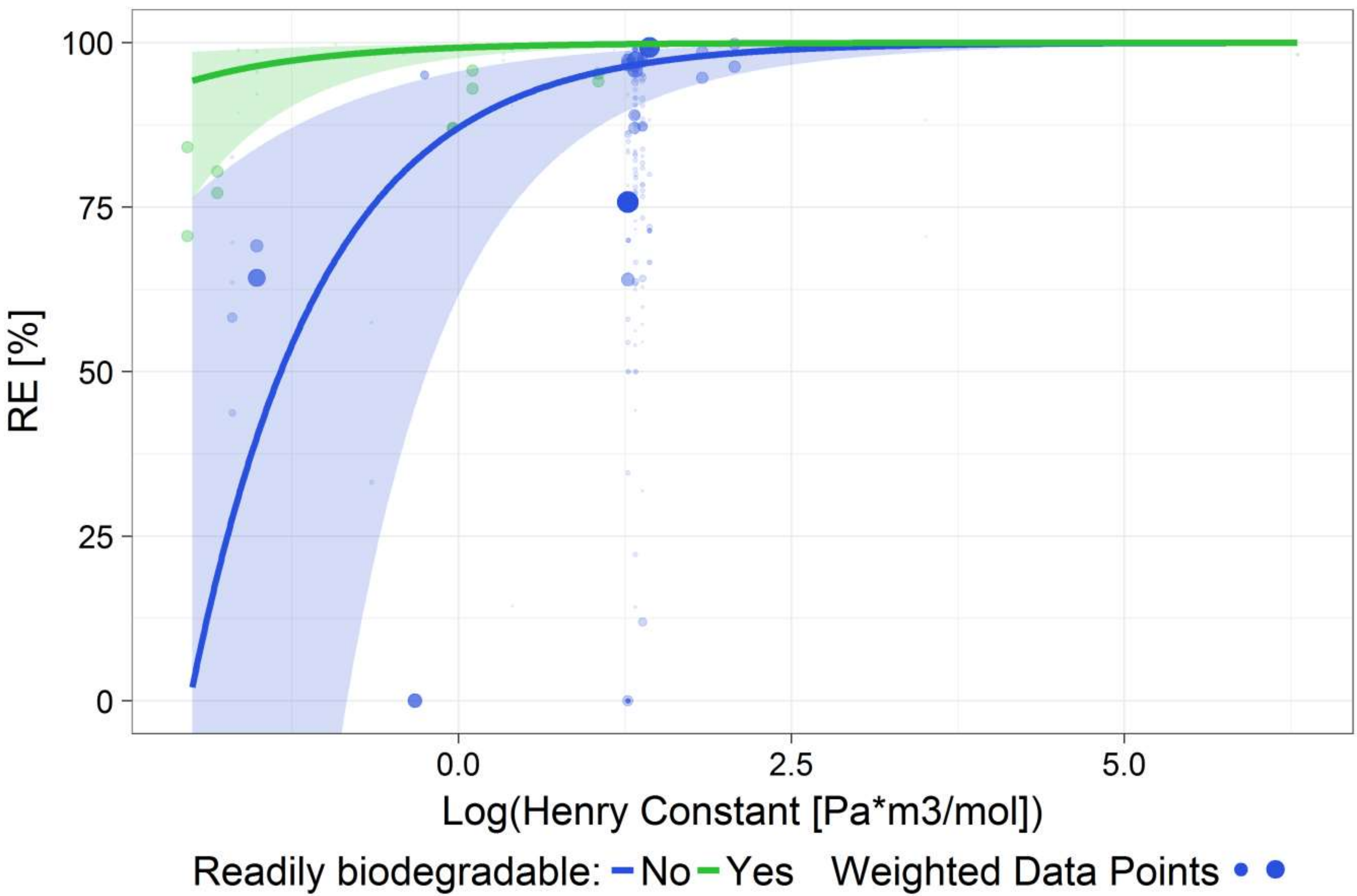
- Fragrances and Surfactants together

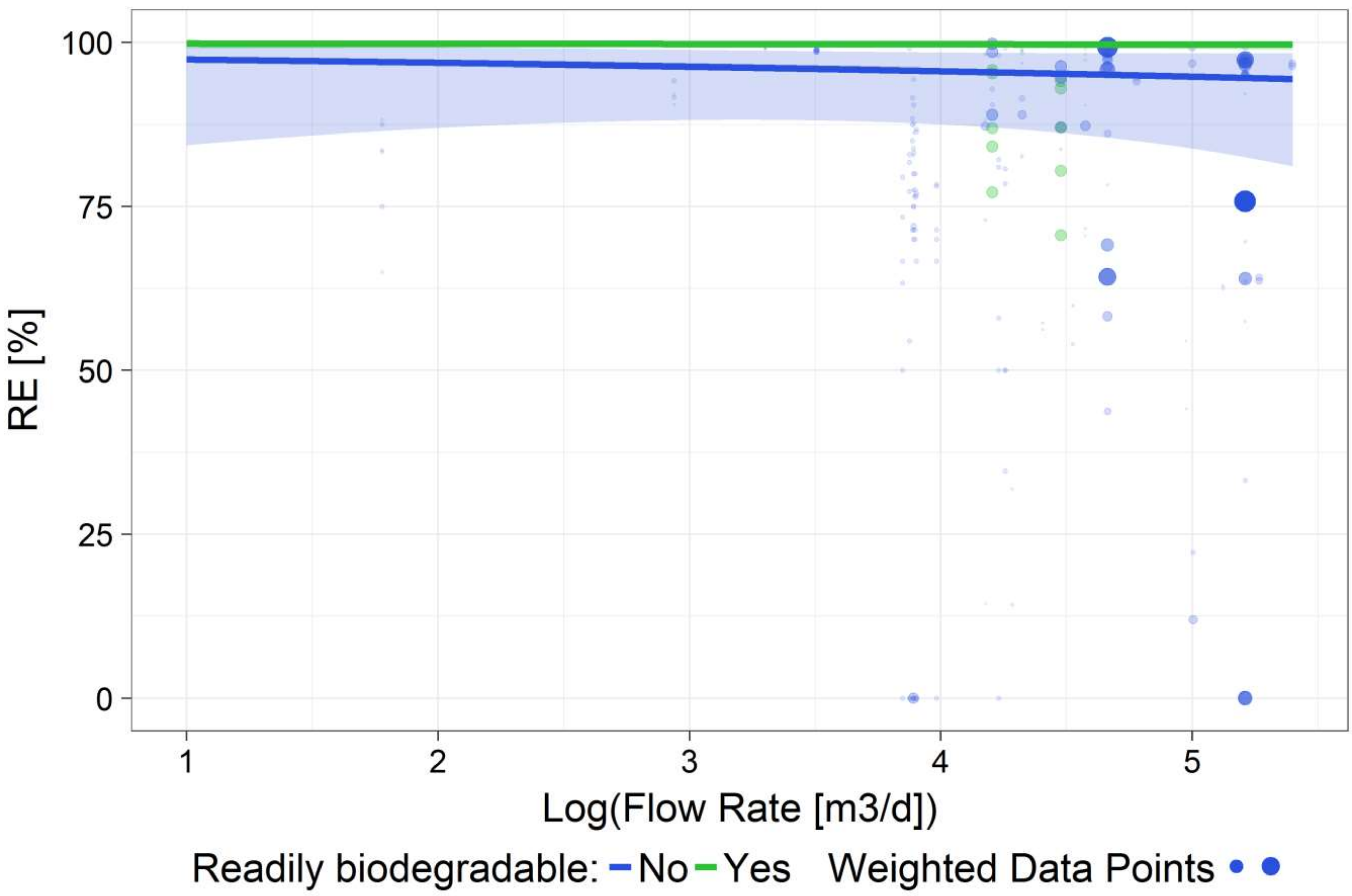
PHYSICO-CHEMICAL PROPERTIES	SPATIAL	TECHNOLOGICAL
- Organic carbon-water partitioning coefficient (K_{OC}) * - Henry Law constant * - Readily biodegradable	- Flow rate * - Share domestic influent	- Reactor configuration (Plug-flow or other)

RESULTS – MIXED-EFFECT MODELS

- Fragrances only

PHYSICO-CHEMICAL PROPERTIES	SPATIAL	TECHNOLOGICAL
- Organic carbon-water partitioning coefficient (K_{OC}) * - Henry Law constant * - Readily biodegradable	- Flow rate * - Share domestic influent	- Reactor configuration (Plug-flow or other)


100
75
50
25
0
RE [%]
0.0
2.5
5.0
Log(Henry Constant [Pa*m3/mol])
Readily biodegradable: No Yes Weighted Data Points


RE [%]
100
75
50
25
0
1
2
3
4
5
Log(Flow Rate [m3/d])
Readily biodegradable: No Yes
Weighted Data Points

CONCLUSIONS

- Average removal of surfactants and fragrances in activated sludge WWTPs higher than 90%
- Readily biodegradability dominates removal efficiency when both chemicals considered together
- Which spatial and technological parameters explain the observed heterogeneities in the removal of surfactants and fragrances in activated sludge WWTPs?
  - Surfactants: hard to explain the small heterogeneity in removal efficiency
  - Fragrances: increase in flow rate tends to reduce removal efficiency

OUTLOOK

- Meta-analysis can help understand the influence of technological and spatial parameters on the removal efficiencies of chemicals in activated sludge WWTPs.
- Would benefit from a uniformization of reported WWTP characteristics during measurement campaigns
  - Temperature, sludge retention time, flow rate
- Multivariate model over larger chemical space
  - Include less efficiently removed chemicals to cover a wider RE range

ADDITIONAL SLIDES

NAMES OF SURFACTANTS IN DATABASE

Abbreviation	Name
C10LAS	
C11LAS	
C12LAS	Linear alkylbenzene sulfonates
C13LAS	
LAS	
C12EO	Alcohol ethoxylates
C12EO1-5S	Alcohol ethoxysulflates
C14EO	Alcohol ethoxylates
C14EO1-5S	Alcohol ethoxysulflates

NAMES OF FRAGRANCES IN DATABASE

Tonalide	Benzyl acetate	Musk tibetene
Galaxolide	g-methyl ionone	Ambrettolide
Celestoide	Hexyl salicylate	Civetone
Phantolide	Hexylcinmaldehyde	Exaltolide
Traselide	Isobornyl acetate	Exaltone
Cashmeran	Methyl dihydrojasmote	Habanolide
Phantolide	Methyl salicylate	Musk MC4
Benzyl salicylate	Musk ketone	Muscone
Eugenol	Musk xylene	Musk NN
Lilial	OTNE	Musk ambrette
Limonene	Terpineol	Musk moskene
Linalool	Acetyl cedrene	