(Lee et al., 2016; Kim and Kannan, 2018; Li et al., 2019c)

Evaluating Organophosphate Flame Retardant (OPFR) Removal in Drinking Water Treatment: A Multi-Site Study in England and Wales

Chesney Swansborough[1], Emma Goslan[2], Mick Whelan[3], Emma Pemberton[4], Lauren Dawson[1], Megan Griffiths[1], Nathan Hobbs[1], Emily Bird[1], Sarah Bull[4], Mick Stanger[5]

1: Ricardo, UK | 2: Cranfield University, UK | 3: University of Leicester, UK | 4: TARA consulting, UK | 5: Drinking Water Inspectorate, UK

Email contact: megan.griffiths@ricardo.com

Introduction

- Organophosphorous flame retardants (OPFRs) are chemicals used to enhance fire safety and can be found in products like electrical devices, polyester fibres, and upholstered furniture.
- OPFRs not chemically bonded can easily be released into the environment through volatilisation, dissolution, and wear.
- OPFRs are potentially mobile and persistent in water, and some have been linked to harmful effects on human health including neurotoxicity, carcinogenesis, and endocrine disrupting activity, making exposure via drinking water potentially hazardous[1].

AIM: Generate a risk-based screening assessment of drinking water sources in England and Wales for OPFRs and conduct a 12-month, targeted, risk-based monitoring survey of raw and treated drinking water in England and Wales

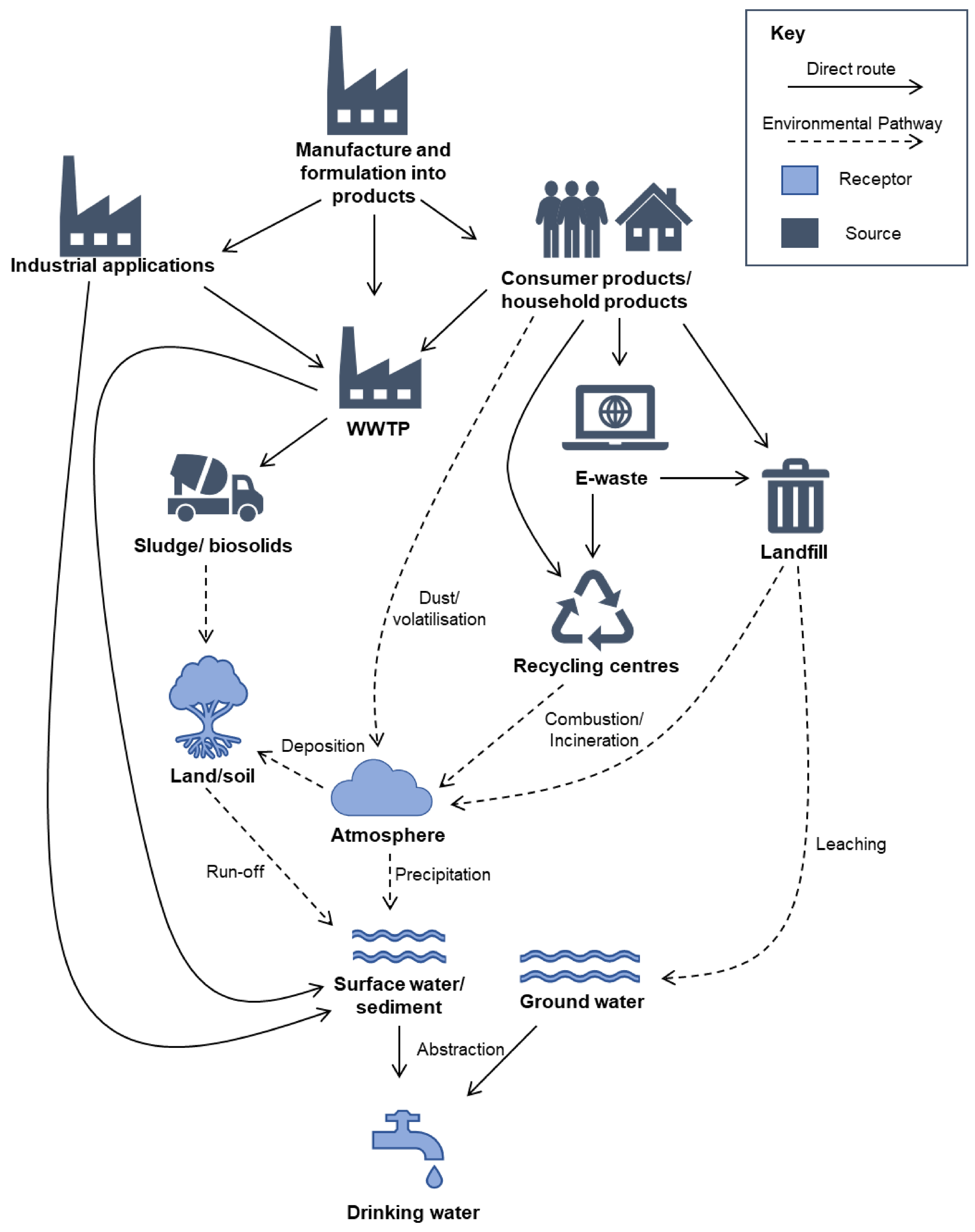

Figure 1: Illustrative framework depicting the sources and pathways of OPFR emissions to the environment

Methodology

Evidence synthesis

Including use and tonnages, toxicological information (health-based guidance values; HGBVs), sources, emissions and removal of OPFRs during drinking water treatment

Risk assessment

Tiered risk assessment with 2 emissions scenarios. Risk characterisation ratios (RCRs) for humans via drinking water exposure in all emission and treatment scenarios were also calculated from HBGVs

Sampling

12-month sampling campaign at three drinking water treatment works across England and Wales, at raw water inlet, mid treatment and final water

Analytical methods

GC-MS/MS detection of 8 OPFRs: tri-n-butyl phosphate (TBP), tri(2-chloroethyl) phosphate (TCEP), tris(1-chloro-2-propyl) phosphate (TCIPP), tris(1,3-dichloro-2-propyl) phosphate (TDCPP), triphenyl phosphate (TPP), 2-ethyl hexyl diphenyl phosphate (EHDP), tris(-2- butoxyethyl) phosphate (TBEP), and tri-m-tolyl phosphate (TMTP)

Results & Discussion

OPFR Detection in Sampling Sites

- The presence of several OPFRs was confirmed. These were all at nanogram per litre (ng L^{-1}) levels.
- Levels of TFA in treated drinking waters range from not detected to 64 ng L^{-1}. Mean values reported from this study are similar to values reported in Korea, China and the US [2,3,4].
- TEHP was the OPFR substance most often detected at the highest concentrations in raw and treated drinking waters (29 – 164 ng L^{-1} and 12 – 64 ng L^{-1}, respectively).
- Removal efficiencies of TEHP varied between 22% and 78%.
- Other OPFRs with common detections in raw and treated waters: TCIPP, EHDPP, TCEP and TEP.
- TPP and TiBP were present in some raw water samples, but at very low levels.
- TDCPP was not detected above the limit of detection in any of the samples collected.

Risk Assessment of OPFRs

- Apparent removal rates for some substances were higher than predicted, but most removal rates were over-estimated.
- **Human health risks for all the OPFRs monitored are likely to be low.** Even with highly conservative assumptions, RCR_T values were <1 for most substances, and without water treatment.
- Two substances had RCRT values > 1 when conventional treatment was assumed (Maximum RCRT = 8.9) but reduced to <1 with advanced treatment except for TEP for 1.7% of abstraction points.
- **Predicted concentrations in surface waters were always several orders of magnitude higher than those measured in raw water intakes.**
- This suggests that emission rates are unrealistically high, with high margins of safety for human health, even in the absence of advanced treatment.

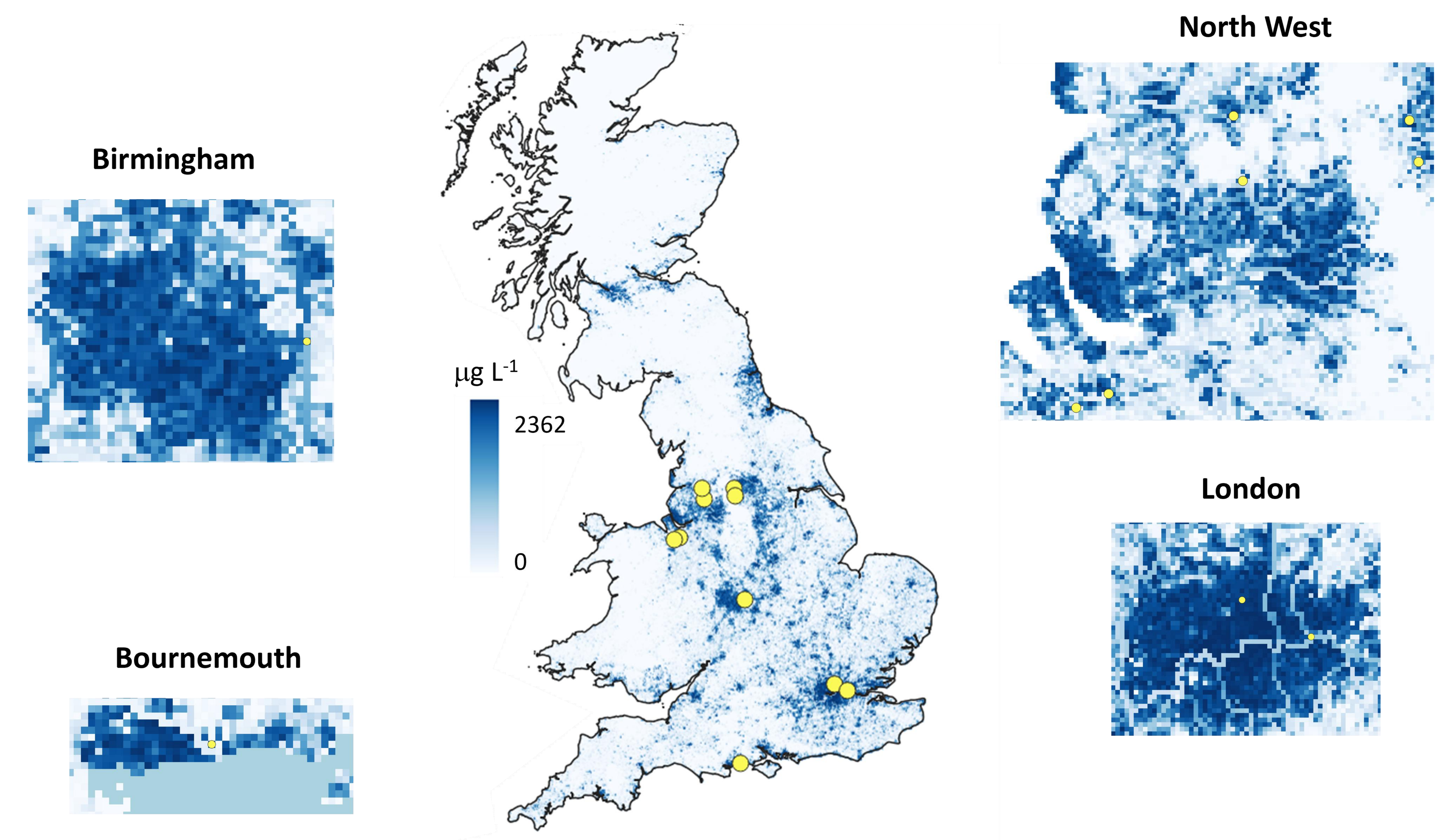

Figure 2: Predicted spatial patterns of the concentration of TEP in river water for Great Britain under Q_{95} conditions. Also shown are the locations of the 10 abstraction points with the highest values of RCRs (RCR_T) (assuming conventional water treatment)

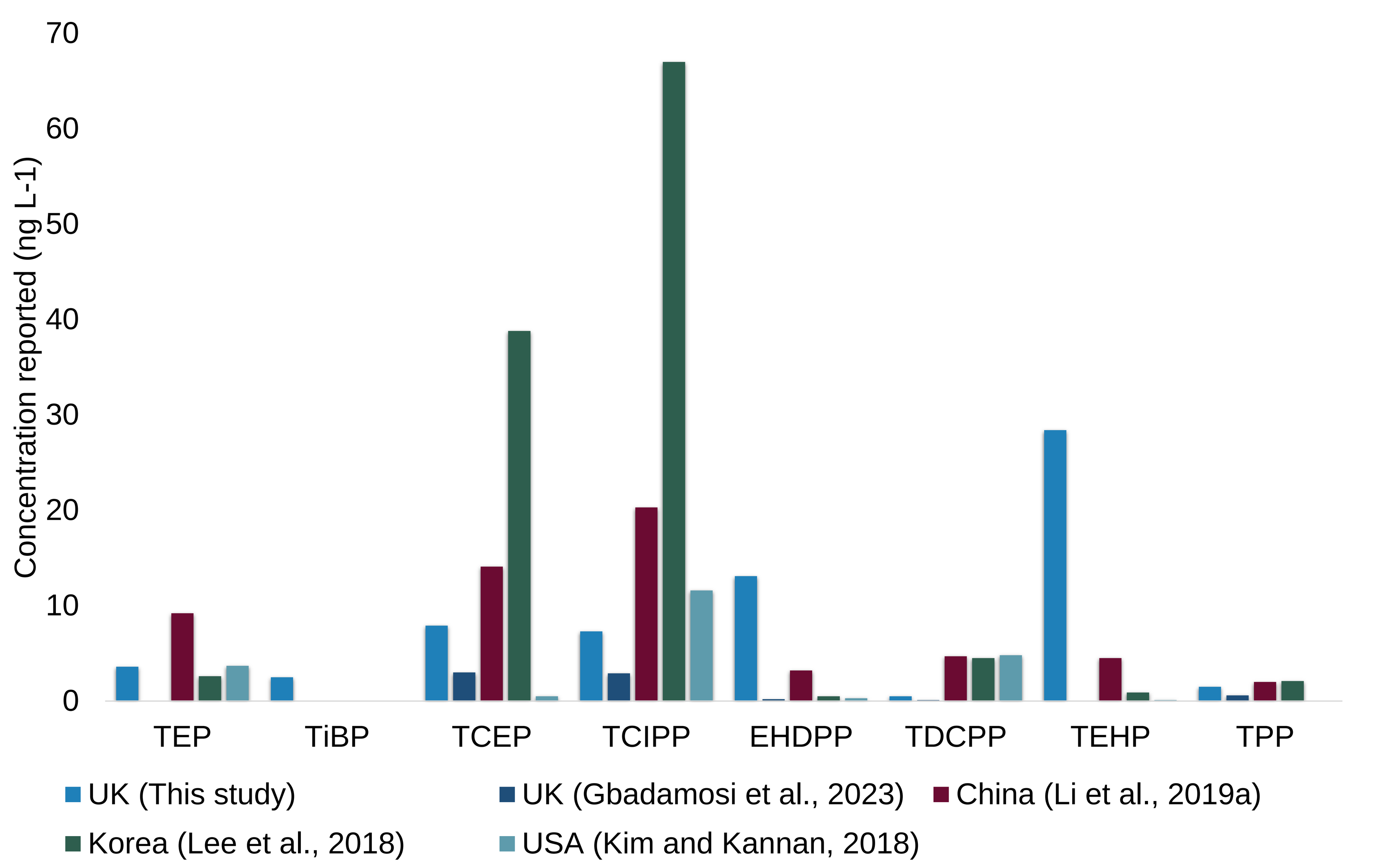

Figure 3: Comparison of average concentrations of OPFRs in tap or final treated waters in different regions.

Conclusions and Recommendations

- There are significant knowledge gaps regarding the use tonnages of OPFRs, needed to improve the understanding of environmental release sources.
- The OPFR substances most frequently detected in raw and treated drinking waters include TEHP, TCIPP, EHDPP, TCEP, and TEP; water companies focus on monitoring these OPFRs in environmental and treated drinking waters.
- The analytical methods used for future monitoring should have a sensitivity in the range of 0.1 ng L^{-1} to ensure that these substances can be detected at levels above the limit of detection.

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