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Towards a risk ranking for improved management of discharges of fats, oils, and greases (FOG) from food outlets

Thomas Collin[a], Rachel Cunningham[b], Jitka MacAdam[a], Raffaella Villa[c], Bruce Jefferson[a] and Paul Jeffrey[a,*]

[a] Cranfield University, Cranfield MK43 0AL, United Kingdom
[b] Thames Water Utilities Ltd, Reading RG2 0RP, United Kingdom
[c] De Montfort University, Leicester LE1 9HB, United Kingdom
*Corresponding author. E-mail: p.j.jeffrey@cranfield.ac.uk

PJ, 0000-0001-6618-0815

ABSTRACT

The understanding of fats, oils, and greases (FOG) pathways in commercial kitchens is relatively poor. In this contribution, we extend our understanding of how FOG is perceived and managed by those working within food service establishments (FSEs). A questionnaire ($n = 107$) exposes awareness of and experiences with FOG and characterises two important behaviours: kitchen appliance cleaning regimes and waste management practices. Findings demonstrate that awareness of issues caused by FOG in sewer networks is independent of job role or position and that a majority of respondents (74%) are acquainted with the impacts of poor FOG management. Application of a risk ranking approach revealed a low risk of emissions from waste frying oils and exposed behaviours which can serve to reduce FOG emission potential including pre-rinsing of plates and cleaning of fryers and extraction hoods. Critically, 69% of FSEs had no means of managing their FOG emissions. We conclude that sampled FSEs were generally unaware of the relative contribution of FOG sources, thereby limiting their ability to respond to the behavioural and technological options available for minimising its impact. The risk ranking developed in this paper could be used to suggest efforts to reduce and mitigate FOG emissions from FSEs.

Key words: FOG, food service establishments, risk, sewer deposits

HIGHLIGHTS

- Extend understanding of how FOG is perceived and managed by those working within food service establishments (FSEs).
- Risk ranking reveals a relatively low risk of emissions from waste frying oils.
- FSEs are unaware of the contribution of the various sources of FOG to sewer blockages.
- Propose a risk ranking that can be used to reduce and mitigate FOG emissions from FSEs.

INTRODUCTION

Over the last decade, uncontrolled discharges of fats, oils, and greases (FOG) from food service establishments (FSEs) have attracted increased attention from both water infrastructure operators concerned about the obstruction of sewers, and from the general public as high-profile sewer blockages appear in media headlines (Engelhaupt 2017; Moss 2018). Once allowed to solidify and/or deposit in sewer lines, such discharges tend to form large assemblages (often called fatbergs), reducing a sewer's effective capacity and leading, in some cases, to sewer flooding. Useful overviews of FOG formation, flows, and control can be found in He *et al.* (2017), Collin *et al.* (2020) and Sultana *et al.* (2022). Uncontrolled discharges of FOG create major challenges for infrastructure owners with accumulations being more severe where FSE density is highest (Nieuwenhuis *et al.* 2018). Both the changing dining habits of people eating out more frequently (Paddock *et al.* 2017) and projected population growth (Office for National Statistics 2017) are driving significant increases in the number of FSEs. As a result, water companies in the UK deploy additional resources to manage FOG problems with an annual spending on control, removal, and clean-up being estimated at £100 million (BBC 2019). The sole legislative mechanism providing for FOG control in the UK is the Building Regulations (HM Government 2015) which states that grease traps and separators must be fitted in commercial hot food premises which complies with BS EN 1825-1:2004 and is designed in accordance with BS EN 1825-2:2002 'or other effective means of grease removal'. The regulation applies to a range of types of establishments including restaurants, hotels and guest houses, bars, cafes, commercial kitchens, and fast-food restaurants and takeaways. Critically, this standard refers to large separators unsuitable for many FSEs with constrained space. Further to this, in the absence of any clarification of the phrase 'other effective means', much is left to interpretation with many FSEs opting for more convenient and less expensive techniques to the detriment of effective FOG control.

Infrastructure operators are becoming increasingly interventionist in their attempts to reduce the impacts of FOG on their assets. Through the promotion of good kitchen management practices in combination with on-site remediation techniques, discharges of FOG can be minimised. However, the experience of one UK water utility showed that 90% of FSEs do not have appropriate FOG management in place (Thames Water Utilities 2018). Consequently, regulatory measures to control discharges of FOG are increasingly being used to deter and penalise inappropriate behaviours. For example, UK sewerage service providers have taken a more aggressive approach towards FSEs under Section 111 of the Water Industry Act (UK Parliament 1991) which makes it a criminal offence to discharge anything into a public sewer likely to prejudicially affect the treatment and disposal of its contents, leading in some cases to prosecution (Thames Water 2021) and the imposition of penalties.

While FSEs are often assumed to be a major source of FOG-induced sewer blockages, their contribution to the problem has not been widely explored. Typically, in an FSE, FOG is present in (i) used cooking oils (UCOs) from fryers and (ii) kitchen wastewaters produced as a result of cleaning processes. A rebate or discount is often provided to FSEs by cooking oil suppliers for returning UCOs (Smith *et al*. 2013). With a financial benefit for FSEs from recycling, we postulate that direct tipping of UCOs in sewers is rare. Kitchen wastewater is produced from washing up activities (e.g. food, dishes, cooking utensils) and cleaning activities, and as such are heavily loaded with FOG as reported by several authors (Chen *et al*. 2000; Chung & Young 2013; Yau *et al*. 2018; Gurd *et al*. 2019). Recent work has demonstrated that the physicochemical characteristics of effluents vary depending on their source (e.g. kitchen sinks, dishwashers) which, in turn, affects the efficacy of remediation techniques (Gurd *et al*. 2019, 2020).

Consequently, an improved understanding of how and where FOG generation occurs and what measures are undertaken to mitigate its impact on sewers is required to ensure effective FOG control. Below, we directly address this knowledge gap by exposing how FOG is perceived and managed by those working within FSEs. The objectives of the study are to expose awareness of, and experiences with, FOG management and fate and characterise two specific mitigation interventions: kitchen appliance cleaning regimes and waste management practices. A questionnaire survey ($n = 107$) of FSE operators was used to expose awareness of FOG generation and disposal options and experiences with FOG management as well as to characterise two important behaviours: the nature and frequency of kitchen appliance cleaning and waste management practices. The information gathered during the study is subsequently used to develop a risk ranking of activities contributing to FOG emissions for use in prioritising future efforts to reduce and mitigate discharges of FOG.

Given the paucity of evidence around the links between FSE waste management practices and FOG issues in drainage and sewer systems, our study is appropriately investigative, constituting a scoping study rather than a test of hypothesis or model. Scoping or exploratory studies (those which are both literature or fieldwork based) are typically deployed to expose a new area of interest or problem set, to describe key phenomena or processes and determine the value of undertaking more detailed analyses (Arksey & O'Malley 2005). The survey reported below was not shaped by theory but rather constitutes a loosely investigative but rigorously executed enquiry, the findings from which may be confidently used to inform future work at more detailed resolutions and surer ambition (Stebbins 2001). Our purpose in reporting the survey results is to provide an overview of the relative risk posed by different types of FSE equipment and their operation. Data are presented in order to illustrate how FOG generation and management practices provide distinctive profiles of FOG release into drainage and sewer systems.

METHODS

A list of FSEs was obtained from the UK Food Standards Agency (Food Standards Agency 2019) and used to identify the locations of commercial kitchens in two towns (both under 200,000 population) in the South East of England. Purposive sampling (following Steinke 2004) was then applied to select a response group of establishments across five categories: restaurants (51% of respondents), cafés (14%), institutional food services such as schools and nursing homes (14%), pubs (13%), and fast-food outlets (7%). Given that there are alone over

46,000 takeaway and fast-food restaurants in the UK as of 2022, this is a very limited sample in terms of population representation. However, the sampling strategy fulfilled two purposes: capturing the variety of food service outlet types, and broadly representing the relative proportions of the major FSE categories within urban environments. Access to respondents involved door-stepping – drawing on the advice proffered in Hazel & Clark (2013) on negotiating researcher and respondent roles. A total of 107 FSEs ultimately agreed to participate in the study.

A semi-structured administered questionnaire was used to gather information on how FOG is perceived by FSE operators and the contribution of cleaning regimes to FOG-related problems with general guidance on survey design and quality control taken from Ruel *et al.* (1986). The questionnaire elicited responses across five topics: (i) characteristics of the FSE, (ii) kitchen equipment and cleaning regime, (iii) food waste and UCO disposal regimes, (iv) means of FOG prevention, and (v) knowledge and experience of FOG-related problems. The survey was conducted with one staff member from each establishment. Participants were selected by requesting access to the individual with the most understanding of FOG generation and control on arrival at the premises. Each visit involved the completion of the survey instrument and observation of relevant processes and equipment and lasted no more than 30 min. Respondents reflected three distinct job roles and functions: business owners (25%), facility or restaurant managers (39%), and kitchen staff (36%). Question formats were exclusively either dichotomous (e.g. Yes/No, Presence/Absence) or descriptive (open-ended) and no rating scales were used. Where results are reported as category variables, grouping was carried out post-survey. Ethical review and approval of the survey instrument were obtained through a university review process. Piloting of the survey with six FSEs included checks for comprehensibility, survey and survey administer bias, query ambiguity, and capability of target respondents to provide meaningful and reliable responses. The pilots resulted in minor changes to the wording and sequencing of some queries. As with most social enquiry research, we are dependent on respondents being truthful and accurate to ensure that collected data are credible. Our use of a face-to-face work-based survey rather than a self-complete questionnaire allowed for ground-truthing of some items via cross-checking and direct observation. Respondents were also advised that the survey was for research purposes and would protect the anonymity of both individuals and businesses. These steps, together with the piloting, allow us to have good confidence in the data precision.

Collected data were recorded in Microsoft Excel and frequency analysis was used to report the relative significance of respondent beliefs, understandings, and behaviours. Results were reported using quantified terms. Cross-tabulation was used to analyse a limited number of pairs of categorical variables (see Tables 1 and 2). Given the exploratory and non-theory-driven nature of the study, we use cross-tabulation in an uncomplicated way to order important parameters rather than test relationships through the use of statistical hypothesis tests such as χ^2. To understand the potential contribution of kitchen equipment to discharges of FOG, interviewees were asked about the method and frequency of cleaning their equipment. Each appliance in each establishment was assessed for the potential severity of its contribution to the FOG problem with activities involving the discharge of FOG-rich waters into the drains considered high risk.

Table 1 | Waste management mechanisms in FSEs

	Waste source		
Waste management mechanism	**UCOs**	**Food waste**	**Other sources of FOG**
Food waste container		36 (34%)	
UCO container	87 (88%)		7 (7%)
General waste container	3 (3%)	66 (62%)	
Third-party servicing			13 (12%)
Other		5 (5%)	
No waste management	9 (9%)		81 (76%)[a]
Not known			6 (6%)
Not applicable[b]	8 (8%)		

[a]FSEs not using any cooking oils.

[b]Both FSEs with no FOG management and those using biological dosing (i.e. no FOG collected).

Table 2 | Cleaning frequency of grease separators

		Observed				
Unit type	**Recommended**	**Daily**	**1–3 weeks**	**1–3 months**	**More than 3 months**	**Unknown**
Grease interceptor	Every 3 months			2		1
Passive grease separator	3 weeks to 2 months		6	5	3	3
Grease Removal Unit	Daily	5	1	1		

Note: Recommended cleaning frequencies are based upon manufacturer recommendations and relevant standards (e.g. BS EN 1825).

RESULTS AND DISCUSSION

Overall, 74% of survey respondents were able to articulate at least one consequence of discharges of FOG in the sewers (e.g. sewer blockages). Establishment owners were found to be slightly more likely to be aware of the impacts of poor FOG management (85% of owners) compared with managers (71% of managers) or kitchen staff (68% of kitchen staff) – perhaps due to them bearing the financial cost of associated maintenance and repair. While about one-third of respondents (34%) had first-hand experience of the effect of FOG in their sewer lines, such direct experience of the impacts of FOG build-up was not correlated with the use of FOG control measures and neither was a lack of direct experience associated with an absence of measures. UK sewerage companies are responsible for private sewers and lateral drains while FSEs are only liable for the section between their property and the lateral drain. Keener *et al.* (2008) reported that FOG deposits tend to form between 50 and 200 m downstream of FSEs. Consequently, sewer operators accrue most of the problems from uncontrolled discharges of FOG with FSEs being spatially removed from the problems they create.

A common theme in conversations with respondents was their reference to cooking oils when asked about their understanding of FOG generation. In commercial kitchens, these oils are mostly used for deep-fat frying. Among the surveyed premises, 93% purchased cooking oils with volumes ranging between 1 and 200 L/week , with a median value of 30 L/week. Encouragingly, 88% of the surveyed establishments which use cooking oils were recycling their UCOs while 3% were disposing of small volumes (deposits on used plates, etc.) into the general waste bin (Table 1). The remaining 9%, while using small volumes of cooking oil (between 0.1 and 2.5 L/week), were not recycled potentially allowing UCOs to reach drainage systems. Volumes of UCOs generated by the establishments ranged from 0 to 200 L/week, with a median value of 20 L/week. Used cooking oil volumes were thereby 33% less than purchased volumes. The data show that significant volumes of UCOs are being generated in the surveyed FSEs. Consequently, it is understandable that UCOs are identified as the most prominent source of FOG by interviewees. In addition, it is worth noting that there is a well-demonstrated economic incentive mechanism for recycling of UCOs for biodiesel production with UCO collectors offering a rebate or discount on the supply of fresh oil.

FOG-rich kitchen wastewaters are produced as a result of washing up and cleaning activities and their relative volumes are linked to the practicalities of food service (Garza *et al.* 2005). FSEs serve food either on washable or disposable dishes with the latter being particularly prevalent in the fast-food sector. Among survey respondents, 68% were using reusable plates while 7% used disposable material exclusively and 24% used a combination of both. Where crockery cleaning was undertaken, FSEs either hand-washed (22% of respondents) or relied on automated dishwashing equipment (76%). For 50% of the respondents, washing up was conducted using either a pre-rinse step or a pot scrubber prior to loading into a dishwasher. The remainder of surveyed establishments relied on only hand washing dishes or loading them directly into the dishwasher. Interestingly, Gurd *et al.* (2019) reported significant differences in the effluent composition from pre-rinse sinks and dishwashers with the emulsified fraction in sink samples representing $42 \pm 16\%$ of total FOG compared to $94 \pm 9\%$ in dishwasher effluents. Different pot-washing methods used by FSE operators will thereby have a direct impact on the type of effluent discharged and on the effectiveness of remediation techniques.

Although dishwashing is one of the largest contributors to FOG emissions from commercial kitchens, cooking and food preparation appliances also contribute to the release of FOG into drainage networks. Among the surveyed establishments, the use of extraction hoods (94% of establishments), conventional ovens (79%), and deep-fat fryers (76%) were common with grills (50%) and combination ovens (34%) also being widely used. Based on the information provided by respondents, 86% of establishments with combination ovens were operating cleaning regimes that potentially contribute to discharges of FOG as they included a steam cleaning cycle, the effluent from which is typically discharged straight to the drain. A second commercial appliance with significant FOG discharge potential was found to be extraction hoods, possessed by 70% of surveyed establishments. These ventilation systems are designed to extract heat, FOG, and other vapour emissions generated within the kitchen. Filters are fitted to prevent FOG from entering the ventilation system. Respondents routinely cleaned these filters in kitchen sinks or over an external drain, thus discharging a slug of accumulated FOG directly into drainage systems. A similar proportion of establishments (70%) operating deep-fat fryers also discharged potentially harmful effluents to the drains as a result of appliance cleaning. In the majority of cases, waste frying oils were drained, and then fryers were filled with water and/or cleaning products. It was common for FSEs to discharge these effluents directly into the drains. Furthermore, fryer baskets were commonly cleaned using dishwasher appliances.

Cleaning practices for conventional ovens and grills were far less risky with only 25 and 36% of establishments respectively adopting behaviours that resulted in discharges of FOG to drain. Good practices for grills included using aluminium foil to prevent grease build-up or wiping surfaces with dry towels to remove any accumulated debris. Cleaning of conventional ovens was typically achieved either by dry wiping internal surfaces and/or using detergents with disposal into the drains. These results clearly indicate that there are several grease contamination points in kitchens that require improved management in order to avoid FOG accumulation in sewers. However, an assessment of the risk needs to be informed by data on cleaning frequencies. For instance, while the cleaning of extraction hoods has a high likelihood to contribute to the discharge of FOG in the drains, reported cleaning frequencies had a high variability with 51% of respondents washing every few days, 20% every few months, 11% every few weeks, and 10% daily (Figure 1(b)). Similarly, fryers were cleaned every few days by 52% of those respondents who owned this type of appliance, typically when the cooking oil was being replaced. By contrast, grills (56% of establishments), combination ovens (42%), and conventional ovens (37%) were found to be more commonly cleaned on a daily basis. Infrequent cleaning can arguably result in periodic high discharges of FOG, in turn impacting the kinetics of deposit formation through the aggregation of excess FOG loads (He *et al*. 2017).

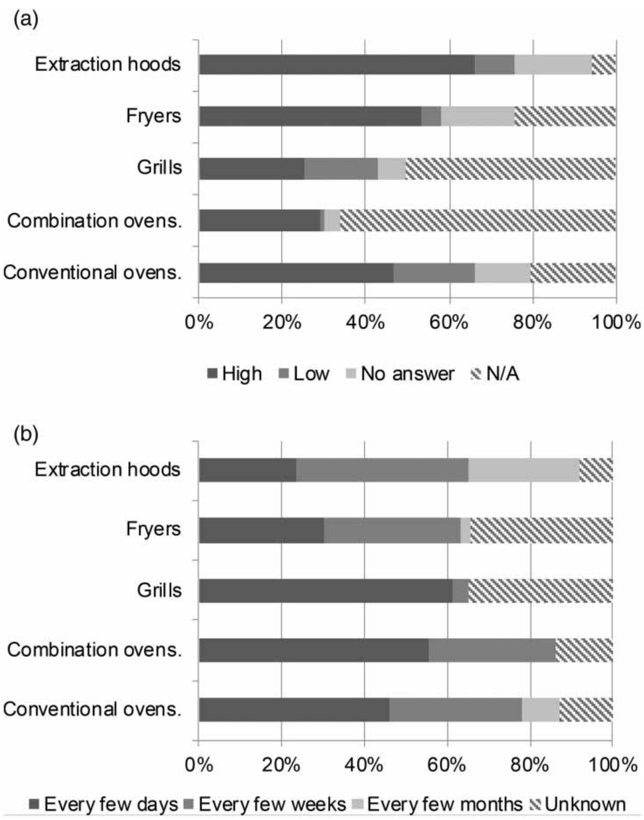

Figure 1 | Risk of contribution to FOG emissions from appliance cleaning (i.e. whether the cleaning process has a high or low probability of resulting in discharges to drain) (a) and appliance cleaning frequencies (b) The *x*-axis marks the percentage of respondents reporting against each appliance for each level of risk (a) and frequency (b).

Despite the legal requirement for commercial kitchens to be fitted with an approved grease separator or other effective means of grease removal, a large number of the surveyed establishments (69%) did not possess any type of FOG remediation system to treat their effluents and only 23% were using physical separation (Figure 2). Other studies have reported similar figures, estimating that only 10–20% of FSEs have a grease separator (Thames Water Utilities 2018). Three types of grease separation devices were recorded through the survey: grease interceptors which are normally located underground in the sewage collection system (2% of respondents), smaller indoor devices which can be either solely or partially gravity operated (11% of respondents), and indoor located hydro-mechanical devices (6% of respondents). It is worth mentioning that two of the surveyed premises possessed a grease collection system which was, in reality, a wet well, allowing FOG accumulation downstream from the kitchen. Indeed both these premises had suffered from blocked drains in the past and the efficiency of the control technique was questioned by the FSE respondent. Another notable finding was that three respondents were using a combination of physical and biological remediation techniques to reduce their discharges of FOG.

To ensure grease separators operate effectively and reliably, frequent maintenance is required (Sultana *et al.* 2022). Maintenance is largely dependent upon the unit type. Typically, large grease interceptors require emptying out on a 3-month cycle (Wallace *et al.* 2017) while pump-out intervals of 3 weeks to 3 months are recommended for smaller grease separators. In comparison, hydro-mechanical units require daily maintenance (e.g. emptying the oil collection cassette and cleaning of wiper blades) with deep cleaning planned every 3–4 months. Maintenance frequencies reported by respondents showed that 24% of grease separators were not maintained as regularly as recommended in existing standards (Table 2). In addition, several installed systems were found to be undersized. In one particular instance, the premises owner had purchased a separator from the internet with no consideration of flow rates. In another case, the grease separator was already fitted when the premises was re-purposed to a food outlet. In their study, Gallimore *et al.* (2011) demonstrated that a doubling of the flow rate to grease separators could reduce their efficiency by up to 96% depending on the type of unit.

FOG retained by grease separators is generally collected by a third-party during cleaning operations (12% of the respondents) or disposed of together with UCOs (7% of the respondents). A small number of respondents ($n = 2$) were unaware of their business' FOG disposal practices, possibly explained by the fact that responsibility for maintenance is often delegated to kitchen staff. In the UK, waste collection must be carried out by a licensed carrier. However, there is currently a lack of understanding about grease trap waste disposal routes used by waste hauliers who often also service septic tanks and cesspits as well as grease separators, providing a possible route for the discharge of FOG to wastewater treatment works which, in turn, puts wastewater treatment assets under greater risk. Similarly, the disposal of FOG rich in polyunsaturated fatty acids with UCOs could pose a problem in the supply chain as the former is known to hamper biodiesel conversion efficiency (Puhan *et al.* 2010; Liu *et al.* 2023).

The fragmentation observed in current FOG management practices is further evidenced by the fact that while local authorities conduct regular inspections of FSEs through their environmental health responsibilities, there

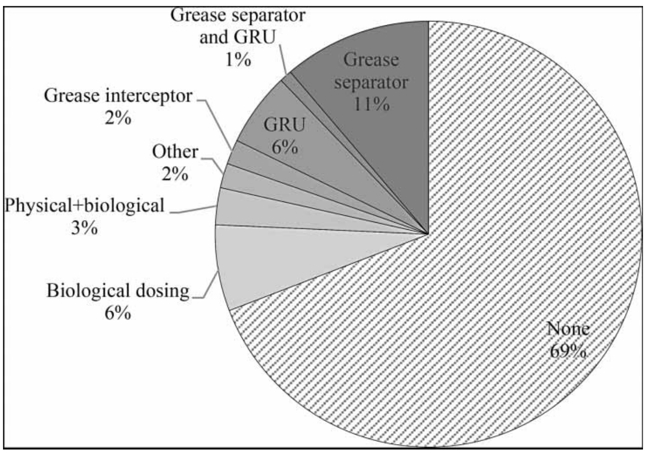

Figure 2 | Types of FOG remediation techniques in FSEs. 'Other' refers to the presence of a wet well FOG retention mechanism downstream of the kitchen.

are recorded cases of Environmental Health Officers (EHOs) recommending the removal of grease separators as a potential health hazard (Drinkwater *et al.* 2017). Only 27% of our survey respondents who possessed operational grease management processes could recall their systems being inspected by an EHO. Some respondents reported odours generated by grease separators, possibly affecting the perception of food safety and providing a design challenge for FOG technology manufacturers.

As an alternative to physical separation, 6% of surveyed FSEs used biological additives as a remediation technique. Numerous products are commercially available that help degrade FOG but a series of inconclusive lab tests and field trials have led to scepticism regarding their efficacy (Shaffer & Steinbach 2007; Mattsson *et al.* 2014; Mosholi & Cloete 2018). Recent research has demonstrated that the biological degradation of FOG in kitchen wastewaters is complex and requires a deeper understanding of the effluent physicochemical properties (e.g. presence and concentration of alternative carbon sources, the ratio of carbon to nitrogen; see Gurd *et al.* 2020).

Finally, respondents were asked about the reasons for the absence of FOG management and this was evident through earlier questioning. Meaningful proportions of the sample were either unaware of the availability of remediation techniques (21%) or did not require grease management in their establishments (37%). During the interviews, a common misconception from FSE operators was that FOG only exists in the form of UCOs and that the recycling of this material is sufficient to avoid the accumulation of grease in sewer lines. More detailed communication with FSE operators is therefore needed to raise awareness of existing FOG sources and remediation techniques. As such, drawing from existing UCO and food waste management models could be beneficial. By contrast to the UCO recycling model, separate food waste recycling incurs additional costs to FSEs, and 34% of the surveyed FSEs had such a system in place compared to 88% of the respondents (using cooking oils) having a UCO collection scheme (Table 1). The willingness to pay for this type of service has been shown to be motivated by environmental concerns or reputational gains through improved environmental credentials (WRAP 2015), yet it further illustrates the importance of cost reduction in motivating behaviour change (Martin-Rios *et al.* 2018). Critically, a viable FOG management model will require a deeper understanding of the volumes of waste produced and its physicochemical characteristics to realise its economic value.

TOWARDS A RISK RANKING

Drawing on both the information gathered through the survey reported above and data from previous studies, a ranking is proposed of kitchen operations, equipment, and behaviours in terms of the potential contribution each can make to FOG deposition in main sewers. Importantly, this risk ranking (Table 3) incorporates technical and behavioural aspects of FOG generation and control, drawing on both data regarding relative levels of FOG generation for different appliances and operations as well as information on cleaning and appliance management

Table 3 | Risk ranking of FSE activities and discharges of FOG

Appliance/Activity	Risk	Comments
Extraction hood	High	Cleaning operations release oil-rich water into the drains through the dishwasher or kitchen sink.
Fryer	High	Cleaning operations release oil-rich water either directly into the drains or through the dishwasher or kitchen sink.
Dishwasher	High	FOG measurements demonstrate high concentrations of chemically stable oil emulsions in dishwasher effluents. Posited to be more difficult to manage using physical methods only.
Pre-rinse sinks	High	A significant source of FOG due to cleaning practices.
Conventional ovens	Medium	Cleaning operations release oil-rich water into drains via the kitchen sink. Lower risk than other sources due to cleaning practices.
Floor and surface cleaning	Medium	Likely to be large volumes but with low to medium FOG content.
Grills	Medium	Cleaning operations release oil-rich water into drains via the kitchen sink. Lower risk than other sources due to cleaning practices.
Combination ovens	Low	While many commercial combination ovens discharge their effluents directly into the drains. Low FOG content as they are typically used as steamers.

regimes in FSE kitchens. The following paragraphs outline the evidence base for each allocated risk ranking using specific appliances and operational behaviours as the categories.

Combi-ovens have been assigned the lowest risk score as in most cases they are used for steaming food rather than for cooking high-fat foods, therefore limiting the amount of grease generated and discharged into the drains. By contrast, cleaning exhaust hoods, in particular their filters, can result in large volumes of FOG entering the drainage system. Based on the efficiency of a prototype for treating grease filter washwater developed by Ghaly *et al.* (2007), FOG concentrations in these wash waters are estimated at 9 g L^{-1}, 10 times higher than that of kitchen sinks. While no data were captured on FOG emissions from fryers, we argue that their impact can be assumed to be of similar significance to that of exhaust hoods. In light of cleaning frequencies captured in Figure 1(b), this would translate into periodical high discharges of FOG into the drains. Similarly, for conventional ovens and grills, estimated at a medium impact, sinks were highlighted as one of the main disposal routes for detergent-rich wash waters.

Although there is reasonable evidence to suggest that both kitchen sinks and dishwashers should be a priority for intervention, the impact of FOG from sink effluents (879 ± 583 mg L^{-1}) has been shown to be significantly higher than that from dishwasher effluents (313 ± 92 mg L^{-1}) (Gurd 2018). Furthermore, sink and dishwasher effluents display different physicochemical properties suggesting they would require to be managed using distinct techniques. To illustrate, dishwashers produce chemically stable oil–water emulsions with droplet sizes smaller than 20 μm (Chan 2010) but conventional gravity-based separators are only believed to efficiently remove oil droplets larger than 30–50 μm (Ryan 1986). This suggests that grease separators might not be well suited for dishwasher effluents. By contrast, Gurd *et al.* (2019) suggested that biological additives were more likely to achieve the removal of these smaller FOG droplets.

Risk scores in Table 3 have been generated by multiplying the likelihood of FOG discharge (taken from the surveyed FSE practices) by the severity or impact of a discharge event (taken from published data on FOG concentrations in waste streams). Values for the impact variable were normalised to a three-point scale to facilitate the generation of a composite risk score between 0 and 0 with three equal ranges then used to allocate risks as High, Medium, or Low.

As the operational and behavioural elements of the ranking presented above are taken from a sample of FSEs, the ranking only provides insight into the FSE sector as a whole and therefore may not be useful in diagnosing the FOG threat from individual premises. Variations in operating and cleaning regimes for example could increase or decrease the risk of a particular appliance. The ranking is also purposely both relative and qualitative in form. The inference is that appliances and activities labelled 'High' risk will, on average, present a higher potential for depositing harmful volumes or concentrations of FOG into mains sewers than those labelled 'Medium' etc.

CONCLUSIONS

This study has explored how FOG is both perceived and managed by FSE operators, allowing us to both contribute to the literature on understanding FOG generation risks from commercial kitchen operations and propose a risk ranking of appliances and activities. Results have exposed a number of behaviours contributing to discharges of FOG into sewerage systems and challenge assumptions about levels of awareness in the sector. The fact that known FOG pathways such as washing up and cleaning kitchen appliances were often unacknowledged by respondents, coupled with low levels of familiarity with remediation techniques and the large number of surveyed FSEs not possessing any system in place to treat their effluent, prompts questions around the effectiveness of awareness raising campaigns. Future education initiatives might deepen their effectiveness by providing more bespoke advice to FSE owners on FOG pathways, impacts, and mitigation options.

Similarly, common practice within the industry recommends a FOG management system at each contamination point. However, research has shown that the efficacy of FOG management is source dependent and, from an FSE point of view, managing several FOG control systems could become a financial burden impacting business profitability. In proposing trade-off solutions, further research will be needed to quantify and characterise the different FOG fluxes. While a case-by-case approach is recommended over a one-size-fits-all approach, it is possible that targeting kitchen sinks would offer the highest benefits in terms of sewer relief.

While UCOs were identified as the main source of FOG by FSE operators, the survey demonstrated other (often unacknowledged) pathways contributing to FOG emissions into drainage systems related to washing and cleaning of kitchen appliances. From information gathered on operation and cleaning practices, four types of appliances (pre-rinse sinks, dishwashers, extraction hoods, and fryers) are proposed as providing a high risk of contributing to discharges of FOG in the network.

The proposed risk ranking offers FSE operators, FOG separation and solution providers, as well as sewer asset owners a tool to help structure and prioritise policies, investments, and interventions. It also provides researchers with an indication of where future efforts may deliver the most impact on managing the adverse impacts of FOG in drainage and sewer systems. FSE inspection and audit visits might usefully be guided by the ranking coupled with a register of appliance assets as a starting point for assessments of FOG discharge risk. The ranking might also inform tailored risk assessments at individual premises to flag up where changes in behaviours and practices can influence FOG discharge.

Although the risk ranking is premised on well evidenced and widely available technical information about FOG concentrations in waste streams, it does constitute a first pass at characterising the threat. We encourage others to critique and mature the risk classification allocations to improve the utility of the ranking and perhaps extend it to additional types of appliances and activities. Further work might expose more detail on how the relative contribution of FOG from different sources (see Table 3) vary with respect to the size or type of catering establishment. Colleagues might also explore productive interactions between this work and recent advances in machine learning which has been used to identify statistically significant indicators of FOG formation in sewers (Yiqi *et al*. 2021) and investigate whether a more conditional form of the ranking which allows for the influence of additional phenomena (e.g. type of food being prepared) might add value to the ranking or merely over-complicate its use and compromise its value. At the least, the ranking will require updating as new evidence comes to light regarding relative FOG loads, the performance and use of novel kitchen equipment, etc.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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