Assessment of highway filter drain fouling and performance considerations

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ASSESSMENT OF HIGHWAY FILTER DRAIN FOULING AND PERFORMANCE CONSIDERATIONS

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ABSTRACT
The road carriageway and pavement sub-surface of many UK highways are drained by Highway Filter Drains (HFD). These are gravel filled trenches fitted with a porous carrier pipe at the base that convey surface and sub-surface water to an outfall. HFD are typically characterized as free draining upon construction however, over time the voids of the granular medium become filled due to the intrusion of fines washed from the adjacent earthworks or pavement surface. The lack of understanding of the deterioration mechanisms and the absence of a structured fouling characterization limit the assessment of operational and residual HFD life to qualitative or subjective estimation of in-service performance. This extends to maintenance procedures that are predominately reactive. This paper reviews the current state of knowledge of HFD performance and drainage media condition assessment. It then presents a method of fouling characterization based on assessment of samples from in service drains. Three fouling scales are thus suggested; the percentage drain fouling, the foulant-aggregate ratio and the free voids ratio. In-service HFD are found to be functioning at an acceptable standard with a limited number of localized failures attributed to highly fouled layers at the surface of the trench. It is proposed that a rational evaluation of a HFD section should employ means other than just visual indicators. The fouling assessment is linked to laboratory permeability tests conducted with different levels of filter material fouling. It is found that the extent, spreading and type of fouling are important to determine how the filter aggregate performs.
INTRODUCTION
Highway Filter Drains have been used in the United Kingdom for considerable time to drain lengths of the highway network. These are aggregate filled trenches fitted with a porous carrier pipe at the base to remove surface and sub-surface water from the pavement system. The granular material used (typically exposed to the surface under most UK construction configurations) allows for efficient removal of pavement run-off due to its highly porous nature. It also enables the removal of water that finds its way into the pavement foundation and structural layers. Filter drains have a number of inherent limitations; most importantly they have a finite operational life due to the reduction of free voids space as road detritus and other introduced fines enter the filter trench restricting the free flow of run-off. (1).
Currently there are limited management systems to monitor the performance of filter drains with maintenance approaches being mainly reactive, based on dealing with areas of failed drainage where they occur (evidenced by pavement flooding), or by periodic maintenance. This paper, as part of ongoing research aiming to present a holistic HFD Maintenance Management system, presents a suggested way forward to allow a quantitative assessment of HFD by evaluating a fouling characterization methodology of the drains (based on similar approaches used for railway ballast), mapped against laboratory permeability assessment of filter drain material as it blocks. HFD are introduced and maintenance thinking, performance and capacity failures are addressed. The paper then presents the fouling characterization thinking used to assess the performance of railway ballast, and suggests how a similar approach could be used for HFD. Fouling scales are subsequently suggested from field and laboratory data, comparing the in-situ condition of filter drain media to laboratory assessment of hydraulic performance.

HIGHWAY FILTER DRAINS
A general definition of Highway Filter Drains is provided in (2) as ‘A drain constructed using permeable materials which allow the entry of water whilst retaining the surrounding material’. HFD consist of gravel filled trench with a porous carrier pipe at the base. Frequently a geotextile is provided on the external faces and/or near the surface of the trench.

The drains are installed in verges and/or central reservations adjacent to low edges of pavements allowing surface water to run off the pavement (or from adjacent earthworks) directly into the trench and permeate through the stone aggregate to the porous carrier pipe at the bottom. The geotextile is used to prevent the entry of fines carried into the trench by either surface or sub-surface water ensuring the drain is kept clear to provide a free-draining path throughout its length.

The gravel used has a porous nature that enables rapid removal of water. Pipe diameters used are usually relatively large (up to 375mm), there is, therefore also a large capacity to intercept groundwater. This can act as a cut-off to below the pavement foundation capping-layer (3).

![Gradation Envelopes For Type A and Type B Adopted In Highway Filter Drains.](image)

(4) specifies two broad granular material gradings for aggregate used in the drains as Type A and B (Figure 2), Type A being a finer material. Type A is selected as a balancing option between permeability and filtration of surface foulants, Type B offers higher permeability (5-6). The different granular fills therefore offer different...
water removal efficiency and hence present different forms of functional failures (Type A is more prone to fouling accumulation near the surface layers).

4 Deterioration and Maintenance

Filter drain fouling is the term used to describe the filling of voids and the gradual clogging of a filter drain trench. This occurs due to the collection of detritus (foulants) being washed into the drain from pavement run-off or infiltration of fine particles from adjacent earthworks resulting in the reduced performance of the drains. Currently there are no standards or guidance to evaluate the level of performance against a quantified level of HFD fouling. However, in some long-term maintenance contracts there is a specified minimum level of permeability performance at their beginning and a minimum requirement for residual life at their end. The justification for these values is not included in the available literature.

Current UK design guidance and empirical experience suggest that highway filter drains should achieve an operational life of approximately 10 years. The filter material is expected at this point to require replacement or recycling, and this is often included in maintenance plans. However, during filter drain field evaluations (5-7) acceptable performance of many drains has been observed after 20 years of operation with minimal or no maintenance undertaken. Studies (6) have shown there’s a differentiation between the service life of Type A and Type B drain aggregate and an implied correlation between aggregate type and modes of failure.

As standard practice, the performance of the drains can be assessed by visual inspection of the surface of the drainage trench (8) resulting in reactive or periodic routine maintenance. The reactive approach results in a number of disruptive performance failure events (i.e. highway surface flooding and/or possible premature pavement failures (7,9,10)) while a time based remedial regime, dependent on the frequency of cleaning, reduces the risk of flooding but inevitably specifies cleaning where it is not actually required. Visual indicators of the failure include surface ponding of water or siltation, vegetation growth and visible wheel rutting at the surface (8). These are usually an indication of large detritus depositions near the surface of the trench. However, water ponding can also be the result of large fouling levels concentrated deeper in the drain. Current UK HFD maintenance practice is broadly limited to three remedial options.

- Removing and replacing the material,
- In-situ aggregate recycling and re-use (10),
- Scarifying of the trench (loosening the aggregate / detritus cake that accumulates at the surface of the trench).

4.1 RAILWAY BALLAST CONDITION EVALUATION

Railway Ballast is composed of uniformly graded angular aggregate that becomes progressively fouled by ingress of foreign particles from the track surface, subgrade infiltration, or fines generated from track/ballast mechanical wear during cycling loading (12). Both railway ballast and filter drains are designed using materials that are highly porous, however their deterioration mechanisms and characteristics required are different as they are generally designed targeting a different operation context (for ballast mainly load related stability, though good drainage is also required). Ballast condition and performance evaluation is based on determining and quantifying the levels of fouling (13) and this approach offers a potential way forward for filter drain fouling assessment.

4.2 Ballast Fouling Measurements

Research has been carried out to correlate ballast-fouling levels to universal fouling scales that can be used for performance monitoring and evaluation. These scales are derived using mass or volume based methods (14).

Such indices comprise a simple method to correlate particle size distributions to a fouling status that can be applied as an indicator of fouling levels and subsequently performance. Typically for ballast the fouling material is defined as the fraction of particles passing the 9.5mm sieve representing the particle matrix that is expected to infiltrate the ballast sections or be generated due to wear and mechanical break-down (12). This is based on gradation requirements and may differ in railway systems in different areas (15).

**Mass Based Indices**

Selig and Waters (12) proposed the Fouling Index (FI) as a means to classify fouling based on grading from representative samples of ballast.

\[
FI = P_{9.475mm} + P_{0.075mm}
\]

(1)

Where:

- \( P_{9.475mm} \) = Percentage by mass passing the 4.75mm sieve, and
- \( P_{0.075mm} \) = Percentage by mass passing the 0.075mm sieve.
By using the $P_{90.075mm}$ in the equation, the importance of finer fractions is highlighted. These fractions, which are expected to have a large impact on the performance of the ballast section due to their inherent lower hydraulic conductivity properties, are also included in the $P_{94.75mm}$ parameter and thus slit/clay fractions are summed twice in the Fl.

### Volume Based Indices

The percentage void contamination (PVC) is defined in (16) as the ratio of the volume of re-compacte fouling material to the volume of the free voids of the ballast

$$PVC = \frac{V_f}{V_{vb}} \%$$  \hspace{1cm} (2)

Where:

- $V_f$ = Recompacted volume of material passing the the 9.5mm sieve
- $V_{vb}$ = Volume of voids extracted by material retained at 9.5mm.

To quantify fouling within ballast layers the Void Contaminant Index (VCI) has also been proposed (17). As with the PVC, the VCI establishes a volumetric classification of fouling levels. The difference between PVC and VCI is based on the method used to extract each index. For PVC, a laboratory approach is followed; the VCI requires a field procedure to obtain the parameters used in the index.

$$VCI = \frac{V_f}{V_{vb}} \times \frac{(1+\epsilon_f)}{1+\epsilon_b} \times \frac{G_{fb}}{G_{sf}} \times \frac{M_f}{M_b} \times 100$$  \hspace{1cm} (3)

Where:

- $V_f$ = ‘actual’ volume of fouling material,
- $V_{vb}$ = volume of voids in fresh ballast,
- $\epsilon_b$ = void ratio of fresh ballast,
- $\epsilon_f$ = void ratio of fouling material,
- $G_{fb}, G_{sf}$ = specific gravity of fresh ballast and fouling material respectively, and
- $M_b, M_f$ = dry mass of fresh ballast and fouling material respectively.

Grading based indices are solely based on sampling and sorting; they may though lead to inconsistent representation of fouling levels; both Fl and PF fail to differentiate between different types of foulant. This is particularly important in ballast evaluation studies due to the presence of different sources of fouling (12, 16).

### Large Scale Permeability Tests

The condition and performance evaluation of railway ballast often extends to drainage performance and how finer fractions of fouling are expected to affect drainage. A number of large-scale constant head permeability studies have thus been conducted on ballast (16-19). In these studies foulants that simulate in-service track deterioration have been used to extract an inferred relationship between a fouling scale and hydraulic conductivity. While the testing methodology and apparatus used may vary, the objectives of these studies are similar. The hydraulic conductivity of the ballast reduces with increasing fouling levels converging eventually to the conductivity of the foulant itself (17).

### FILTER DRAIN FOULING EVALUATION AND ON CONDITION MAINTENANCE

By using standard rules for treatment selection and established intervention levels inferred from measured performance, a consistent approach could be utilised to specify works across the HFD network. The adoption of such rules should eradicate under or over (reactive / periodic) maintenance of the highway asset and ensure acceptable performance throughout its operational life based on predictive and preventive approaches.

To move to a proactive maintenance management system, the case of railway ballast maintenance management has been presented where a structured condition assessment hierarchy is used that addresses the evaluation of fouling concentrations within the ballast layers and integrates hydraulic performance and ‘drainability’ within the evaluation process.

As described above, visually assessing filter drains can be a quick evaluation approach. In practice though, only a limited amount of information can be extracted from this, potentially leading to unexpected drainage failures or unjustified maintenance interventions. Based on the rail approach, evaluating fouling levels for in situ drains and establishing performance boundaries using hydraulic testing offers a more rational
The following section presents work from a field and laboratory study to evaluate and quantify the levels of fouling within in-service HFD and, to investigate the impact of fouling on the effective ‘drainability’ of the material. Condition assessment and performance evaluation are presented here as precursors to determine the optimal level and type of maintenance that should be carried out to ensure HFD operate at the standard of service required.

**HFD Fouling Classification And Fouling Scales**

They key challenge in evaluating HFD fouling is to establish a fouling scale that reflects the influence of the fouling material, yet can be easily attained to characterise the condition of the drain. Three fouling indices are thus proposed for filter drain condition evaluation. The concepts developed for filter drains are derived using the specified HFD aggregate grading requirements (Figure 1).

A mass based index is suggested, namely the Percentage Drain Fouling (PDF). The formula includes the 10mm size sieve as the aggregate size cut-off that signifies the fouling material concentrations within the sample. This originates on the minimum particle size anticipated to be used in a 20/40 aggregate material in filter drains (Type B). All particles extracted by sampling and grading below the 10mm boundary are assumed to form the introduced foulant particle matrix. The 0.063mm size sieve is also used to highlight the anticipated increased weight of fines’ concentration on the overall permeability of the section, based on the silt/clay fraction. In addition, two volumetric scales are developed; the first as the ratio of the solid volume of foulant to the solid volume of aggregate and the second as a quantification of the free voids space in the sample. The later is established by estimating the available void space within a ‘fresh’ Type B sample (which is expected to remain constant for the Type B aggregate but to vary if different types of aggregate are used as backfill) and the volume of the introduced material by extracting a representative sample and the basic material properties of the backfill and foulants (namely specific gravity and voids ratio).

**Percentage Drain Fouling (PDF)** Based on material grading,

\[
P_{DF} = P_{\%10mm} + P_{\%0.063mm} \tag{4}
\]

Where:
- \(P_{\%10mm}\) = Percentage by mass passing the 10mm sieve (as fouling material)
- \(P_{\%0.063mm}\) = Percentage by mass passing the 0.063mm sieve.

**Foulant - aggregate ratio (R_{F-A})** Based on calculating the ratio of the solid volume of foulants to the solid volume of aggregate (material retained at the 10mm sieve size after grading). This index requires the extraction of the specific gravity parameter of both aggregate and fouling material.

\[
R_{F-A} = \frac{V_F}{V_A} = \frac{M_F \times G_{SA}}{G_{SF}} \tag{5}
\]

Where
- \(V_F, V_A\) = volume of fouling and aggregate respectively,
- \(M_F, M_A\) = Mass of fouling and aggregate respectively, and
- \(G_{SF}, G_{SA}\) the specific gravity of fouling and aggregate materials.

**Free-voids ratio (R_{FV})** Based on calculating the ratio of the volume of free voids of the in-service back-fill (voids of fresh material – volume of fouling) to the volume of free voids of fresh material.

\[
R_{FV} = \frac{V_{VFRA-VF}}{V_{VFRA}} = \frac{e_{fr} V_A M_F}{\frac{\pi F}{4}} = \frac{\frac{M_F}{V_A}}{\frac{M_A}{V_A}} = \frac{M_F}{M_A} \frac{V_A}{V_A} \tag{6}
\]

Where
- \(V_{VFRA} = \) Volume of voids in fresh aggregate,
- \(e_{fr} = \) Void ratio of fresh aggregate.

**Design Of Experiments, Materials And Methodology**

Field Evaluation Sampling And Sorting
To study the extent of filter drain fouling, studies of in-service drains were conducted on five locations on a selected highway section. The objectives of the study were to identify and characterize the foulant and fouling concentrations within the filter drain trenches and subsequently to correlate these to an engineered fouling status as a means of performance characterization.

The trenches in this study were constructed in 2003 using Type B material as backfill and a larger (up to 75mm nominal size) aggregate as trench top-up; design information for the drains indicated that a geotextile layer should have been provided at a depth of 300mm (below the top-up material); this was not observed during excavation but a geotextile was found at a depth of about 1m. It is assumed that during their life these drains will permit free vertical flow of runoff and detritus will enter the system and will be retained at the geofabric deeper in the trench. The minimum permeability requirement for these drains upon construction was established at 6 mm/sec.

Trial holes were extracted on the carriageway verge in the drain at each location (named holes A to E); as material was removed layer by layer (approximately 300mm per layer, up to a predefined depth of 1m), an initial visual assessment of fouling levels was made. At two locations (C and D) the excavation depth reached the geofabric located 1m deep in the drain. It should be noted that trial holes and sample extraction were limited due to severe weather conditions and reduced visibility (locations A and B). Samples from each point were collected and taken to the laboratory for further analysis.

**FIGURE 2** Schematic Of Large Scale Permeameter Designed For Type B Aggregate Hydraulic Trials

Hydraulic Trials

After completing the fouling evaluation a series of large-scale permeability tests were conducted to assess hydraulic performance of the filter material. In the tests clean aggregate had foulant added to simulate the process of ongoing fouling over time and as fouling progressed, changes in flow performance were assessed.

**Large Scale Permeameter** The large-scale permeameter (Figure 2) allows the measurement of hydraulic conductivity values for samples with radius of 375mm and depth of 450mm with varying fouling levels under a relatively low constant head.

Four manometers are installed in the permeameter to enable accurate measurement of head drops between three layers of aggregate. In order to prevent fine particles from washing out of the tank, a geofabric was installed on top of uniformly graded coarse aggregate at the lower end of the permeameter.

**Materials And Gradation Selection** Type B filter material has been used in the trials to match the material found in the field study; this was installed in three layers. Two types of foulants (sand and clay based) were used. The grading curves and specific gravity of the aggregate fill and foulants are illustrated in Figure 3.

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FIGURE 3 PSD Of Fouling Types And Aggregate Fill, $G_{c,\text{Agg}} = 2.7 \text{ Mg/M}^3$, $G_{c,\text{Sand}} = 2.6 \text{ Mg/M}^3$, $G_{c,\text{Clay}} = 2.77 \text{ Mg/M}^3$

**Procedure**

To simulate the in service degradation of the trench, fouling material was added at the surface of the tank and allowed to infiltrate within the fill with percolating water flowing into the drain under a low head (maintained by a weir in the apparatus). The effect of different fouling levels, materials and fouling spreading within the tank, was evaluated under fully saturated constant head conditions and assumed laminar flows. Separate permeability measurements were made of the foulant using constant and falling head permeameters.

When steady flow through the permeameter was established, the pressure drop across the four tapings was measured to extract the energy loss between the three layers of material. The mass of water exiting the tank was collected and using Darcy’s law permeability values are assessed.

After the test, the sample was excavated and assessed for the position of foulants by grading. The test is repeated twice with the second attempt aiming to represent the effects of surface scarifying on the material. This is achieved by loosening up the surface aggregate and allowing the foulants trapped near the surface to infiltrate deeper in the tank.

Two permeability values are thus assessed for each fouling level, the full sample and lowest by-layer values. The former represents the value between manometers at the top and bottom ends of the permeameter and thus the hydraulic conductivity of the full 450mm fill used in the tank. The lowest by-layer permeability value represents the lowest value recorded at any given layer at the first or second trial (before and after scarifying).

**Results**

Site evaluation, sampling and fouling indices

It was evident from the initial visual assessment of the site-collected material, that fouling levels increase at greater depths within the trench (this generally agrees with published data for Type B aggregate (5-7)). The filter drains assessed have been in service since 2003 and only limited cases of localised water ponding have been reported over the period of operation; this is attributed to the collection of detritus at the surface layers of the trench. As a general remark the filter drains within the network appeared to be functioning at an acceptable level.

The subsequent grading of the material from each layer (typical data are presented in Figure 4 for trial hole C) reveals a location and depth specific variation of fouling levels. For trial hole C, the particle percentage (by mass) passing the 10mm sieve size increases from 27% (surface level) to 60% (800mm deep) whereas in trial hole D and for the same depths, the percentages are measured to increase from 12% to 34%. Table 1 presents the fouling levels of all samples collected.

The fouling material composition is also found to vary according to depth; deeper within each trial hole the percentage by mass passing the 0.063mm size sieve increases. Higher fractions of clay and silt are found at layers further down the drain; it is thus expected that the foulant deeper in the trench will have a bigger impact on drainability, as it is found to be ‘richer’ in fines content.

The hydraulic conductivity value of the detritus/foulant alone collected at the surface of the trench is measured to range between 1.7 and 2.26 mm/sec. Fouling material collected at lower layers is expected to fall at a lower end of this range. The void ratio of the 75mm top-up material is measured to range between 0.82 and
1.017 while the one for Type B material is calculated between 0.60 and 0.68.

Adopting the three fouling scales proposed above, Table 1 illustrates how the PSD curves of the 14 samples can be expressed in terms of $P_D$, $F_A$, and $F_V$. Higher values of $P_D$ and $F_A$ indicate higher concentrations of foulants whereas lower values of $F_V$ suggest a smaller available free void space and thus an anticipated lower hydraulic performance. Taking for example sample C at depth between 600 and 800mm the percentage drain fouling is calculated at 79.5% indicating large concentration of foulants within the sample. As anticipated the foulant to aggregate ratio is also high, 2.24, indicating that the solid volume of fouling material in this particular sample surpasses the solid volume of the Type B aggregate. Lastly as expected the fouling material for the same sample occupies 100% of the available void space giving a free voids ratio of 0. At this point the drainability of the section is expected to be a function of the foulant rather than the aggregate itself.

The bigger particle size adopted at the surface of the trench offers a larger void space and in principle allows detritus to infiltrate into the drain faster, limiting obstructions and the levels of fouling near the surface of the trench. This suggests that the 75mm surface material in this particular design will generally remain free of road detritus; the data presented in Table 1 supports this assumption. For Location C, the $P_D$ at the top 300mm is calculated at 30% the $F_A$ at 0.47 and the $F_V$ at 0.42. As the Percentage Drain Fouling increases by 4% for the next layer, the Fouling to Aggregate ratio increases by 0.07 and the Free Voids Ratio reduces by 0.30; the reason here being the smaller void space offered by the type B material when compared to the 75mm top up aggregate.
TABLE 1 Fouling Levels And Fouling Characterisation Using P_{DF}, R_{F-A} and R_{FV} for Field Samples

<table>
<thead>
<tr>
<th>Depth</th>
<th>Location</th>
<th>P_{10} - P_{0.063}</th>
<th>P_{DF}</th>
<th>R_{F-A}</th>
<th>R_{FV}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 300 mm</td>
<td>A</td>
<td>27 - 3</td>
<td>30</td>
<td>0.42</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>23 - 3</td>
<td>26</td>
<td>0.37</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>27 - 3</td>
<td>30</td>
<td>0.47</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>12 - 2</td>
<td>13</td>
<td>0.17</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>21 - 4</td>
<td>24</td>
<td>0.34</td>
<td>0.58</td>
</tr>
<tr>
<td>300 - 600 mm</td>
<td>C</td>
<td>27 - 8</td>
<td>34</td>
<td>0.54</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>16 - 3</td>
<td>19</td>
<td>0.26</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>11 - 4</td>
<td>15</td>
<td>0.15</td>
<td>0.76</td>
</tr>
<tr>
<td>600 – 800 mm</td>
<td>B</td>
<td>13 - 6</td>
<td>19</td>
<td>0.16</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>60 - 20</td>
<td>80</td>
<td>2.24</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>34 - 8</td>
<td>42</td>
<td>0.69</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>29 - 8</td>
<td>37</td>
<td>0.55</td>
<td>0.11</td>
</tr>
<tr>
<td>&gt;1m</td>
<td>C</td>
<td>21 - 2</td>
<td>23</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>15 - 5</td>
<td>20</td>
<td>0.25</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Note: G_{Sa} = 2.90Mg/m^3, G_{SF}=2.56Mg/m^3

Also sample >1m are extracted below the geofabric that limits particle ingress thus the observed drop in fouling levels.

Hydraulic Trials

The permeability of the laboratory sand foulant was measured in the range of 1.62 to 1.94 mm/sec whereas the one for clay was measured in the range of 1.48 to 3.42 x 10^{-3} mm/sec. The former loosely coincides with the permeability value of the foulants as extracted from an in situ drain (1.7 to 2.26 mm/sec) thus the sand foulant is expected to realistically simulate the in service fouling conditions.

As anticipated, the hydraulic conductivity of the aggregate drops with increasing levels of fouling (see Figure 5). Even though the drop for relatively small levels of fouling (higher values of R_{FV}) is steeper, the overall drainability of the section (full sample value recorded) is still safely above minimum performance requirements established in the network’s HFD contractual requirements.

At R_{FV} values below 0.6 the reduction in the layer specific (lowest by layer value extracted in Figure 5) value for increased levels of fouling becomes marginal for both sets of trials (sand and clay based). A convergence between the two values is reached at a lower R_{FV} values (0.46 and 0.49 for sand and clay fouling respectively). This suggests that the fouling material has occupied a significant amount of the previously free voids, and dominates the overall flow performance of the evaluated aggregate fill.

Within a full 450mm sample, highly concentrated fouling in a thin layer affects the performance of the whole material. The minimum by layer permeability value is initially extracted at the top layer for generally fouling-free samples (R_{F} > 0.65). By ‘scarifying’ the aggregate during the second run for each fouling level, the overall capacity (full sample value) of the fill would then increase as the previously concentrated foulants spread within the lower sections of the material. As it is, the initially highly fouled state of the surface material largely impedes the free flow of water through the top layers of the aggregate. For R_{FV} values lower than 0.65, pushing the fouling material deeper in the tank further reduces the overall permeability (the full sample value extracted before scarifying is higher than the one extracted after allowing foulants to infiltrate deeper within the aggregate). This suggests that the fouling levels within the lowest two aggregate layers in the tank move towards a critical state and steadily converge to a terminal hydraulic conductivity value, which will be a function of the fouling material. This describes a bottom up fouling pattern. It also suggests that scarifying the top 100-300mm of a trench for sections with R_{F} values below 0.65 may lead to reduced performance.

The minimum hydraulic conductivity of sand based fouling trials is converging to a permeability value near 1.9 mm/sec. Increasing the foulants within the tank below R_{F} = 0.50 resulted in no significant drop in this. The average performance of the whole fill (full sample permeability value) is at that point approximately twice as large as the minimum value extracted at the lowest layer, suggesting that enough free void space is still available in the top two layers of the permeameter. Since the assessment of the backfill should be based on the full extent of the drain, it can be safely assumed that even with the lower sections of the fill being in a highly fouled state, the sample will still carry enough runoff removal (and storage) capacity if the foulants have infiltrated deeper within the tank leaving the voids space higher up largely free of detritus (to also allow...
horizontal flow to outfall assuming a bottom up failure pattern). The minimum service performance of 6 mm/sec is reached in the sand fouling based trials near the $R_{fv} = 0.55$ (this occurs at a higher $R_{fv}$ when clay fouling is used). When highly fouled states are approached near a $R_{fv}$ value of 0.45, the vertical permeability measured is approximately half the initial design value required.

For the clay-based fouling trials, and when the concentration of fines is higher within the fouling matrix, the terminal hydraulic conductivity value of the aggregate will be significantly lower; the lowest recorded value is at 0.5 mm/sec. While the trials aimed to extract the effect of scarifying for each sample, clay infiltrates within the aggregate material swiftly and builds up near the geofabric at the bottom of the tank rather than at the surface. In principle this particular foulant composition fails to capture the extent of in service fouling materials; clay-based fouling will have orders of magnitude lower hydraulic conductivity compared to that measured for the in-service fouling conditions. It is though used here to illustrate the importance of evaluating both the levels and composition of the foulants found in a highway filter drains. The nature of the fouling material will affect the value of permeability in the critical range of $R_{fv}$ and evidently clay has a larger impact on hydraulic performance than sand based foulants.

![FIGURE 5](https://example.com/figure5.png)

**FIGURE 5** Extract of Permeability As A Function Of $R_{fv}$ Using Sand And Clay Fouling Material in Type B Filter Material.

### Discussion

The hydraulic conductivity and thus the in-service performance of the aggregate fill drops with increasing levels of foulant filling up the aggregate voids. The three fouling scales presented offer an engineered condition assessment methodology requiring different evaluation approaches. Where the Percentage Drain Fouling is the most easily extracted index, it fails to address the variation in void space that arises due to the large gradation envelopes and the two types of aggregate than can be used in design of HFDs (Type A and Type B). This is particularly important in the assessment of the in-service drains also because of the nature of the top-up material used in the network under evaluation (larger particle diameters and thus larger anticipated void space in the top 300mm of the drain trench). The use of $P_{DN}$ could drive unnecessary maintenance requirements higher by underestimating the available free voids volume in the surface layers of the trench. The two volume based indices can potentially tackle this. The Foulant to Aggregate Ratio is based on establishing the volumetric ratio of foulants (particles passing the 10mm size sieve) to the aggregate volume (particles retained at the 10mm size sieve). However, similar to the Percentage Drain fouling it doesn’t take directly into account the void space of the evaluated samples. The suggested Free-Voids Ratio, $R_{fv}$, is calculated by estimating the initial void space in the trench and extracting a representation of the available free voids volume. It is thus expected to denote the fouling levels of the aggregate with higher accuracy in the field. It is also in the intention of the writers to prioritise the use of a volumetric fouling scale with Non Destructive Testing and Evaluation assessments as part of the ongoing research project. $R_{fv}$ is thus the index taken forward in the hydraulic trials and evaluated in context.

The field evaluation and subsequent sampling and sorting suggest a location and depth specific variation of fouling levels and foulant composition in drains. The drains generally seem to operate at an acceptable level (no significant water ponding during rainy field evaluation or past evaluations) and the fouling
index indicates $R_{FV}$ values ranging from 0.79 to 0 while the permeability of the foulant collected at the surface of
the trench is similar to a sand based fouling material (1.7 – 2.2 mm/sec). This suggests that a number of highly
fouled layers can be found within the field dataset but in most cases the full drains’ capacity still surpasses the
minimum performance requirements against deterioration predictions of a 10-year operational life; this due to
large trench sections with high $R_{FV}$ values and also potentially due to horizontal flow in the trench that is not
considered in design and build operations that solely factorize vertical permeability.

The main in-situ fouling pattern identified on site, is that of increasing fouling levels deeper within the
trench and a bottom up failure; location B being the exception with higher concentrations of foulants near the
surface of the HFD section. If the latter holds true and high levels of foulants are concentrated at the surface of a
trench, the initial runoff removal would be largely impeded near the surface, resulting in water ponding on the
carriageway. Scarifying is included as a network-wide maintenance requirement as a preventive measure against
reduced drainage performance. The hydraulic trials suggest that pushing foulants deeper within the trench will
eventually result in reduced hydraulic performance. A point is reached where fouling concentrations surpass a
critical level deeper in the drain and a foulant-dominated layer is formed. It is generally accepted (5-7) that
scarifying has been used to effectively tackle reduced performance in the field caused by increased levels of
fouling near the surface of the trench. The approach may not work in the longer term if proper evaluation of the
full trench depth is omitted from any condition assessment.

CONCLUSIONS

The existing design manuals suggest a 10-year HFD asset operational life but fail to employ any significant
performance standards, a fact that could lead to unnecessary renewal or maintenance interventions if applied
universally within a highway section or unexpected drainage failures. Through 10 years of operation, evaluated
filter drains are found to be functioning at an acceptable standard with a limited number of localised failures
attributed to highly fouled layers at the surface of the trench.

In the absence of any rational assessment methodology, this paper describes a possible way forward for
filter drain fouling characterization by employing a set of basic sampling techniques and hydraulic testing.
Mapping a fouling scale with a hydraulic performance enables a rational condition classification, which can be
assessed via simple laboratory tests. The permeability of foulant collected from an in-service drain is calculated
to range between 1.7 and 2.26 mm/sec suggesting a sand-dominated particle matrix. Based on the hydraulic trials
it can be assumed that for highly fouled states the permeability of the trench will converge to the one of the
foulant itself.

The requirement to establish a suitable in-service drainage performance boundary is required. It is
shown that a holistic and rational evaluation of a filter drain section should employ means other than surface
visual indicators that are subjective and potentially misleading. The fouling characterization through a mass or
volumetric fouling index can be correlated to an in-situ hydraulic performance and the Free-Voids Ratio is
proposed as a means to evaluate fouling concentrations within the filter drain trench.

The permeability testing suggests that the extent, spreading and type of fouling is of paramount
importance in determining how the filter aggregate performs. It is also suggested that existing maintenance
approaches could be problematic as they lack rational justification. This goes on to suggest that i) a layer by
layer analysis of the filter trench is required and ii) scarifying the surface of the trench will be less effective and
possibly problematic if the concentrations of fouling material in the trench are above a specific level.
REFERENCES


[8] Interim Advice Note 147/12, Drainage surveys and data. Highways Agency, 201


