Effective distribution of domestic wastewater effluent between percolation trenches in on-site treatment systems

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Abstract On-site treatment systems discharging to groundwater rely on the effective distribution of effluent across a percolation area to provide an appropriate loading rate for the subsoil. In Ireland, this is achieved in a distribution box which splits the effluent evenly between the requisite number of percolation pipes. The flow regime experienced at four different distribution boxes was monitored continuously over twelve month periods which established that the most common flow rates at the distribution unit were in the range 1–4 litres/minute for a four to five person dwelling. In addition, the average flow rate from the four sites was only 100 litres per person per day, compared to recommended design value of 180 litres per person per day. Two distribution boxes were also tested in the laboratory to assess their distribution efficiency over a range of loading rates. The most commonly installed unit was found to significantly favour two out of the four trenches and both units were shown to perform particularly poorly at a range of different off-level installation angles. Modifications to the boxes were also tested, involving plastic V-notch inserts which were shown to greatly improve the hydraulic distribution and make the unit much less sensitive to off-level installation or subsidence.

Keywords Distribution box; on-site wastewater treatment; percolation

Introduction
In Ireland, the domestic wastewater from over one third of the population (approximately 400,000 dwellings) is treated by on-site systems often comprised of a septic tank followed by a suitable soil percolation area (DoELG, EPA, and GSI 2000b). If a conventional percolation area is not suitable, the effluent from the septic tank can also be treated by one of the ever increasing variety of packaged secondary treatment systems available before the improved effluent is discharged to the subsoil. The Environmental Protection Agency (EPA) in Ireland have recently introduced guidelines (EPA, 2000) which aim to standardise the site assessment procedure used to determine the suitability of a site for on-site wastewater treatment. The guidelines aim to assess the suitability of the subsoil to accept specific effluent loading rates, whereby the pollutants are attenuated to an acceptable level en route to the groundwater resource, based on the concept of risk management and risk assessment (DoELG, EPA, and GSI, 2000). The assessment is a standardised procedure involving an on-site trial hole and percolation test carried out in the field to establish the saturated hydraulic conductivity of the layer of subsoil into which the effluent is being discharged (Mulqueen and Rodgers, 2001). As a result of such an assessment, a suitable level of treatment is specified (such as septic tank, or secondary treatment unit) before the effluent is distributed across a percolation field by a series of pipes laid in trenches at 2 m centres. Hence, a key assumption behind the guidelines is that the effluent is split evenly between the requisite number of percolation trenches to provide the appropriate loading rate on the subsoil across the area. This split is achieved in a distribution box, normally sold as a pre-cast unit in Ireland. The septic tank and percolation trenches...
are sized according to the number of people in the house, calculated from a design waste-
water production value of 180 litres per head per day (EPA, 2000).

Whilst several research projects have concentrated on the flow of effluent and mechan-
isms of pollutant attenuation in the subsoil (Nicosia et al., 2001; Robertson, 1995), little
research has focussed on the equal distribution of effluent across the percolation area, an
inherent factor to achieving the design loading rates. The design of an ideal distribution
box should be based on the principle of minimal maintenance since once it is installed an
average house owner is unlikely ever to consider it again. It should also have a minimal
head loss which can be a crucial factor for sites in areas where high water tables abound, a
common situation in Ireland. A common solution to a distribution box in the past has been
to use a branched pipe network. However, these behave erratically at different hydraulic
loading rates and have been shown to be ineffective (Siegrist et al., 2000). Another com-
mon method in Ireland is to use a simple sump with pipes emanating from it. This leads to
solids deposition and eventually channelling and poor hydraulic distribution. More refined
designs based on tipping buckets, for example, have been produced in other countries but
the long term sustainable performance of such systems has yet to be assessed.

The aim of the study was to assess typical flows reaching distribution boxes on four
separately monitored sites, both directly from septic tanks and from a secondary treat-
ment unit. The distribution efficiency of currently available designs at realistic flow rates
was then measured in the laboratory and a simple modification retrofitted to a box to
improve the efficiency out in the field.

Methods

Field work
As part of a three year study into the effectiveness of the new EPA guidelines, four
percolation areas were constructed on separate sites each consisting of four 20 m
trenches, two sites receiving effluent from a septic tank, the other two receiving effluent
from a secondary treatment peat filter system (Puraflo© by Bord na Mona). All rainwater,
surface water and runoff associated drainage had been diverted in accordance with the
regulations, although experience has shown that this is often not the case in many houses.
The flow rates experienced at the distribution box from each system were monitored con-
tinuously on each site for over 12 months. Flow rates were monitored by level monitoring
in a sump using an Omega LVU-90 Ultrasonic Level Transmitter connected to a data
logger. The time between recorded readings was 45 seconds and the data logger was
downloaded once per week. Flows were calculated by multiplying by the change in depth
in the sump by the cross-sectional area of the sump across each time step.

Individual flow rates from household appliances and unit devices (toilets, baths,
showers, dishwashers, washing machines and sinks) were measured in the dwellings by
an appropriate series of trials: a falling head test on baths and sinks, volume capture on
showers and outlet pipe capture from dishwashers and washing machines. This generated
a typical input “flood hydrograph” into the foul drainage pipe network which could then
be routed down a hypothetical 110 mm diameter pipe at 1:60 using the Muskingum river
routing method into the septic tank (Bedient and Huber, 1992). This input into the septic
tank was then routed across the septic tank by a reservoir routing method to provide an
output into the effluent pipe which was finally routed again at a 1:60 gradient to provide
a representative hydrograph down at the distribution box.

Experimental set-up
Two distribution boxes commonly used in Ireland, as shown in Figure 1, were tested in
the laboratory to assess their distribution efficiency over a range of hydraulic loading
rates. The boxes were also tested at a range of different off-level installation angles representing a more realistic situation on site due to subsidence or poor workmanship in such unregulated construction work. A modification to Box 1 in the form of a plastic V-notch insert which could easily be retrofitted to an existing box was also tested, as shown in Figure 2.

A 110 mm diameter PVC pipe was set-up in the laboratory as an inlet channel at gradient of 1:60 to mimic design conditions. The length of the pipe was calculated to be long enough to reduce the influence of gradually varied flow conditions and to establish normal flow in the pipe before entering the box. The discharge into the pipe was controlled by a constant head tank regulated by a valve. In each trial, flow was discharged into the channel at a fixed rate for approximately one minute and the volume of water was simply collected in a container from each effluent port.

Results and discussion
On-site monitoring
All the flow data from the four sites has been analysed in terms of both frequency and net volume with respect to flow rate (see Figures 3 and 4). The mean flow rate with respect to frequency and total volume was determined by the method of moments (Bedient and Huber, 1992). Mean daily flow rates have also been calculated for the four sites (see Table 1) which give an overall average value of only 77 litres per head per day. This reveals that that the assumption of 180 litres per head per day appears to grossly over-predict the wastewater production in such one-off dwellings with typical sized family units. It may be that the design value may have been skewed in past from studies that have included some element of rainwater flow or infiltration.

Septic tank
The three separate flow distributions for Sites 1, 2 and 3 have been normalised and then combined to produce an average distribution of flow rates emanating from a septic tank
These statistics reveal that the average flow frequency was 1.3 litre/minute but the average flow rate per unit volume of effluent was typically discharged at 3.6 litre/minute. It should be noted that all periods of zero flow have been removed from the graphs to preserve the clarity. Nevertheless, it is important to note that such zero flow frequencies occurred for 70% of the time steps on average across the three different septic tank sites.

Secondary treatment peat filter

The flows measured on Site 4 were downstream of a peat filter which was fed by septic tank effluent pumped periodically from a sump. Hence, a fixed pumped flow rate is obviously imposed upon the natural hydraulic regime which can be clearly seen in Figures 4(a) and (b). The majority of flow frequencies form a tight band from 2–3.5 litre/minute but also discrete higher rates are evident, presumably linked to the frequency of pumping events. The average flow frequency was 3.3 litre/minute, whilst the average volume of effluent was typically discharged in the range 2–4 litre/minute.

The results from tests carried out on appliances and fixtures in the houses are presented in Table 2. The resultant inlet hydrographs were also routed down through a standard septic tank to produce a respective hydrograph and mean flow rate expected at a distribution box located 50 m away from the house. These values, in the range of 0.5–3.5
Trials were carried out on both distribution boxes over a range of flow rates from 0.5 l/min up to 20 l/min. The efficiency of each box was simply calculated as a percentage of total flow received at each distribution point, shown graphically on Figures 5–7. It should be noted that these trials are idealised since clean water was used and hence the effect of solids sedimentation, for example, was not represented.

Box 1. Trials on the distribution box when it was set exactly level on all axes (Figure 5(a)) reveal that the majority of the flow at most flow rates (especially in the critical 1–4 litre/minute range) were only discharged into two trenches (Pipes 1 and 4).

Table 1 Summary of flow statistics measured at the distribution box for the four sites

<table>
<thead>
<tr>
<th>Upstream treatment process</th>
<th>House occupancy</th>
<th>Mean daily flows (l/d)</th>
<th>Flow range (l/min)</th>
<th>Average flow rate (l/min)</th>
<th>Av. flow rate per unit volume (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1 Septic tank</td>
<td>4</td>
<td>400</td>
<td>0–18</td>
<td>2.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Site 2 Septic tank</td>
<td>5</td>
<td>290</td>
<td>0–20</td>
<td>0.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Site 3 Septic tank</td>
<td>4</td>
<td>305</td>
<td>0–17</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Site 4 Peat filter</td>
<td>5</td>
<td>385</td>
<td>0–20</td>
<td>3.3</td>
<td>5.1</td>
</tr>
</tbody>
</table>
with no flow at all passing down Pipe 3 until the flow rate passes 5 l/min. When the box was set 10 mm off-level (towards Pipes 3 and 4), it can be seen that even such a moderate disturbance acts to drastically effect the distribution whereby over 50% of the flow favoured Pipe 4.

When the V-notch insert was placed into Box 1, there was a significant improvement to the flow distribution with the box positioned level (Figure 6(a)) and also the distribution is less sensitive to disturbance, particularly at the common 2–4 litre/minute flow rates.

Box 2. This distribution box acts as a small sump of 50 mm depth with three outflow pipes. When positioned exactly level, the distribution between the three pipes was excellent. However, when this box was set 10 mm off-level (towards Pipe 1) the distribution was badly affected with the majority of flow at all flow rates passing down Pipe 1 indicating its extreme sensitivity to slight settlement or poor installation. The design of this box also promotes sedimentation of solids and only allows direct distribution between three percolation trenches.

### Table 2
Mean inlet flow into wastewater system from fixtures and appliances and calculated flows at distribution box

<table>
<thead>
<tr>
<th>Fixture/appliance emptying</th>
<th>Mean flow (l/min)</th>
<th>Mean flow at dist. box (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bath</td>
<td>48</td>
<td>4.2</td>
</tr>
<tr>
<td>Toilet</td>
<td>65</td>
<td>5.8</td>
</tr>
<tr>
<td>Kitchen sink</td>
<td>19</td>
<td>1.1</td>
</tr>
<tr>
<td>Bathroom sink</td>
<td>60</td>
<td>5.7</td>
</tr>
<tr>
<td>Shower</td>
<td>8</td>
<td>0.7</td>
</tr>
<tr>
<td>Washing machine</td>
<td>23</td>
<td>1.8</td>
</tr>
<tr>
<td>Dish washer</td>
<td>30</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure 5 Results from laboratory trials on distribution box 1 (a) level and 10 mm off-level (dropping towards Pipes 3 and 4)
Figure 6 Results from laboratory trials on distribution box 1 with V-notch weirs (a) level and (b) 10 mm off-level (dropping towards Pipes 3 and 4)

Figure 7 Results from laboratory trials on distribution box 2 (a) level and (b) 10 mm off-level (dropping towards Pipe 1)
On-site implementation of V-notch weirs

The V-notch weirs were inserted into the four distribution boxes at the beginning of the twelve month on-site trials and an even distribution was confirmed on all sites by chemical and microbiological water quality parameters sampled from different subsoil horizons across the percolation area in suction lysimeters (O’Súileabháin et al., 2004). Specific tracer studies using bromide were also carried out in addition to soil moisture profiles calculated from tensiometer readings and meteorological data, both of which again confirmed the effectiveness of the modified distribution boxes.

Conclusions

A detailed study of flow rates from three septic tanks and one peat filter on-site treatment system established the critical hydraulic loading rates at distribution boxes to be in the range of 1–4 litre/minute for a normal family dwelling. The monitoring also established that the design of percolation systems based on 180 litres per person per day was found to grossly over predict the effluent production in the four sites which was more in the order of 80 litres per person per day. Distribution boxes tested in the laboratory at a range of flow rates performed poorly if installed slightly off-level, which is a realistic situation in the field due to subsidence or poor workmanship. However, a relatively simple V-notch insert muted such sensitivity and promoted an even distribution between four percolation trenches which was confirmed in four separate on-site trials.

Acknowledgements

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References