G3) Implications of grey water re-use on solid transport in building drainage systems.

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Abstract

Grey water re-use has presented real benefits in terms of water conservation of domestic and commercial potable water supplies in recent years. While the benefits of water usage reductions are clear, the costs are less obvious and require a more detailed investigation. One such cost is the possible increased likelihood of maintenance due to the blockages caused by the reduction in water available to transport solids away from the building drain to the main public sewer. One particular problem concerns the re-use of large volume drain cleansing discharges such as those from baths. In the grey water re-use scenario this bath water is used to flush a WC, thus replacing a surge wave of long duration with a series of much smaller amplitude surge waves from a WC discharge. In this research the implications of grey water re-use have been assessed in a number of installation scenarios, from single dwellings to a small housing estate with a common collection drain leading to the public sewer. The numerical model 'DRAINET' was used to model the scenarios incorporating known and assumed usage patterns. These simulations lead to conclusions that, in the main, grey water re-use does not have a major impact on the solid transport characteristics of a drainage system. There are however significant exceptions and great care should be taken in mitigating against the increased risk of blockages associated with these cases. The simulations also confirm the importance of correct pipe diameter selection in order to maximize system efficiency and reduce risk of failure.

Keywords

Grey water re-use, solid transport modelling, building drainage systems.

1. Introduction

Water recycling systems offer many benefits, such as reducing the strain on the freshwater supplies and reducing the amount of wastewater entering the sewage pipes. This research aims to investigate the impact that water recycling systems, in particular grey water recycling systems, have on domestic drainage systems and to assess the implications of this water conservation method.

In recent years, the topic of global warming and climate change cannot have gone unnoticed amongst the general public regardless of their personal stance on the issue. While the issue of Climate Change is often seen as ‘carbon’ issue, and this is not in dispute any more, the consequences of a seemingly inevitable change in climate are as much to do with ‘water’ as carbon. In some places too much water exists, in the case of flooding, and in others, there is too little water. This has led some to proclaim that ‘water is the new carbon’ [1] as adapting to more erratic climate conditions falls easily under the remit of the practicing Engineer.

Water agencies around the world are rapidly realising the benefits of treated recycled water, especially with the increasing pressures on water resources due to growing populations, increase in the numbers of households and water wastage [2] It has been shown that the issues of water reclamation, recycling and reuse constitute an important part of water and wastewater management [2], [3]. Angelakis & Bontoux highlight that the benefits of using recycled water which include the protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, savings in wastewater treatment, and sustainability of water resource management [4]. Despite the diversity of the benefits of recycled water, care should be taken to ensure that water recycling systems are implemented in conjunction with other water conservation measures [2].

The re-use of grey water for flushing WCs and other non-drinking purposes such as irrigation has become more commonplace in recent years. Current WCs use 6 litres of water to flush and pressure exists to push this down even further. The transportation distances of waste material from WCs is dependent mainly on the volume of water used in the flush. In many ways building drains (especially those with long horizontal runs) depend on contributing flows from other appliances to achieve self-cleansing. In many cases these flows are of longer duration (e.g. a bath or a continuously draining shower) and therefore assist in cleaning drain lines with much more efficacy than a short duration WC flush. The removal of grey water as a ‘contributing flow’ may compromise this self-cleansing. This research seeks to quantify the effect of removing grey water, with it’s original discharge characteristics, and re-using it in a much less efficacious manner.

2. Water consumption and conservation

It is widely accepted that using high quality potable water within some appliances, such as WCs, is a waste of a resource, especially in countries where water of such a high quality is in rare existence and reasonably inaccessible [5], [6]. It is also true to say that arid countries would benefit from reducing the amount of high quality potable water used by these appliances.

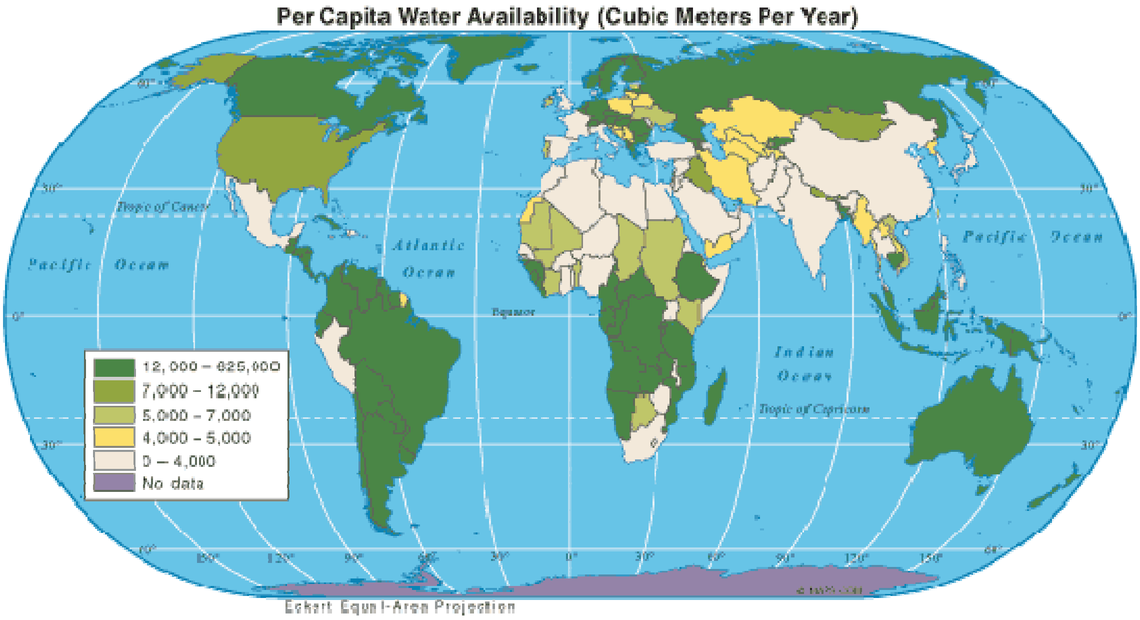

Figure 1 – Per Capita Water Availability (Source: WWDR)

Water consumption has increased over the years. Moran *et al*, present figures that suggest an increase of 35% in the supply of water between 1971 and 2001 for unmetered properties [7]. In the UK, the average domestic water consumption is 149 litres per person per day [8]. There are factors such as climate, culture and economy that will have an impact on the domestic water consumption in different countries as discussed by Lazarova *et al*, who also discuss the factors that result in variable per capita consumption, which include age, sex, type of domestic appliances and metering arrangements [9]. It is also true that as a result in these increases in water consumption, that many areas have suffered and endured "periods of man made drought, depletion of environmental flow in natural water systems and the decrease in the quality of drinking water reservoirs, including groundwater systems" [6].

3. Grey water recycling systems

In many applications the largest savings in mains water are likely to be obtained by using reclaimed water for toilet flushing [10]. Low public acceptance of using grey water for activities such as watering vegetables has been widespread, and it could be suggested that users may prefer to use rainwater for such activities and use grey water for non-personal activities such as toilet flushing. This would certainly improve the acceptability of water recycling systems, especially since it has been suggested that public acceptability improves after exposure to such systems [11]. It would also fit in with the views of Dolnicar *et al*, who want to exploit the powers of word of mouth and use influential people to endorse and publicise these alternative systems [6].

It has been suggested that there is a "cumulative flow balance" between the grey water collected and the volume of water required for the WCs [3],[12]. Jefferson further explains that although there is this “cumulative flow balance”, grey water is generated over short time periods and not always in tandem with toilet flushing, which occurs more consistently throughout the day [3]. Figure 2. depicts these variations in times of supply and demand, that will generally result in a deficit in water during the afternoon and later evening [13], which therefore require the recycled water to be stored to balance out the variations between generation and use [12]. However, it should be noted that residence time in systems dramatically affects the characteristics of grey water and care should be taken to ensure that grey water is not stored for long periods of time. An investigation by Dixon et al into storage tanks found that a $1m^3$ tank was suitable for a wide range of occupancy scales [14]. Jefferson et al found that increases in storage capacity over $1m^3$ provided marginal rises in water saving whilst also enhancing problems associated with grey water degradation and disinfection reliability, due to prolonged storage [3],[6].

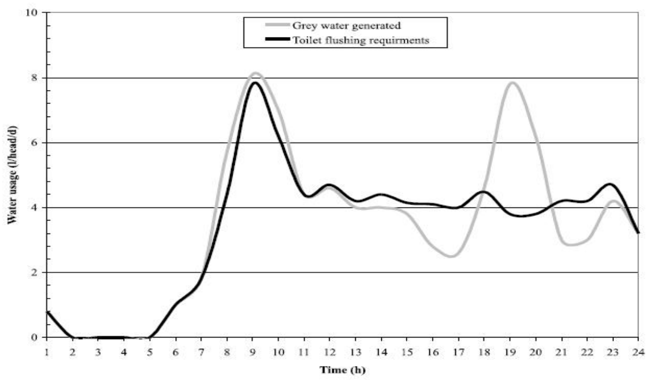

Figure 2 – Grey water Collected v WC Flushing Requirements
(Source: Jefferson *et al*, 2000 courtesy of Surendran & Wheatley, 1998)

4. Simulation of systems using DRAINET: building types and usage scenarios

It is of great importance to consider the different types of buildings and the habits of their occupants (scenarios) in order to gauge their water consumption and therefore assess the implications of grey water re-use. Although there are stated volumes of water associated with different activities such as showering, it can be difficult to ascertain the exact amount of water used by an individual. It is true to say that lifestyle choices and personal attitudes towards environmental issues will differ from person to person. Despite increased promotion of the benefits of saving water, it cannot be assumed that everyone will follow this advice. Hence, the values used in these simulations will be based on the usage patterns of a person who is not environmentally conscious. It can be said, however, that in reality these values may vary and thus have an impact on the outcome.

Each of these scenarios will be simulated using the numerical model DRAINET and the first simulation will be run with all the water (waste and grey) entering the sewerage system to assess solid transportation distances and to determine whether or not the entire system will be self cleansing. The scenarios will then be run again, with only the wastewater from the WCs entering the drainage system. This will allow a comparison of the final transportation distances of the two simulations and determine the impact of removing the grey water from the drainage system.

The results from the individual households will be input into the fourth scenario, which will simulate a ten house estate, and will allow an assessment to be made on the implications of grey water reuse on the operation of the drainage system. To investigate this issue further, the ten-house estate scenario will be re-run (for both grey water reuse and all water to drain) with differing pipe sizes.

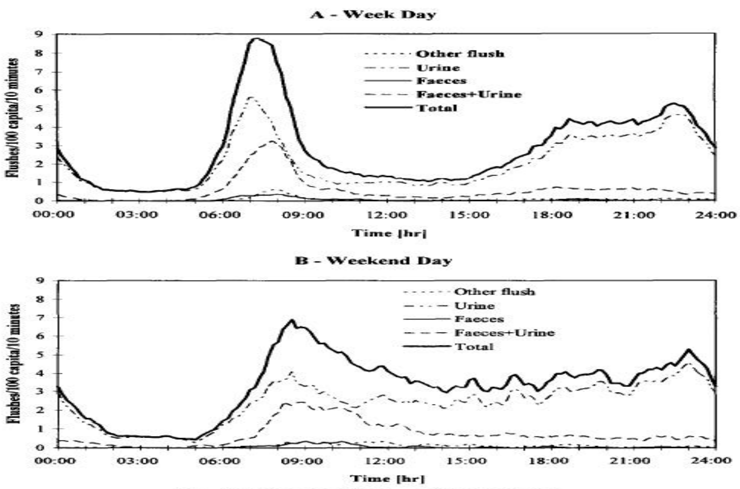

Figure 3 – WC modes of use - diurnal patterns
(Source: Friedler *et al*, 1996)

Within each scenario, the week has been divided into typical weekday and weekend usage. Figures by Friedler [15] and assumptions were used to generate a table of the typical appliances and their associated usage. While it is possible to divide the day into three distinct time zones, morning, day and evening, the simulations run in DRAINET will be based only on the morning peak time between 6am and 9am, by which time the house will be vacated for the working day. Simulating the morning will give a good indication of the usage patterns of each appliance and assess the requirements of the drainage system. Figure 3 depicts weekday and weekend WC modes of use found from the survey undertaken by Friedler [15].

Each of the scenarios/households had the same appliances and pipe layout to aid comparisons and to eliminate any extra parameters that could impact on the operation of the drainage system. The system was designed to meet European standard EN12056:2000 [16]. Figure 4 depicts the domestic appliance and drainage layout – It should be noted that pipe 19 connects to the main sewer, and the two crossed boxes at pipes 7 and 9 represent a washing machine and dishwasher respectively.

It has been assumed that all buildings are single storey and are attached to mains sewerage. It is also assumed that all houses will have $1m^3$ grey water recycling storage tanks as suggested by [3]. Table 1 indicates the assumed quantities of water consumed by domestic appliances.

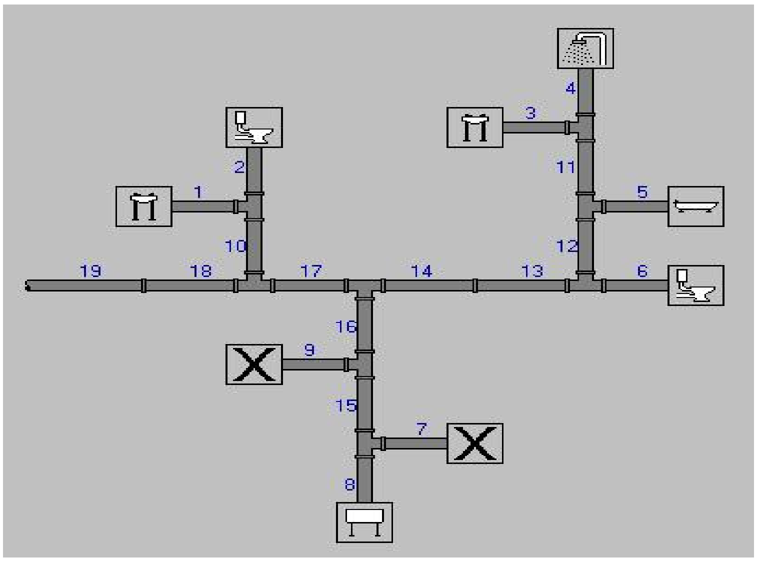

Figure 4. Domestic Appliance & Drainage Layout

Table 1 – Appliances & Associate Volume of Water Used

Appliance	Water Used (litres)	Dishwasher	15
Bath	75 to 90	Sink	6 to 8
Shower	5 to 7 per min	Wash face & heads	3 to 9
WC	6	Teeth cleaning (tap on)	5 to15
Washing Machine	50	Teeth cleaning (tap on/off)	1 to 2

(Source: The Water School)

5. Usage Scenarios

5.1 Scenario 1 (Single Occupant)

The first scenario is a single house with one occupant. The gender and age of the occupant has not specified, however it is noted that the domestic WC usage patterns could be affected by these parameters [15]. For all scenarios, the simulation of each scenario in DRAINET will be based on the timeframe 6am-9am.

Table 2 illustrates which appliance the occupant uses and when. This information can then be used to determine how much water will be entering the drainage pipe and when. This information will be important in ascertaining whether or not the pipe will self-cleanse.

Table 2 – Morning Water Usage for Single Occupant Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	0						
Shower	1				1		
WC 1	1	1					
Basin 1	1	1					
WC 2	1					1	
Basin 2	1		1			1	
Washing Machine	1		1				
Dishwasher	1						
Sink	1			1			

5.2 Scenario 2 (Standard Household)

The second scenario represents a house with a group of four occupants. It is presumed that all four occupants will be out of the house by 9am, with activities happening at various times between 6 and 9am. Table 3 below shows the number of times each appliance in the house is used between 6 and 9am. In order to simulate these in DRAINET, the morning has been subdivided into 6 half hour slots and the second part of the table lists the appliances used in each half hour timeslot and how many times. It could be suggested that despite installing two WC's in each house, one WC may be used more often than the other. It is assumed that the two WC's are equally popular, especially as the larger the household, the more likely one or other bathroom will be occupied.

Table 3 – Morning Water Usage for Standard Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	1					1	
Shower	3	1	1	1			
WC 1	4	1		1	1	1	
Basin 1	6	1		1	1	1	2
WC 2	4	1	1	1	1		
Basin 2	6	1	1	1	1		2
Washing Machine	1	1	1				
Dishwasher	1		1	1			
Sink	6		1		1	2	2

5.3 Scenario 3 (Large Household)

This scenario looks at the usage patterns of a household that is occupied by 6 people. This was to incorporate larger families or households with a number of unrelated persons such as student accommodation or young professionals. Although it is expected that the number of smaller household would increase in future years in the UK, it is still important to assess the water consumption and usage patterns of a variety of household dynamics hence the inclusion of the multi-occupied household.

Table 4 – Characteristics of sample households

Household size distribution

Number of occupants	Household No.	Sample %	U.K.*
1	32	24	23
2	62	46	32
3	14	10	17
4	19	14	18
5+	8	6	10

Household age distribution

Age range	Sample No.	Sample %	U.K.†
0–14	59	18.8	19.4
15–29	64	20.4	21.5
30–44	107	34.1	21.2
45–59	63	20.1	17.3
60–74	10	3.2	13.7
75+	1	0.3	6.9
Not indicated	10	3.2	—

(Source: Friedler *et al*, 1996)

The same methodology was used to determine the contribution of each appliance to overall drainage flows due to the assumed usage patterns. Table 5 shows the results of this exercise for the large household.

Table 5 – Morning Water Usage for Large Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	1			1			
Shower	5		1	1	2	1	
WC 1	6	1	1	2		1	1
Basin 1	9	1	1	2		3	2
WC 2	6			3		1	2
Basin 2	9			4		1	4
Washing Machine	1						1
Dishwasher	1						1
Sink	6			1	1	2	2

5.4 Scenario 4 (Ten-House Estate)

The fourth scenario investigated a housing estate of ten houses. A mix of single occupant, single family and multi-occupant households made up this estate. Having investigated the effects of water consumption and grey water recycling on the domestic drainage system within the actual house, it was imperative to ensure that once all the houses were connected to the main sewerage system, that there would be adequate flow to avoid blockages. In order to simulate this scenario, the results for the first 3 scenarios were used to make up the profile for the estate and were run twice as previously discussed.

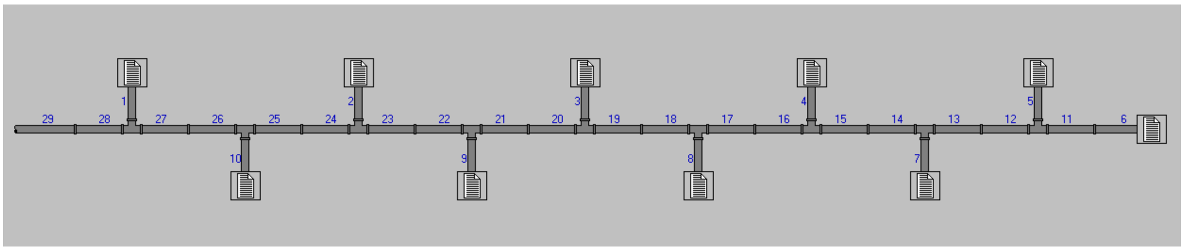

Figure 5 – Scenario 4 simulation layout

6. Results and discussion

The rationale behind this research was to establish whether removing grey water from the drainage system completely would increase the risk of blockages occurring in the house drain and collection drains for houses in different configurations. Simulations of solid transport were carried out on different house types and combinations to assess this risk.

6.1 Solid transport in the house drain

Figure 6 shows the results obtained from the assessment of solid transport within each of the house types described above. Since the usage scenarios describe many appliance operations with combinations of WC flushes with and without solids, the approach taken was to assess whether or not solids leave the house drain and enter the main sewer as a result of all the appliance activity during the peak period of 6 am to 9 am. In order to assess this all solid transport distances were calculated in relation to the distance to the main sewer i.e. actual transport distance (m) / distance to main sewer (m). This produces a transport index where greater than 1 represents solid which clear the house drain and an index of less than 1 are solids which remain in the house drain despite the significant activity during these peak hours.

It can be seen from Figure 6 that the only house type/usage scenario of concern is the single occupancy house where all the grey water is recycled, all other scenarios clear the house drain during these peak hours.

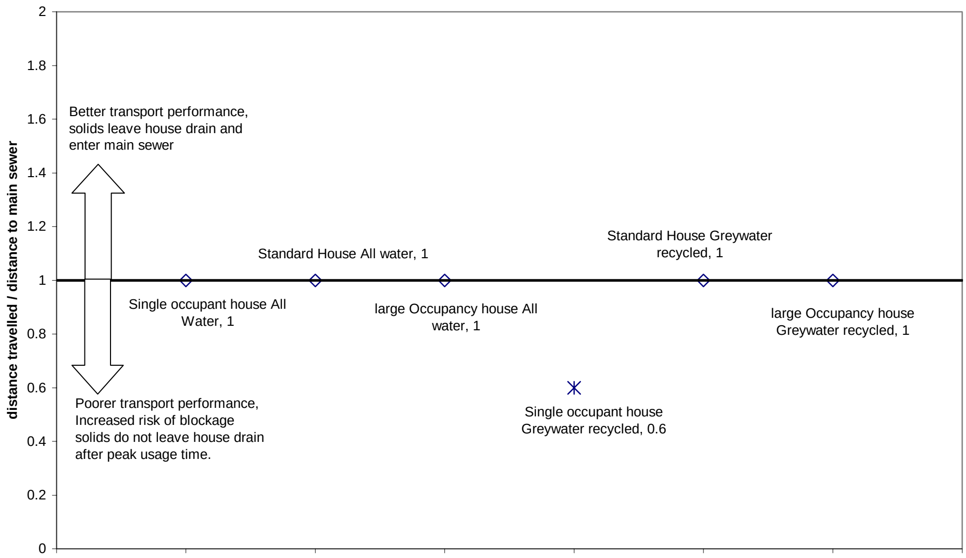

Figure 6 – Assessment of solid transport distances for individual house drain scenarios.

6.2 Solid transport in the main collection drain

The transport of solids away from the building and into the public sewer network is also of significance when assessing the risk of blockages in relation to the quantities of water available to ensure drain self-cleansing. An assessment of solid transport distances was carried out in the configuration of 10 houses as shown in Figure 5 above. In this assessment the critical issue is one of contributing flows from the different houses. Solids need to travel far enough so that they can be moved on from flows from adjacent houses. So a critical transport distance is the distance between houses. Again, as in the case with the house drain above, a solid transport index is a useful tool for assessing the risk of blockages. In this case transport distances are cast in terms of the number of adjoining flows contributing to the final transport distances for a particular scenario i.e actual transport distance (m) / distance between adjoining flows (m). The critical number for this index again is 1. A scenario producing an index of less than 1 is at an elevated risk of blockage, since it has travelled its maximum distance (no further transport possible due to upstream flows) and not yet reached a point where an adjoining flow could assist transport further.

It can be seen from Figure 7 that as pipe diameter decreases solid transport performance increases, and as would be expected, as the quantity of water available for solid transport decreases so solid transport performance decreases. Figure 7 also shows the critical transport index of 1 and the only scenario which falls below this is the case where all grey water is recycled and the main collection drain is 150 mm.

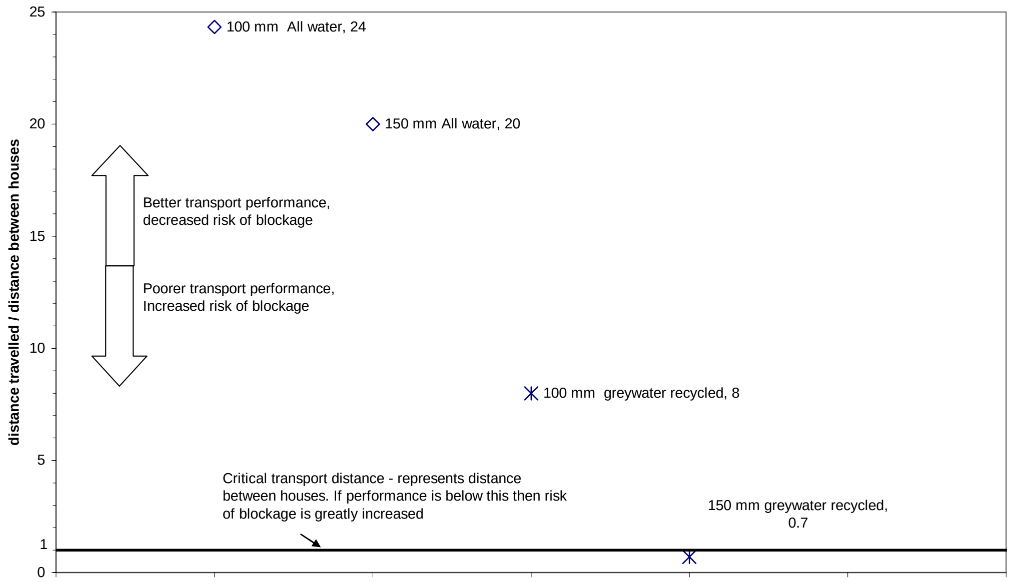

Figure 7 – Assessment of solid transport performance in multi – house configuration (scenario 4)

7. Conclusions

This research has shown that it is possible to recycle grey water whilst minimizing the risk of blockages in house drains and main collection drains between houses in U.K. configurations. Areas of concern are clearly properties where there is little activity due to the small number of occupants. Another cause for concern is the over specification of pipe diameter, with performance being severely reduced where larger diameter pipes are used with smaller quantities of water.

The introduction of solid transport performance indices linking transport distances to known limiting parameters such as distances between adjoining flows and maximum distance to the collection drain from a house installation has proved very useful in assessing risk of blockage and system performance.

Overall the research has confirmed that, with some exceptions, 100% grey water can be tolerated in terms of maintaining adequate flows for the transport of solids in the system. The research has also confirmed that the choice of pipe diameter is crucial in minimizing the risk of blockages and maximizing performance under water conservation criteria.

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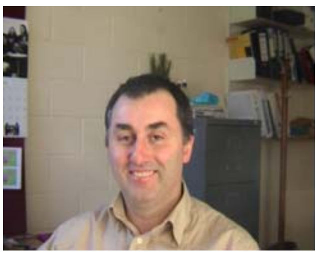
9. Presentation of Authors



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Sophie Dickenson is a recent graduate from Heriot – Watt University where she attained an MEng (Hons) degree in Architectural Engineering with merit. This paper is based on the findings from her final year research dissertation. She is currently working as a Sustainability Engineer for DSSR, Building Services Consulting Engineers in Glasgow, Scotland.