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Less water to waste

Impact of reductions in water demand on wastewater collection and treatment systems

Science project SC060066

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Steve Killeen

Head of Science

Executive Summary

The current policy and regulatory changes in water efficiency are intended to result in significant reductions in the demand for water. One potential consequence of this will be a reduction in wastewater flowing to sewer. It is often suggested that reducing demand will adversely affect the sewer collection systems, cause blockages and other operational problems and potentially lead to property flooding. Hence, there was a need to investigate the effect of reduced water usage on the sewer and sewage treatment systems.

This study set out to examine the impact of demand management (through increased efficiency of water-using appliances) on wastewater flow, wastewater collection systems (drains and sewers) and wastewater treatment. The links between potable water use, wastewater discharges and the ability for sewer solids to be carried away in the wastewater flows were examined by modelling water-using appliance usage in typical households.

This modelling indicated that:

- Reduced WC flush volumes offer the greatest demand reduction opportunities.
- The most significant wastewater discharges to drain/sewer are from the bath and WC, with the WC providing the most force to move sewer solids.

The potential effect that reducing WC flush volumes may have on sewer solid movement has been examined. Sewer solid movement data available from an earlier WRc (Water Research Centre) test programme was used in conjunction with typical wastewater discharge information gained from the modelling mentioned above. The solid movement data analysed were for a dual six litre full flush and three litre partial flush WC. The assessment indicated that solid movement would be significantly reduced with the lower flush volume.

The results therefore indicate that, in some circumstances, wastewater discharges with reduced water consumption are likely to cause a deterioration in solid removal. It is also likely that the problem will be most apparent in drains taking very little flow, such as those serving either a single property or a few single occupancy properties.

The three litre flush volume does not represent the WC characteristics that are necessary to meet the various demand reduction scenarios that may be necessary to comply with various levels of the Code for Sustainable homes, or that would be seen after retrofitting existing properties. Nevertheless, the difference in solid movement ability of the two flush volumes is considerable. Therefore it is reasonable to expect the same trend, to some extent, in any flush volume less than the current six litre norm.

The literature review found no practical examples of drain or sewer blockages that could be attributed to reduced water demand. However, this could be due to the fact that very few studies have specifically considered the effect of demand management on drains and sewers. The majority of studies have focused on the impact of WC flushing on solids movement. There are a number of papers that suggest reduced water demand will lead to an increase in operational problems in drains/sewers. However, it is uncertain if these conclusions are based upon fact or are opinions based on related information.

It is suggested that further research be carried out to obtain sewer solid flow characteristics for a wider range of reduced WC flush volumes. The impact on wastewater transport of switching from a single to a dual flush WC, particularly in existing properties, is uncertain. Therefore, this work should include rig-based testing to establish the sewer solid flow characteristics for a range of single and dual flush WC volumes.

Whilst WC flushes are the most important element of solid movement in drains, other wastewater discharges (from baths, showers etc) are also important. This is because other discharges keep solids damp and easier to move by a WC flush wave. However, reductions in these other wastewater discharges are not likely to adversely affect solid movement.

Thus, whilst the overall levels of water efficiency are unlikely to cause a problem for the operation of drains and sewers, it is the reduction in WC flush volumes that may be an issue. The available data suggests that a reduction from six- to three-litre flushes in a conventional WC could pose a significant problem for current drainage systems.

New technology could help to reduce WC flush volumes without causing problems in the drainage system. For example, work undertaken on the Propelair toilet (which uses air as well as water to move solids) has demonstrated that this can be achieved, provided that appropriate modifications can be made to the drain receiving the lower WC flushes.

The likelihood of blockages and other operational problems caused, in part, by reduced wastewater flows, could be reduced by changing design standards for drainage systems. These alterations could include the use of smaller diameter pipes (subject to certain practical limitations), pipes with steeper gradients and pipe layouts with fewer pipes taking very little flow.

This opens up opportunities for new build construction. However, far less freedom is available when retrofitting an existing system – the pipe gradient will be fixed and, whilst reducing pipe diameter by relining is possible, it will rarely be a cost effective, affordable or sustainable option.

Accordingly, different approaches to reduced water demand are required for new build and retrofitting an existing property. For new build, this study recommends a revision of existing drainage design standards to accommodate planned reductions in demand. This may require more practical and theoretical work to fully understand the implications of reduced pipe diameters and steeper graded pipes, and to develop robust proposals.

In existing properties, the drainage layout needs to be taken into account before deciding whether replacing an old WC with a new lower flush model is viable. Properties most at risk from blockages are those served by drains serving a single property or a few single occupancy properties. More comprehensive monitoring of wide scale retrofitting schemes could provide valuable information to inform future programmes.

The study also considered the impact on treatment following a reduction in wastewater discharged from houses. There is some uncertainty regarding the likely overall impact, as effluent concentration depends upon both the volume of water discharged and infiltration of the sewer system. However, a number of key factors may need to be addressed in future plant design or operational procedures in order to ensure treatment and operational efficiency.

We conclude that, while the full impact of demand reductions on wastewater flows is not fully understood, it may result in increased sewer blockages and other operational problems such as odour complaints and sewer flooding. However, other issues also contribute to these problems. These include:

- The inappropriate use of sewers to dispose of unwanted food and material based wipes etc.
- The poor condition of some drainage systems.
- In some circumstances, the removal of storm water through the diversion to a SUDS (sustainable urban drainage systems) scheme or rainwater harvesting.

Therefore, the implications of reduced water demand need to be seen in a larger context and a wider view taken when considering such schemes. It is therefore recommended that investigations be undertaken to better understand the interplay of these other issues with the effects of demand reductions, in particular minimising the effect of inappropriate use of sewers for disposal.

Contents

1 Introduction

1.1 Background

The 2007 announcement by Communities and Local Government on the future of regulations for water efficiency and the Code for Sustainable Homes aim to reduce water use in new buildings.

The government is also examining the potential of reducing demand in existing buildings.

Reducing household water use could be accomplished through:

- The fitting of more water efficient devices, such as washing machines, dishwashers, lower flow showers and lower flush volume toilets.
- Through public awareness to encourage water saving.

At the same time, there is a change in water usage due to:

- Changes in personal washing behaviour which may lead to fewer baths and more showers being taken.
- Public expectation (increased inclusion of luxury products in houses, for example).
- A reduction in average household size (which leads to a higher water consumption per person).

Any change in water use (total volume or flow pattern throughout the day) will result in a change in the amount and flow pattern of wastewater to the drainage system.

It is often suggested that reducing demand for water in the home could adversely affect the sewer collection systems, with lower flows potentially leading to a lack of self-cleansing, and therefore blockages and property flooding.

In turn, a reduction in wastewater to the drainage system will also result in a reduction in the total volume of wastewater arriving at treatment works. It is suggested that this may adversely affect the performance of wastewater treatment works.

1.2 Aim of the study

The overall aim of this study is to examine the impact of proposed water efficiencies, in new and existing houses, on drains, sewers and sewage treatment systems.

1.3 Objectives of study

Specific objectives are:

1) To review international experience and other relevant information.

2) To examine the magnitude of potential wastewater flow reductions due to demand management measures.

3) To examine the effect of reducing domestic demand for water on wastewater collection systems. This will include:

   - An assessment of the likely increase in blockage problems, including an assessment of the locations where the change is likely to be most significant.

   - An assessment of other operational problems (if any) caused by reduced wastewater flows and increased concentrations.

4) To assess potential effects on wastewater treatment caused by reduced wastewater flows/increased concentrations.

5) To make recommendations on ways of mitigating the risk of drain blockages and problems with sewage treatment, such as changing pipe diameters, gradients, pipe design, and building in resilience to treatment systems.

1.4 Project overview

The project will consider a range of potable water reduction scenarios in order to investigate the likelihood and significance of negative impacts on wastewater collection and treatment systems.

The water reduction scenarios are based upon the Code for Sustainable Homes. In addition, a scenario for retrofitting of an existing property has been included. Other developments such as rainwater harvesting and greywater recycling are also considered, but are only applicable for the most significant demand reduction scenario required by the Code.

Household water usage patterns for the various scenarios can be established using data from WRc's Identi*flow*® database. This enables discharges to sewer to be estimated for a matrix of household occupancy patterns and water use scenarios, and includes likely discharges from individual appliances such as WCs, showers and baths.

A literature review will be undertaken prior to carrying out the investigations to examine both the experiences and concerns of others, including both UK and overseas papers.

Information gained by WRc from previous projects will be supplemented with information from the literature review in order to predict the passage of solids through drains/sewers with low and intermittent flows. The significance, or otherwise, of these potential changes will be assessed.

Similarly, the potential effects of reduced wastewater flows on wastewater treatment will be investigated. As with the sewer system implications, a range of different reduction levels will be considered.

1.5 Structure of this report

The report details:

- Information collected through the literature review (Chapter 2).
- The modelling of impacts of water efficiency measures on drain/ sewer flow (Chapter 3).
- The impact on different configurations of drains and sewers (Chapter 4).
- The impact on sewage treatment (Chapter 5).

The key findings are discussed in Chapter 6. Conclusions and recommendations for further work are given in Chapters 7 and 8 respectively.

2 Literature review

2.1 Introduction

The purpose of the literature review was to examine international experience and other relevant information to identify whether work of a similar nature to this study had been carried out and whether information useful to this study could be used to supplement data available to the project.

WRc reviewed information from a range of sources, including:

- Related WRc project information, where this could be released or was already in the public domain.
- Information from other studies.

Information found through this review is summarised against the key issues of relevance to this study, namely:

- The impact of water reduction on drainage systems.
- The behaviour of flushed solids in the drainage system.
- The impact of drain diameter on flushing of solids.
- The impact of water recycling/harvesting on drainage performance.
- The impact of water reduction on wastewater treatment works.

In summary, no practical examples of drain/sewer blockages with a definite link to lower demand were reported. However, much of the research analysed appears to have focused on WC flushing rather than the performance of the downstream drain and sewer system.

Information on the relationship between pipe diameter and solid movement is available and can be used in this project.

2.2 The impact of water reduction on drainage systems

2.2.1 Experience from USA

Water used per WC flush in the USA has reduced from 18.9-26.5 litres (pre-1980s) to 13.2-15.1 litres (Marshall & Batis 1993). Since 1993 this has further reduced, often down to a six litre flush.

Two examples of low flush WC installations are reported by Siegrist (1983). In one study across 150 homes in Phoenix incorporating three-litre WCs, low-flow showerheads and flow restrictors, no complaints from the homeowners and no problems with drains and sewers were recorded. After one and a half years of operation, the developers consider the installations successful. Siegrist goes on to comment that, as the size of the service area increases, the potential for sedimentation problems and odours in conventional gravity sewers may increase because of increased sewer sizing, reduced slopes, and longer reaches.

In a second study, a practical evaluation to minimise wastewater disposal on a campsite (Northern Michigan, USA) is reported. The retrofitting of air-assisted (two litre) WCs and low-flow showerheads (9l/min) achieved the necessary reduction in wastewater discharge (reduction of 50-60 per cent). Wastewater is discharged to a holding tank between each property and the drain, before releasing to the drain. It is not clear whether the wastewater is released to the drain when there is sufficient volume or whether release is time related.

Studies on the impact of appliances on overall water use have also been carried out (Siegrist 1983). However, none have reported on the impact on sewer system performance.

Trials (Anderson & Siegrist 1989) comparing the impact of Ultra Low Volume (ULV) WCs (3.6 litre) with a conventional (for the USA) 13 litre WC found that there were no greater incidents of 'in-house' WC blockages with low flush WCs. In addition, conventional WCs more often required repeat flushing to clear the bowl than the low flush WC. No problems with sewer blocking were reported for either system.

Unfortunately, whilst the trials enabled the performance of the house drainage and sewers immediately downstream to be compared, the same cannot be said of the public sewers. This is because:

- Conventional vitrified clay sewers were used in the catchment with conventional WCs, whereas PVC truss sewers[1] were used in the ULV WC catchment.
- The pipes serving the low flush WC households were 3" (76mm) plastic pipe to the footpath and 4" (101mm) plastic pipes to the sewer.

Therefore the impact on sewers could not be compared in these studies.

Also, pipe gradients are stated between 0.0037 ft/ft for clay pipes and 0.0038 ft/ft for PVC pipes (approx. 1: 270) – this is far shallower than recommended in the UK.

It should be noted that there are other American studies which refer to the use of low flush WCs. However, in the USA a six litre flush WC is often referred to as low flush or ultra low flush. This is in contrast to the UK & Europe, where six litre flush

[1] A truss sewer is a sewer constructed of a concentric twin wall plastic pipe braced by a truss type structure. The truss voids are filled with lightweight concrete.

WCs are now regarded as standard. Hence, caution should be exercised when reading such reports.

2.2.2 Experience from the UK

The current view of UK researchers (Littlewood *et al*. 2007) is that there is little scope for further reduction beyond a 6/4 litre dual flush WC for households connected to conventional large bore sewers, without compromising performance in terms of solid transport and blockages.

The introduction of 4.5 litre single flush toilets in a primary school in the UK (Keating & Styles 2004) was reported to deliver good, reliable performance with much reduced flush volumes. However, this report deals with the performance of the toilets and immediate associated plumbing - it did not report on the impact on drain/sewer system performance.

WRc carried out a practical evaluation of an ultra-low flush toilet, Propelair WC, to assess its ability to transport solids (Littlewood *et al*. 2007). The 1.5 litre flush is assisted by high volume, low-pressure air. The report concluded that the prototype performed well, with no reported problems in terms of drain/sewer blockages. In addition, only one report of repeat flushing to clear the bowl was reported during the study (WRc 2006).

However, the WC was connected to a drainage system that also took flushes from conventional WCs. Thus it was not possible to assess the performance of a drainage system fed solely by a Propelair WC. With this in mind, a supplementary test rig-based study was undertaken. This study found that, when connected to a 50mm diameter drainage pipe, the ultra-low flush toilet performed as well as a standard (6/4 litre dual flush) WC. However, solid transport performance when connected to a conventional 100mm diameter drainage pipe was unsatisfactory and led to blockages in the drain. It was concluded that, in order to best use this low-flush technology, new building drainage rules will need to be devised.

The Beddington Zero Energy Development, or BedZED, is the UK's largest eco-village. The use of water efficient appliances has led to a 35 per cent reduction in water use (based on 150 litres UK average). Information provided to WRc (personal communication, August 2007) suggests that there has been no impact on wastewater collection or treatment systems.

2.2.3 Experience from other countries

A number of studies (Johnen 2006, Water Demand Management Bulletin, Issue 84, August 2007) have reviewed the impact of water re-use/recycling and water efficient technologies on water use in Germany. None of these studies have, however, considered the impact of water reduction on drain/sewer system performance.

Siegrist (1983) states that flush volumes have been reduced in Scandinavia without waste transport problems. However, no details of pipes sizes, gradients or materials are provided.

2.2.4 Impact on pipe materials

As a result of reduced wastewater discharge, solids may remain in the drains/sewers for a longer period of time (Marshall & Batis 1993). This could lead to settled solids and grease forming dams in the pipes. In addition, biochemical activity in the sewage will reduce oxygen and increase septicity in the drain/sewer.

Increased maintenance (regular sewer cleaning, flushing and tree root removal) might be required to reduce damming and deal with the septic conditions caused by a combination of settled solids/blockages. There will be a cost associated with this.

In a study in Cambria Community Services District, California (Marshall & Batis 1993), increased sewage concentration leading to increased levels of hydrogen sulphide was reported. This in turn can lead to:

- odour complaints;
- lethal atmospheres;
- damage to manholes, pipes and joints due to sulphuric acid corrosion[2].

However, other work by wastewater agencies in the USA reported that, in practice, there was little change in maintenance requirements and only a minor increase in odour complaints or pipe deterioration.

It is unlikely that septicity and hydrogen sulphide attack will become a serious issue in UK sewer systems where the average sewer temperature is below 20ºC.

2.3 The behaviour of flushed solids in the drainage system

When there are insufficient upstream inputs to keep the solid moving in a continuous flow, gross solids move along a pipe in an intermittent mode. Solids are then pushed along the pipe by successive large flushes.

Researchers in the UK have expressed a concern that water efficiency measures (in particular the reduction of WC flush volumes) could lead to reductions in solid transport in the intermittent flow regime, which could in turn lead to increased blockages (Littlewood & Butler 2003).

It is the view of some UK researchers (Littlewood & Butler 2003) that it is the WC that is responsible for most of these large flushes. Therefore a reduction in WC flush volume could impact on the operation of the drain/sewer.

[2] Note: damage is limited to concrete and metal components and would not impact on clay and plastic pipes commonly used in UK drains.

Another paper (McDougall and Swaffield 2003) also discusses these issues. The authors state that as the predominant percentage of the drainage flow within the building envelope will emanate from WC discharge, it follows that the interaction between WC operation and drainage network performance should form the basis for drain size design criteria. Solid deposition leading to increased maintenance costs is clearly a concern as throughflows fall, and hence definition of the connection between reduced flush volume and drain sizing becomes essential.

However, in a further paper (Lauchlan *et al*. 2003) it is considered that baths have the greatest influence on wastewater flow. It is not clear if this is a reference to volume of flow, velocity or flushing ability, as further details are not given. It should also be noted that whilst bath volumes are not expected to drop dramatically as the result of any water conservation measures, the frequency of bathing may drop, as there is a shift from the use of baths to showers.

Practical studies (Littlewood & Butler 2003) have found that, for any discharge of water, there will be a maximum distance that a solid could be transported due to the dissipation of forces as the discharged water moves along the pipe. This is referred to as the Limiting Solid Transport Distance (LSTD). The LSTD has been established for some combinations of pipe diameter, solid and flush volume. Unsurprisingly:

- The velocity of movement and the LSTD increases as the pipe diameter decreases.
- The LSTD was found to be shorter when using a lower flush volume or a larger solid.

However, it is noted that a minimum diameter of pipe is required to avoid clogging.

Littlewood subsequently added to the earlier work by undertaking further practical investigations. The have subsequently been continued by WRc and the results back up the earlier work (Littlewood and Butler 2003).

2.4 Solid transport performance versus drain diameters

The diameter of the drain pipe will directly affect the velocity of wastewater travelling down the pipe. Various studies have considered the effect of drain diameter on the ability of the pipe to transport solids.

- Practical trials in the UK (Littlewood 2000 and subsequently WRc) comparing gross solids transport performance for different pipe sizes showed that solids transport was superior in smaller diameter pipes, with the solid typically being transported twice as far in a 100mm diameter pipe than in a 150mm diameter pipe. It is proposed that reducing pipe diameters could improve solid transport and counter the reductions in wastewater discharge due to water efficiency.

- Practical studies in Canada (Gauley and Koeller 2005) investigated the wastewater flow and movement of solids for pipes of different diameters and gradients, and different wastewater discharge volumes. The results are consistent with those found in the UK (Littlewood and Butler 2003).

- The effect of the number of houses connecting to a 150mm diameter pipe, and therefore the volume and pattern of wastewater discharge, has been modelled (Lauchlan *et al*. 2003). Foul flows from a limited number of properties (up to 10) will provide a satisfactory flow in 100mm diameter pipes. The paper states that this will apply for both current (conventional) and low water use scenarios.

- A substantial reduction in wastewater discharge resulted in some pipe systems not meeting the criteria for gross solids transport for high probability flows (Lauchlan *et al*. 2003). Normal rule of thumb design for drains serving above 10 properties is 150mm diameter pipe at a gradient of 1:150 to provide a self-cleansing regime (Sewers for Adoption 2006). However, it is uncertain (Lauchlan *et al*. 2003) whether this would be satisfactory to maintain gross solid movement when water use in the home is reduced. No further guidance was given on this.

- It is suggested (McDougal & Swaffield 2003) that the growing importance of water conservation and reduction in wastewater discharge will inevitably lead to increased maintenance costs unless consideration is given to corresponding reductions in drain or horizontal branch diameters. No further evidence is provided to support these statements.

2.5 Water efficiency and drainage performance

The storage of rainwater for use in household appliances will impact on the total volume of water (potable + rainwater) discharged to the drain/sewer. Despite this, there is no identifiable work on the impact of rainwater harvesting on drains and sewers.

2.6 Water efficiency – possible effects at wastewater treatment works

The effects of minimising wastewater flow on the design and performance of wastewater treatment facilities have not been clearly established.

There are conflicting thoughts (Siegrist 1983) in that major reductions in wastewater discharge could:

- Help with hydraulic overloading of existing treatment plants, thereby extending the service life of components or reducing overall operation and maintenance requirements).

- Change the type of sewage discharged to the treatment plant (reduced oxygen content, increased concentrations of total suspended solids, composition of wastewater due to type of appliances such as macerators, air-assisted or chemical assisted). This could affect the design and performance of wastewater treatment facilities.

- Reduce the volume of sewage discharged to the treatment plant but not the pollutant load, resulting in an increased concentration of pollutants in the wastewater stream.

There is no specific evidence as to the impact of water efficiency on wastewater treatment operation.

The effect of the composition of wastewater on the composition of the wastewater discharge is also unknown (Siegrist 1983).

2.7 Key points from literature review

In summary, there are very few studies specifically considering the impact of water efficiency on drains and sewers.

The following information can be drawn from the literature review to guide this current study:

- The review found no practical examples of drain or sewer blockages that could be attributed to reduced water demand. The majority of studies focused primarily on the impact of WC flushing on solids movement.

  A small number of studies did consider the impact of water reduction on drains and sewers, and no increase in blockages or other operational problems were reported. However, additional drainage design/operational measures were taken in some of these studies to help ensure that the likelihood of blockages and other problems occurring were minimised.

- A number of authors were of the opinion that WC flushes provide most of the force to move solids along drainage pipes close to houses. Thus a reduction in WC flush volumes will, in some circumstances, reduce the ability of solids to be moved along the drainage pipes. This in turn could lead to an increase in the occurrence of sewer blockages and sewer flooding.

- The review identified a number of test rig-based studies where the ability of a solid to be moved along a pipe had been examined against various scenarios. Comparison of data for different WC flush volumes showed a worsening of the ability of a sewer solid to be moved with the lower flush rates. The implication of this could be significant, particularly in terms of an increased likelihood of sewer blockages.

Solid movement problems resulting from lower flush WCs can be countered by changes in sewer design, in particular a reduction in pipe diameter and/or an increase in pipe gradient. For example:

  - The inclusion of very low flow or assisted flush WCs could be accommodated with a change in drain diameter (for new houses).
  - Solids transport is superior in small diameter pipes - twice the distance in 100mm pipe compared to 150mm pipe.
  - Plastic pipes of 3” (76mm) and 4” (101mm) can accommodate the reduction in water use offered by three litre flush WCs in the USA.
  - Foul flows for up to 10 properties can be accommodated by a 100mm diameter pipe.

- The review found no studies specifically on the impact of rainwater harvesting on the performance of combined drains or sewers. Similarly, there are no reports of the impact of water reductions from other appliances on drains/sewers.
- A number of potential pipe maintenance issues associated with lower flows were highlighted. These were associated with septicity and chemical attack on concrete pipes and are particularly problematic in warmer climates.
- There is no specific evidence of the impacts of water efficiency on wastewater treatment and operation.

3 Modelling of impacts of water efficiency measures on drain/sewer flow

3.1 Background

The first part of this study is to determine the water consumption in a standard house (volumes per use and flow rates) against a number of possible scenarios. This will determine the wastewater discharged from the house.

Water entering a household can be used in any number of appliances, including external taps for watering gardens and cleaning cars, and internal taps for filling watering cans. For the purposes of this report it has been considered that all water, excluding external tap consumption, will reach the sewer.

The domestic consumption of water consists of a number of ‘microcomponents’. Typically these are appliances such as washing machines or dishwashers, personal washing by bath or shower, toilet use, and the use of internal or external taps.

Measurement of these microcomponents provides reliable information on the way in which domestic consumers use water in the home. WRc has a microcomponent model which can be used to determine the potential impact on household water use from different demand interventions. This model and the data underpinning it was developed and used during the recent collaborative research programme CP187.

This approach can be used, with some modification, to model the potential impact on volume flow and frequency of flow to sewer from a single property or a group of properties. Although the model is based on a sample of ‘existing’ rather than ‘new’ properties, the frequency of use and ownership of appliances should not be different between older and newer properties. The volume per use of appliances will vary, and this will be covered within the scenarios devised within this chapter.

A number of water reduction scenarios have been agreed with the Environment Agency, based upon levels of the Code for Sustainable Homes and the recent Environment Agency publication on dual flush retrofit in the South of England (Environment Agency 2007a, b). These scenarios have been agreed at:

- 130l/h/d to represent the impact of retrofitting existing properties with low flush WCs.
- 120l/h/d to represent levels 1 and 2 of the Code for Sustainable Homes.
- 105l/h/d to represent levels 3 and 4 of the Code for Sustainable Homes.

- 80l/h/d to represent level 5 of the Code for Sustainable Homes.

The likely impacts of these scenarios on microcomponent water consumption (volumes per use and flow rates) have been considered, along with the importance of the changes in the context of their impact on wastewater discharge.

3.2 Diurnal flows

A database of measured microcomponent water use has been compiled by WRc based on Identi*flow*® monitoring of 400 properties across England and Wales. The database consists of a wide variety of property types (such as flats, semi-detached, detached) and day types (including peak summer weekday, rest of year weekend) and provides reliable information on the frequency of use of appliances, the volume of water used with each use, and the ownership of appliances. Further analysis at an individual household level provides information on the flow profile associated with individual appliances, including duration of use and both average and peak flow rates.

In any 24-hour period, there will be a range of different microcomponents in use and times when more than one device is being used. The uses of these microcomponents, and total volume being used at any individual time, contribute to the ***daily diurnal profile*** of water use.

Water use patterns can be divided into four distinctly different ***season-day*** time periods: 'weekdays' and 'non-weekdays' for each of 'summer peak days' and 'rest of year'. For instance, on a peak summer day, a large amount of external water use might be expected in evenings, as people return from work and water their gardens.

There is a large diurnal variation in microcomponents between the four season-day time periods. Weekend water consumption by all microcomponents is generally higher than weekday use, as people have a less regimented daily structure, and are also at home for longer hours during the day and therefore use the WC, white goods, basin and kitchen taps more frequently than on weekdays.

Figure 3.1 depicts diurnal microcomponent water consumption on the four season-day time periods – that is, 'weekdays', 'non-weekdays' for 'summer' and 'rest of year'.

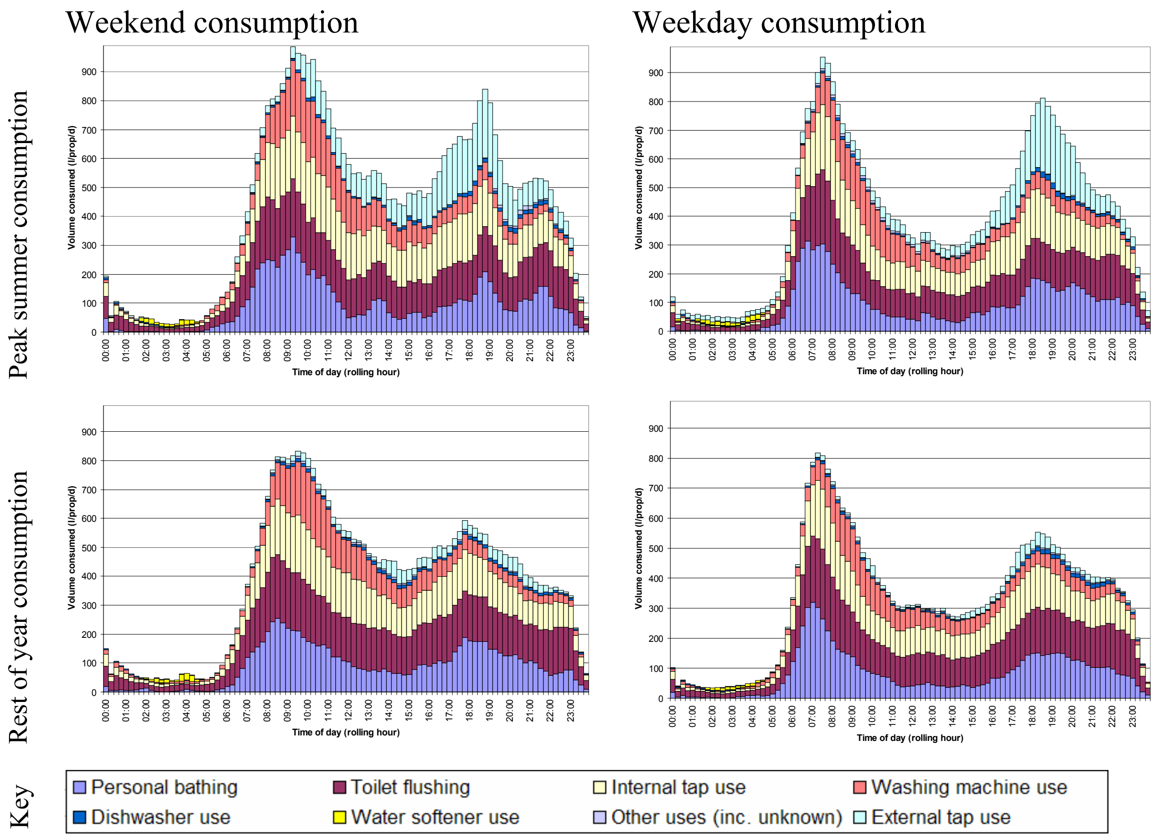

Figure 3.1 Season-day diurnal variations[3] © WRc plc 2004

The total volume, as well as the profile, of household water consumption varies between the four season-day periods. The highest volume of water is used on peak weekend days, and the least on 'rest of year' (non-peak) weekdays.

For this modelling work, the 'rest of year weekday' profile has been selected as the most appropriate season-day type to use. This is because the average household water consumption is lowest on this type of day and it is the lowest flows that are most likely to cause the greatest problems in terms of operational problems/serviceability in the sewer system and sewage treatment works.

3.2.1 Outputs for group of properties

The CP187 model provides a profile of flow within a property for 'average' usage. For instance, Figure 3.2 shows the profile generated for a non-peak weekday.

[3] Note: the unit of volume consumed is based on rolling hours, i.e. if the rate of water consumption in any given 15 minute period was sustained for 24 hours, the total volume consumed would be as per the bar.

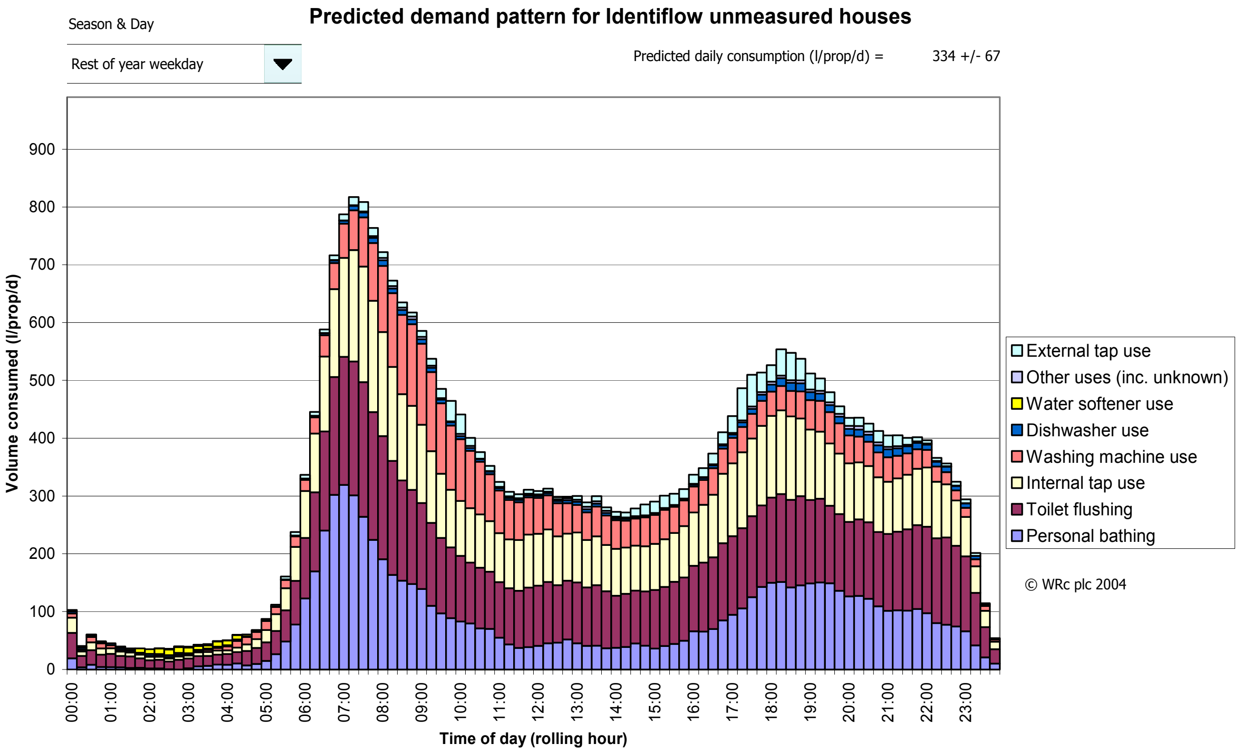

Figure 3.2 Non-peak weekday diurnal water consumption

This profile indicates the expected trends, towards having a large peak in the morning when people are getting up, lower water usage during the day when many people will be at work, or at school, and then another smaller but wider peak over the evening as people return home and cook, do washing, bathe etc.

The profile is associated with water in use in the home, not wastewater reaching the sewer, and this is indicated by the external tap use evident. For the purposes of this study it is assumed that all water consumption, except external tap use, reaches the sewer system.

When considering the potential impacts of reduced water consumption on sewer systems, finer detail is required to know the exact timing of different microcomponent events, and the duration and volume of water that individual events contribute to the sewer. The flows that are of most importance for moving solids in sewers are the ‘plug flows’ from particular microcomponent usage. In addition, the sewers most likely to suffer from blockages are small diameter pipes collecting waste from one or a small number of properties where flows are relatively small and intermittent (see Chapter 2). The larger diameter sewers serving a large number of properties, with larger and continuous flows, are far less likely to experience blockages of this nature.

3.2.2 Outputs for single properties

The diurnal profile of water consumption in the home varies greatly according to both occupancy and structure of the household. In some cases, there might be no occupants during the day, but many in the evening, and for others there might be one or two occupants in all day every day.

In order to assist this study, four 'typical' household types have been identified from within the Identi*flow*® database that cover the majority of household types across the UK. The four household types also provide a good variation in patterns of water use, ranging from those households where water consumption is fairly constant and of high volume, through to those where water consumption is quite sporadic and of smaller volume. Whilst it is appreciated that no household could ever be generalised and that patterns of water consumption will vary from day to day, using these examples will give a broad range of examples with which to consider the impact of reductions in water consumption on wastewater collection and treatment systems. The household structures have been identified from the Identi*flow*® database as given in Table 3.1.

Table 3.1 Household structures

Household structure identity	Number of occupants	In during day?	In during evening?
HH1	1	Yes	Yes
HH2	2	No	Yes
HH3	3+	Yes	Yes
HH4	3+	No	Yes

One example, the rest-of-year weekday profile, (see Section 3.2) has been identified within the Identi*flow*® database for each of these household structures. This has provided an example diurnal profile of consumption for individual households of different structure. The examples identified have different total water consumption and appliance use to the average for households with occupancy of the same size. This is because the average is a composite of many individual house flows, of all house types, and the precise timing of flows and frequency, duration etc for any individual house will be particular to each household.

An example of the profile for a two occupant household, where both are absent during the daytime (HH2) is given in Figure 3.3. This has been extracted directly from the Identi*flow*® database.

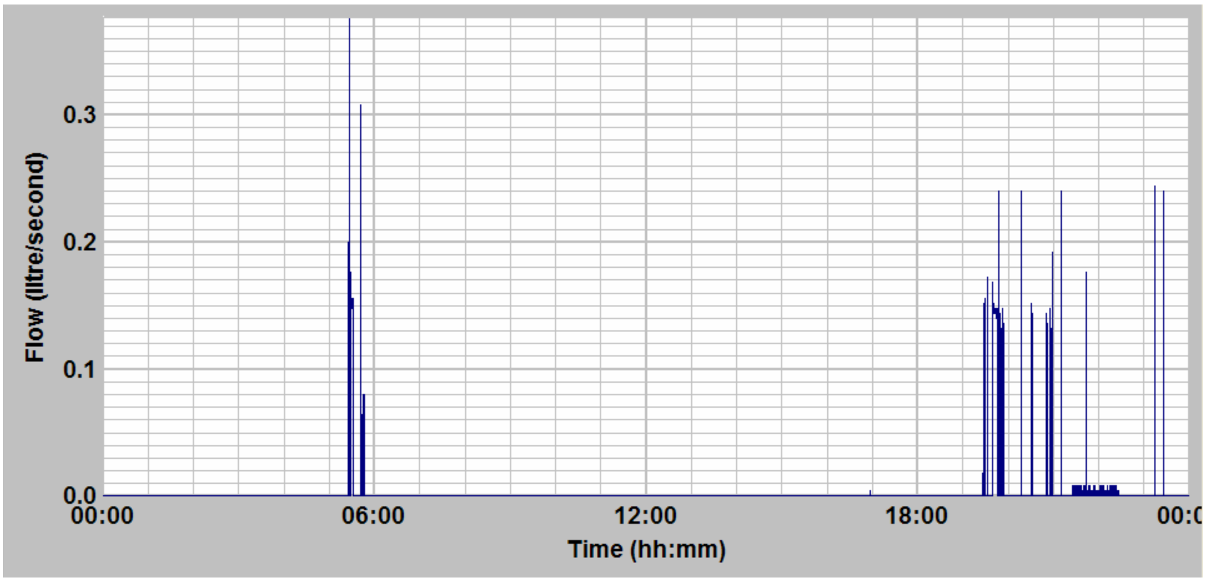

Figure 3.3 Water consumption for a 2 occupant household (HH2)

The total volume of water shown in Figure 3.3 is 231 litres, used through a combination of toilet, shower, bath, taps and a washing machine. Flows that potentially contribute to moving solids, and are hence of importance to this study, are those from the toilet, shower, bath and washing machine.

Figure 3.4 shows in detail the time of day that these flows take place, along with typical volumes.

Standard volumes for appliances have been assumed within all household types, to allow for accurate comparison between scenarios. The timing of events is as per the original data from Identi*flow*®.

Summary 24-hour graphs for potable water entering each of the four household types can be found in Appendix A, Figures A.1 to A.4.

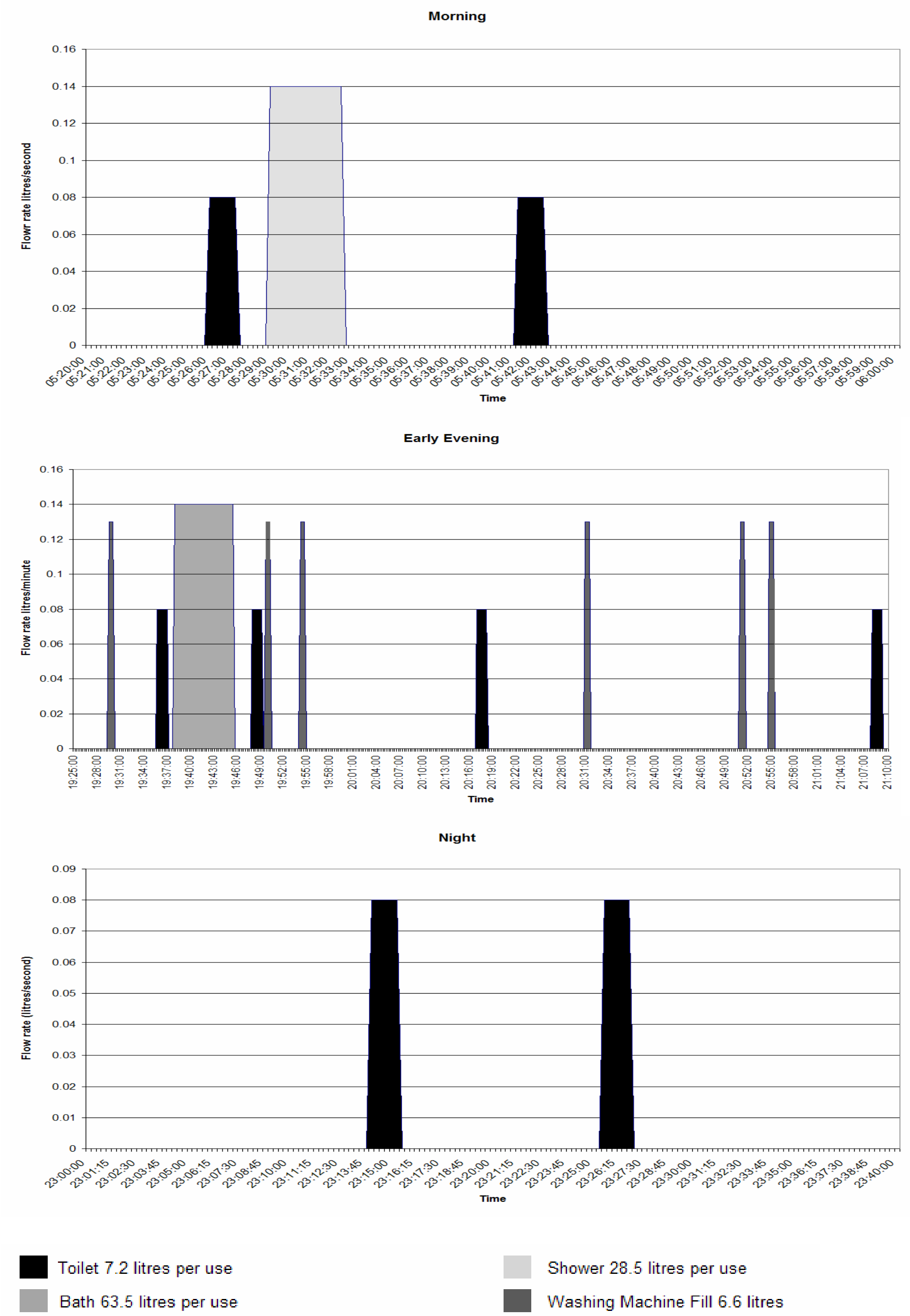

Figure 3.4 Key events for HH2, morning, evening and night

When examining the impact of demand management scenarios on wastewater collection (drains and sewers), it is necessary to consider the flow rates of wastewater exiting, rather than water entering, the various water-using appliances. For this reason, diurnal profiles (of water used by different appliances) need to be transformed to reflect the likely 'existing' flow rates as given in Table 3.2.

Table 3.2 Volumes and flow rates for key device events

	Device volume	Device flow rate entering appliance (from Identi*flow*®)	Device flow rate exiting appliance
Toilet	7.2 litres	0.08l/second	1.85l/second[4]
Bath	63.5 litres	0.14l/second	0.26l/second[5]
Shower	28.5 litres	0.14l/second	0.14l/second[6]
Washing machine fill	6.6 litres	0.13l/second	0.13l/second[7]

Information from these profiles will be used in the assessment of factors affecting sewer flow performance in Section 4. The flow rates of appliances will be adjusted to reflect the rate when the water exits the appliance in question. Adjusted summary 24-hour graphs for wastewater exiting each of the four household types can be found in Appendix A, Figures A.5 to A.8.

3.2.3 Reduced water use scenarios

The modelling work in Sections 3.2.1 and 3.2.2 show the typical situation for 'existing' properties. The appliances installed in new properties, and certainly those meeting different levels of the Code for Sustainable Homes, will be of higher efficiency and therefore use less water. In some circumstances, such as showers, this will be brought about by a reduction in flow rate. In other situations, such as WCs, the flow rate (entering and exiting) of the appliance will not be altered, but the total volume of water used will change.

There is no reason to believe that the pattern of water use in new homes is any different to that of existing homes, and therefore whilst the volumes per use of the

[4] WRc - NSF Ltd, Evaluation & Testing Centre (2000) WRAS test & acceptance criteria 15112.
[5] A bath takes approximately 4 minutes to clear, giving a flow rate of 0.26 litres per second.
[6] For showering, it is assumed the flow rate to the sewer is equivalent to the flow rate of the showerhead as water clears the appliance immediately, assuming no obstacles prevent water from doing so.
[7] No information is available on the rate at which water is expelled from washing machines; therefore we assume the flow rate is equivalent to the entry flow rate.

individual appliances will differ from the base scenario for each household type, the timing of the events will remain the same.

The 130l/h/d scenario is aimed at recreating the impact of likely retrofitting activity on existing housing. The Environment Agency report *Assessing the cost of compliance with the Code for Sustainable Homes* explores options for meeting the Code through the use of various fittings.

Note: The Building Research Establishment (BRE) water calculator contained within the technical guidance to the Code could be used to calculate the standard of appliances that are necessary to meet each level of the Code.

Table 3.3 shows the appliance efficiencies necessary to meet each level of the Code.

Table 3.3 Example appliances to meet levels of Code for Sustainable Homes

	130l/h/d (Illustrating likely impact of retrofitting activity on existing households)	120l/h/d (Level 1 & 2)	105l/h/d (Level 3 & 4)	80l/h/d (Level 5)
WC	6/4 litres dual flush	6/4 litres dual flush	4.5/3 litres dual flush	Any WC
Shower	6l/minute	6l/minute	6l/minute	6l/minute
Bath	Standard (200 litres)	165 litre small bath	145 litre small bath	145 litre small bath
Basin taps	3l/minute	3l/minute	1.7l/minute	1.7l/minute
Kitchen taps	4l/minute	3l/minute	3 /minute	1.7l/minute
Washing machine	Standard 49 litre	Standard 49 litre	Standard 49 litre	Standard 49 litre
Dishwasher	Standard 13 litre	Standard 13 litre	Standard 13 litre	Standard 13 litre
Grey water recycling	-	-	-	Required[8]

[8] Grey water recycling is required to meet 80l/h/d. It has been selected over rainwater harvesting as the use of grey water means that the flows to sewer will be as minimal as possible.

In terms of wastewater flows and the impact on sewers, the most significant reduction to meet any level of the Code is the reduction in WC flush volumes. Figure 3.5 indicates the potential impact that reduction in flush volume has on the length of time the water takes to exit the bowl of the WC.

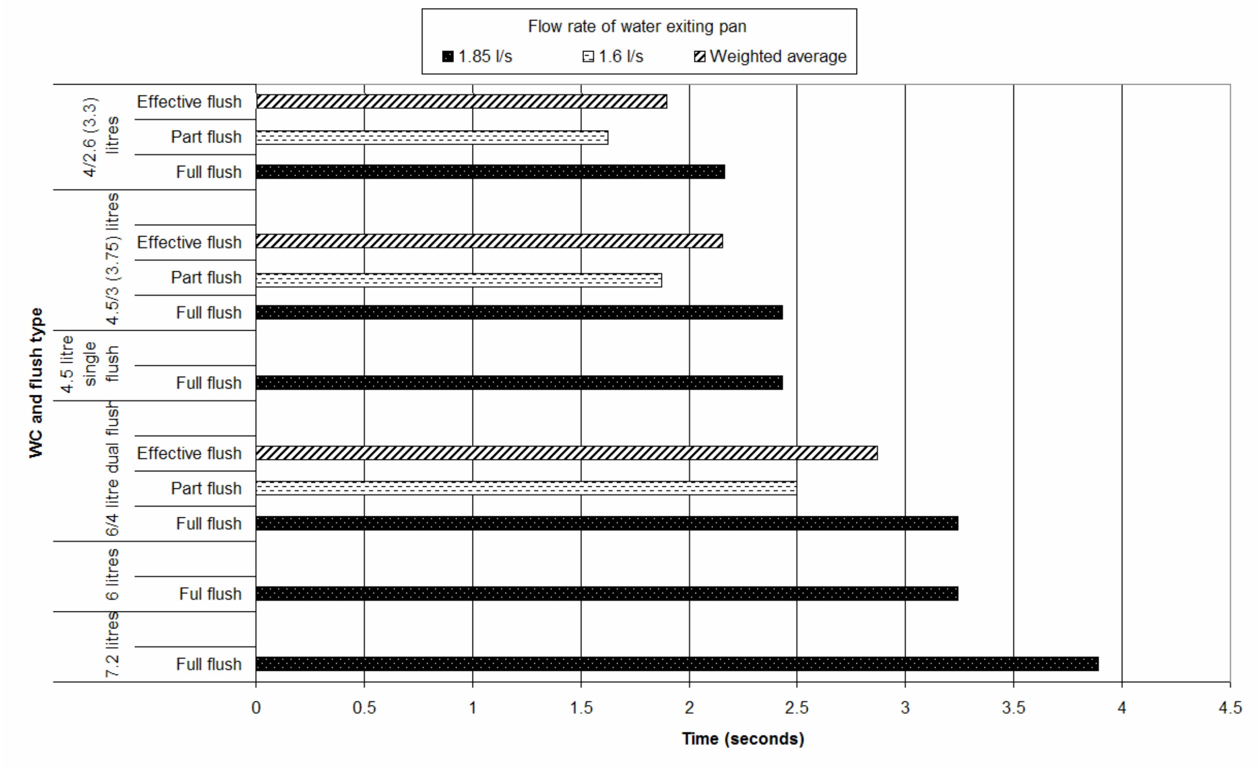

Figure 3.5 Duration of WC flush for different cistern sizes

Figure 3.5 indicates that WCs with large, single flush volumes have both the fastest flow rate of water exiting the pan, and also the longest flush duration.

The duration of WC flush is based upon an exiting flow rate of 1.85 litres per second for full flush, 1.6 litres per second for part flush[9], and an effective flush ratio of 1 full flush : 1 part flush. It is recognised that there will be a variation in the flow rate and not all WCs will comply with the WRAS (Water Regulations Advisory Scheme) criteria. However, no further information is currently available and, for the purpose of modelling the impact of reducing WC volume, this flow rate can be considered appropriate. Following flush activation, it can also be expected that there will be a trickling of water due to 'drain down' of water from the rim and flush pipe for approximately 8-10 seconds. The amount of water and length of trickling will vary accordingly to type and age of WC, but is negligible with regards to solid movements in the sewer.

As flush sizes decrease, the length of time for the full flush also decreases. Coupled with this, in dual flush WCs the flow rate of the part flush is lower, meaning that a

[9] WRAS test & acceptance criteria, test 15112. See also BS 14516:2006.

smaller volume of water takes proportionally a longer length of time to exit the pan. The effective flush (based on a 1:1 ratio) of the dual flush WCs will have a flow rate of approximately 1.75l/second, although this will vary depending on the exact ratio of the full: part flush volume[10].

Thus, in the case of water reductions to meet Code for Sustainable Homes Levels 3 and 4, the duration of the WC flush is likely to reduce from the current 3 to 4 seconds to just over 2 seconds. If changes are also made from single flush to dual flush, the overall flow rate from the WC will drop marginally.

3.2.4 Relationship between water use and the operation of the drain/sewer

A minimum level of flow is required in drains close to property to ensure that sewage related solids do not become 'stranded' in the external drainage pipes. This 'stranding' could develop into a sewer blockage and, ultimately, cause sewage flooding of gardens and property.

Whilst a reduction in the WC flush volume is likely to have a significant impact on sewer flows, other wastewater flowing through sewers helps to keep solids moving. No detailed information on the contribution of each appliance to volume of wastewater was gained from the literature review (see Chapter 2).

Table 3.4 indicates the volume of water used by each microcomponent under each of the reduction scenario outlined in Section 3.2.3. Water consumption has been modelled based on the water calculator contained in the technical guidance to the Code for Sustainable Homes.

In Chapter 4, the impact of these various scenarios on drains and sewers is modelled.

[10] Justification for the 1:1 full to part flush is given in Market Transformation Programme (MTP) document *BNWAT05: Water closets water efficiency performance testing.*

See also Environment Agency (2007) *Assessing the cost of compliance with the Code for Sustainable Homes* for evidence of effective flush ratios.

Table 3.4 Microcomponent consumption under Code Level Scenarios

	130l/h/d (Retrofitting)	120l/h/d (Level 1 & 2)	105l/h/d (Level 3 & 4)	80l/h/d (Level 5)
WC	22.4	22.4	16.8	Grey water used, worst case 16.8
Shower	18.0	18.0	18.0	18.0
Bath	32.0	26.4	23.2	(6.4)[11]
Basin taps	15.9	15.9	9.0	9.0
Kitchen taps	21.2	15.9	15.9	9.0
Washing machine	16.7	16.7	16.7	16.7
Dishwasher	3.9	3.9	3.9	3.9

[11] Grey water reuse is used within this scenario. The value indicated shows the volume that would be discharged to sewer if all the WC flush requirements were taken from the bath water discharge.

4 Impact of demand reductions in different drain and sewer configurations

4.1 Introduction

The second part of this study considers the impact of changes to the volume and pattern of wastewater discharged to the drain/sewer on the performance of those drains/sewers.

The wastewater flows discharged to foul drains and sewers contain solids. Some of these, such as human waste and toilet paper are termed ‘sewer solids’ and are correctly discharged to sewer and will soon begin to disintegrate. Unfortunately other solids, such as face wipes, which should be disposed of in the waste bin, are often flushed down the toilet. They do not necessarily break up once in the sewer system.

It is essential that there is sufficient flow in the drainage system to carry all solids away.

4.2 Solid movement in drainage systems

There is normally sufficient flow in branch and trunk sewers to enable the solids to be carried in the body of the flow. However, there is often very little flow in local drains and sewers immediately downstream of the property that they serve. This is because the only flow in many of these local pipes is generated by the intermittent wastewater discharges from the properties that they serve (see in Figure 4.1 and Appendix B).

Solid movement in local drainage systems normally occurs by a series of events initiated by the more significant wastewater discharges. These discharges enable solids to be pushed along the pipe, though the wave will eventually overtake the solid and the solid will come to rest. The next significant discharge will push the solid along and, through successive discharges, the solid continues to travel along the pipe.

The most significant wastewater discharges, in terms of solid movement, are WC flushes. This is because they have the greatest flow rate as illustrated in Table 3.2 and Appendix A, Figures A5 to A8.

Discharges from other appliances also assist in solid movement. This is because a solid that has settled out in the pipe will begin to move more easily if it is still damp, especially if there is a dam of water behind it. A damp solid offers less resistance to movement than a solid that has started to dry out.

Therefore, to enable solid movement in drains and sewers, it is important that:

- WC flushes are of a frequency and flow rate that enable solids to be moved along the pipe at intermittent intervals.

- Other discharges are sufficient to enable stranded solids to remain damp, preferably with a dam of water behind them.

Typical wastewater flow patterns from individual properties are discussed further in section 4.5.

Implications of reduced wastewater flows
A solid will begin to come to rest once there is no longer sufficient force to keep that solid moving. The smaller the flush, the sooner the solid will come to rest.

A reduced WC flush may result in either the solid moving a very short distance or not moving at all. If the solid fails to be removed by subsequent flushes, there is a likelihood that it will start to cause a sewer blockage. The significance of reduced flows is further investigated by the modelling of wastewater discharge patterns and solid flow movement in section 4.5. This enables the impact of different levels of WC flush reduction to be assessed.

An undetected blockage can lead to sewer flooding, both externally and within a property.

4.3 Drain and sewer systems and typical configurations

This section describes typical drain and sewer layouts and helps to identify those parts of a drainage system that are likely to be at greater risk of blockage by sewer solids.

Solid movement problems will be most acute in the parts of the local drainage system that take very few wastewater discharges. This will normally be in pipes taking discharges from:

- a single property (or part of a single property);

- a small number of single occupancy properties.

4.3.1 Drains and sewers

A drain conveys foul sewage and/or surface water from a single property.

Sewers convey foul sewage and/or surface water from more than one property. As the flows from a greater number of houses combine, the flows will eventually become continuous.

4.3.2 Combined drainage systems

Older properties are likely to be served by a single drainage system that takes both foul sewage and surface water. This is known as a ***combined system*** and may take surface water from both the roof and yard. Most of these combined drains will be of 150mm (6”) diameter or larger.

4.3.3 Separate drainage systems

The practice of combining wastewater and storm water drainage has gradually ceased over the last sixty years. This is because it is far more convenient to keep foul sewage and surface water separate, from both a drainage and sewage treatment perspective. In some areas, notably parts of London, separate drainage systems have been used since the 1920s. In other areas, combined systems were still being constructed in the late 1950s.

Most new properties are served by two drainage systems – a foul system and surface water system:

- The ***foul system*** connects with the main sewer system and eventually terminates at a sewage treatment works. (Note: in some remote rural areas cesspools/septic tanks are used).
- The ***surface water system*** may connect to a piped drainage system which leads to a watercourse, soakaway, storage pond or other system.

Local foul drains and sewers should have sufficient capacity to be able to cope with the flows which result when all toilets and other appliances are operating at the same time. In reality, local foul drains have very little flow in them for the majority of the time and operate on an intermittent flow basis.

Most foul drains from houses are constructed to satisfy a minimum size requirement, as specified in Part H of the Building Regulations – this is based on the size required to cope with the solids, and is more than sufficient to cope with the volume of wastewater generated. Most local foul drainage pipes are of 100mm (4”) or 150mm (6”) diameter.

4.3.4 Typical configurations

Drainage from one property sometimes connects directly to a public sewer. More commonly, further individual drains may connect into the pipe before it joins the public sewer.

Figure 4.1 shows examples of drainage layouts, as follows:

- For the houses at bottom of diagram, a drain from a single property is connected directly to the public sewer.
- For the house on the top right-hand side of the diagram the drainage arrangement is (moving from right to left):
    - The drain from one property;
    - The continuation of that drain (termed lateral drain) outside of the curtilage of the property;
    - The sewer taking further discharges from the 2nd, 3rd and 4th properties; and
    - Eventually connecting to the public sewer.

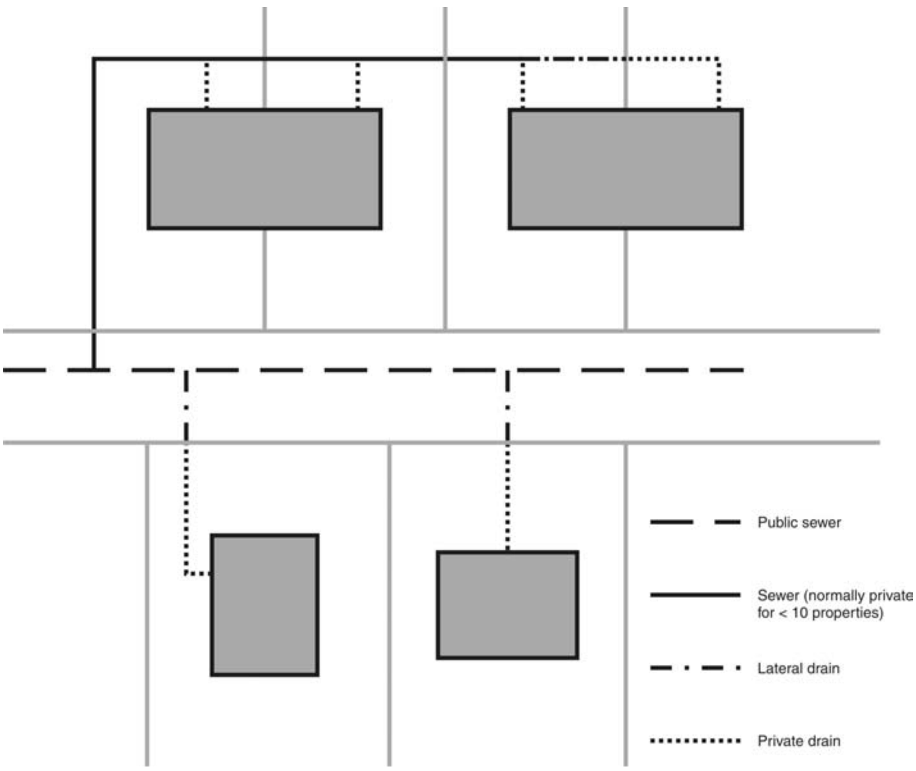

Figure 4.1 Example layout of drains and sewers

The exact layout will depend upon the design of the property. In particular:

- ‘Wet rooms’ are traditionally located at the rear of the house (kitchen/bathroom/utility etc). Thus, in older properties, the drain will initially run along the rear of one or a number of properties before routing down the side of the property to join the public sewer (which is normally under the highway).

- For properties constructed in the last 20 years, wet rooms are more commonly found at the sides and front of houses. This has been brought about by the greater use of en-suite bathrooms and, more recently, the need to provide disabled access toilets near to the front entrance. This means that foul drainage is just as likely to leave the property at the side/front of the house and is no longer restricted to the rear gardens.

Referring to Figure 4.1, the pipe lengths at greatest risk of solid stranding/blockages are:

- The pipes taking wastewater from the two properties at the bottom of the diagram – each property is individually served by a drain connecting to the public sewer.

- The pipe taking wastewater from the far right property of the group of four semi-detached houses at the top of the diagram. This is because the pipe takes wastewater from only one property. Wastewater flows will increase and the risk of solid stranding will decrease as the discharges from each property join the sewer.

This study (see sections 4.4-4.6) has therefore focused on the effect of reduced flows on drains and sewers with a smaller number of connecting properties, specifically drains and sewers serving houses with a low occupancy.

Complex local drainage systems with numerous bends and junctions, and poor access can also lead to blockage problems. However, these issues are outside the scope of this report.

A number of other typical drainage configurations are shown in Appendix B.

4.3.5 Recent changes in drainage configurations

Most new housing developments are of a high or very high density. Therefore, the likelihood of significant lengths of drain or a sewer serving very few properties is considerably less than has been the case with the lower density housing built over the last forty years. Accordingly, blockage problems associated with very low flows may be less common in drains serving this type of development.

Also, there is a greater tendency towards cost engineering in house construction. One aspect of this is the use of just one foul drain per property, with all the wastewater outlets connecting to that one line. Previously, drainage systems were often designed in such a way that drainage pipes exited the property at the rear, side and front, as illustrated in some of the layouts in Figure B5 (Appendix B). Having only one line per property will result in only one drainage line per property, as illustrated in some of the layouts in Figure B6 (Appendix B). In terms of low flows and sewer blockages this means that there will be:

- Far less length of external drainage taking very little flow.
- Proportionally more flow in each of the external drains that would otherwise have been the case.

4.4 Flow patterns in the foul drain

4.4.1 Diurnal flow patterns

Typical potable water use patterns within the house are described in Section 3 of this report. As explained and illustrated in Figures 3.1 and 3.2, the majority of this water, with the exception of external tap use, will find its way to the foul drain/sewer.

The diurnal flow pattern in a foul sewer taking wastewater from a significant number of dwellings will therefore look very similar to the typical flow pattern for potable water consumption seen in Figure 3.2.

4.4.2 Flow at an individual property level

At an individual property level, the foul flows will be very intermittent and spiky in nature.

Water entering four typical households (Types 1 to 4, see Section 3.2.2) is shown in Appendix A, Figures A.1 to A.4.

Flow patterns for wastewater exiting the same four typical households are shown in Appendix A, Figures A.5 to A.8. The peaks (in excess of 1.8 litres per event) are attributed to WC flushes.

The main difference between the potable water use and wastewater discharge patterns will be WC usage. Unlike other appliances, the foul water discharge rate (WC flush) will be significantly higher than the potable water draw off rate (cistern filling). As illustrated in Table 3.2, the flow rate leaving the WC bowl will be in the order of 1.85l/s, whereas the flow rate entering the WC tank will be closer to 0.08l/s.

4.5 The influence of flow patterns on solid movement in the foul drain

4.5.1 The influencing factors

Previous research by Littlewood and Butler (2003) and others has shown that the ability of a solid to continue moving along a pipe is dependent upon a number of factors, in particular:

- The volume and flowrate of wastewater discharged in each event.

  The greater the discharge, the greater will be the distance the solid moves following a discharge.

- The pipe size.

  The ability of a drain/sewer to transport solids diminishes with increasing pipe size. This is because in smaller pipes the solid obstructing the flow will tend to be pushed forward by the build-up of water behind it. In larger pipes this is less likely to be the case because the water can flow around the stranded solid.

  Accordingly, 100mm diameter pipes are now recommended, in preference to 150mm pipes, for pipes taking foul drainage from 10 properties of less. This is consistent with the finding from the literature review (see section 2.7).

  The pipe gradient.

  Solids will travel further the steeper the gradient. This is because the increased energy enables the solid to be transported further.

- The pipe condition.

  Poor pipe joints, tree root intrusion, stones/rubble in pipes etc will result in the discharge wave being dissipated more quickly than would otherwise be the case. This would give additional opportunities for a solid to strand and/or snag in the pipe. Thus, pipes in a particularly poor condition are more susceptible to solid stranding/blockages than pipes in a good/moderate condition.

Various experimental programmes have been undertaken to better understand the relative significance of the above factors on solid movement. The results from some of these are detailed in Appendix C of this report.

4.5.2 The influence of WC flushes on solid movement

There is evidence from practical experiments (Littlewood and Butler 2003) to suggest that the ‘plug’ or sudden discharge of water from a WC (seen in Figures A.5 to A.8 as peaks of 1.8l/s) is sufficient to move solids along the pipe.

There is no evidence to suggest that the discharge rate from a bath alone is sufficient to move solids along a pipe. However, bath discharges will, when combined with a WC flush, help to move a solid along a pipe. Bath discharges also provide water to keep solids damp and maintain a dam behind the solid, and so aid movement (see section 4.2.1).

The number and frequency of WC flushes will depend upon the household occupancy. For example:

- In Figure A5 (single occupancy scenario), there are 7 flushes, spread throughout the day.
- In Figures A7 and A8 (flushes from property occupied by at least three people) there are a greater number of flushes, spread throughout the day.

Thus, it is possible to combine the information on WC flush patterns (Figures A5 to A8) with the solid travel information (Figures C.1 etc) to predict the progress of a solid moving along a pipe with respect to time. Furthermore, comparisons using different flush volumes give an indication of the reduced solid movement that may be expected with smaller flush volumes.

The worst case scenarios will be the households that produce the lowest number of flushes over a given time period, i.e. household types 1 or 2.

Taking the household type 1 discharge pattern and combining the flush distances travelled in Figure C.1, suggests that for a 100mm plastic pipe:

- Assuming six-litre flushes, the solid would travel a distance a little over 16 metres after 7 flushes.
- Assuming three-litre flushes, the solid would travel a distance of just over four metres after eight flushes, and go little further in successive flushes.

A similar comparison using 150mm diameter clayware pipe (Figure C.2) shows that the solid would travel just over nine metres with a six-litre flush, but less than four metres with a three-litre flush.

The above examples are the worst case scenarios as they do not take into consideration discharges from other sources such as baths, washing machines etc.

The comparisons used three- and six-litre flushes because the results from those tests were already available. It is recommended that additional solid distance travel tests are undertaken with other WC flush volumes, for example the 4.5 litre single flush and dual flush combinations, as detailed in Figure 3.5. It is, however, anticipated that there will be a general deterioration in solid flushing ability with other flush rates below six litres, though the level of deterioration has yet to be determined.

4.5.3 The influence of discharges from other appliances on solid movement

The volume and flow rate from WC flushes have the most significant influence on the movement of solids in drains/sewers.

However, as explained in Section 4.2 other discharges to the drain/sewer are important in terms of solid movement, particularly regular small discharges such as hand washing.

It is therefore important that some water continues to be discharged to the drain/sewer between the larger discharge events (e.g. WC flushes).

4.5.4 The influence of minimal discharges on solid movement

As previously explained, the lower the wastewater discharges the greater the likelihood of blockage problems occurring. Thus, the trend towards more single occupancy properties may have as great an impact on the potential for sewer blockages as the drive to reduce water consumption.

4.6 Impact on new and existing drains

In summary, the investigations in Sections 4.4 and 4.5 and Appendices A and C show that:

- For an existing pipe system, where the size and gradient are fixed, a reduction in maximum discharge volume could significantly affect solid movement.

  Improvement of the drain condition could aid solid movement.

- For a new pipe system, where parameters can be changed in the design and construction stages, an increase in gradient and/or a decrease in pipe diameter could aid solid movement.

  It will be necessary to set a minimum pipe diameter. This will need to be large enough to allow sewer solids to pass through. It will also lead to a rationalisation of minimum sizes to ensure that a variety of slightly different minimum sizes are not used, leading to difficulties in connecting, for example, a 90mm and 100mm pipe.

It may be technically feasible to aid solid movement by reducing the diameter of existing drainage pipes by relining. However, this would be a costly exercise and would not be viable in terms of costs and benefits, sustainability and customer value.

For new developments, there is the opportunity to design drains and sewers to a revised standard to accommodate anticipated changes in water use. In practical terms, this is likely to mean steeper pipe gradients and smaller pipe diameters. It could also mean that flows from a number of properties are combined as early as possible in the pipe length in order to maximise flow. However, more research needs to be undertaken to better understand the issues before revised standards can be proposed.

For new properties, alternative technologies that reduce water consumption but maintain adequate solid movement through the pipe could be introduced. A similar approach may be possible in certain retrofit situations, however, caution will need to be exercised and the full implications on the existing drainage system must first be assessed.

As single occupancy households increase in number there is a greater potential for blocking/stranding because of the reduced number of flushes. Designs should accommodate this change.

4.7 Further work

The scenarios considered in this study have shown that there is an increased risk of solid stranding and blockages occurring in some drain/sewer systems if existing WCs are replaced with lower flush units (four litres or less). However, there will be other household/drainage system combinations where a lower flush WC should not be too problematic.

There are a number of issues which need to be addressed to quantify the size of the problem and/or provide appropriate design guidance. These include:

- Rig-based testing, to establish the sewer solid flow characteristics for a range of WC flush volumes.

  This work is additional to the six-litre full flush and three-litre partial flush data already available from previous research. Testing should include the WC flush modes/volumes most likely to be adopted, for example those required to practically meet the reduction levels indicated in the Code for Sustainable Homes.

- Rig-based testing to better understand the attenuation of WC flush waves in drains, with particular emphasis on assessment of the affects of altering flush rate and volume on solid movement.

- Theoretical and practical investigations into the effects of reduced WC flush volumes on the parts of the drainage system most susceptible to blockages due to low flows (pipes taking flows from a single property or two/three single occupancy properties).

The investigations should include the consideration of:

  - How many properties have only one occupant, or are likely to have only one occupant at some time.
  - How many properties are served by long lengths of drain before combining with flows from other drains/properties.

- Theoretical investigations supported by rig-based testing to establish acceptable pipe gradients/diameters required to enable the movement of sewer solids under reduced wastewater discharge conditions.

- A review of drainage design to enable the movement of sewer solids under reduced wastewater discharge conditions.

  The review should include consider the feasibility of adopting new technology.

  The review should primarily be aimed at new build drainage. However, retrofitting of existing should also be considered where appropriate.

5 Impacts on flows to treatment

5.1 Background

The third part of this study considers the impact of a reduction in discharged wastewater on treatment.

The wastewater which is conveyed to treatment plants by sewer systems includes contributions from a number of different sources. Domestic wastewater derives from households, and trade effluents are produced by a wide variety of industrial concerns. Most sewer systems contain varying levels of groundwater that has infiltrated the network, and many sewer systems also collect rainwater from the catchment area and deliver this to the treatment plant.

The amount and nature of the wastewater produced in a community is a function of the habits of the resident population, industrial production schedules and the frequency and duration of rainfall events in the catchment. Wide variations in flowrate and composition occur on a daily and seasonal basis.

A typical value of domestic water consumption is about 150l/d per capita. It is reasonable to assume that daily wastewater production per capita will be similar. Measured values of actual wastewater flow arriving at a treatment plant are usually in the range of 200-250l/d per population equivalent (PE) in the catchment served. The difference between per capita water consumption rate and the actual flow to the treatment plant is made up of industrial effluents, infiltration and rainfall, though the relative proportions of these components is highly catchment dependent.

Typical mixtures of domestic and industrial wastewater are extremely complex and it is virtually impossible to define their composition by detailed analysis.

It is standard practice to characterise the polluting potential, or ‘strength’ of a wastewater, by reference to the values of a few parameters such as Biochemical Oxygen Demand (BOD), suspended solids (SS) and ammonia nitrogen (NH_3-N). The loads and concentrations of BOD, SS and ammonia nitrogen that arrive at wastewater treatment sites are important factors in the design of treatment processes.

In most sewer systems the wastewater flow increases during periods of rainfall in the catchment. The flow which must receive full treatment at a treatment plant (FFT) is set as a multiple of the flow which arrives at the treatment site during dry weather (DWF). The value of FFT is part of the consent for each site. Flows above FFT usually receive partial treatment before discharge to the receiving water through a storm overflow. Experience has shown that in many catchments, the average flow that arrives at a treatment plant is about 1.2 to 1.3 x DWF. Average flow and FFT are important considerations in treatment process design.

DWF can be defined as follows:

DWF = PG + I + E

Where:

P = population in the catchment;

G = wastewater production per capita (m^3/d);

I = rate of infiltration into sewer system (m^3/d);

E = the rate of industrial discharges in the catchment (m^3/d).

FFT is typically defined as:

FFT = 3PG + I + 3E

Experience has shown that it is possible to establish values for the amount of BOD, SS and ammonia nitrogen discharged in catchments on a ‘per PE’ basis. Typical values are 60g/d per PE for BOD, 70g/d per PE for SS and 6.5g/d per PE for ammonia nitrogen. These values allow for per capita contributions and additional contributions from minor industrial discharges. Such values can be used as a basis for treatment process design in the absence of actual values, but it would be necessary to take separate account of any large industrial discharges in the catchment.

The concentrations of BOD, SS and ammonia nitrogen in the wastewater arriving at a treatment plant can be calculated from the PE served by the catchment, the ‘standard’ values of BOD, SS and ammonia nitrogen loads as given above, and the flow delivered to the plant. Calculations performed at average flow will produce average concentrations, and calculations performed using the value of FFT will give lower concentrations which are indicative of those that would occur after a period of sustained rainfall.

Reductions in potable water demand would result in increased concentrations of BOD, SS and ammonia nitrogen at existing treatment plants, assuming that other contributions to wastewater flow remained constant. If it is assumed that potable water demand per capita is equal to wastewater production per capita, then the increases in BOD, SS and ammonia nitrogen concentration which would result from reductions in potable demand can be calculated as shown in Tables 5.1 to 5.4. The calculations were made using the ‘per PE’ contributions given previously. Tables 5.1 and 5.2 show the results for a typical ‘large catchment’, with fairly high levels of infiltration and industrial effluent discharges. Tables 5.3 and 5.4 show the results for a typical ‘small catchment’ with small amounts of infiltration and industrial effluent. The total flows were calculated from the formulae for DWF and FFT given previously. In Tables 5.1 and 5.3, the total flows are assumed to include rainfall and can therefore be considered as average flows.

Table 5.1 Effect of reductions in water demand on wastewater characteristics – large catchment

Average Flow

Flow per capita (l/d)	I (l/d per PE)	E (l/d per PE)	Total (l/d per PE)	BOD (mg/l)	SS (mg/l)	NH_3-N (mg/l)
150	60	30	240	250	292	27.1
130	60	30	220	273	318	29.5
120	60	30	210	286	333	31.0
105	60	30	195	308	359	33.3
80	60	30	170	353	412	38.2

Table 5.2 Effect of reductions in water demand on wastewater characteristics – large catchment

FFT

Flow per capita (l/d)	I (l/d per PE)	E (l/d per PE)	Total (l/d per PE)	BOD (mg/l)	SS (mg/l)	NH_3-N (mg/l)
450	60	90	600	100	117	10.8
390	60	90	540	111	130	12.0
360	60	90	510	118	137	12.7
315	60	90	465	129	151	14.0
240	60	90	390	154	179	16.7

Table 5.3 Effect of reductions in water demand on wastewater characteristics – small catchment

Average Flow

Flow per capita (l/d)	I (l/d per PE)	E (l/d per PE)	Total (l/d per PE)	BOD (mg/l)	SS (mg/l)	NH_3-N (mg/l)
150	5	5	160	375	438	40.6
130	5	5	140	429	500	46.4
120	5	5	130	462	538	50.0
105	5	5	115	522	609	56.5
80	5	5	90	667	778	72.2

Table 5.4 Effect of reductions in water demand on wastewater characteristics – small catchment

FFT

Flow per capita (l/d)	I (l/d per PE)	E (l/d per PE)	Total (l/d per PE)	BOD (mg/l)	SS (mg/l)	NH_3-N (mg/l)
450	5	15	470	128	149	13.8
390	5	15	410	146	171	15.9
360	5	15	380	158	184	17.1
315	5	15	335	179	215	19.4
240	5	15	260	231	269	25.0

The results in Tables 5.2 and 5.4 were obtained by direct application of the equation for FFT. The increases in apparent flow per capita would actually be due to sustained rainfall in the catchment.

The results in Tables 5.1 to 5.4 show that the absolute values of the increases in concentration which would occur as a result of reductions in per capita wastewater production depend on the level of infiltration in the sewer system. The average total flow of 240 l/d per PE used as a 'starting point' in Table 5.1 is a typical value for a large catchment in England, but much higher values (in the range of 300-500l/d per PE) are fairly common. Average wastewater production rates per PE for catchments in Scotland and Northern Ireland can be even higher. It is reasonable to assume, by reference to actual measured values of wastewater production rates, that many sewer systems must be affected by significantly higher amounts of groundwater infiltration than were used in the calculation of results in Tables 5.1 to 5.4. In such cases, the effect of reductions in per capita wastewater production on BOD, SS and ammonia concentrations would become gradually less noticeable with increasing levels of infiltration.

5.2 Effect on treatment process performance

Reductions in per capita potable water demand could result in a reduction of the average wastewater flow received at treatment plants and to corresponding increases in BOD, SS and ammonia concentration as shown in Tables 5.1 to 5.4. Such changes might be expected to have an effect on the performance of existing treatment processes, and the significance of such effects might also be expected to depend on the type of treatment process and the size of the treatment plant. It would also be necessary to take account of changes in potable demand during the design of new treatment plants.

Reductions in per capita potable water demand might also be expected to have indirect effects on wastewater characteristics caused by factors such as increased sewer retention times and a greater tendency for anaerobic conditions to develop during periods of low flow.

Treatment plants are designed to deal with specified flow and load values, and it is normal practice to design for projected flows and loads which might not occur until up to 10-20 years after the plant is commissioned. The treatment plant must also be capable of dealing with the flows and loads which occur after construction. These flows and loads are often significantly less than those projected for the future. Traditional design procedures for treatment processes were originally based on fairly simple relationships which used flows and loads as design variables. The imposition of increasingly stringent consent limits for effluent quality has resulted in the development of more sophisticated design procedures, which use the concentrations of relevant parameters in combination with wastewater flows. These design procedures often involve the use of computer-based process simulations. However, the starting point for the design of many treatment processes is the selection of an appropriate value of wastewater retention time. This means that, for the same pollution load, a large amount of weak sewage will require more process volume than a small amount of stronger sewage. The capital costs of treatment processes increase with tank volume.

The potential for reductions in potable water demand to result in smaller tank volumes and capital cost savings would depend on the timescale over which the reductions would occur, and comparison of this period with the planned lifetime of a new treatment plant. Most projections of future flow and load would show increases caused by catchment population growth and industrial development. Reductions in potable demand would tend to counter such increases, but prediction of the net effect would be site- and catchment-specific. There is no apparent reason why the design procedures currently in use could not be modified to take account of reductions in potable demand and any concentration changes which result from such reductions.

The results in Tables 5.1 to 5.4 suggest that the greatest potential for capital cost savings would occur in catchments with small amounts of infiltration and industrial effluent discharges. In such cases, the reduction in potable demand has the most significant effect on the total flow arriving at a treatment plant.

It is worth noting that the current planning and regulatory cycles in the UK Water Industry mean that many plants are substantially rebuilt every 5-10 years or so in order to meet new discharge consents. Thus, many treatment plants never receive the projected flows and loads they were designed to receive before being reconstructed.

The results in Tables 5.1 to 5.4 were obtained by assuming constant loads of BOD, SS and ammonia nitrogen in wastewater. It is well known that the actual flows and loads received at wastewater treatment plants vary both seasonally and diurnally. Typical diurnal flow and load variations are caused by the habits of the catchment population rather than by rainfall events.

Treatment plants are normally designed to treat a specified or assumed variation in influent load according to the effluent quality standard required in a particular contract. It is usual to define influent loads in terms of the same parameters that are used to assess effluent quality (for example, influent loads are specified in terms of BOD, SS and ammonia if effluent quality must comply with BOD, SS and ammonia concentration limits). It is important to specify the probable limits of influent load variation so that the plant can be designed to accommodate peaks without the use of excessive safety measures.

It is unlikely that reductions in potable demand would have a significant effect on load variations since any flow reduction would tend to be accompanied by an increase in concentration. However, it is known that there is a tendency for suspended solids in wastewater to settle as sediment in certain sewer systems during periods of dry weather. Sudden rainfall after prolonged dry periods increases the sewer flow rapidly and disturbs sewer sediment. The result is often a so-called ‘foul flush’ of highly concentrated sewage which imposes a very high load of short duration on the wastewater treatment processes at the end of the sewer system. Such events are typically associated with sewer systems which contain sections with minimal gradients and which do not contain much infiltration. The BOD and SS loads which result from foul flush events are often above the maximum limits specified for treatment plant design and performance tests for newly constructed processes are usually designed to exclude them.

It is possible that reductions in potable demand might increase the tendency for wastewater solids to settle as sediment in a greater number of sewer systems. The frequency of foul flush events could therefore increase to an extent where design procedures would need to be modified to take account of greater differences between average and maximum influent loads.

There are approximately 10,000 wastewater treatment plants in the UK serving populations of around 50 to over three million people. Only about 500 plants serve population equivalents of more than 25,000.

Wastewater treatment is performed by a series of processes arranged successively so that the effluent from one becomes the influent to the next in the sequence. The number and complexity of the processes is a function of the effluent quality required and also, to a lesser extent, on the size of the overall treatment plant. Physical and biological processes are involved, and it is convenient to classify them as preliminary, primary, secondary and, perhaps, tertiary, depending on where they occur in the treatment sequence. Generally speaking, the simplest processes are located earliest in the treatment sequence.

Preliminary treatment involves screening to remove material such as rags and plastics, and the elimination of grit and sand through sedimentation. Tertiary treatment includes processes such as sand filters for enhanced SS and BOD removal and UV systems for effluent disinfection. It is unlikely that either preliminary or tertiary treatment processes would be affected by reductions in potable water demand.

Primary treatment processes follow the initial processes of screening and grit removal, and are installed at nearly every wastewater treatment site. Typical wastewaters contain only a small proportion of pollutant material, and this material can be divided into settleable and non-settleable fractions. The basic principle of primary treatment involves removing the settleable material by gravity settlement in large tanks. Well-designed and properly operated primary tanks should achieve reductions in SS of 50-70 per cent and BOD removals of 30-50 per cent, depending on the fractions of settleable organic material in the wastewater.

The settled material which accumulates on the floor of the tank is known as primary sludge and is periodically removed and sent for further treatment before ultimate disposal.

Primary sedimentation processes perform better with strong sewage than weak sewage. The average removal of BOD and SS increases as the sewage becomes stronger. The increases in BOD and SS concentrations which result from reductions in potable demand can be expected to increase BOD and SS removal rates in existing primary sedimentation tanks. The proportion of total BOD and SS loads passed to secondary treatment processes would be reduced and there would be a change in the ratio of primary to secondary sludge. However, it is unlikely that total sludge production, or sludge treatment and disposal costs, would change significantly.

Until recently, secondary treatment processes consisted either of biological filtration or some type of activated sludge system. Biological filtration is more expensive in terms of capital cost and occupies a greater land area than activated sludge, but is much cheaper in terms of operating cost. The high operating costs of activated sludge systems are generated by the energy required to supply air to the process. However, it is now generally accepted that a properly designed and operated activated sludge process is more effective in producing a high quality effluent than a biological filtration process, and the older filtration installations are gradually being replaced to meet the demands of new legislation. Replacement of an existing biological filter with an activated sludge plant is therefore widely implemented when new consent conditions are enforced. All of the largest treatment sites in the UK now use some variant of the activated sludge process for secondary treatment. Biological filtration is still widely used at smaller sites, but is not always the system chosen when a replacement installation is required at such sites. It is unlikely that the performance of existing biological filters would be affected by reductions in potable demand.

Increased removal of BOD and SS in primary tanks could reduce the amount of air required for treatment in an existing activated sludge process. The potential for saving aeration energy would depend on the existence of a control system for matching air supply to the process demand.

The micro-organisms in activated sludge processes respond to local concentrations of nutrients. Thus, although a large volume of weak sewage might contain the same loads as a small volume of strong sewage, it is possible that increases in BOD, SS and ammonia concentration could change the spatial demand for oxygen in an aeration tank. The overall effect would depend on the ability of an existing aeration control system to supply air at the required rate and maintain the optimum concentration of dissolved oxygen. In plants with no aeration control system, it is possible that changes in the concentration of the wastewater could result in periods of operation at low aeration tank dissolved oxygen concentrations. Compliance with effluent consent limits, particularly those imposed for ammonia nitrogen concentrations, could then be at risk.

An increase in the frequency of foul-flush events could have an adverse effect on existing activated sludge processes. Highly variable BOD and SS loads could cause rapid fluctuations in activated sludge plant operating conditions and make control of the process more difficult. A series of high BOD and SS loads separated by short intervals could produce a longer-term deterioration in effluent quality from which recovery might be slow. It is likely, however, that most of the additional SS load associated with a foul-flush would be retained in primary sedimentation processes.

Reductions in potable demand could result in extended periods of low flow in some sewer systems. The combination of low flows and high concentrations of biodegradable material could then be expected to promote the development of anaerobic conditions and the production of ‘septic’ wastewater.

Septic wastewater contains the products of anaerobic degradation of organic material. Such wastewater will usually contain appreciable concentrations of volatile fatty acids and will often possess an offensive odour caused by the release of hydrogen sulphide. In general, anaerobic degradation increases the proportion of soluble BOD in wastewater. Soluble BOD will not be removed by primary sedimentation and will pass through to secondary treatment. The expected performance improvement of primary sedimentation caused by higher concentrations of BOD and SS might therefore be countered by increases in the proportion of soluble BOD.

The effect of the products of anaerobic degradation on the settleability of sludge in activated sludge processes is of more concern. All activated sludge processes involve biological oxidation of organic material by micro-organisms in an aeration tank, followed by gravity settlement of the sludge containing the micro-organisms to produce final effluent of the required quality. This process relies on satisfactory performance of both the oxidation and gravity settlement stages. When the settleability of activated sludge deteriorates, incomplete separation in the settlement stage can cause high concentrations of suspended solids in the final effluent. In severe cases, consent failures may occur.

The term "bulking" has been used for many years to describe problems associated with the separation of activated sludge. Bulking is associated with the excessive development of filamentous species of micro-organisms in the sludge, with over twenty different types of such organisms having been identified.

The filamentous micro-organism *Thiothrix* is known to cause poor sludge settleability and, according to technical literature on the subject, development of this micro-organism is normally due to the presence of reduced sulphur compounds in influent sewage in combination with readily degradable organic material for growth. These requirements are met by septic sewage, which contains sulphides and materials such as volatile fatty acids produced under anaerobic conditions.

Reductions in potable demand could therefore result in an increase in instances of bulking caused by *Thiothrix*. The formation of sulphides is enhanced by high sewage temperatures, so it is likely that settleability problems would be worse in periods of warm weather.

Wastewaters which contain sulphides can give rise to odour nuisance at treatment sites. It is likely that reductions in potable demand would increase the risk of odour nuisance by promoting the conditions for sulphide production. The development of septic conditions in sewers can often be prevented by the addition of oxidative chemicals to the wastewater at an appropriate point in the network. This practice can, however, result in significant increases in operating costs.

5.3 Impact on treatment

In summary, the investigations in 5.1 and 5.2 show that:

- There is a potential impact on the design of the treatment process:
    - A reduction in potable water demand would increase concentrations of Biochemical Oxygen Demand, suspended solids and ammonia nitrogen in the effluent to be treated.
    - The absolute increases would depend upon the level of infiltration of groundwater into the sewer system – loading on the plant is therefore uncertain.
    - The volume of effluent would be less than the design volume for the plant – the plant would operate inefficiently.
    - There is the potential for increased settlement of solids in sewers especially during dry weather – this is disturbed by rain and leads to ‘foul flush’ or high loading of the plant over a short duration.
- There is a potential impact on retention times and a greater tendency for anaerobic conditions to develop at periods of low flow which could cause odour problems.
- In the longer term, capital expenditure could be reduced through the use of smaller tank volumes.

6 Discussion

This study set out to examine the impact of demand management (water efficiency of appliances) on wastewater flow; wastewater collection systems (drains and sewers) and wastewater treatment.

The links between potable water use, wastewater discharges and the ability for sewer solids to be carried away were examined by modelling usage in typical households. The results indicated that in some circumstances there is likely to be a deterioration in the ability of solids to be removed in wastewater discharges with reduced water consumption. It is also likely that the problem will be most apparent in drains taking either a single property or a few single occupancy properties.

The most important findings of this modelling are:

- Reduced WC flush volumes offer the greatest demand reduction opportunities. Various domestic water consumption scenarios were considered, these were based on the Code for Sustainable Homes, plus a scenario based on retrofitting.
- Most potable water use and wastewater discharge flow rates are similar. The main exception is the WC, where the discharge rate is over 20 times the potable water draw off rate.
- The most significant wastewater discharges to drain/sewer are from the bath and WC. Bath discharges are the most significant in terms of volume. However, various researchers have stated that flow rate is the most significant factor in terms of solid movement in drains/sewers. It is difficult to ascertain whether this is opinion or fact, though at least three groups of researchers have examined this topic from slightly different perspectives and all have drawn similar conclusions.

These observations suggest that WC flushes are the most important consideration. With this in mind, sewer solid movement information was used to gain an indication of the potential effect that reducing WC flush volumes may have. This information requires detailed, time consuming and costly rig-based testing, so data that was already available from an earlier WRc test programme was used. These data were for a six-litre full flush and three-litre partial flush WC - a comparison of the data indicates that solid movement is significantly less with the lower flush volumes.

It is appreciated that these flush volumes do not represent the WC characteristics that are widely accepted as necessary to meet the various demand reduction scenarios as detailed in the Code for Sustainable Homes. Nevertheless, the difference in solid movement ability of the two flushes is considerable. It is therefore reasonable to expect that the same trend would be evident, at least to some extent, in any flush volume less than the current six-litre norm.

The literature review found no practical examples of drain or sewer blockages that could be attributed to reduced water demand. However, this could be due to the fact that very few studies have specifically considered the effect of demand management on drains and sewers. The majority of studies have focused on the impact of WC flushing on solids movement. There are a number of papers in which the authors suggest that reduced water demand will lead to an increase in operational problems in drains/sewers. It is, however, uncertain as to whether these assertions are based upon fact or opinions based upon related information.

The applicability of some overseas studies is uncertain. This is because the WC flush volumes and physical characteristics of the drainage systems may be different. The absence of papers from Germany and Scandinavia is interesting; it may be that sewage related problems associated with low demand are not an issue here.

It is suggested that further research be carried out to obtain solid flow characteristics for the WC flush volumes necessary to meet the reduction scenarios indicated in the Code for Sustainable Homes. This is necessary as the literature review did not find hard evidence of a link between reduced water demand and operational problems. Whilst tests undertaken on the WRc test rig have indicated a reduction in solid movement with lower WC flushes, the range of test data is insufficient to draw any firm conclusions.

The data presented on the impacts of reducing flush volumes on solid movements are from tests involving a dual flush WC. As the wastewater flow rate from a full flush is higher than that of a partial flush, these tests are not representative of the impact of reducing the full flush of WCs, though could give some indication of possible effects. It is also worth considering whether switching from single flush WCs to dual flush WCs could have more of an impact on wastewater transport than reducing the flush volume of single flush WCs.

The modelling of various levels of water efficiency indicated that there are a number of other ways of saving water. While reduced WC flush volumes may be the most obvious option, there are other opportunities. Similarly, although WC flushes are the most significant contributors to solid movement in drains, other wastewater discharges are important. This is because the other discharges keep solids damp and this makes them easier to move by a WC flush wave. The extent of reductions in these other wastewater discharges will not be sufficient enough for solids to start drying out and in doing so adversely affect solid movement.

Thus, whilst the overall levels of water efficiency are unlikely to cause a problem for the operation of drains and sewers, it is the reductions in WC flush volumes that may be an issue. Current available data suggests that a reduction from six- to three-litre flushes in conventional WCs could cause a significant problem for drain carry under current drainage design.

In some circumstances however, it may be possible to reduce WC flush volumes significantly below three litres without causing problems in the drainage system. For example, work undertaken on the Propelair system (which uses air as well as water to move solids) has demonstrated that this can be achieved. Investigations on the WRc test rig demonstrated that, for the system to be effective, the exit pipe would ideally need to be considerably smaller than those used in conventional drainage systems.

It may also be possible to alter drainage design to reduce the likelihood of blockages and other operational problems caused, in part, by reduced wastewater flows. These alterations could include the use of smaller diameter pipes (subject to certain practical limitations), pipes with steeper gradients and pipe layouts where there are less pipes taking very little flow.

The possibility of countering reduced wastewater flow with alterations in the way that drainage systems are designed and constructed opens up opportunities for new build construction. However, far less freedom is available when retrofitting an existing system – the pipe gradient will be fixed and, whilst reducing pipe diameter by relining is possible, it will rarely be a cost effective, affordable or sustainable option.

Accordingly, different approaches to reduced water demand will be required depending upon whether a new build or retrofitting in an existing property is being considered. Reduced water demand, in particular reduced WC flush volumes, should not be a major issue for flows in new build drains/sewers provided that appropriate alterations in design and construction practices are made first. While some information is available upon which to base these revised designs, considerably more work is required before detailed proposals can be made. This work should aim to include a better understanding of the implications of reduced pipe diameters and steeper graded pipes, as well as considering various construction design alterations.

Care will need to be taken when retrofitting in exiting properties, especially when replacing an old WC with a new lower flush model. This is particularly so where the external drainage is in less than perfect condition, for example in pipes that are over 50 years old. This does not mean that retrofitting is not possible, more that care should be exercised particularly where drains take very small flows, such as those serving a single property or a few single occupancy properties.

Reducing demand in existing properties is likely to exacerbate any existing problems evident in the sewer system, for instance slack gradients, sewer abuse etc. While previously a high volume of flow could still allow solids to be transported through a problematic sewer, reducing the volume of flow would cause the limiting threshold of loading to be reached sooner, and could result in solids remaining stationary.

Problems associated with sewer abuse – using sewers for inappropriate disposal – have not been fully considered within this study. However, it is of note that if no sewer abuse took place, there would be a far lower likelihood of problems in terms of wastewater transport when water demand reductions occur. Intensified sewer abuse campaigns running alongside water demand reduction policies could help prevent such problems from occurring. Likewise, the use of macerating toilets could lessen the likelihood of blockages.

An increase in the number of partial blockages in drains/sewers could result in some sewage remaining in pipes for far longer than is currently the case. In extreme cases this could result in sewage becoming septic. It is, however, unlikely to become a significant problem in a relatively cool climate such that of the UK.

The third part of this study considered the impact of a reduction in wastewater discharged from the house on treatment. There is some uncertainty about the overall impact as effluent concentration will depend upon both water discharged and infiltration of the sewer system. However, a number of key factors may need to be addressed in future plant design or operation to ensure efficient plant operation and prevent pollution incidents.

Although reduced wastewater flows may result in an increased likelihood of sewer blockages and other operational problems such as odour complaints and sewer flooding, other issues may also contribute to these problems. These include:

- The inappropriate use of sewers to dispose of unwanted food and material based wipes etc.
- The poor condition of some drainage systems.
- In some circumstances, the removal of storm water through diversion to a SUDS scheme or rainwater harvesting.

Therefore, the effects of reduced water demand need to be seen in the context of a bigger picture and a wider view taken when considering such schemes.

7 Conclusions

It is concluded from this study that:

- There is limited practical evidence of the impact of water reduction on drains and sewers.

  The limited evidence that is available suggests that reduced wastewater discharges can, in some circumstances, lead to a reduction in the ability of solids to be moved through the drainage system close to houses.

- Reduced WC flush volumes offer the greatest demand reduction opportunities. However, WC flushes are also the most significant wastewater discharges to drain/sewer in terms for sewer solid movement. This is because the flow rates are significantly higher than other wastewater discharges and it is this high flow rate that is the main driver for solid movement.

  Thus, reduced water consumption in wastewater discharges will cause a deterioration in the ability of solids to be removed. It is likely that the problem will be most apparent in drains serving either a single property or a few single occupancy properties.

- Data already available from an earlier WRc test programme was used to compare the difference in sewer solid movement potential from a six-litre full flush and three-litre partial flush WC. A comparison of the data indicates that solid movement is significantly less with the lower flush volume. With the government's demand management initiatives likely to result in increased uptake of low flush toilets, further investigation into different flush volumes is needed in order to fully assess any implications.

  The above mentioned tests were undertaken with a dual flush WC and are therefore not truly representative of what may happen when using a reduced volume full flush WC. Nevertheless, the strong trend indicates that the flush from a lower volume full flush WC will result in significantly worse solid movement characteristics.

- The literature review found no practical examples of drain or sewer blockages that could be attributed to reduced water demand. This could be because very few studies have specifically considered this issue. However, some authors suggest that reduced water demand will lead to an increase in operational problems in drains/sewers, though it is uncertain if this is based upon fact or opinion.

- There are a number of other ways of saving water, aside from reduced WC flush volumes. These other discharges are important as they keep solids damp and aid movement following a WC flush, though any reductions would not be sufficient to adversely affect sewer solid movement.

- Water reduction will lead to an increased chance of sewage ponding in pipes due to increased deposition of solids, which could lead to an increased likelihood of septicity and chemical attack of concrete pipes. However, these problems are likely to be very limited in relatively cool climates such as in the UK.

- In some circumstances it may be possible to reduce WC flush volumes to significantly less than three litres without causing problems in the drainage system. This would rely upon new technology and it would be necessary to modify the exit pipe system for it to be effective. This approach has the greatest potential in new builds and is unlikely to a practical option in most retrofitting situations.

- Alterations in drainage design could help to minimise solid flow problems caused by reduced wastewater flows. These alterations could include steeper graded pipes, pipes of a smaller diameter and revised pipe layouts to avoid pipes with very few wastewater discharges.

  These alterations will be most appropriate for new build construction. There will be far less opportunities when retrofitting an existing system – the pipe gradient will be fixed and, whilst reducing pipe diameter by relining is possible, it will rarely be a cost effective, affordable or sustainable option.

- Different approaches to minimising the likelihood of problems caused by reduced water demand will be required, depending upon whether considering new build or retrofitting in an existing property.

  Reduced water demand, in particular the use of reduced WC flush volumes, should not lead to problems in new build drains and sewers provided that appropriate alterations are first made to design and construction practices. There is, however, currently insufficient information available on which to base revised designs and standards for new build drainage.

  Care will need to be taken when retrofitting an existing property. There is currently insufficient information available to give detailed guidance regarding retrofit options. Post-project monitoring of retrofitting schemes could help provide this information. Retrofitting could be aided by the use of macerating toilets and pump-assisted low flush WCs. However, the technical merits and costs of using alternative engineering solutions are not well understood and require further investigation.

- Despite the long-running “bag it and bin it” campaigns, sewer abuse is a major cause of sewer blockages. If no sewer abuse took place, there would be a far lower likelihood of problems with wastewater transport when water demand reductions occur.

- A reduction in the volume of wastewater discharged could have an impact on sewage treatment process. There is some uncertainty about the overall impact, with any effect dependent upon the level of water reduction and infiltration into the sewer system. These issues would need to be addressed in future plant design.

- Wastewater flow reduction due to demand management must be seen as part of a 'bigger picture' of issues affecting the operation of drainage close to property. It should be considered alongside issues such as user abuse/responsible use of sewers, the transfer of storm runoff to SUDS schemes, and the transfer of ownership of most of these local systems to sewerage undertakers.

  It is unlikely that there will be a single preferred solution to ensure that reduced water demand does not result in an increase in sewer blockages and associated problems. The most appropriate course of action when designing a programme to reduce demand should be dictated by individual circumstances, with different requirements for new and existing buildings.

8 Recommendations

It is recommended that further work is undertaken, with particular emphasis on:

- A review of drainage design: development of new guidance and standards for new build and, where necessary, for improvements to existing networks. This should include:
    - Theoretical investigations supported by rig-based testing to establish the pipe gradients and diameters required to enable the movement of sewer solids under reduced wastewater discharge conditions.
    - Rig-based testing to establish the sewer solid flow characteristics for a range of WC flush volumes and to better understand the attenuation of flush waves in drains. This work is additional to the six-litre full flush and three-litre partial flush data already available from previous research. Testing should include the WC flush modes/volumes most likely to be adopted, for example those required to practically meet the reduction levels indicated in the Code for Sustainable Homes.
    - Assessing the feasibility of adopting new technology.
- Development of guidance regarding retrofitting, so that risks are better understood. This should include:
    - A programme of increased monitoring of retrofitting programmes, to better understand the practical implications of these schemes. The monitoring should include both WC bowl clearance/user perceptions and the operation of the downstream drain/sewer system.
    - Theoretical and practical investigations into the effects of reduced WC flush volumes on the sections of the drainage system most susceptible to blockages due to low flows (pipes taking flows from a single property or two/three single occupancy properties).

      The investigations should include quantification of the number of potentially vulnerable properties with:

        - Only one occupant, or at some time likely to have only one occupant.
        - Long lengths of drain, serving only one property.

    - Investigations into other ‘changes’ in discharges to drain/sewers close to property that could, in combination with reduced water demand, exacerbate problems. These changes include reducing surface water discharge, for example through rainwater harvesting or diversion to SUDS.

- A review of the efficacy of publicity campaigns relating to the responsible use of sewers (such as the “bag it and bin it” campaign) and recent advice relating to the disposal of fats, oils and greases (for example the Water UK advice leaflet to commercial food outlets).

  The benefits of such campaigns should be maximised by running them in parallel with demand reduction initiatives.

- Development of guidance to ensure that water efficiency is considered as part of a bigger picture in terms of building and drainage design and sewer use.

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Appendix A – Potable water use and discharged wastewater flow patterns

Figures A.1 to A.4 represent the flow rates of water entering a property for use in WCs, baths, showers and washing machines.

Figures A.5 to A.8 represent the flow rates of wastewater exiting a property after use in WCs, baths, showers and washing machines as described in Table 3.2 of the main report.

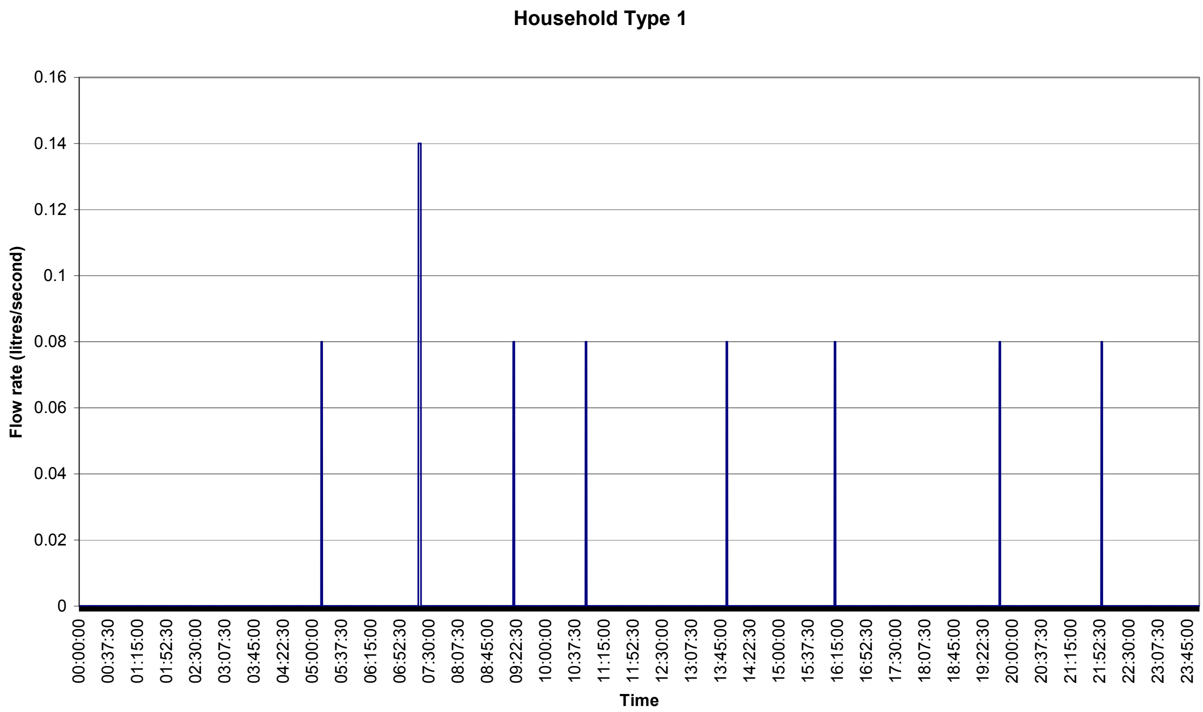

Figure A.1 Water entering household for household type 1

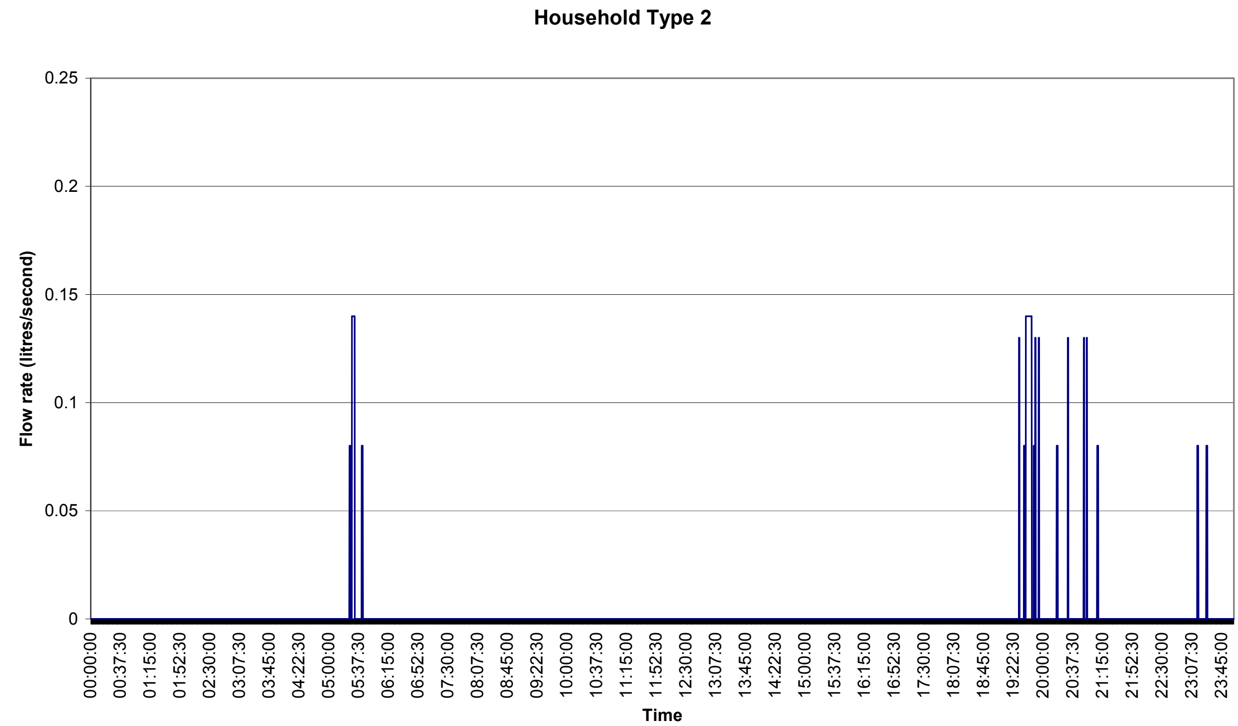

Figure A.2 Water entering household for household type 2

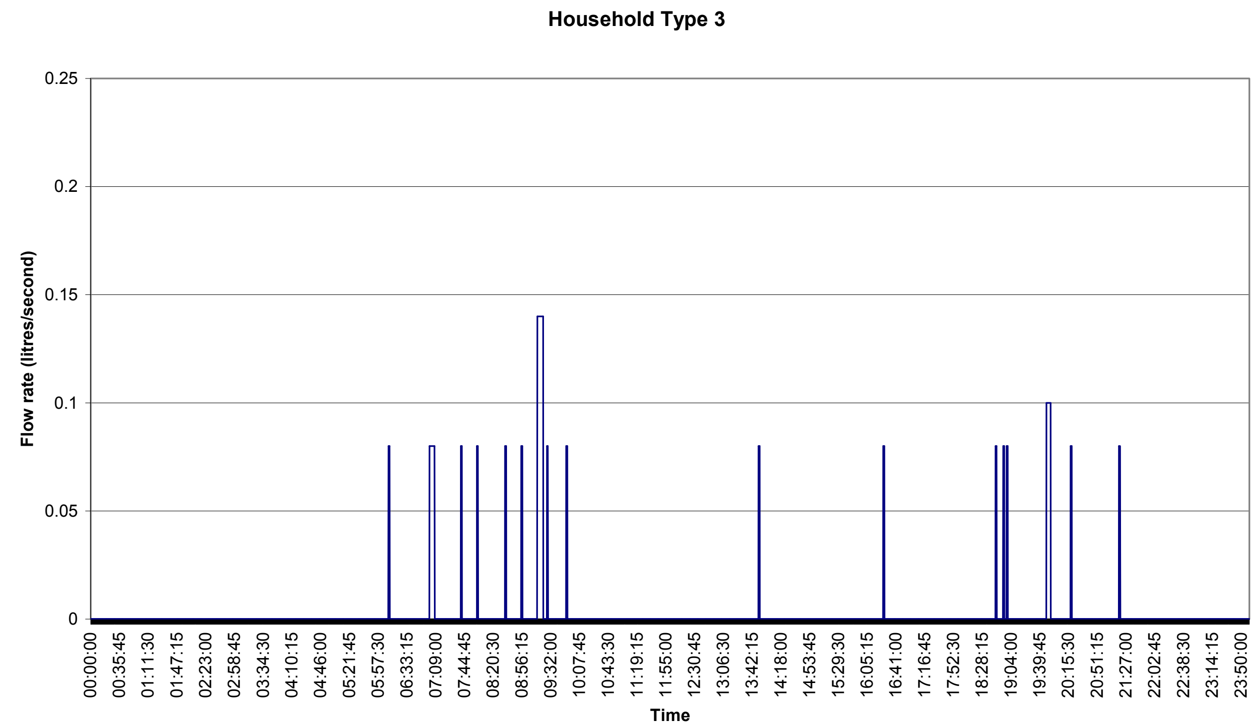

Figure A.3 Water entering household for household type 3

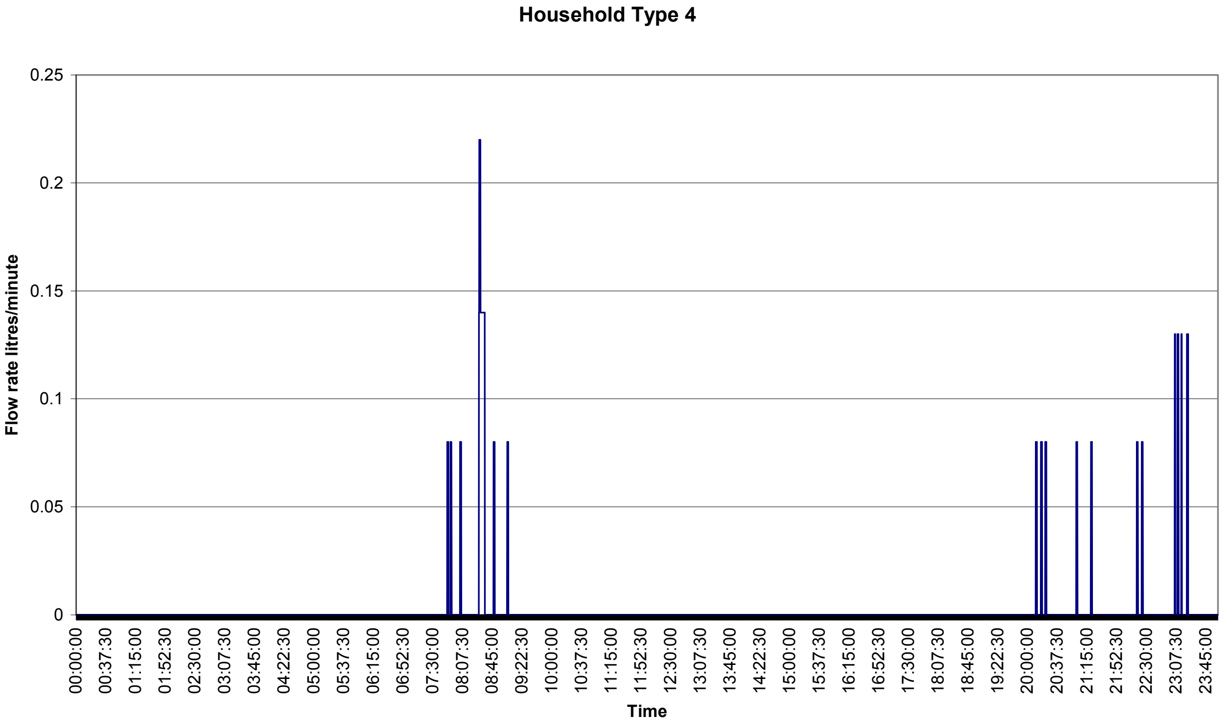

Figure A.4 Water entering household for household type 4

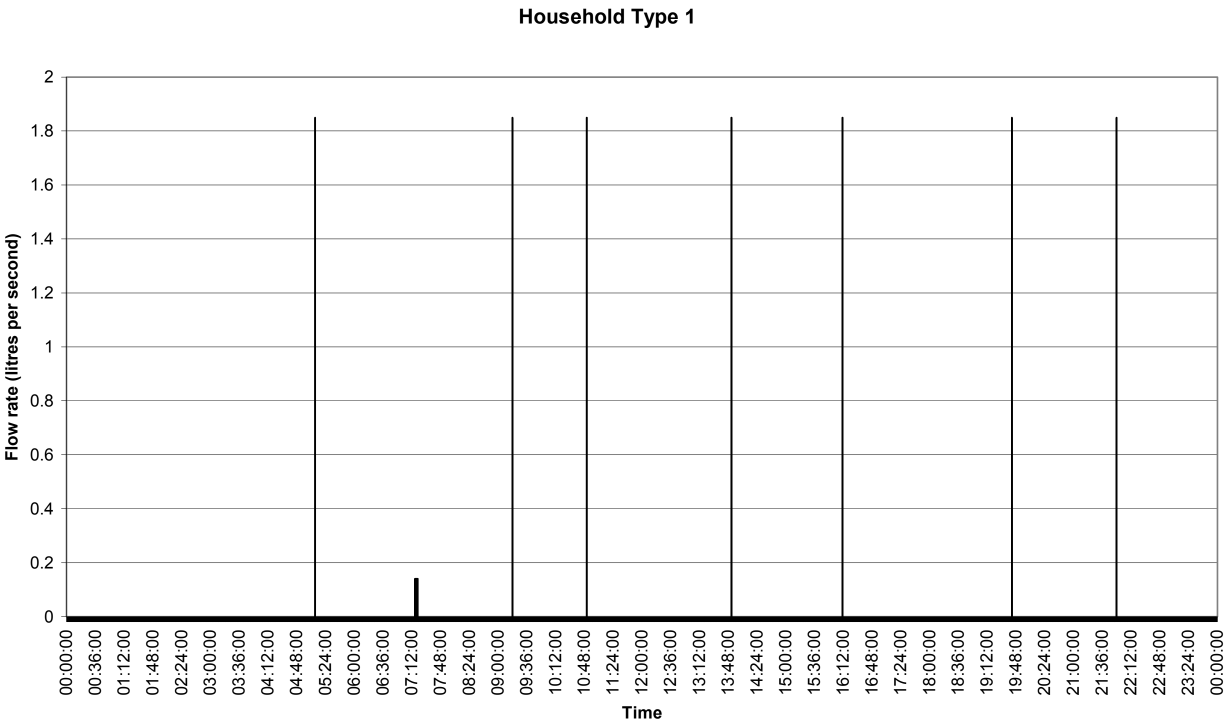

Figure A.5 Wastewater exiting household for household type 1

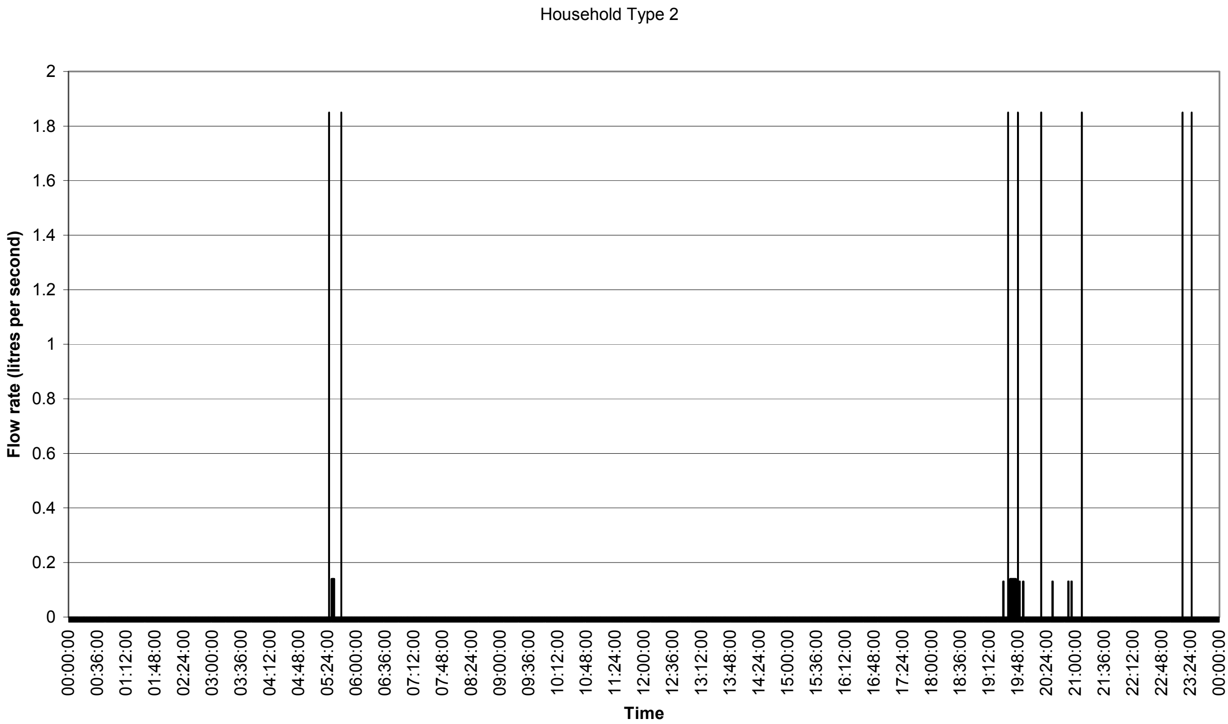

Figure A.6 Wastewater exiting household for household type 2

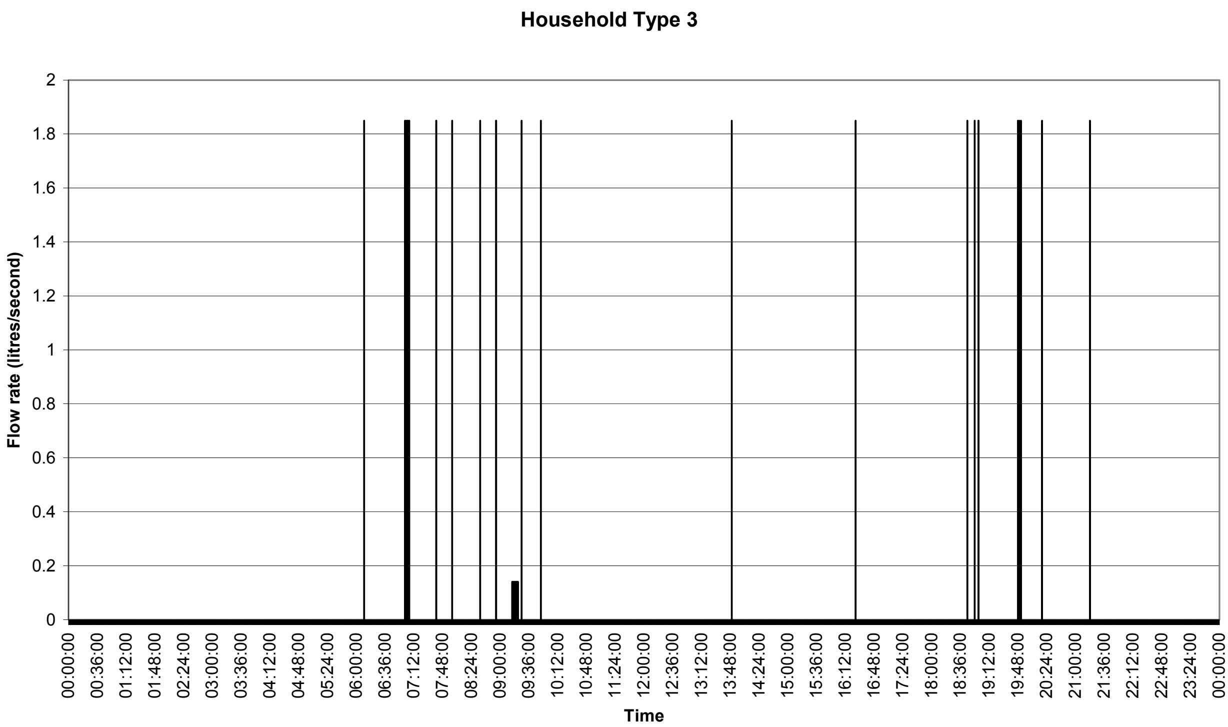

Figure A.7 Wastewater exiting household for household type 3

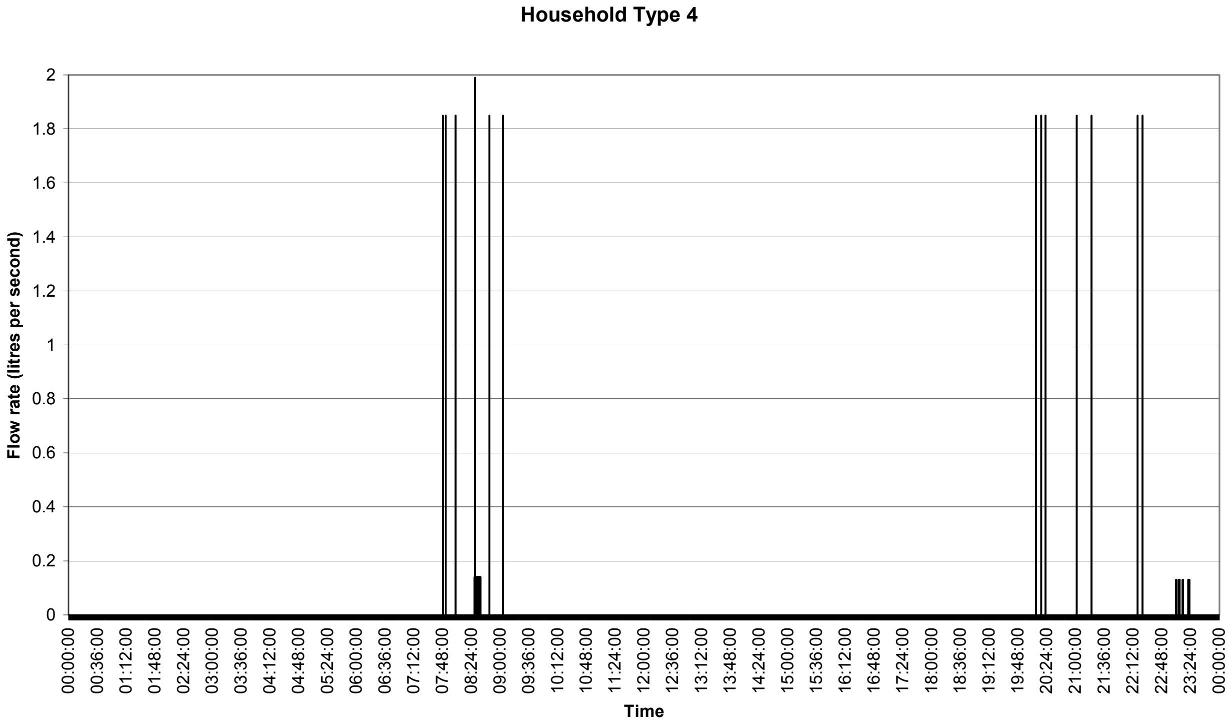

Figure A.8 Wastewater exiting household for household type 4

Appendix B – Typical configurations

Typical configurations of drains and sewers for older properties are shown in the following figures:

- Figure B.1 – A Victorian terraced layout where all the wet rooms are at the rear and drainage is to a sewer running along the rear access passage.
- Figure B.2 – Inter-war detached and semi-detached layouts where the drainage from two properties joins before connecting to the public sewer under the highway.
- Figure B.3 – Post-war semi-detached housing where the drainage from eight properties joins at the rear before connecting to the public sewer under the highway.
- Figure B.4 – 1970s/1980s housing where the drainage from ten properties joins at the rear before connecting to the public sewer running under the footway. These properties could be town housing, link-detached housing or aged persons dwellings.

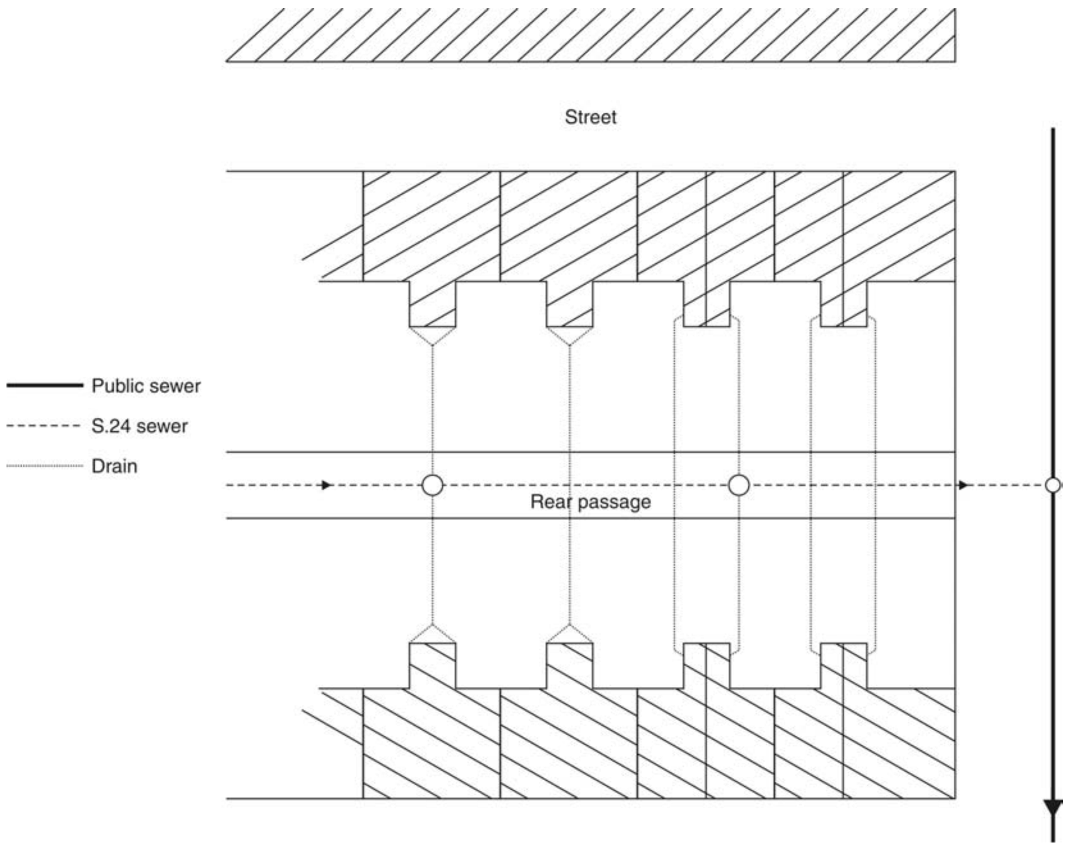

Figure B.1 Typical layout around Victorian terraced property

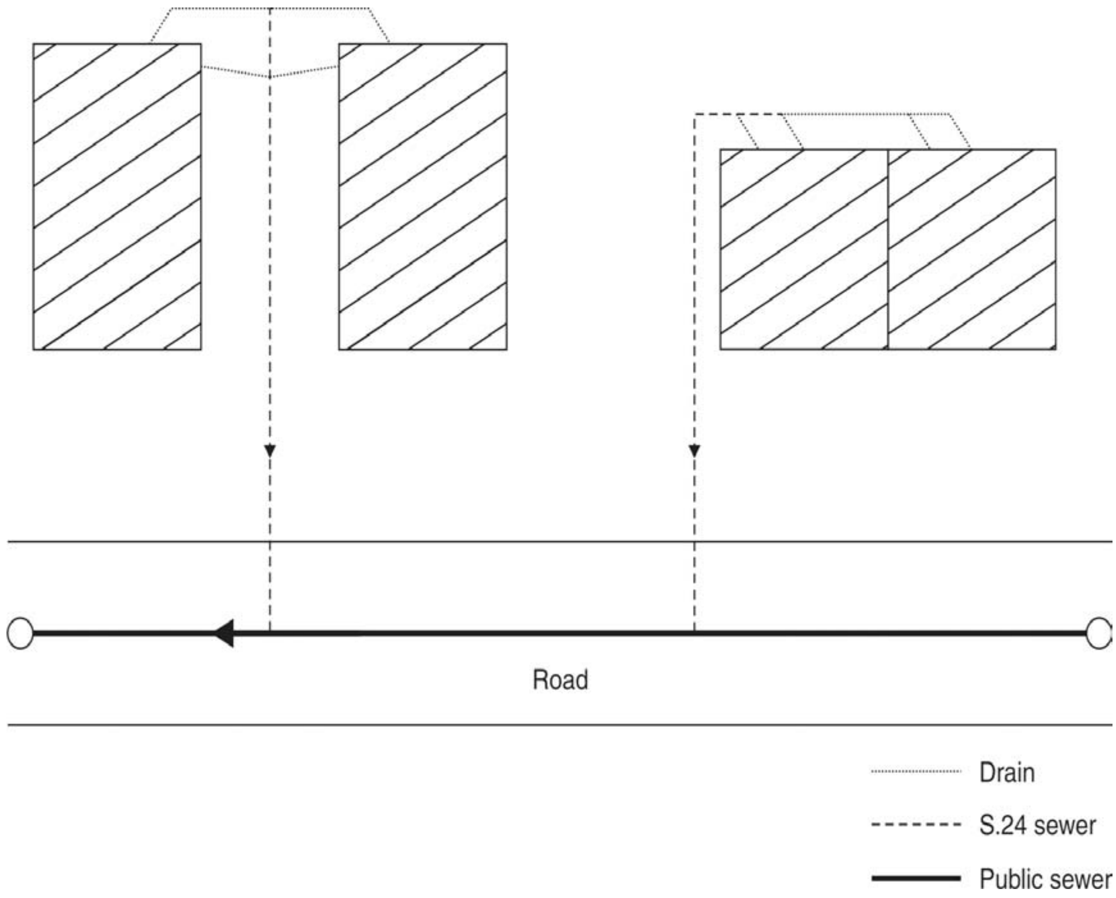

Figure B.2 Inter-war detached and semi-detached property foul drainage layout

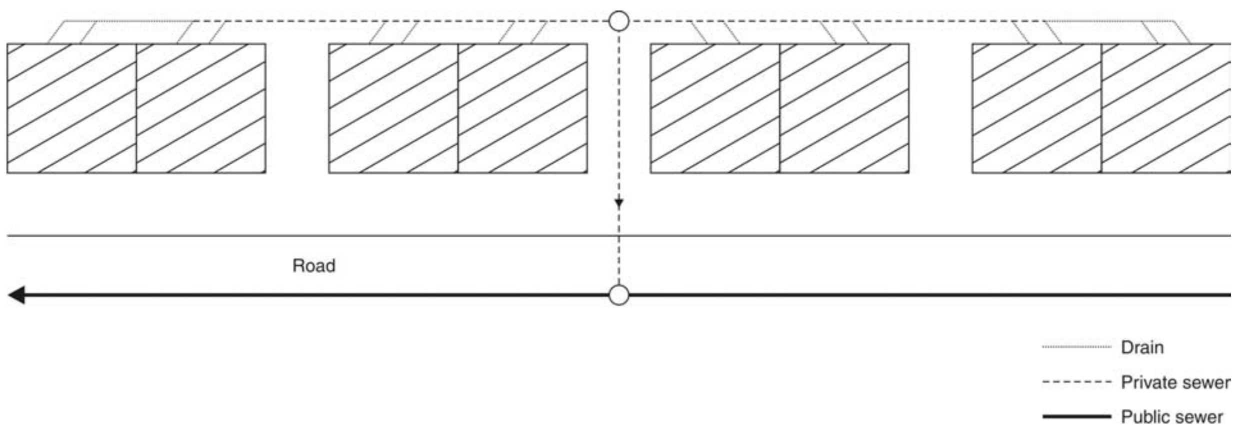

Figure B.3 Post-war semi detached property foul drainage layout

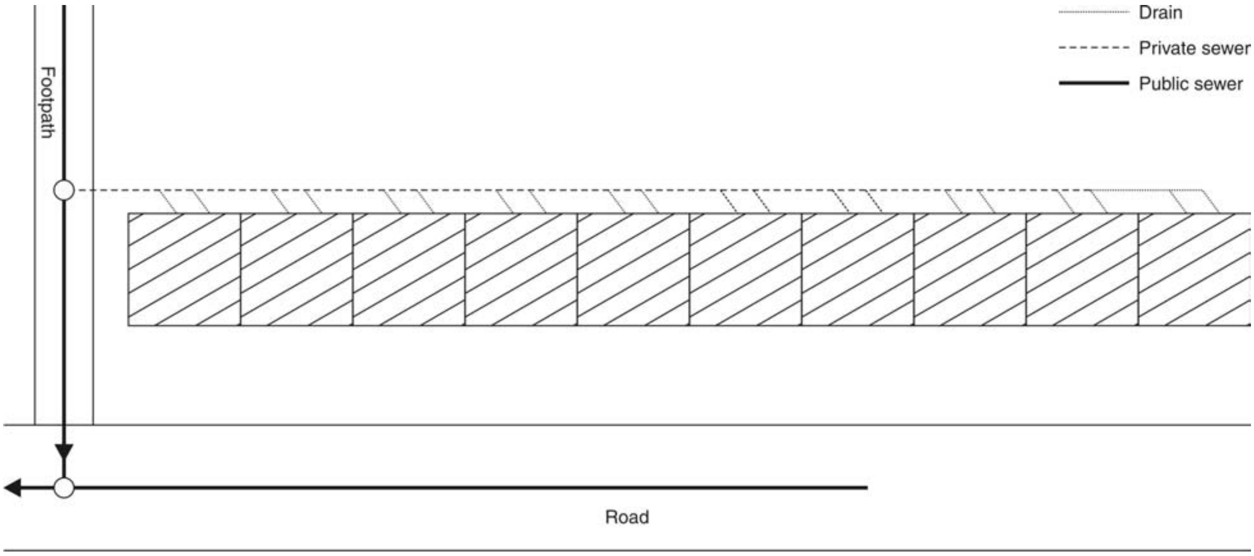

Figure B.4 1970s/1980s town house/terraced property foul drainage layout

Typical configurations for newer properties are illustrated below in Figures B.5 and B.6.

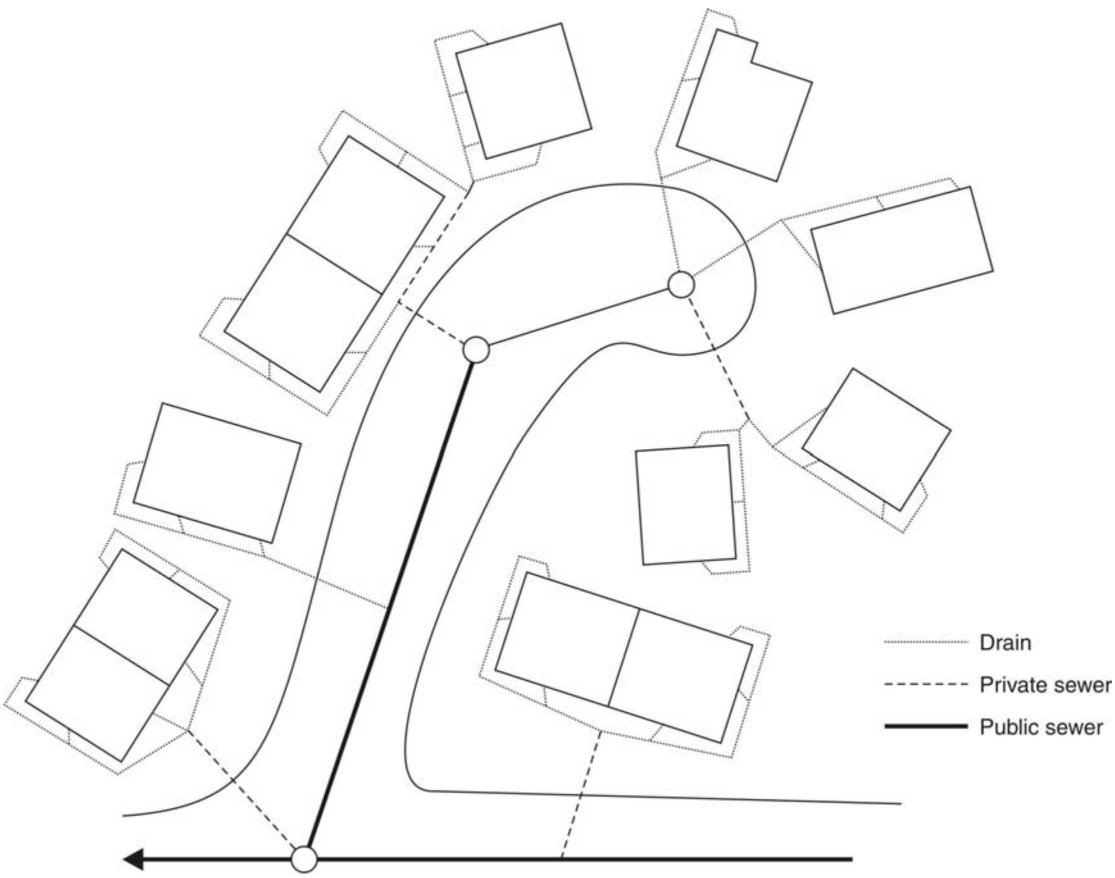

Figure B.5 Detached and semi-detached property foul drainage layouts

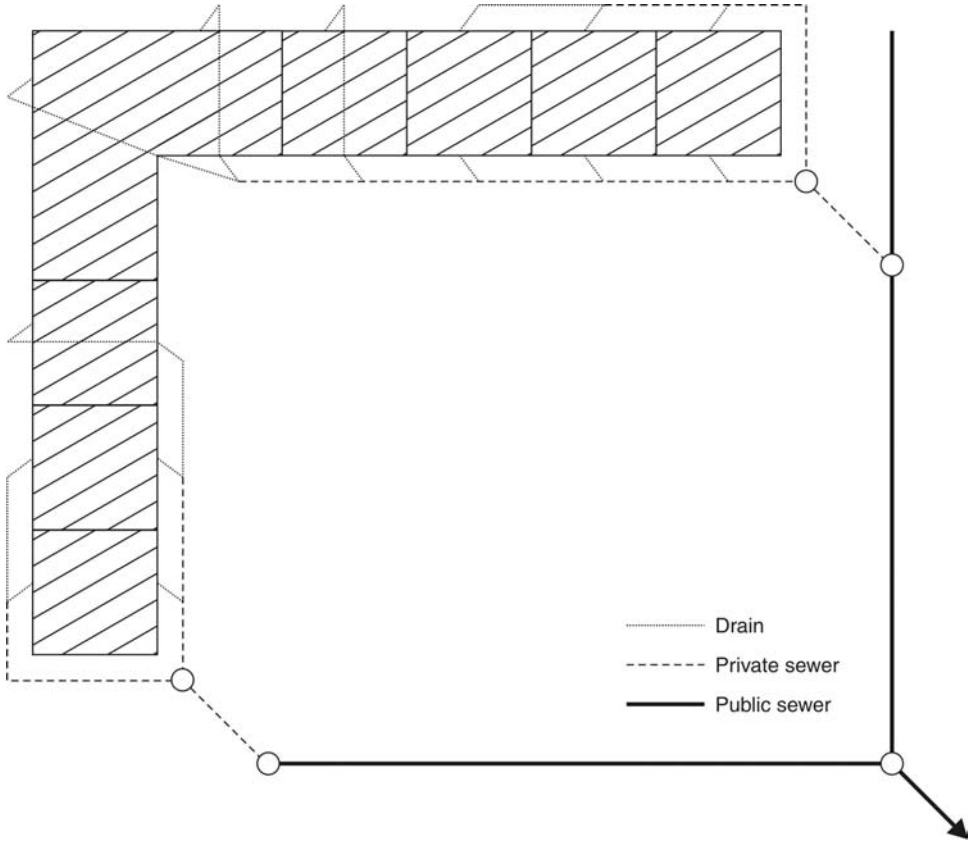

Figure B.6 Terraced/link detached property foul drainage layouts

Blocks of flats often have a single connection to the public sewer system. Figure B.7 illustrates a typical layout.

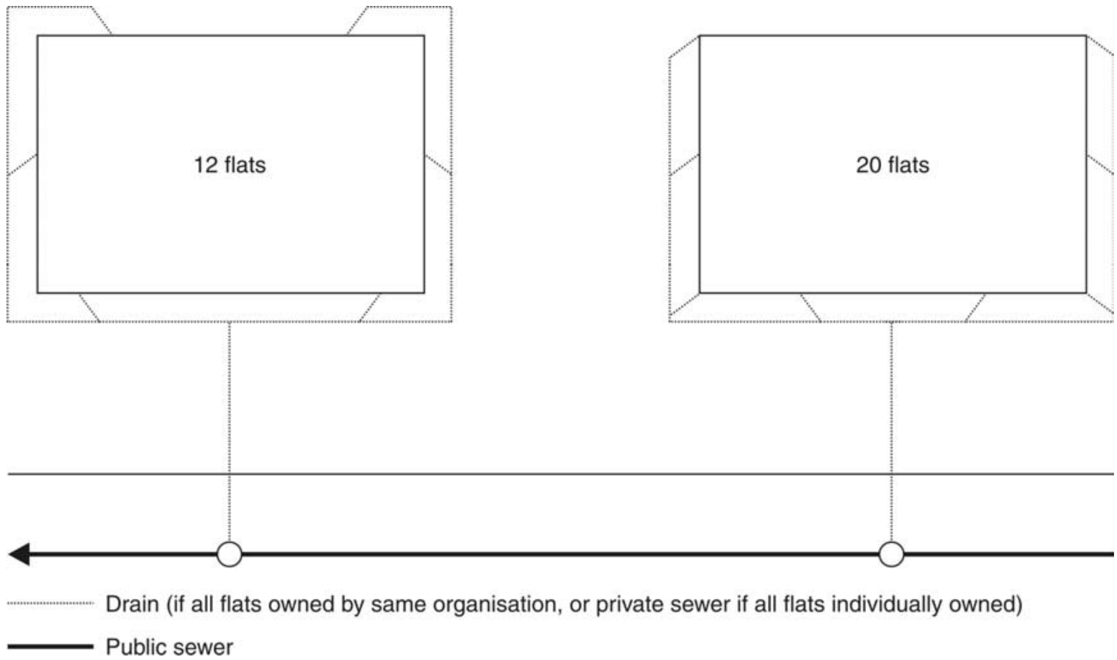

Figure B.7 Foul drainage layouts around blocks of flats

Appendix C – Practical experimental programmes on solid movement in drains

Gauley and Koeller (2005) outline in some detail the results of a series of investigations carried out in North America. Similarly, Littlewood and Butler (2003) reported on a programme of tests undertaken on the WRc Swindon drain rig. The results from these tests have recently been supplemented by further work carried out by WRc.

Encouragingly, whilst slightly different units and parameters were examined by the two research teams, the results in terms of solid movement performance are very similar with no significant disparities in the findings.

The following information refers to the tests reported by Littlewood and Butler (2003), as subsequently supplemented by WRc.

Test configuration

A test rig was used whereby:

- A WC was connected to an above ground pipe rig. A 6/3 litre dual flush WC was used for the tests.
- The pipe rig was capable of accepting pipes of different sizes (100mm or 150mm diameter), different materials, different gradients and varying condition, for the purpose of examining solid travel distance.
- A solid (Westminster Solid) was flushed via the WC (in either a six-litre or three-litre flush mode) for specific combinations of pipe size, material, gradient and condition and the solid travel distance noted.
- The WC was flushed again and the additional distance travelled by the solid was noted.
- The procedure was repeated until the solid either cleared the test rig or did not move for three successive flushes, in which case it was deemed that the solid had become 'stranded'.

The tests were repeated for each combination of pipe size/material/gradient/condition, for between five and 10 sets of tests (depending upon the consistency of the results). The results were then averaged.

Westminster solid
A "Westminster solid" was used in the tests undertaken on the WRc drain test rig. This is a plastic cylinder of size and density to represent a standard faecal stool and was developed by Littlewood (*et al*) in the earlier Imperial College/WRc investigations. It can be argued that the solid does not exactly represent reality, however it was developed with the standard faecal stool in mind. Above all, the solid is a repeatable device and is ideal when investigating the influences of different parameters on solid movement.

Test results
Figures C.1 to C.5 illustrate a selection of solid movement test results.

These results show:

- Distance travelled by the solid (metres), y-axis.
- Number of flushes, x-axis.
- In figures C.1 and C.2, the upper line is for a six-litre flush and the lower line represents a three-litre flush from a dual flush WC (in the other figures the upper and lower lines represent changes in different parameters, for example in figures C.3 and C.4 the comparison is between solid movement in pipes of a different diameter (100mm and 150mm)).

All the above tests were done on pipes laid at a gradient of 1 in 100.

For example, Figure C.1 shows that with six-litre flushes the solid will move eight metres in the first flush and a distance of 16 metres after five flushes. However, the flush wave has all but dissipated after five flushes and two further flushes move the solid only another metre. For the three-litre flush the solid travels a far shorter distance; only a little over two metres in the first flush and just over four metres after eight flushes.

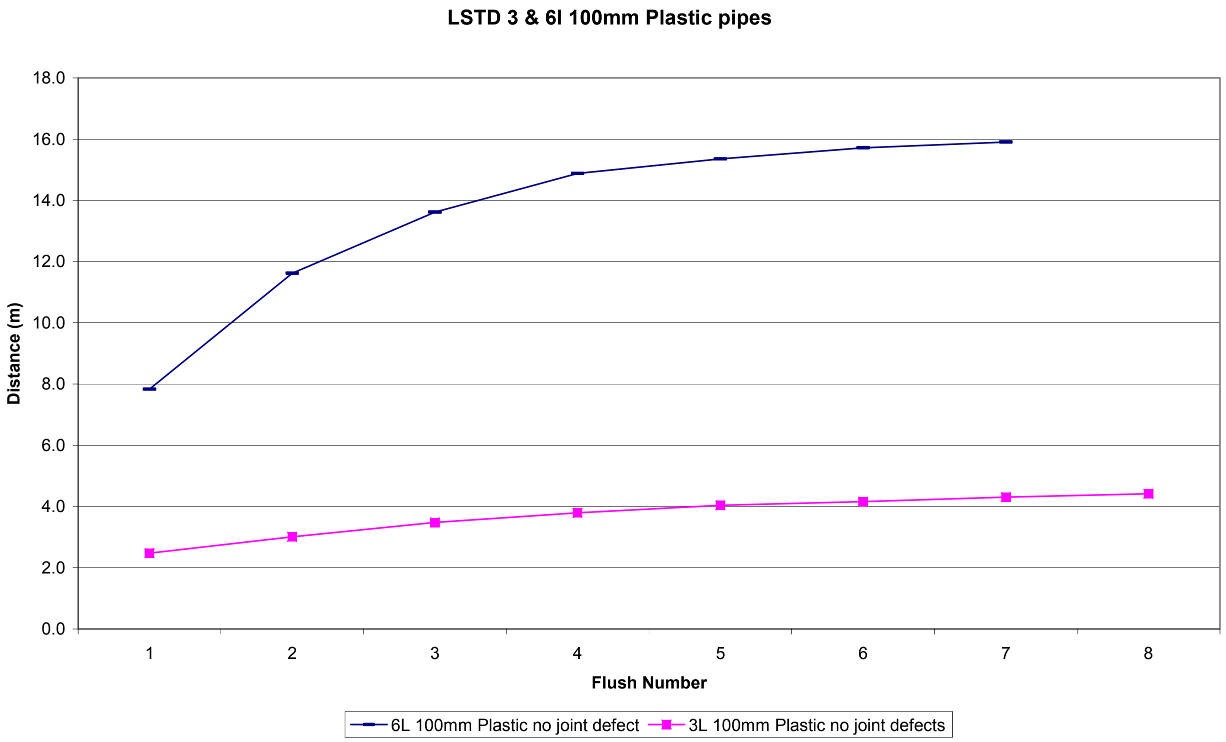

Figure C.1 Progress of a "Westminster solid" in 100mm plastic pipes, for 6 litre and 3 litre flushes

Figure C.2 shows results for a conventional 150mm diameter clayware pipe. This shows the solid travelling a far shorter distance - just over nine metres for a six-litre flush compared with almost twice that distance in the 100mm plastic pipe. The solid in the three-litre flush travels almost four metres, approximately 15 per cent less than the distance travelled in the 100mm tests.

This indicates that, for an existing pipe system where all the physical parameters are fixed (size, gradient, condition), a change in maximum flush volume could be significant.

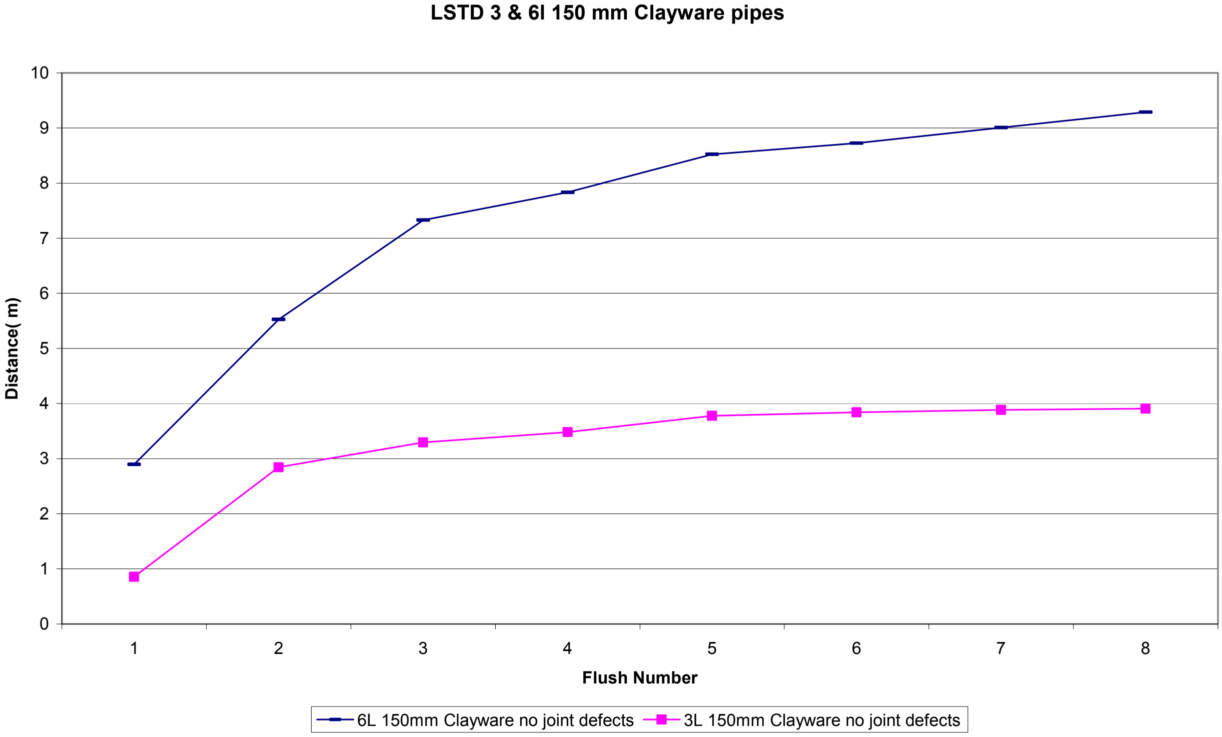

Figure C.2 Progress of a "Westminster solid" in 150mm clayware pipes, for 6 litre and 3 litre flushes

Figures C.3 and C.4 show the distances travelled in pipes of different sizes, all other parameters being the same. Figure C.3 shows three-litre flushes in plastic pipes (100mm and 150mm) and Figure C.4 shows six-litre flushes in clay pipes (100mm and 150mm).

These indicate that the solid travels further in the smaller pipe; almost twice the distance in the case of the clay pipe.

Figure C.5 demonstrates the influence that gradient has over solid travel; the steeper the gradient the greater the distance travelled.

Figure C.6 illustrates the effect of two bad joints upon solid travel distance. The solid takes three flushes to clear the second bad joint and then only travels a further two metres, some distance short of its travel distance in a similar pipe free of bad joints.

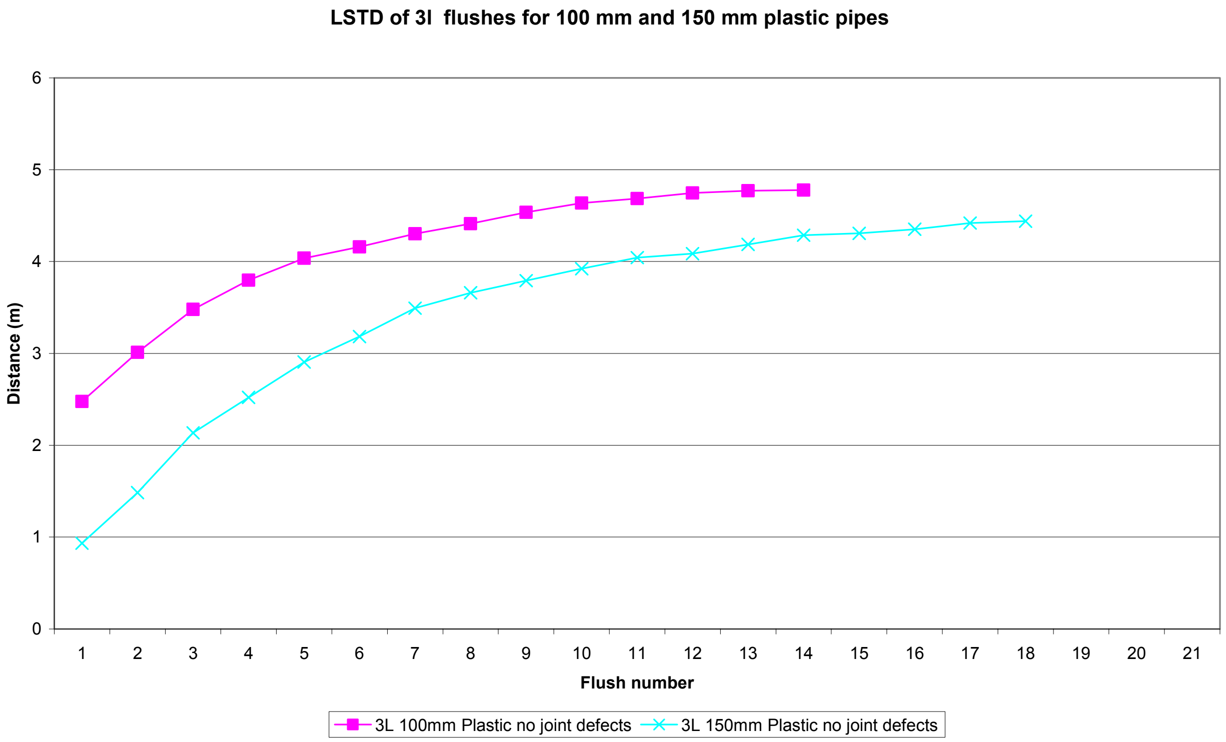

Figure C.3 A comparison of solid travel distance for 3 litre flushes in 100mm and 150mm diameter plastic pipes

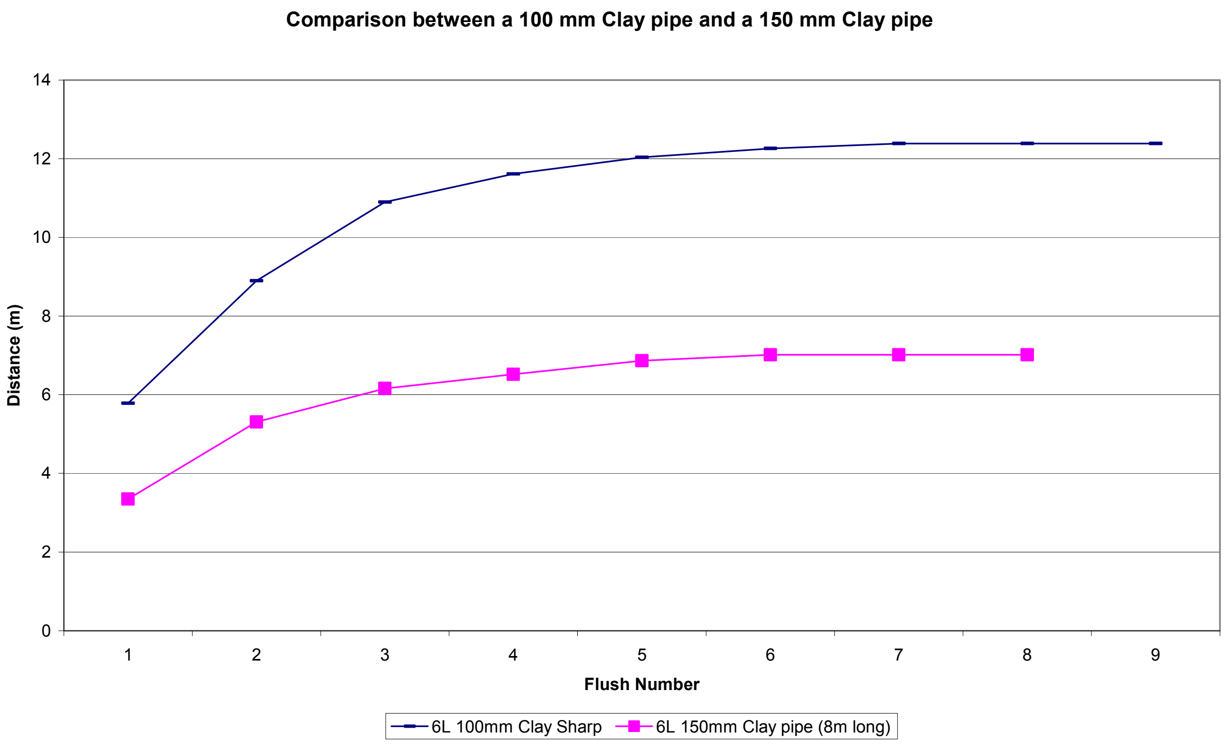

Figure C.4 A comparison of solid travel distance for 6 litre flushes in 100mm and 150mm diameter clay pipes

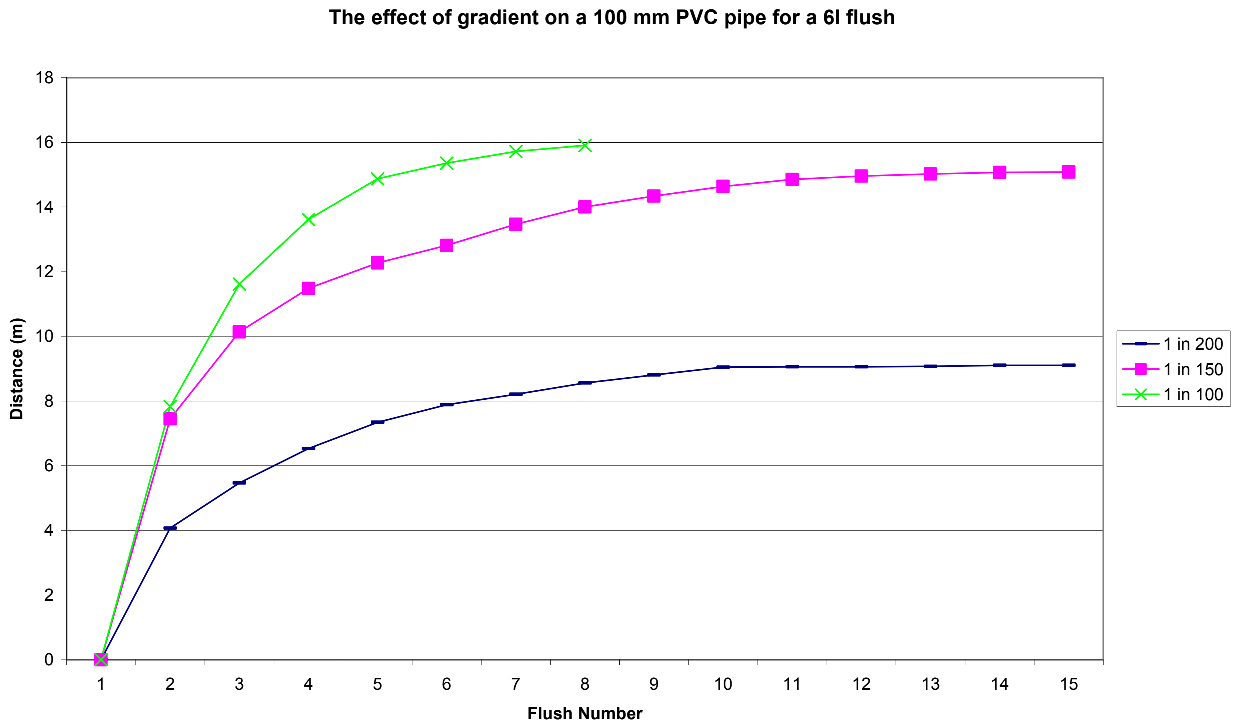

Figure C.5 The effect of pipe gradient on solid travel distance (100mm plastic pipe and 6 litre flush)

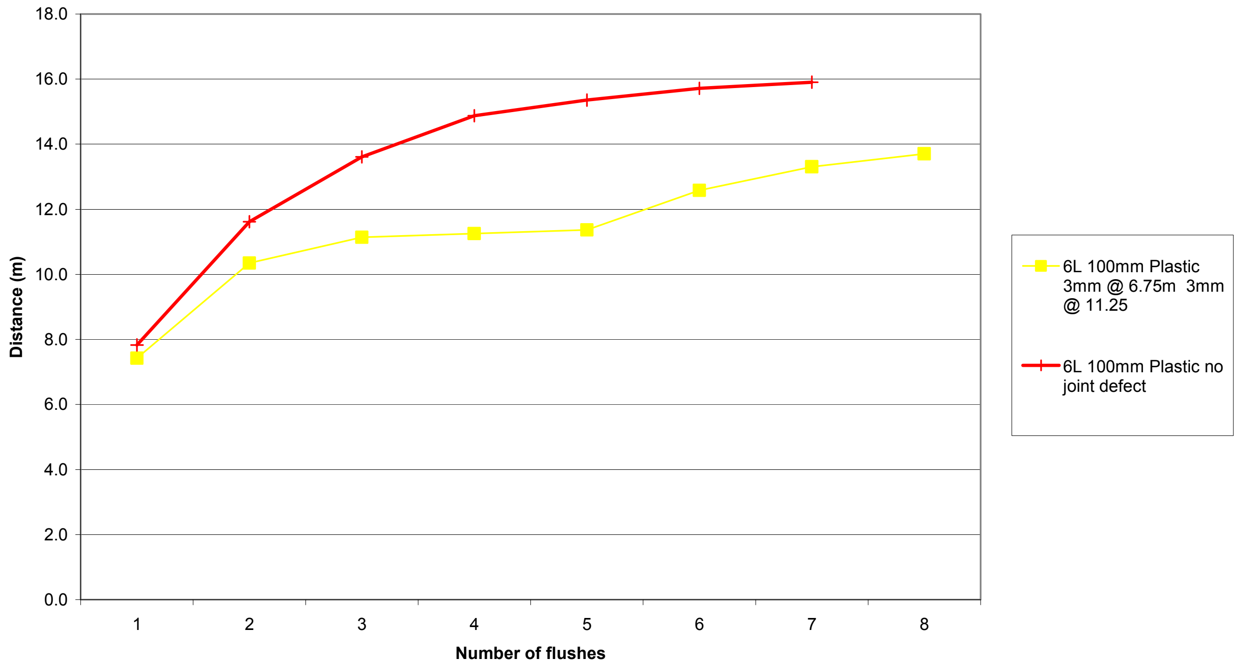

Figure C.6 The effect of poor joints (located at 6.75 m and 11.25 m) on solid movement in a 100mm plastic pipe

Glossary of terms

Drain (England and Wales)	A pipe taking the drainage from one property or from within one curtilage.
Limiting Solid Transport Distance	The distance that a “Westminster solid” will travel along a pipe before becoming stranded.
Population Equivalent	A term used to describe the size of a treatment works, whereby all industrial/commercial capacity is converted into a population equivalent.
Sewer	A pipe taking drainage from two or more properties or two or more curtilages.
Public Sewer	A sewer vested in the sewerage undertaker, i.e. a sewer that is the responsibility of the sewerage undertaker.
Private Sewer	A sewer that is not the responsibility of the sewerage undertaker, i.e. a sewer that is owned by and the responsibility of those that it serves.
Section 24 Sewer (S.24)	A sewer that become the responsibility of the sewerage undertaker by virtue of the 1936 Public Health Act.
Stranded/stranding	A term used to describe a sewer solid that will not move any further following the action of a WC flush.
Westminster Solid	A plastic solid of a specific size and density to represent a faecal stool for the purpose of measuring solid travel distance in drains/sewers.

List of abbreviations

DWF	Dry weather flow
FTFT or FFT	Flow to full treatment at a treatment plant
gpd	Gallons per day
l	Litres
l/d	Litres/day
l/h/d	Litres/head/day
LSTD	Limiting solid transport distance
m	Metres
mm	Millimetres
PE	Population equivalent
SS	Suspended solids
TSS	Total suspended solids
ULV	Ultra low volume (toilet)

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