Sewer sediment management and hydraulic modelling

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Abstract

In combined systems during rainfall events, surface washoff takes place. As a result, sediment and litter are carried into combined sewer systems, mainly through highway gully pots. There is a high probability that these solids may cause a loss of capacity in the sewer (due to solids deposition) or they may escape via overflow discharges during storm conditions. Sediment deposition causes major problems for wastewater system operators (e.g. blockages and sludge disposal problems) and leads to significant economic and environmental impact on stakeholders and the area into which storm water is discharged. The case study presented in this paper deals with solids (particularly grit) in sewer systems for a real catchment. The study involved a mass flow analysis of solids that enter the sewer using an *InfoWorks* CS hydrodynamic model.

1 Introduction

In the UK, sewer systems are designed to convey two types of water that require drainage - wastewater and stormwater. Both types of water typically convey different types of solids including sediment into the system. These solids may deposit in the system and hence cause operational problems: loss of hydraulic capacity, in-pipe septicity and contribute to the pollutants in foul flushes (Ashley *et al.*, 2000). Furthermore, the solids may escape via combined sewer overflows (CSOs) during wet weather conditions to urban streams causing aesthetic and other pollution. A review conducted in the UK found that 80% of the UK's urban drainage systems had at least some permanent sediment deposits (Butler and Davies, 2000; Ashley *et al.*, 2004a).

The sewer solids problem was acknowledged in Britain in the 19th Century (Bertrand-Krajewski, 2003). A number of innovations were introduced in an attempt to ensure that the solids collected in the drains and sewers of London were '*conveyed most cheaply and innoxiously to any distance out of towns'* (Chadwick, 1842). Some engineers in the UK advocated the need for flushing tanks to clean the sewers of deposited solids at that time (Bertrand-Krajewski, 2003). Other countries (e.g. France, Germany and the United States) have also been aware of sewer solids problems since the 19th century.

The early practices of sewer solids management have been overtaken by an increasing emphasis on developing new materials for sewer pipe fabrics (including joint materials), better understanding of hydrology and hydraulics of flow in the sewer systems and wastewater treatment processes. This is due to increasing urbanisation and population densities, and the need to provide society with adequate water supply and sanitation. These factors have influenced the advances in sewerage design and sewer sediment management. In the UK, it is understood that water service providers are changing their asset investment priorities towards operational expenditure and there is a greater awareness of sewer maintenance costs, as part of the need to maintain assets and improve levels of service.

Sediment may enter sewer systems via domestic appliances, gullies with surface runoff in combined sewer systems, faulty joints with infiltrated flow, sewer decay and sewer pipe collapse. There are several techniques that can be used to manage solids/sediment that enter sewer systems. Hydraulic models offer the potential for providing the data needed for managing sewer solids and hence these are useful for infrastructure provision evaluation and asset management (Gouda, 2004). Independently or by complementing other techniques, sewer sediment modelling can direct the water service providers (WSPs) towards the more sustainable/preferred investment solution to maintain their sewer systems.

2 Sediment Sources and Characteristics

Grit forms the bulk of what is termed *sewer sediment* and is defined as the inert granular inorganic material retained on 150µm sieve with specific gravity of 2.6. Grit is introduced to combined sewer systems via surface runoff and foul sewage. The grit sources are various and are now well established. Ashley *et al*. (2004a) and Ackers *et al.* (1996) have identified the main sources of inorganic surface sediment (e.g. road surfacing material and road work, winter de-icing, construction works, industrial and commercial activities, ingress of soil around pipes, manholes and gullies, washoff from adjacent area and sewer fabric decay).

Solids washed off from impervious areas have been identified as the main sources of solids transported, via runoff, into the sewer system (Ashley *et al*., 2004a). This includes grit from abrasion of road surfaces, exposed soil, sand and gravels washed or blown from the catchment or adjacent areas. The size of washed off sediment varies from very fine sand to gravel. There are a number of parameters affecting the mass of solids being washed into sewer systems. These include: rainfall intensity, duration, topography, particle physical characteristics and condition of paved surfaces (Ashley *et al*., 2004a).

In winter, salts and sand used to keep roads, parking lots and pavements free of ice often drain into combined sewers, as a result of snow and ice melt and spring rainfalls. Some Highway Authorities spread salt and sand to maintain road traction on snow and ice, and this is eventually transported into sewer systems during a de-icing period. Winter de-icing has been reported by

Hedley and Lockley (1975) to be a major source of solids in motorway runoff. Similar results were reported by Ashley *et al*. (2004a) when high concentrations of suspended solids were found in sewers during dry weather flows, particularly during de-icing periods in the sewers of Dundee (Scotland).

Sediment ingress from soil around pipes, manholes and gullies mainly depends on the local condition of the sewerage system. The age, the quality of system's materials and construction may increase the risk of solids entering the sewer systems. The information is very scarce about the associated mass of solids that could infiltrate due to leaks or pipes, manholes and poor gully structural condition or failure.

Wastewater generated by domestic appliances may contain solids including sediment that can deposit in the sewers (e.g. from toilets, shower/bath, laundry and kitchen sinks). Ainger *et al.* (1997) have shown that a typical default suspended solids value for UK catchments lay in the range of 180 – 450 mg/l, in which fixed suspended solids is 60mg/l. Solids concentration, size and density from industrial activities can be very different, as this depends on the type of industry. Ashley *et al*. (2004a) have also presented illustrative values of suspended solid concentrations and loads for various industrial activities. The data have shown that the total suspended solids (TSS) concentration can vary from a minimum of 30 mg/l up to 5000 mg/l depending on type of industry.

Figure 1 shows the sediment fluxes in drainage systems. This outlines how solids/sediment can transfer through the system and points where it can accumulate/escape to the environment.

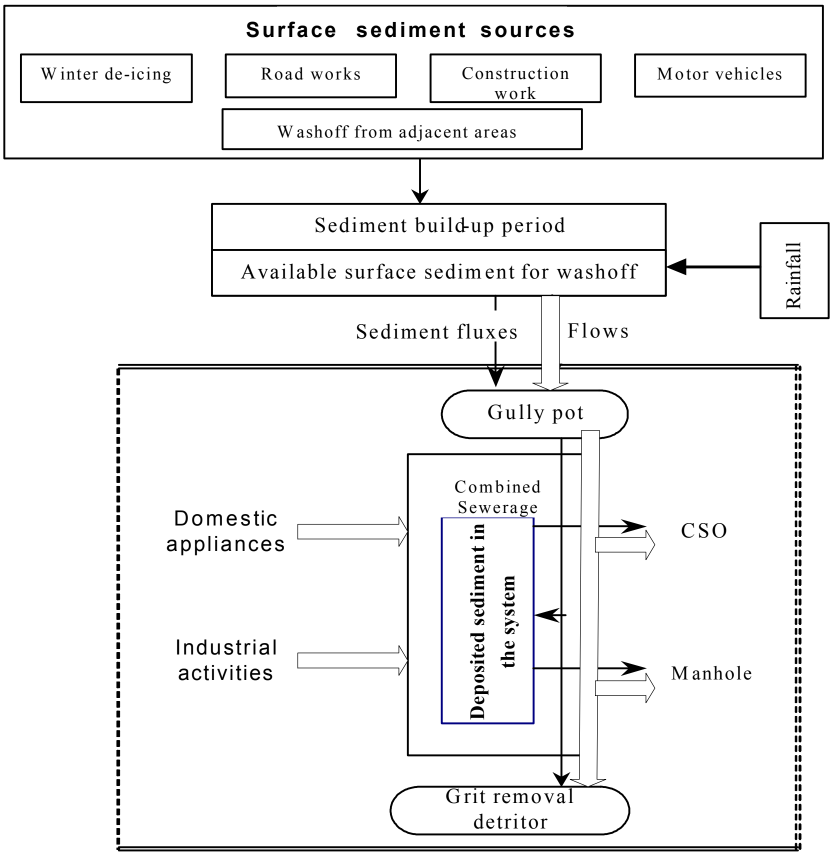

Figure 1 - Flow diagram of sediment fluxes in drainage systems (Gouda, 2004)

3 Sewer Sediment Management

The need for management of sewer deposits may be prompted by regulations or may be customer driven, e.g. a high number of customer complaints about local flooding or property flooding or in fulfillment of levels of service criteria as defined by OFWAT in England and Wales.

Sediment management generally relies on low technology practices that are applied by individuals, municipalities and industrial establishments. In the UK the current practices to control sediment in urban drainage catchments entail street, gully and sewer cleaning. Other techniques (e.g. sediment traps, flushing tanks and flushing gates) have been considered elsewhere as an effective method of controlling sediment deposition in the sewer provided that regular cleansing and maintenance are carried out (Ashley *et al*, 2004a; Pisano *et al*., 2003; Ashley *et al*., 2000). Sewer sediment modelling can be used to identify the locations where network needs improvements and/or further investigation to reduce flooding and sedimentation using any of the proposed techniques.

4 Sewer Solids Modelling Approach

The approach used in this study to investigate the sediment (particularly grit) input, transport, and its relevant impacts in the catchment utilised *InfoWorks* CS (A proprietary package from Wallingford Software, UK). *InfoWorks* CS provides a tool to simulate flow quality and hydrodynamic performance of sewer systems. The quality model is based on a series of deterministic modules that represent the quality of surface runoff, sediment and pollution transport within a sewer pipe network. The model is based on the principles of predicting surface sediment build-up; erosion and washoff. and sediment transport in sewers along with the associated flow quality parameters.

Suspended load transport is modelled in the *InfoWorks* CS software by using erosion-deposition criterion and the advection equation for suspended solids transport. Sediment transport rate is predicted from a single total-load equation utilising the Ackers-White equations. The evolution of bed deposits in sewers depends on repeated cycles of deposition and erosion processes. The critical parameter controlling sediment disposition and erosion is flow maximal suspended solids concentration carrying capacity C_{max}. When the actual sediment concentration exceeds C_{max}, sedimentation will occur until the actual concentration is equal to maximal carrying capacity. Sediment particles will be eroded when the actual concentration is smaller than C_{max} until the actual concentration is equal to the maximal carrying capacity.

InfoWorks CS includes two other erosion-deposition models, namely Velikanov and KUL. The Velikanov model is based on energy dissipation whilst the KUL-model is based on shear stress comparison. The Velikanov model is based on energy dissipation whilst the KUL-model is based on shear stress comparison. Fraser (2005) has reported that while the Velikanov and KUL models are largely untested, they are simple conceptual models to apply as long as suitable parameters are selected for the model variables.

A pre-calibrated network has been used for this case study. The modelled network had variable sediment depths in about five percent of the total number of sewer pipes. The modelling was carried out using 99 chronological local rainfall events, which represent the annual pattern at the study location. The events were created using an appropriate annual rainfall time series as the source data. The inter-event dry weather period between consecutive events was considered in the simulation. Sewer sediments arising from domestic appliances and industrial activities were also taken into consideration. Figure 2 shows a schematic diagram for the modelling approach used for sewer sediment modelling for combined and separate sewerage systems.

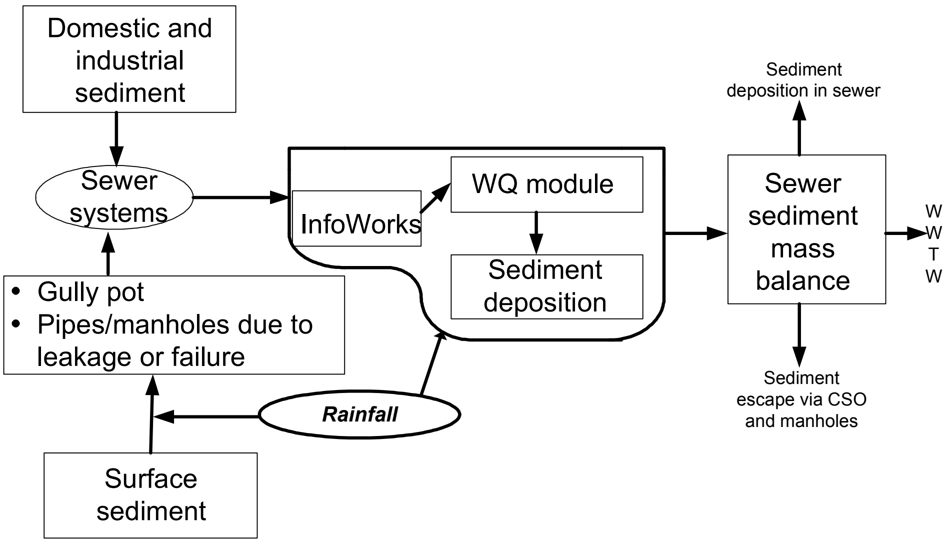

Figure 2 - Overall conceptual approach to sewer sediment modelling using *InfoWorks CS*

5 Study Area

The study area is located in England with a sewerage system of total pipe length 73,700m serving about 31,500 inhabitants. Pipe sizes vary from 150mm-1750mm, with a total contributing area of 770 ha. The runoff surface (paved area) is about 42% of the total contributing area. The system has a number of hydraulic structures: 14 storage tanks; nine fixed orifices, seven weirs and five outlets.

6 Sewer Sediment Quantification

The quantity and characteristics of sewer sediment deposits vary widely according to sewer type and location, nature of the catchment, local sewer operating practices and habitat customs. The sediments of main interest in this case study are the inorganic coarse and loose granular sediment, which could deposit in the sewer invert. It comprises coarse and loose granular material with a bulk density of 1730 kg/m^3 and total solids typically 73% formed on sewer inverts.

In *InfoWorks* CS, only two sediment fractions could be simulated; one associated with surface sediment washoff and the other with foul sewage. Hence, it was necessary to quantify and identify the physical characteristics of the two representative types of sediment; one representing the surface sediment and other representing the foul sediment.

6.1 Surface Sediment

An extensive literature review for sewer sediment sources, quantities and characteristics has been carried out. The amount and nature of eroded surface solids entering the sewer systems is site specific. For example, the mass of eroded sediment entering sewer systems from construction activities, road surfacing and road works. However, they are the largest direct source of human-made sediment loads that enter sewerage systems. The data from the UK sites show that surface sediment has a median d_{50} size of approximately 400µm (Butler and Clark, 1995). However, sewer sediment data have shown a range of 0.2-20 mm of grain size distribution d_{50} with variation according to the location in the sewer network (Ashley *et al*., 2004a). Therefore, for this study, a sediment fraction d_{50} of 0.9mm and specific gravity of 2.6 t/m^3 was selected to represent the grit associated with surface runoff for the catchment under study.

The surface sediment (grit) build up/supply rate is assumed to be 23 kg/ha/day from November to April and 20 kg/ha/day from May to October. These values consider the different sources of sewer sediment and seasonal variation (e.g. winter de-icing, construction activity, road surfacing and road works, etc.).

The sediment quantities and characteristics selected above are based on UK data from different locations than the catchment under study but they can still be considered as representative data for the study catchment. Nevertheless, sensitivity analysis has been carried out for the selected sediment fraction and specific density for the simulation output and compared with the available CCTV data for the study catchment.

6.2 Sediment from domestic appliances and industrial activities

In *InfoWorks* CS, only one sediment fraction can be used to simulate the sediment from domestic appliances and industrial activities. Accordingly, the sewer sediment characteristics from domestic appliances and industrial activities are assumed to be 40mg/l for sediment size distribution d_{50} of 0.150 mm with specific gravity 1.7 kg/m^3. Sediment from domestic appliances and industrial activities is considered in this study in order to determine the sewer sediment build up rate.

7 InfoWorks CS WQ Model Verification and Sensitivity Testing

A pre-calibrated hydrodynamic network has been used in this study. The hydrodynamic model is well calibrated, as it is one of the vital requirements before starting the *InfoWorks* CS quality model simulation (Bouteligier *et al*., 2002a).

A series of simulations representing one-year of rainfall were performed for the catchment under study using *InfoWorks* CS, with the sediment outputs from one event being used as the input for the next. The sediment fraction d_{50} of diameter 0.9mm with specific gravity of 2.6 was utilised to represent the surface sediment. Subsequently, the CCTV records verified the sediment deposition results from the modelled network. The data analysis indicated that the *InfoWorks* CS prediction of sedimentation in the network is about 66% without considering the mismatch due to model simplification. Three more different specific gravity values (2.1, 1.7 and 1.4) for the same fraction size of surface sediment have been simulated and results are presented in Table 1. The results indicated that grit size of 0.9 mm with specific gravity of 1.7 portrays the best prediction percentage value for the sewer network when compared with the CCTV data as shown in Figure 3.

Table 1 Surface sediment sensitivity analysis results

	S. G = 2.6		S. G = 2.1		S. G = 1.7		S. G = 1.4	
	No. of pipes	% of Pipes of total pipes	No. of pipes	% of Pipes of total pipes	No. of pipes	% of Pipes of total pipes	No. of pipes	% of Pipes of total pipes
Pipes match the CCTV	108	66	112	68	116	71	113	69
Pipes that do not match the CCTV records without any reason	37	23	33	20	29	18	32	20
Pipes that do not match the CCTV records due to simplification	19	12	19	12	19	11	19	12

Total	164	100	164	100	164	100	164	100

S. G. is the grit specific gravity in t/m^3

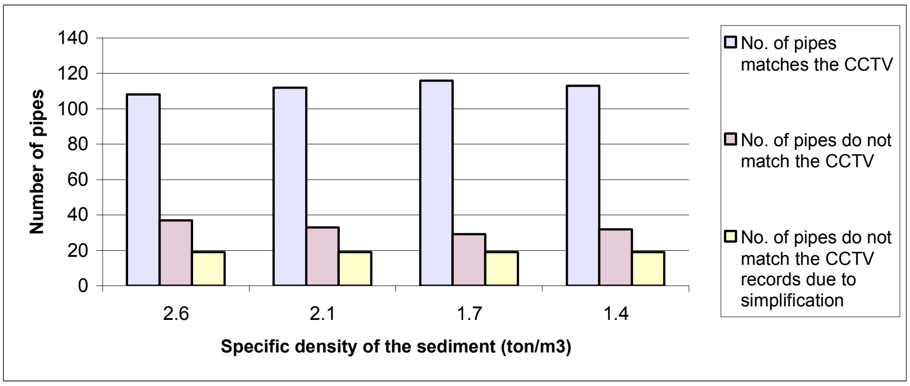

Figure 3 - Grit specific density sensitivity analysis results for diameter of 0.9mm

Consequently, sensitivity analysis testing has been carried out for different grit size diameters of 0.5, 0.7, 0.9, 1.2 and 1.4 mm. The sensitivity results show that the numbers of pipes that have deposited sediment modelled in them has slightly increased by increasing the sediment size from 0.9 to 1.4mm. On the other hand, it was noticed that the results from size fraction ranges from 0.5 - 0.9 mm were almost identical when compared with the CCTV records. Accordingly, a sediment fraction of 0.9mm with specific gravity of 1.7 is preferred in order to represent grit from the impervious areas for the catchment under study. The data analysis showed that by increasing the sediment size diameter, the number of pipes in the network susceptible to sedimentation increased to 21 and 39 for sediment diameters of 1.2mm and 1.4mm respectively. Conversely, by decreasing the particle size diameter from 0.9mm to 0.7mm and 0.5mm the sedimentation decreased in 11 and 28 pipes in the modelled network.

The CCTV data for the inspected sewer pipes in the catchment included sediment depth, but it did not include the sediment-deposition build up duration. This means that the sediment depth data in the CCTV records cannot be considered for verifying the deposition rate. Therefore, sediment depth data collection prior cleansing or during CCTV survey by contactors or operations is vital for sediment build rate verification and hence predicting the cleansing frequency.

8 Conclusions

This paper has demonstrated that the quality module of *InfoWorks* CS using the Ackers-White equation has proved to be effective for predicting the sediment deposition in the sewers by using the sediment particle size as a calibration parameter. An appropriate maintenance frequency can be determined if consistent records of sediment depth are available for use in the model sediment build up verification. The model results can be used to identify the locations where the network needs improvements and/or further investigation to improve serviceability and to reduce the need for CCTV. The model results can be utilised to advice stakeholders upstream of the locations where blockage is imminent due to solids deposition and not to flush SW items via the WC but to bin these to reduce the risk of flooding due to blockages (Ashley et al, 2005).

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