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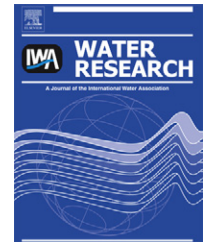

A database and model to support proactive management of sediment-related sewer blockages

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ABSTRACT

Due to increasing customer and political pressures, and more stringent environmental regulations, sediment and other blockage issues are now a high priority when assessing sewer system operational performance. Blockages caused by sediment deposits reduce sewer system reliability and demand remedial action at considerable operational cost. Consequently, procedures are required for identifying which parts of the sewer system are in most need of proactive removal of sediments. This paper presents an exceptionally long (7.5 years) and spatially detailed (9658 grid squares – 0.03 km^2 each – covering a population of nearly 7.5 million) data set obtained from a customer complaints database in Bogotá (Colombia). The sediment-related blockage data are modelled using homogeneous and non-homogeneous Poisson process models. In most of the analysed areas the inter-arrival time between blockages can be represented by the homogeneous process, but there are a considerable number of areas (up to 34%) for which there is strong evidence of non-stationarity. In most of these cases, the mean blockage rate increases over time, signifying a continual deterioration of the system despite repairs, this being particularly marked for pipe and gully pot related blockages. The physical properties of the system (mean pipe slope, diameter and pipe length) have a clear but weak influence on observed blockage rates. The Bogotá case study illustrates the potential value of customer complaints databases and formal analysis frameworks for proactive sewerage maintenance scheduling in large cities.

1. Introduction

Wastewater and stormwater carry a variety of solid particles which, when hydraulic conditions do not assure their transportation, form deposits. Solids accumulated in sewer systems can affect discharge capacity, increasing flood risk and frequency of overflow spills. Recent research has identified that drainage system conditions can make larger contributions to the risk of urban flooding than the occurrence of heavy storm events (e.g. Arthur et al., 2009; ten Veldhuis et al., 2009; Caradot et al., 2011). For example, in England and Wales about 75% (>23,000) of sewerage derived flooding incidents per year are due to blockages (Arthur et al., 2009). In Australia, blockages affect almost 70,000 properties across the country every year (Marlow et al., 2011). Besides this, water from sewer flooding incidents is likely to be contaminated

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thus posing potential health risk to citizens via waterborne pathogen exposure (e.g. ten Veldhuis et al., 2010a); furthermore, the flushing of accumulated sewer sediment is one of the major sources of pollutants in urban wet-weather flow discharges (e.g. Verbanck et al., 1994; Rodríguez et al., 2010). For example, 65 out of 70 water utilities recently surveyed in the USA are using sediment control in order to protect or improve stormwater quality (Black and Veatch, 2010).

Traditionally, municipal water utilities have addressed the maintenance and operation of sewer systems with a reactive approach, solving any problems only after they cause a failure. However, the cost of sewer failure (i.e. the cost of service disruptions, adverse publicity, and health and safety problems) can be significantly higher than the cost of implementing proactive maintenance. Some studies have identified regular sewer cleaning as a cost-effective way of dealing with flooding problems (e.g. Ashley et al., 2000; ten Veldhuis et al., 2009; Caradot et al., 2011; ten Veldhuis and Clemens, 2011), and a move away from reactive maintenance to a more proactive approach is encouraged (Fenner, 2000). However, Wirahadikusumah et al. (2001) indicated that the major reason for using reactive approaches is lack of monitoring and record keeping, so that a system's deterioration is not evident until major failures occur. Lack of data on the condition of sewers also hinders the development of predictive models and the evaluation of effects of changes in the maintenance policy (Wirahadikusumah et al., 2001).

Efficient monitoring of sewer system condition would ideally include a survey of sediment accumulation as well as the structural condition of the sewer. There are a variety of technologies available for assessing sediment accumulation in sewer systems such as closed-circuit television (CCTV), and sonar/ultrasonic and laser profiling (Feeney et al., 2009). Furthermore, recent advances in acoustic-based instrumentation are allowing more rapid inspections (Bin Ali et al., 2011; Romanova et al., 2011). However, due to cost and time constraints, collection of data on sediment accumulation covering the entire sewer system is not sustainable in large urban areas (Fenner et al., 2000; Mashford et al., 2011). Therefore, analytical procedures are required for forecasting which of the sewer system structures are in most need of cleaning (Fenner and Sweeting, 1999).

The complex physical mechanisms of sediment deposition, and the number of factors that may contribute to a sediment-related blockage, make forecasting a challenging task (Laplace et al., 1992; Bachoc, 1992), and successful forecasting procedures are, in general, those based on statistical analysis of recorded sediment-related blockage events. Water utilities in many cities have dedicated call centres to handle customers reporting problems occurring in the urban drainage system. However, despite the availability of customer complaints and/or failure records there has been little formal analysis of the data, partly because of the lack of effective data storage (Fenner, 2000; Arthur et al., 2009; ten Veldhuis et al., 2010b). In cases where structured customer complaints/failure databases exist, these can be used to identify and study the various hydraulic and serviceability problems that are occurring within the sewer system (e.g. Arthur et al., 2008; ten Veldhuis et al., 2009; ten Veldhuis and Clemens, 2010; ten Veldhuis et al., 2010b; Caradot et al., 2011; ten Veldhuis and Clemens, 2011). In particular, Arthur et al. (2008) have combined complaints data and detailed hydraulic modelling to study blockage formation; and ten Veldhuis and Clemens (2010) and ten Veldhuis et al. (2010b) have shown that automatic procedures to filter and classify complaints data can support prioritisation of operations. However, this previous research was applied to relatively small urban areas (ranging from about 20,000 to 170,000 inhabitants) and identified the lack of studies at much larger spatial scales.

This paper first reviews the factors affecting sediment-related blockages and options for forecasting. The paper then describes an exceptionally long and spatially detailed data set from a customer complaints database covering the 7.5 million inhabitants of Bogotá (Colombia). The paper goes on to describe and test a new statistical model to help identify the factors most affecting sediment-related blockages, to identify how the blockages rates are distributed in time and thus to help prioritize sewerage maintenance.

2. Review of factors affecting sediment-related blockages and modelling approaches

2.1. Hydraulic deterioration of sewer systems: definition and triggering factors

Hydraulic deterioration of sewer systems has been defined as a continuous process that reduces the discharge capacity through a reduction of cross sectional area and an increase in pipe roughness (Tran et al., 2010). It is caused, among other factors, by sediment accumulation (Fenner and Sweeting, 1999; Kannapiran et al., 2007; Tran et al., 2010; Marlow et al., 2011), which this paper focuses on. Previous research has looked at gaining better understanding of the role of sewer network properties in promoting solid deposits and sewer blockages (e.g. Laplace et al., 1992; Bachoc, 1992; Chebbo et al., 1995; Gerard and Chocat, 1999; Fenner and Sweeting, 1999; Savic et al., 2006; Arthur et al., 2008; Ugarelli et al., 2009; Ugarelli et al., 2010; Marlow et al., 2011). It is known that the propensity for sediment deposition depends upon the location of a sewer in a network and some of its physical characteristics. Nevertheless, there is no consensus on which physical properties can be considered as influential factors. Fenner and Sweeting (1999) have concluded that urban catchments with brick sewers, long pipe lengths, small diameters, shallow depths, moderate to slack gradients and foul sewers tend to have more frequent blockages. Ugarelli et al. (2009) concluded that, in addition to previous properties, system age and function (sewage, stormwater and combined sewer systems) seem to have a marked influence on proneness to blockages. However, Ugarelli et al. (2010) did not find slope to be a clear significant factor, possibly due to limited data availability. Tran et al. (2007) argued that the number of nearby trees and climatic conditions can also influence the state of deterioration. Tran et al. (2010) identified that older pipes or those with more surrounding trees, tend to be in better hydraulic condition. In the same study, Tran et al. (2010) also concluded that soil type and soil wetness were not significant factors and no conclusions could be drawn about the significance of pipe