Water Research 88 (2016) 245–256

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Monitoring and statistical modelling of sedimentation in gully pots

J.A.B. Post [a], [*], I.W.M. Pothof [a], [b], J. Dirksen [c], E.J. Baars [c], J.G. Langeveld [a], [d], F.H.L.R. Clemens [a], [b]

[a] Section Sanitary Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, PO Box 5048, 2600 GA, Delft, The Netherlands
[b] Deltares, PO Box 177, 2600 MH, Delft, The Netherlands
[c] Waternet Foundation, PO Box 94370, 1090 GJ, Amsterdam, The Netherlands
[d] Partners4urbanwater, Javastraat 104A, 6524 MJ, Nijmegen, The Netherlands

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form
13 October 2015
Accepted 14 October 2015
Available online 17 October 2015

Keywords:
Sediment accumulation
Gully pot blockage
Bayesian inference
Generalised linear mixed modelling

ABSTRACT

Gully pots are essential assets designed to relief the downstream system by trapping solids and attached pollutants suspended in runoff. This study applied a methodology to develop a quantitative gully pot sedimentation and blockage model. To this end, sediment bed level time series from 300 gully pots, spanning 15 months, were collected. A generalised linear mixed modelling (GLMM) approach was applied to model and quantify the accumulation of solids in gully pots and to identify relevant physical and catchment properties that influence the complex trapping processes. Results show that the retaining efficiency decreases as sediment bed levels increase. Two typical silting evolutions were identified. Approximately 5% of all gully pots experienced progressive silting, eventually resulting in a blockage. The other gully pots show stabilising sediment bed levels. The depth of the sand trap, elapsed time since cleaning and the road type were identified to be the main properties discriminating progressive accumulation from stabilising sediment bed levels. Furthermore, sediment bed levels exhibit no residual spatial correlation, indicating that the vulnerability to a blockage is reduced as adjacent gully pots provide a form of redundancy. The findings may aid to improve maintenance strategies in order to safeguard the performance of gully pots.

1. Introduction

Street inlets are essential sewer assets responsible for collecting and conveying excess water from the urban surface. These structures are commonly designed as gully pots, referring to the presence of a sand trap. By capturing suspended particles in runoff, silting and wear of downstream sewer components are reduced. In addition, the impact on the pollutant wash-off to the sewer system is considerable (Ashley et al., 2004; Butler et al., 1995). Therefore, gully pots decrease the pollution load to receiving water bodies, especially for storm sewers. Depending on the retaining efficiency of the sand trap, the supply of solids induces progressive silting over time. When the trap capacity of is exceeded, the hydraulic performance of the gully pot is impaired. In the absence of alternative flow routes, water will pond and spread over adjacent areas causing potential health risks (De Man et al., 2014; Ten Veldhuis et al., 2010) and tangible damage (Arthur et al., 2009). The role of gully pot blockages as main contributor to sewer flooding events has been recognised by several studies (e.g. Ten Veldhuis et al. (2011) and Caradot et al. (2011)).

Unlike most sewer system components, gully pots are generally maintained with a proactive preventive approach (Butler and Davies, 2004; Karlsson and Viklander, 2008). It comprises of cleaning activities that are undertaken after a fixed period of time. Currently, the cleaning frequency is based on either the available budget (Fenner, 2000), expert judgment, or vulnerability of the urban environment. The effectiveness of this type of management depends on the number of a blockages in a system within the specified interval (Swanson, 2001). Yet, authorities lack quantitative data to support observed blockages. If data on the operational condition of gully pots are utilised to determine the maintenance interval, it is possible to balance the effectiveness of strategies and the associated resources to provide cost-effective service provision.

Adopting a condition-based approach for maintenance requires prediction tools and field data (Van Riel et al., 2014). Prediction models for solids transport in gully pots are described by e.g.

---

[*] Corresponding author.
E-mail address: j.a.b.post@tudelft.nl (J.A.B. Post).

http://dx.doi.org/10.1016/j.watres.2015.10.021

Nomenclature

t	observation number
i	gully pot identity
p	the probability of 'success'
ε	random part of the generalised linear model
η	Linear predictor containing the deterministic part of the generalised linear model
d	available sump depth
y	measured sediment bed level
v	normalised sediment bed level with respect to the sump depth
x	quantitative explanatory variable
β	model weight assigned to explanatory variable x
ϕ	autocorrelation strength
ω	noise term
a	shape parameter for the beta distribution
b	shape parameter for the beta distribution
θ	over-dispersion parameter
$\mathbf{z}$	row incidence vector for the random effects

Fulcher (1994) Butler and Karunaratne (1995) and Deletic et al. (2000). These models are based on dense time series with a duration varying from one to several storm events or artificial events for a limited (1–60) number of gully pots. Although this duration is adequate to simulate transport processes during individual events, the characteristic time scale of the solids induced blockage process in gully pots calls for time series covering a period of at least one year. Considering the complex transport processes and the corresponding parameter uncertainty, Rodríguez et al. (2012) and Pratt et al. (1987) opted for a probabilistic approach. This study modelled the long term accumulation of solids that leads to blockages by applying a generalised linear mixed modelling (GLMM) approach to time series of multiple gully pots. This approach allows for the identification of catchment and physical properties of gully pots that affect the accumulation of solids. Sufficient monitoring locations are essential for probabilistic modelling, as the potential correlation between successive measurements over time results in less unique information. To this end, sediment bed levels of 300 gully pots were measured monthly for over a year. Findings from this study may support overall maintenance strategies on a system scale and improve gully pot design. Furthermore, this work complements previous research on sediment accumulation and water quality aspects (e.g. Ellis and Harrop (1984), Memon and Butler (2002) and Butler and Karunaratne (1995)). This paper first presents an overview of literature on the relevant processes to identify the main explanatory variables that influence the occurrence of gully pot blockages. Second, the collection of sediment bed level data is discussed. Subsequently, a procedure for modelling is introduced and applied to these data.

2. Relevant transport processes and parameters

Various processes govern sediment accumulation. The following review identifies properties that are relevant for modelling sedimentation in gully pots.

2.1. Supply to gully pots

Particles present in the urban environment are predominately inorganic, comparable to sand and silt (Lager, 1977; Sartor and Boyd, 1972). These particles originate from different sources, such as local traffic (Deletic et al., 2000), construction activities (Ashley and Crabtree, 1992), weathering of buildings (Jartun et al., 2008), animal wastes, litter, and de-icing materials (Brinkmann, 1985). Particles that are transported to gully pots during storm events are generally not well removed by street sweeping (Brinkmann, 1985; Sartor and Boyd, 1972). Material available for wash-off to gully pots may vary spatially, as the presence of potential sources is subject to local circumstances. Pratt and Adams (1984) reported a relation between characteristics of the contributing area (e.g. size, drainage path length) and the mean mass of the measured sediment wash-off in the field. These data did, however, originate from the same gully pots, indicating a potential dependence between successive measurements over time. In addition to spatial variation, the supply to gully pots may also vary temporally. Grottker (1990b) analysed the organic content of sediment samples and found a higher organic loading (5–10%) in autumn. Peaks in the material supply in June, autumn and after snowmelt were mentioned by Pratt et al. (1987), indicating seasonal variation. On a shorter timescale, flow characteristics dominate the temporal variation. Ellis and Harrop (1984) found that the antecedent dry period was only weakly correlated with the sediment loading to gully pots. Rainfall intensity was, however, strongly correlated. Similar results lead Pratt and Adams (1984) to the conclusion that the shear force required to suspend material is limiting, rather than the availability of material. The overall variation in particle loading results in models that typically calls for several site specific calibration parameters (Memon and Butler, 2002).

2.2. Retaining efficiency

The fraction of solids captured by gully pots has been studied extensively. Field studies reported retaining efficiencies ranging from 20 to 50% (Deletic et al., 2000; Pitt and Field, 2004). Both Butler and Karunaratne (1995) and Grottker (1990a) conducted lab experiments where the solids supply to gully pots was varied. They found that the retaining efficiency was independent from the solids concentration, which support model results from Butler and Memon (1999). Butler and Clark (1995) found the build-up rate to vary between 14 and 24 mm/month for urban areas. This variation may well be related to the substantial variation in grain size distributions of samples from different gully pots (Jartun et al., 2008), as solids with a smaller diameter are captured less efficiently (Butler and Karunaratne, 1995; Lager, 1977).

Laboratory tests by Butler and Karunaratne (1995) with varying sediment bed levels up to the level of the outlet pipe of a gully pot show a marginal increase in the retaining efficiency with increasing sediment depths. This is contradictory with experimental results reported by Lager (1977), who found that solids removal efficiencies decreased when a threshold of 40% of the gully pot storage was exceeded. The latter is supported by the increase in the retaining efficiency with an increasing cleaning frequency (Memon and Butler, 2002; Mineart and Singh, 2000). Field measurements from Butler and Clark (1995) indicate that equilibrium sediment bed levels were reached at the level of the outlet pipe. Conradin (1990) reported similar results for 63 gully pots monitored for 16 months; sediment bed levels did not exceed the level of the outlet pipes and equilibrium depths were generally reached in 6 months.

2.3. Re-suspension of sediments

There is a general consensus that the sedimentation rate is inversely proportional to the rainfall intensity (e.g. Morrison et al. (1988), Deletic et al. (2000) and Ciccarello et al. (2012)). Depending on the particle size, the jetting effect induces erosion of the gully pot sediment bed (Butler and Memon, 1999). Sartor and Boyd