Monitoring sediment accumulation in urban drainage systems with temperature measurements

Utilisation de mesures de température pour surveiller l'accumulation de sédiments dans les assainissements.

Manuel Regueiro-Picallo[1], Antonio Moreno-Rodenas[2], François Clemens-Meyer[2,3], Jörg Rieckermann[4]

[1] Universidade da Coruña, Water and Environmental Engineering Research Team (GEAMA), A Coruña, Spain. manuel.regueiro1@udc.es
[2] Deltares, Hydraulic Engineering Department, Delft, the Netherlands. Antonio.MorenoRodenas@deltares.nl, Francois@SkillsInMotion.nl
[3] Norwegian University of Science and Technology, Department of Civil Engineering, Faculty of Engineering, Trondheim, Norway. francois.h.l.clemens@ntnu.no
[4] Eawag, Swiss Federal Institute of Aquatic Science and Technology, CH-8600 Dübendorf, Switzerland. joerg.rieckermann@eawag.ch

RÉSUMÉ

La mesure de l'accumulation de sédiments dans les systèmes de drainage urbain demeure un problème. Les alternatives existantes incluent des campagnes d'inspection ponctuelles ou des solutions aux coûts d'installation et de maintenance élevés. Cette étude prouve qu'il est possible de monitorer l'accumulation des sédiments par des mesures de température et l'analyse des processus de transfert de chaleur dans les systèmes de drainage urbain. Pour ce faire, deux campagnes expérimentales ont été réalisées afin de reproduire les conditions de température dans les canalisations d'égout et dans les collecteurs. Ces deux systèmes présentent des processus de transfert de chaleur similaires en ce qui concerne les sédiments. Par conséquent, l'idée dans les deux situations consiste à mesurer l'épaisseur des sédiments à partir de la différence de température entre la phase aqueuse et le fond des sédiments. La caractérisation des propriétés thermiques des sédiments étant également nécessaire, des méthodes d'analyse de la chaleur active ont été développées pour cela. Cette méthodologie permet d'estimer l'épaisseur des sédiments avec une précision de ±0.5 cm. Les prochaines étapes comprennent la validation de cette méthodologie dans des environnements réels. Finalement, nos résultats démontrent le potentiel de ces mesures à faible technicité et faible coût pour observer l'accumulation des sédiments dans les systèmes de drainage urbain afin d'optimiser les stratégies d'inspection et de décontamination.

ABSTRACT

Measuring sediment accumulation in urban drainage systems is still a challenge. Existing options include punctual inspection campaigns or solutions with high installation and maintenance costs. This work shows that through temperature measurements and the analysis of heat transfer processes in urban drainage systems it is possible to monitor sediment accumulation in sewer pipes as well as gully pots. As both systems show similar heat transfer processes at the sediment bed layer, the idea is to identify the sediment thickness from temperature differences in the water layer and the bottom of the sediment layer as well as applying physically-based heat transfer models. To obtain satisfactory predictions, we also developed experimental methods with active heating to characterize the thermal properties of different sediments. As an innovative result, references were provided for the thermal properties of organic sediments. Our results suggest that sediment thickness can be estimated with an accuracy of ±0.5 cm. The next steps include validating this methodology in real environments. Ultimately, the results illustrate the potential of these low -tech and -cost measurements to monitor sediments in urban drainage systems to optimise inspection and cleaning strategies.

KEYWORDS

Monitoring, sediment accumulation, sensing, temperature sensors, urban drainage

1 INTRODUCTION

Sediments in urban drainage systems represent a major factor in maintenance and cleaning operations. Although the investment in these tasks represents a significant amount, there is still a lack of consensus on, for example, inspection work in sewer systems (Ertl et al., 2022). In addition, we must consider the limited monitoring due to adverse conditions, such as lack of coverage in underground infrastructures (Bertrand-Krajewski et al., 2021). This paper presents a methodology for sediment monitoring in urban drainage systems. In particular, the work was focused on sewer pipes and gully pots. This work shows a methodology based on studying the heat transfer processes between the fluid (wastewater or drainage water) and the sediment bed to determine its thickness. The temperature gradients in the fluid are attenuated through the sediment layer through a conduction process. Thus, the larger the sediment layer, the greater the temperature attenuation at the sediment bottom (Sebok et al., 2017). Therefore, measuring the temperature difference between the fluid layer and the sediment bottom is essential, as well as determining the thermal properties and the heat loss through the contours. Furthermore, previous work proved that hydrodynamic conditions barely influence on the heat transfer process in the sediment layer (Regueiro-Picallo et al., 2022a). As a result, monitoring campaigns may be limited to the deployment of temperature sensors, which can be low -cost and -power, avoiding data on the hydrodynamics.

2 METHODOLOGY

This section describes the methodologies for measuring the sediment accumulation in sewer pipes and gully pots based on heat transfer processes. Although we are analysing the same heat transfer process, the daily temperature oscillations and the geometric features are different in each system, which requires the development of methods from different perspectives. Likewise, the sediment thermal properties are a key parameter in heat transfer processes. For this purpose, we developed a Dual-Probe Heat-Pulse (DPHP) system to measure the thermal properties through active temperature measurements. The DPHP system set heat pulses from a heater cartridge were introduced in the sediment bottom and a temperature sensor was placed nearby.

2.1 Heat transfer processes in sewer pipes

Sewer systems are susceptible to flow and temperature daily oscillations. Temperature patterns are commonly found in a sewer pipe, characterised by an increase in temperature in the early hours, followed by a small decrease at midday, an upturn in temperatures in the evening, and finally a significant decrease during the night. This pattern is daily repeated, although its appearance shows spatial and seasonal variations. The periodicity of the temperature patterns allows them to be analysed as a harmonic series. Following past studies carried out in river streambeds, differences in the amplitudes and phase lags of the daily temperature series in a fluid and in the sediment-bed can be related to the position of temperature sensors (Sebok et al., 2017). The relationship between the first harmonic (defined by its amplitude and phase) and the sediment thickness in sewer systems was analysed in Regueiro-Picallo et al. (2022b). For this purpose, measurements of the temperature time series in the fluid and in the sediment-bed are required (passive measurements).

An experimental campaign was carried out at Eawag facilities (Dübendorf, Switzerland), in which 4 thicknesses of 6 samples with different organic matter contents were analysed. For each test, a uniform sediment thickness and a water layer were poured into a methacrylate cylinder with a PVC bottom (Fig. 1a). A closed temperature-circuit submerged in the water layer was used to reproduce daily temperature patterns in sewer pipes. For this purpose, reference data from the Urban Water Observatory were used (Blumensaat et al., 2021). Temperature sensors were placed at the bottom, at the sediment-water interface, and outside the system. Under real pipe-flow conditions, we can assume that the temperature is constant in the water column up to the interface with the sediment. In addition, commercial sensors were installed at the bottom of the lab-scale model to measure the water content and to measure the thermal properties of the sediments. These measurements were compared with those obtained from the active DPHP system. The duration of each test was 72 hours.

2.2 Heat transfer processes in gully pots

Heat transfer processes in gully pots are of significance when rainfall events occur. The temperature of the runoff water entering the gully pots is usually different from the temperature of the ponded water layer inside, creating a temperature gradient that is transferred to the accumulated sediment layer by diffusion. In contrast to sewer pipes, this phenomenon does not follow a cyclical pattern, thus requiring a different approach. For this purpose, 1D, 2D, and 3D heat transfer models were developed to simulate the temperature measurements as a function of the established sediment thickness.

An experimental campaign was carried out at Deltares facilities (Delft, The Netherlands). A gully pot 1:1 scale model (Rietveld, et al. 2020) was used, in which 5 sediment thicknesses, 2 temperature gradients (ΔT= -3ºC and -5.5ºC), and 3 inflow hydrographs were analysed (Fig. 1b). Two temperature control systems were used to setup the temperature gradients between the runoff water and the ponded water layer in gully pots. For this purpose, field data were used as a reference. Temperature sensors were placed at the bottom, and on the walls of the gully pot every 5 cm up to a height of 30 cm. Besides, sensors were installed in the temperature control systems and at the gully pot inlet. The test duration varied between 4 and 6 hours for ΔT= -3ºC and -5.5ºC, respectively.

a)

b)

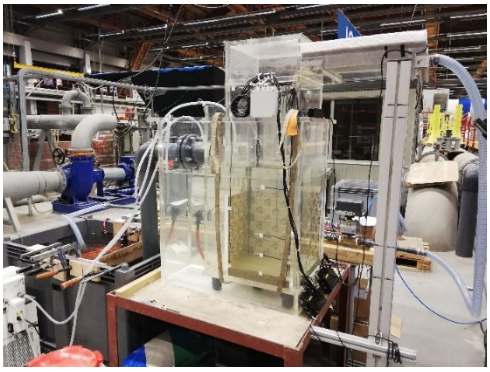

Figure 1. Physical models at Eawag and Deltares facilities to simulate heat transfer processes in sewers (a) & gully pots (b).

3 RESULTS AND DISCUSSION

3.1 Bed deposits in sewer pipes

Fig. 2a shows the temperature time series in the water (interface sensor) and at the bottom of the sediment bed for a thickness of 8.5 cm. The temperature peaks at the sediment-bed sensor represent the response to the DPHP active heat system. By analysing these peaks as a function of the quantity and geometry of the heating cartridge, the sediment thermal properties can be obtained (He et al., 2018). Consequently, samples with low organic matter content (<5%) showed thermal conductivity (k_t) and diffusivity (k_e) values ranged between [0.85 – 1.5] W/m/ºC and [0.49 – 0.63]×10^{-6} m^2/s, respectively. In contrast, samples with high organic matter content (>5%), k_t and k_e values ranged between [0.53 – 0.57] W/m/°C and [0.21 – 0.24]×10^{-6} m^2/s, respectively.

Once the thermal properties of each sample were identified, sediment thickness could be estimated from the ratio of amplitudes and differences in phase changes between the temperature series in the water and the bottom of the sediment-bed (example, Fig. 2a). For this purpose, a data driven model developed from a 1D diffusion heat transfer model was used to generate multiple scenarios from the water temperature series and the sediment thermal properties (Regueiro-Picallo et al., 2022b). Measurement errors of less than 2 cm were estimated from comparing the experimental results to the ground-truth, i.e. the measured thickness of the actual sediment beds in the vessel. The average observed errors were estimated to ±0.5 cm.

3.2 Bed deposits in gully pots

Fig. 2b shows the comparison between experimental temperature measurements and those obtained with a 3D numerical heat transfer model for an inorganic sediment (sand) with a thickness of 10 cm at the bottom of the gully pot model. As a result, the experimental measurements at the bottom and wall-side contours were successfully reproduced by the 3D model. The installation of sensors in the middle of the sediment layer was discarded, as this would be an obstacle for gully cleaning under real-world conditions.

The geometry of the gully pot model has a square section of 35 cm x 35 cm, which is typical for Dutch streets. At these dimensions, the 2D and 3D models are suitable for estimating the accumulated sediment thickness, as they can reproduce the influence of the wall contours. Furthermore, the sediment surface homogeneity and the thickness were measured before and after each test by applying the Structure from Motion (SfM) photogrammetric technique. Like in the previous section, the DPHP system was used to obtain the sediment thermal properties: k_t = 2.00 W/m/ºC y k_e = 0.75·10^{-6} m^2/s.

A limitation of these tests is that sediment input, as described in Rietveld et al. (2020), was not performed. The methodology presented in this study is not suitable for studying the sediment accumulation dynamics on a short-time scale. Therefore, the entire rainfall event and its subsequent heat recovery must be considered for estimating the sediment thickness. Nevertheless, we can assume this error since the increase in sediment thickness per rainfall event is not significant (Rietveld, 2020).

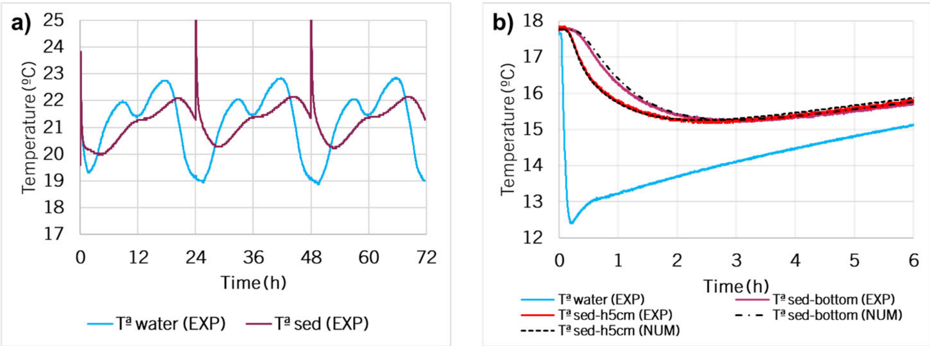

Figure 2. Temperature measurements at the bottom and at the water-sediment interface of the Eawag lab-scale model (a) and comparison between experimental and numerical temperatures at Deltares gully pot model (b).

4 CONCLUSIONS

The methodology for measuring sediment accumulation based on a combination of active and passive temperature measurements represents an interesting alternative to monitor sediment thickness and related processes in urban drainage systems. Lab-scale tests were performed assuming heat transfer conditions like sewer pipes and gully pots. Under these conditions, sediment thicknesses could be measured with errors below 2 cm. This methodology was developed by using temperature low -cost and -power sensors, which also provides a competitive advantage. Further measurements are currently being carried out in real urban drainage systems to test the feasibility of the methods presented in this study.

5 ACKNOWLEDGEMENTS

The work of Manuel Regueiro-Picallo is funded by the postdoctoral fellowship program from the Xunta de Galicia. This work includes the results from a transnational access and a joint research activity funded by the EU under the Horizon 2020 INFRAIA program (Co-UDlabs project. GA No.101008626). The authors are indebted to the User Group of the Transnational Access HALL-Eawag for their support in the experimental campaign at Eawag and the municipality of Rotterdam and Van der valk+De groot for their support in the field measurement campaign. We also thank Christian Ebi, Peer Wohlwend and Florian Züger of the Sensorlab of Eawag for the design, development and implementation of the prototype.

LIST OF REFERENCES

Bertrand-Krajewski, J.L., Clemens-Meyer, F., Lepot, M. (2021). *Metrology in urban drainage and stormwater management: Plug and pray*. IWA Publishing. https://www.iwapublishing.com/books/9781789060102/metrology-urban-drainage-and-stormwater-management-plug-and-pray

Blumensaat, F., Bloem, S., Ebi, C., Disch, A., Förster, C., Maurer, M. (2021). *The Urban Water Observatory - Long-term monitoring of urban water resources dynamics in very high spatiotemporal resolution using low-power sensor and data communication techniques*. https://uwo-opendata.eawag.ch/.

Ertl, T.W., Plihal, H., Kerres, K. (2022). *New approach for condition-based sewer inspection combined with demand-based sewer cleaning assisted through innovative tools*. In proceedings of the 10th Sewer Processes and Networks, Graz, Austria.

He, H., Dyck, M. F., Horton, R., Ren, T., Bristow, K. L., Lv, J., Si, B. (2018). *Development and application of the heat pulse method for soil physical measurements*. Reviews of Geophysics, 56(4), 567-620.

Regueiro-Picallo, M., Figueroa, A., Rieckermann, J. (2022a). *Improving Sediment Monitoring Strategies based on Analysing Heat Transfer Processes in Sewer Pipes*. Water Science and Technology, under review.

Regueiro-Picallo, M., Anta, J., Naves, A., Figueroa, A., Rieckermann, J. (2022b). *Towards urban drainage sediment accumulation monitoring using temperature sensors*. Environmental Science: Water Research & Tech., under review.

Rietveld, M., Clemens, F., Langeveld, J. (2020). *Solids dynamics in gully pots*. Urban Water Journal, 17(7), 669-680.

Sebok, E., Engesgaard, P., Duque, C. (2017). *Long-term monitoring of streambed sedimentation and scour in a dynamic stream based on streambed temperature time series*. Environmental Monitoring and Assessment, 189(9), 1-15.