Monitoring sediment build-up in gully pots using temperature-based systems

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Highlights

- MONitoring Temperatures in SEdiments can be used to estimate sediment depths in gully pots.
- Heat transfer processes in gully pot can be described using simplified surrogate models.
- Field measurements showed errors of less than 3 cm compared to sediment depth references.

Introduction

Sediments in urban drainage systems stem from various sources, such as traffic, construction activities, and vegetation (Rietveld et al., 2020). Solid particles are washed out by the surface runoff into the gully pots during rainfall and settle to the bottom according to their size and density. They may also absorb pollutants that can be remobilized from the gully pots during rain events, thereby increasing the suspended solid loads in drainage systems, which can cause impacts on receiving waters (Westerlund and Viklander, 2006). Sediments also lead to a decrease of hydraulic capacity, resulting in an increased risk of urban flooding (Butler et al., 2018).

Sediment build-up control remains challenging. Sediments are often only detected during visual inspections, which are costly and resource intensive. Gully pots could be monitored, providing continuous data on sediment accumulation, but there are not sensor-based solutions commercially available. For this purpose, temperature-based systems could be installed to estimate sediment build-up. Temperature measurements were commonly used as a tracer of groundwater and surface water interactions in fluvial environments and sediment transport in streambeds in rivers (Anderson, 2005; Sebok et al, 2017). In addition, promising results were obtained by using temperature sensors to estimate sediment depths in urban drainage systems (Regueiro-Picallo et al., 2023a).

The work described in this abstract shows the development and application of a surrogate model, which transforms the difference between the temperatures in the water and sediment into a sediment depth estimation. Field measurements were performed in two gully pots, where sensors were installed to monitor the temperature and determine the sediment thermal properties as inputs of the surrogate model. Reference sediment depths were also measured to evaluate the performance of temperature-based systems. The study highlights the potential of temperature sensors for monitoring sediment accumulation in gully pots.

Methodology

Temperature-based systems

First, the heat transfer processes in gully pots need to be understood to apply temperature sensor-based systems for sediment depth estimations. The temperature of the ponded water inside a gully pot rapidly changes when influenced by external factors, such as rainfall. The sensors inside the sediment measure a slow change in temperature due the isolation of the sediment. For this purpose, devices for MONitoring Temperatures in SEdiments (MONTSE) were developed for field measurements. Each device consisted of an insulated box that contained a data control and collection system for temperature sensors, which was powered by a battery. MONTSE uses sensors to measure the temperature at different heights of the gully pots, including the pounded water layer, the sediment-bed and the air. In addition, a Dual-Probe Heat-Pulse (DPHP) system could be included to measure the sediment properties. The DPHP system consisted of a heater cartridge coupled with a temperature sensor at the bottom of the gully pot. The sensor measured the heat-pulse introduced in the sediment-bed by the heater and the subsequent heat-recovery. Finally, the thermal properties could be determined according to the temperature recovery measured by the temperature sensor, the power supply and the distance between the heater and the temperature sensor, similar to Ravazzani (2017).

The 2D diffusion heat equation served as the basis for a surrogate model to estimate sediments depths, similar to Regueiro-Picallo et al. (2023b, under review). This model relates sediment depth estimations to temperature time-series features in the water and sediment layers, sediment thermal properties and heat loss at the wall and bottom boundaries. The features extracted from the temperature time series during the rainfall-runoff events were the horizontal (temporal) and vertical (temperature) components of the graph centroid. For this purpose, the event start was established at the temperature change in the water layer and the duration was 3 hours. The sediment thermal properties were measured using the DPHP system or by taking samples and analysing them in the laboratory (Table 1). Additionally, the boundary condition at the walls and bottom was defined by the convective heat transfer coefficient (19.3 and 20.0 W/m^2/ºC, respectively) and the soil temperature. The soil temperature was assumed to be equal to the sediment temperature at the beginning of the rainfall-runoff events because they show similar stratification processes.

Table 1. Thermal conductivity (W/m/ºC) and volumetric heat capacity (MJ/m^3/ºC) of the sediments. Minimum and maximum values. Laboratory measurements were performed under submerged conditions.

Sample location	Measurement system	Thermal conductivity [W/m/ºC]	Volumetric heat capacity [MJ/m^3/ºC]
Dübendorf (Switzerland)	DPHP system (MONTSE)	0.83 – 1.17	3.01 – 3.22
Delft (The Netherlands)	TP01 sensor (laboratory)	0.57 – 0.81	1.80 – 3.50

Field campaigns

Two experimental campaigns were designed to evaluate the performance of the MONTSE system for sediment build-up estimations. The locations were Dübendorf (Switzerland) and Delft (The Netherlands), respectively. The gully pot in Dübendorf was cylindrical, with a diameter of 70 cm and a height of 160 cm (Figure 1, left). The MONTSE system was equipped with the DPHP system to measure the sediment thermal properties. The build-up process was manually accelerated in this campaign by introducing sediment layers periodically. In addition, some of the rainfall-runoff events were artificially simulated by introducing a constant flow through the top of the gully pot because of the lack of rainfall (spring and summer seasons).

The surveyed gully pot in Delft was a rectangular box with a top-section of 35 X 35 cm^2 and a height of 100 cm (Figure 1, right). For this campaign, natural build-up process was observed, i.e., neither runoff nor sediment accumulation was controlled. Likewise, no DPHP system was installed, so the sediment thermal properties were measured by analysing samples in the laboratory. Furthermore, sediment depth references were measured for both campaigns and compared with the estimations from MONTSE. For this purpose, a graded stick was used to take references of the gully pot bottom and the surface of the sediment bed. The disadvantage of this system was the sediment-bed compaction while taking the reference of the bed surface, disturbing the real measurement of the sediment depth. As a general procedure, stick measurements were performed at several locations inside the gully pot and the average was considered as the reference.

Figure 1. Photos of the MONTSE devices installed in gully pots in Dübendorf (left) and Delft (right).

Datasets

The surrogate model was developed and validated by Fuchs (2023). In addition, the data of the field campaigns are available in Fuchs et al. (2023) and Regueiro-Picallo et al. (2023c) under CC BY-NC 4.0 licenses.

Results and discussion

Temperature variations were observed for 20 and 14 rainfall-runoff events in Dübendorf and Delft experimental campaigns, respectively. Figure 2 shows the differences between the temperature time series in the water and sediment layers for two events measured at the surveyed gully pots. The attenuation of water temperature with respect to temperature sensors located at 30 cm (Figure 2, left) and 10 cm (Figure 2, right) from the bottom showed that both sensors were buried in the sediment bed and, therefore, the sediment depth exceeded that reference.

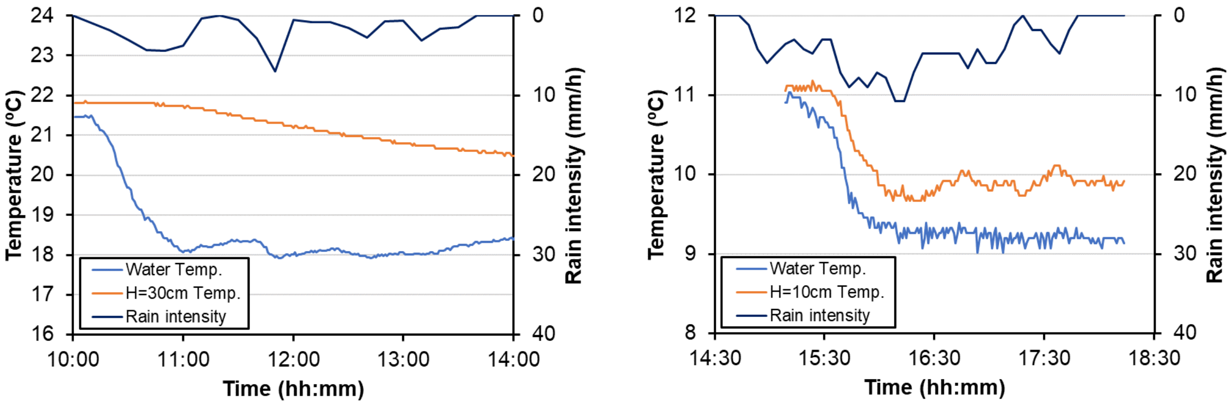
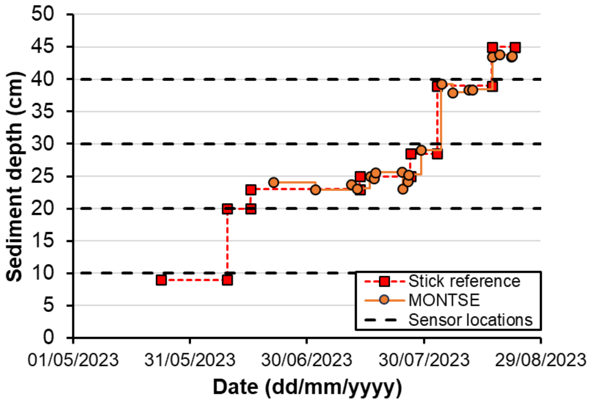


Figure 2. Temperature time series in the water layer (light-blue lines) and sediment bottom (orange lines) for rainfall-runoff events in Dübendorf (left) and Delft (right) gully pots. Rain intensity data was collected from local meteorological stations: MetOffice (2023) and Fuchs (2023), respectively.

The features extracted from the temperature series were applied to quantify the temperature attenuation and, applying the surrogated model, to estimate sediment depths. Sediment depths estimated applying the surrogated model agreed with the reference measurements, resulting in maximum errors of 3 cm (Figure 3). The reference measurements in Dübendorf were conditioned by manually-introduced sediments and were monitored before, during and after each step (Figure 3, left) and, in between, the rainfall-runoff or simulated events were measured to estimate the sediment depth. Regarding the surveyed gully pot in Delft, sediment depth references were measured coinciding with scheduled visits for data collection and equipment maintenance (Figure 3, right). Therefore, the natural process of sediment accumulation could be observed as no sediment was manually supplied and no artificial rainfall-runoff events were simulated. The results of the surrogated model generally showed that the estimation uncertainty increased as the water-sediment interface moved away from the sensors buried in the sediment bed. For this reason, the methodology only considers the sensor closest to the interface and discards measurements from sensors installed below.



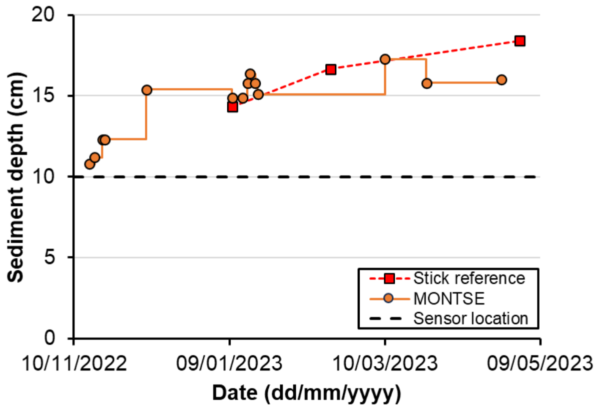


Figure 3. Sediment build-up process in Dübendorf (left) and Delft (right) gully pots. Comparison of the sediment depths estimated with MONTSE and the reference measurements. Dashed lines symbolize the location of the temperature sensors.

Conclusions and future work

The MONTSE system and the analysis of heat transfer processes showed satisfactory results in the estimation of sediment build-up in gully pots. Sediment depths could be estimated when runoff entering the gully pot caused sufficient heat exchange in the water layer. As a result of the field campaigns, the heat exchange was considered sufficient to estimate sediment depths when the temperature gradient was $|\Delta T|>1°C$ by comparing water temperature over 30-min periods. Furthermore, the surrogate model could be developed to integrate sediment depth estimation in the microcontroller (edge computing). Surrogate models simplify the solution of differential equations and, subsequently, computational cost is reduced. Likewise, the data transfer could be reduced by avoiding the transmission of temperature time series. All these improvements could result in updated MONTSE systems to monitor sediment build-up in urban drainage systems. MONTSE could be used to determine optimal cleaning strategies to avoid the loss of hydraulic capacity and, therefore, reduce the risk of flooding and pollutant overflows.

Acknowledgements

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