Co-UDlabs

Data Storage Report

Combining active and passive temperature signals for estimating sediment depths

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DATASET DETAILS

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Dataset Information	
Activity	Transnational Access project
Dataset ID	COUDLABS_TA_EAWAG_02_HALL_Langeveld
Dataset title	Combining active and passive temperature signals for estimating sediment depths
Data sources	Data from laboratory experimental campaign where the variations of water and sediment bed deposits temperature were measured, and intermediate heat-pulses were introduced to both measure the sediment thermal properties and sediment depths (time series format). Dataset includes also mechanical, thermal, and volumetric moisture content properties of sediments.
Content	Processed temperature time series and sensor calibration process: T [ºC] Sediment characteristics: Mass moisture content (%), Volumetric moisture content (m^3/m^3), Organic matter (%), Density (kg/m^3) (wet, wet-bulk, dry-bulk), Thermal conductivity (W/m/ºC), Volumetric heat capacity (J/m^3/ºC).
Formats	csv
Volume	12.5 Mb

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Executive summary

This document is the data storage report of the Co-UDlabs Transnational Access project: *Characterization of thermal properties in sediment samples from urban drainage systems with temperature probes*, by Langeveld et al. The TA project was funded under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008626.

The aim of this document is to describe the experimental campaign and how the accompanying data were collected on the research activity so that others can use and reproduce.

1. INTRODUCTION

1.1. SCIENTIFIC BACKGROUND

Urban drainage systems are often affected by problems of solid particle settling which cause a reduction in their hydraulic capacity, and which can be episodically eroded and transported due to changes in hydraulic conditions, e.g., during rain events. It is estimated based on sampling that between 50 and 70 % of the suspended solids in combined sewer overflows (CSO) are caused by the entrainment of sediment deposits of the network itself (Chebbo and Gromaire, 2004). This range has later been confirmed by using continuous monitoring (Schilperoort et al., 2012). However, the processes involved in this sedimentation are still largely unknown. One of the main reasons for the lack of knowledge about sedimentation processes is the difficulty in obtaining data in UDS, as these are harsh environments in which it is difficult to perform continuous measurements (Bertrand-Krajewski et al., 2021). There are field campaigns in which sediments were characterised, but all of them were at a specific location and occasional (Ashley et al., 2004).

The idea of this research is to use heat transfer processes as a proxy for measuring sediment-bed accumulation. Studies in river streambeds proved the application of methodologies based on the analysis of daily temperature patterns to measure accumulation and erosion processes (DeWesse et al., 2017; Sebok et al., 2017). As for urban drainage systems, the study of heat transfer dynamics has recently emerged in the literature (REF Tait, Figueroa et al., 2021). This study focuses on the analysis of heat transfer processes for measuring sediment accumulation in sewer pipes, which occurs mainly because of solid particles settling under dry weather and insufficient flow velocity conditions. For this purpose, a laboratory-scale model was built to reproduce the heat transfer processes in sewers. The current research applies the methodology developed by Regueiro-Picallo et al (2023a) to analyse the heat transfer processes regarding the presence of sediment accumulation.

Sediment thermal properties are of major importance for the characterisation of heat transfer processes. For this purpose, a Dual-Probe Heat-Pulse (DPHP) was developed to monitor the thermal properties. The DPHP system works by applying a heat source at the sediment-bed bottom and measuring temperatures in the heating and cooling phases. This system is widely used for the characterisation of soil mixtures for agricultural uses (Shehata et al., 2019), river and marine beds (Rui et al., 2019), and groundwater flux studies (Simon et al., 2020).

1.2. OBJECTIVES

This report presents the data collected from a lab-scale campaign. The experimental campaign is framed in a Transnational Access (TA) project within Co-UDlabs. The experiments were designed to further develop an innovative methodology for measuring sediment bed deposits in UDS based on temperature data analysis (Anta et al., 2022; Regueiro-Picallo et al., 2023b). Particularly, the aim of this campaign was to prove the application of this methodology for measuring sewer sediment accumulation. Therefore, the main objectives of this project are the development of a system based on active temperature sensors and its application in the measurement of sediment thermal properties of UDS. Furthermore, this system was completed by installing additional temperature sensors at different height locations to allow the estimation of the sediment depth. The purpose of these measurements is to deepen the understanding of sedimentation and sediment transport processes. The results of this project converge with the scopes of the Co-UDlabs project, such as In-sewer processes, and with some of its objectives, such as the development of innovative techniques for the improvement of UDS management and operation.

2. LABORATORY EXPERIMENTAL CAMPAIGN

2.1. PHYSICAL MODEL DESCRIPTION

A laboratory-scale model was built to reproduce heat transfer processes in sewer pipes. The model consisted of a cylinder 900 mm high and 250 mm in diameter. The walls of the cylinder were made of plexiglass and the lids (top and bottom) of rigid PVC (Figure 1a). The model was placed in a temperature-controlled room. However, it was introduced inside an insulating FOAM case to ensure complete insulation and temperature control.

The tests were carried out by pouring a layer of sediment at the bottom of the cylinder and a layer of water on top. A water bath was used to develop a temperature-controlled system to simulate daily temperature variations in a sewer pipe. For this purpose, water was pumped from the temperature-controlled system into the water layer of the model. A coil system was built to distribute the temperature uniformly in the water layer. Figure 1 summarizes the experimental setup performed in the HALL facilities at Eawag (Dübendorf, Switzerland).

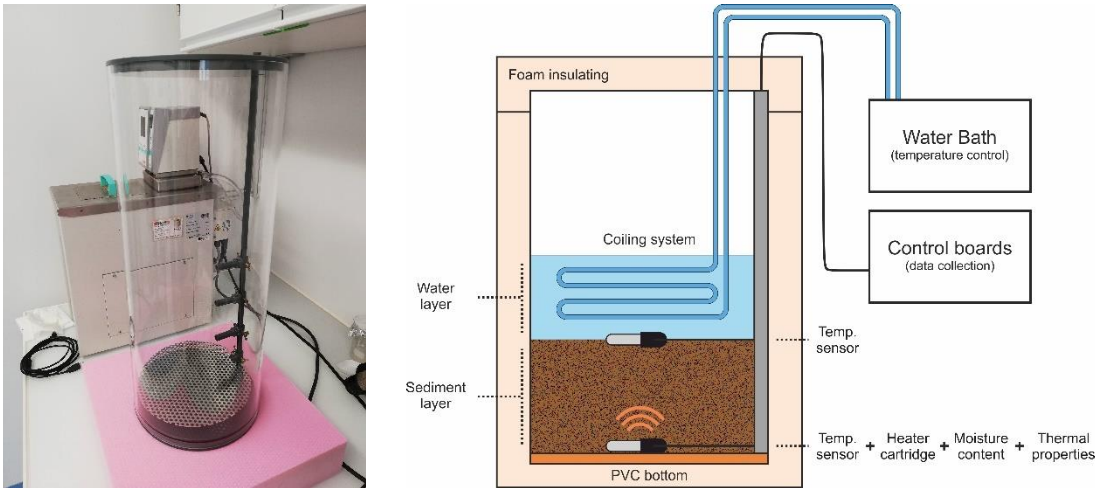

Figure 1. Photo (left) and scheme (right) of the experimental setup.

A device for **MON**itoring **T**emperatures in **SE**diments (MONTSE) was developed for measuring temperatures in the lab-scale experiments. A microcontroller was used to measure and data logging the temperatures in the model. For this purpose, five temperature sensors and a heating cartridge were used. The temperature sensors were placed as follows: two at the bottom, one at the water-sediment interface, one in the water layer, and one outside the cylinder. The heater was placed at the bottom of the cylinder as part of the DPHP system to measure the thermal properties of the sediments. To validate the measurements of the DPHP system, a commercial sensor was installed. Additionally, an electrical conductivity probe was installed at the bottom of the cylinder to measure the relationship between sediment moisture content and porosity.

Figure 2. First version for MONitoring Temperatures in SEdiments (MONTSE) (left) and top view of the cylinder including all the sensors (right).

2.2. EXPERIMENTAL PROCEDURE

The lab-scale experiments replicated the water temperature variations in sewer pipes, which show marked daily patterns that depend on basin activities, habits, and network operation strategies. For this purpose, real in-sewer measurements were taken as a reference from the Urban Water Observatory (UWO) (Figure 3a), operated by Eawag in the municipality of Fehraltorf (Switzerland) (Blumensaat et al., 2021). To reproduce daily temperature patterns in the laboratory model, a function was programmed in the water bath (Figure 3b).

Tests were carried out by combining passive and active temperature measurements:

- Passive temperature measurements: the objective was to measure the temperature time series in the system (water layer, interface, and sediment-bottom) caused by the daily temperature pattern. The sediment depth can be determined by analysing these time series. Three daily cycles (72 hours) were simulated for each test to avoid the subsequent influence of the initial conditions on the analysis of the temperatures.
- Active temperature measurements: corresponding to the DPHP system. Heat pulses were introduced into the sediment layer to measure the thermal properties of the sediments. An active measurement was programmed every 24 hours.

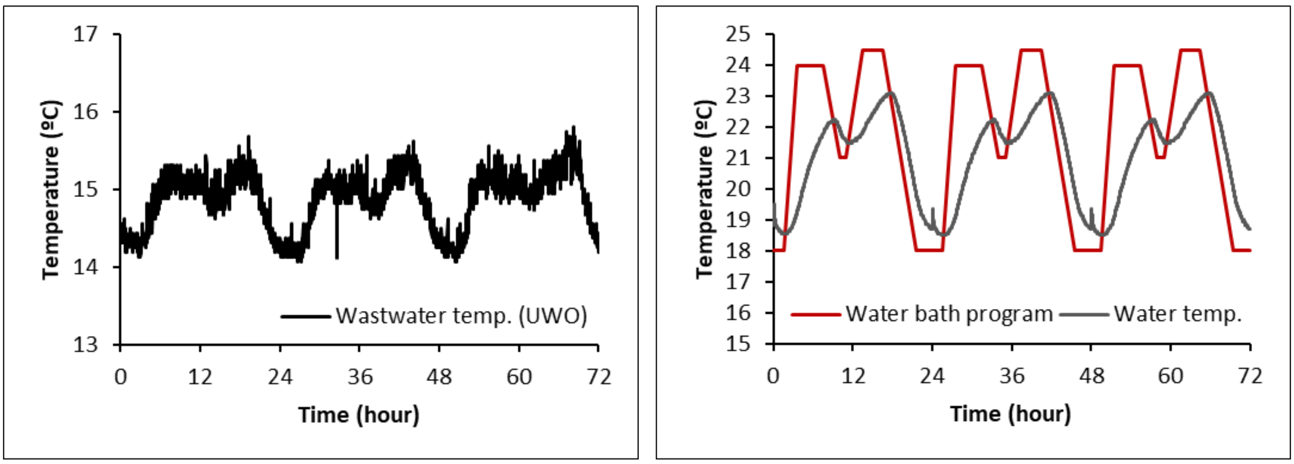

Figure 3. Wastewater temperatures observed at UWO (left) and programmed daily temperature patterns in the lac-scale model (right).

A total of 24 tests were carried out as a result of the combination of the following parameters:

- 4 sediment depths: between 30 and 160 mm.
- 6 sediment mixtures:
  - **Inorganic-sand**. Washed sand with a grain size distribution between 0.315 – 0.5 mm was used as inorganic sediment.
  - **Gully pot**. Two samples were collected from different locations: Eawag (industrial area, Dübendorf) and Wipkingen (residential area, Zürich).
  - **Stormwater tank**. A sample of sediments was collected from a stormwater tank in Zürich.
  - **Sewer pipe**. Two samples were collected from two different main collectors in Zürich.

Table 1 summarizes the experiments performed, also included in the file *\LAB_CAMPAIGN\LAB_measure_info.csv*.

Table 1. Temperature test configurations.

Experiment ID	Sediment type	Sediment depth (m)
Sand_hsed1	Sand	0.027
Sand_hsed2	Sand	0.056
Sand_hsed3	Sand	0.082
Sand_hsed4	Sand	0.120
Gully_1_hsed1	Gully pot	0.032
Gully_1_hsed2	Gully pot	0.058
Gully_1_hsed3	Gully pot	0.084
Gully_1_hsed4	Gully pot	0.117
Gully_2_hsed1	Gully pot	0.037
Gully_2_hsed2	Gully pot	0.065
Gully_2_hsed3	Gully pot	0.101
Gully_2_hsed4	Gully pot	0.137
Tank_hsed1	Stormwater Tank	0.042
Tank_hsed2	Stormwater Tank	0.077
Tank_hsed3	Stormwater Tank	0.118
Tank_hsed4	Stormwater Tank	0.150
Sewer_1_hsed1	Sewer pipe	0.033
Sewer_1_hsed2	Sewer pipe	0.064
Sewer_1_hsed3	Sewer pipe	0.097
Sewer_1_hsed4	Sewer pipe	0.115

Sewer_2_hsed1	Sewer pipe	0.038
Sewer_2_hsed2	Sewer pipe	0.073
Sewer_2_hsed3	Sewer pipe	0.093
Sewer_2_hsed4	Sewer pipe	0.122

2.3. SPATIAL AND TEMPORAL REFERENCE SYSTEMS

Three graded system were set up outside the model to measure the sediment depth. The origin of the coordinates was set at the bottom of the cylinder.

A relative temporal system was used for data collection. The test started when the daily temperature program was initiated in the water bath and ended after 3 cycles of 24 hours. The time resolution of the temperature measurements was established for MONTSE system as follows:

- State 1: Pre-heater activation phase.
  - Time interval: 30 s.
  - Time resolution: 1 s.
- Estado 2: active heat phase.
  - Time interval: 120 s.
  - Time resolution: 1 s.
- Estado 3: Initial phase of heat recovery in the sediment.
  - Time interval: 450 s
  - Time resolution: 1 s.
- Estado 4: Passive measures phase, like versions 1 and 2.
  - Time interval: 85,800 s.
  - Time resolution: 60 s.

States 1 to 3 required a higher temporal resolution due to the DPHP system.

2.4. FIXED PARAMETERS

The following parameters have been assumed to be fixed:

- Mechanical and thermal properties of the sediments were assumed to be constant, regardless of sediment depth (i.e., no sediment stratification was assumed).
- The same calibration parameters of the temperature sensors were applied during the entire campaign.

3. TEMPERATURE MEASUREMENTS

3.1. INSTRUMENTS

Temperature measurements were recorded with DS18B20 (DFROBOT, China) and PT100 sensors (PROBAG, Switzerland). The DS18B20 sensors has an accuracy ±0.50 ºC, while the PT100 (class B) has an accuracy of ±0.30 ºC. Temperature sensors were connected to Arduino MKRZero boards, which included a MicroSD card and a RTC DS3231 board (Accuracy of time clock: ±2 ppm). The electronics were mounted on a PCB board (Figure 4a). In total, 5 DS18B20 sensors, 1 PT100 sensor, and 1 heater cartridge were connected to the microcontroller. The PT100 sensor was included in the heater cartridge.

The sensors were distributed as follows. The heater was placed at the bottom of the cylinder next to two DS18B20 temperature sensors. The distances between the heater and the sensors were 12.5 and 25.5 mm, respectively. In addition, one DS18B20 sensor was placed at the water-sediment interface which varied in each test (Table 1), one DS18B20 sensor was submerged in the water layer, and one sensor was placed outside of the cylinder to measure the temperature at the contour. Table 2 summarizes the information on the temperature sensors installed in the laboratory experimental campaign, also included in the file *\LAB_CAMPAIGN\Sensor_info.csv*.

Table 2. Temperature sensor information for laboratory test campaign.

Sensor ID	Measure	Sensor	Position (*)	Acquisition units
LabDS_1603F5	Temp.	DS18B20	Out-boundary	deg.C
LabDS_170421	Temp.	DS18B20	Interface (*)	deg.C
LabDS_17045F	Temp.	DS18B20	Water layer (*)	deg.C
LabDS_160420	Temp.	DS18B20	Bottom	deg.C
LabDS_1603FC	Temp.	DS18B20	Bottom	deg.C
LabPT_100	Temp.	PT100	Bottom	deg.C

(*) sediment depth dependent (see Table 1).

The heater cartridge was designed specifically for this study. The objective was to develop a DPHP system that minimizes the intrusion in the wastewater flow. The dimensions of this device are shown in Figure 4b and are like those of a DS18B20 sensor. Power is supplied to the heater through a MOSFET connected to the microcontroller board. The amount of power is regulated through a pulse-width modulation (PWM) system. The main features of the heater cartridge are listed below:

- Probe diam.: 6.5 mm. Heating resistor diam.: 4 mm.
- Probe length: 72 mm. Heating resistor length: 46 mm.
- Input voltage: 11.96 Volts.
- Resistance: 3.87 Ohms.
- Power: 50 Watts.
- % PWM: 30%.

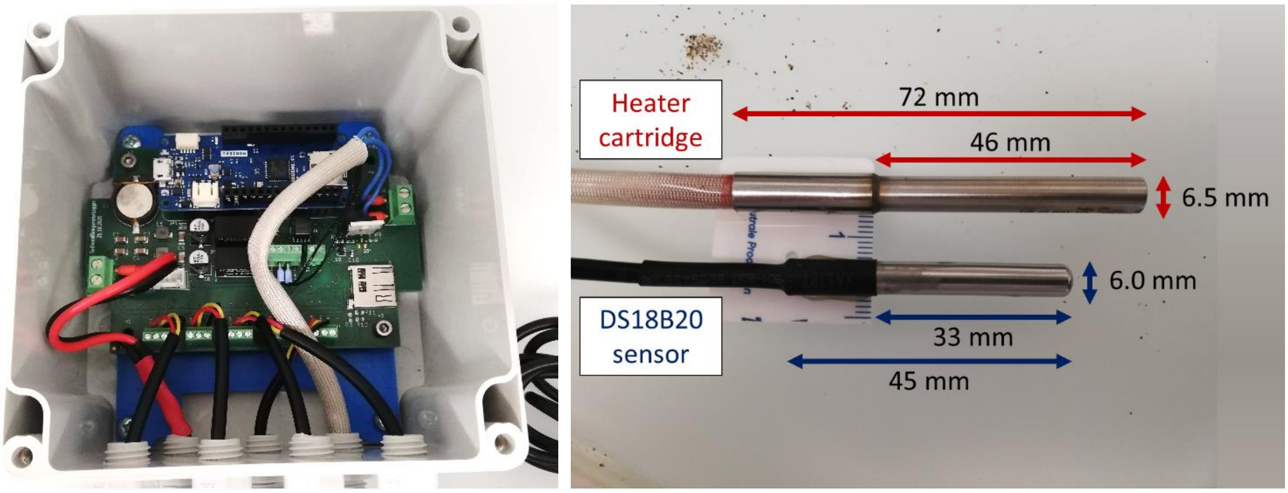

Figure 4. Control and data logging board (left), and heater cartridge and DS18B20 sensor dimensions (right).

3.2. MEASURED PARAMETERS

DS18B20 digital thermometers were programmed to provide 12-bit Celsius temperature measurements (0.0625 ºC resolution). Each DS18B20 communicates over a 1-Wire bus that requires only one data line (and ground) for communication with the Arduino MKRZero board. On the other hand, PT100 sensors measure the temperature through the resistance of a Platinum strip. As a reference, they present a resistance of 100 ohms at a temperature of 0ºC. In this project, we directly record the temperature values from DS18B20 and PT100 sensors by using the Arduino libraries *ds18b20_utils.h* and *pt100_utils.h*, respectively.

3.3. DATA COLLECTION

Raw temperature measurements were saved as text files by the Arduino microcontrollers in microSD cards. Subsequently, raw measurements were corrected by introducing calibration coefficients, which were previously obtained from controlled-uniform temperature measurements. For this purpose, calibration of DS18B20 and PT100 sensors was performed by comparing the temperature measurements with those of the water bath (resolution 0.01ºC). Data were saved in calibration-corrected formats. Next section summarizes how to introduce the calibrating coefficients.

3.4. POST-PROCESSING

DS18B20 and PT100 sensors were calibrated before the experimental campaign by setting constant temperatures in the water bath, within the temperature range expected to be used in the experiments (15-35ºC). For this purpose, temperature measurements were measured once each water temperature was stabilized in the water bath (*\Sensors_calibration*). Temperature measurements were compared and adjusted with the temperature programed in the water bath, which was taken as a reference. Therefore, a linear regression was applied to perform the transformation from raw to corrected temperature measurements (see *Temp_Processed(degC).csv* files). See Appendix 10.1. for further details regarding the calibration coefficients.

Furthermore, sediment-bed temperatures could be also applied to obtain the sediment thermal properties, i.e., by setting a DPHP system. The DPHP system provides the thermal properties by fitting heat pulse models according to the heat source characteristics (See Section 3.1), similar to Kluitenberg et al. (1995). Please note that sediment thermal properties obtained from the DPHP system are not included in this report.

3.5. ADDITIONAL REMARKS

NA

4. SEDIMENT DEPTHS

4.1. INSTRUMENTS

Three graded systems were sticked to the plexiglass cylinder to obtain sediment depth measurements (Figure 5). Sediment depths during the experimental campaign are included in the file *\LAB_CAMPAIGN\Measure_info.csv*.

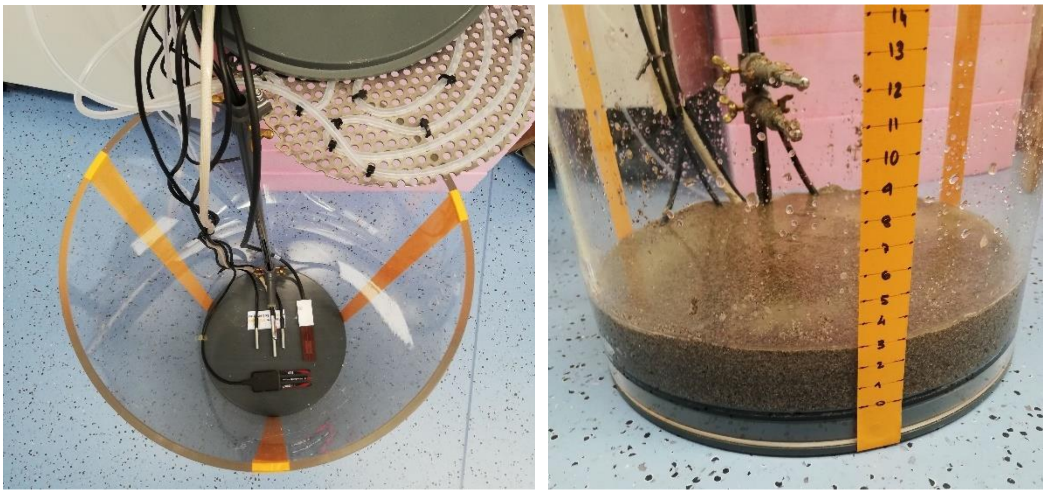

Figure 5. Plant view of the lab-scale model (left), and graded rod for sediment depth measurements (right).

4.2. MEASURED PARAMETERS

The sediment depth was directly measured in the tests where the ruler and graded rod were applied.

4.3. DATA COLLECTION

Sediment depths were measured during each test. At least 3 measurements were taken at different points with graded rods stuck to the model.

4.4. POST-PROCESSING

The sediment depth was obtained by averaging the values from the ruler and graded rod measurements with a tolerance of ±2.5 mm.

4.5. ADDITIONAL REMARKS

NA

5. SEDIMENT PROPERTIES ANALYSIS

5.1. INSTRUMENTS

To carry out the analysis of sediment properties, several sub-samples were taken and analyzed according to standardized methods (APHA, 1998). For this purpose, laboratory equipment such as test tubes, capsules, high-precision weighing scales, drying ovens, etc. were used. Additionally, specific devices were also used for measuring the thermal properties and volumetric moisture content of the samples.

Reference measurements for thermal conductivity and volumetric heat capacity were performed by using a TP01 sensor (Hukseflux, The Netherlands). This sensor contains a wire that heats the surrounding sediment. A thermopile sensor generates a voltage output, as a reaction to the radial temperature difference around the heating wire. The sensitivity of the voltage output was provided by the manufacturer (Sensitivity, S = 139.7 × 10^{-6} V/ºC, and uncertainty = ± 14.0 × 10^{-6} V/ºC).

The volumetric moisture content was measured by using a 5TE sensor (Decagon Devices, USA). The accuracy of the sensor is ±0.03 m^3/m^3 for soils that have an electrical conductivity < 10 dS/m. We can assume that the 95% uncertainty interval is ± 3% of the full-scale readouts.

5.2. MEASURED PARAMETERS

This study was focused on characterizing mechanical and thermal properties of sediments. The properties analyzed are listed below (see also *SEDIMENT_PROPERTIES*):

- Mass moisture content (kg/kg).
- Volumetric moisture content (m^3/m^3).
- Volatile fraction (kg/kg).
- Density (kg/m^3): wet-bulk and dry-bulk density, and specific gravity (wet density).
- Thermal conductivity (W/m/ºC).
- Volumetric heat capacity (J/m^3/ºC).

5.3. DATA COLLECTION

Subsamples from sand, gully pot (2 samples), stormwater tank and sewer pipe (2 samples) sediments were analyzed by following several standard methods, which are listed in the following Table 3.

Table 3. Standard methods for sample analysis.

Parameter (sediment property)	Standard method reference
Moisture content	2540G, APHA (1998)
Organic Matter	2540G, APHA (1998)
Wet density / Specific gravity	2710F, APHA (1998)

To obtain the properties of the sediment with the TP01 sensor, a power supply device (1Volt, 2A) was used to heat the wire as well as a DAQ6510 Digital Multimeter (Keysight, Germany) to measure and storage the voltage on the thermopile sensor. Measurements were carried out manually at a frequency of approximately 24 hours. Raw measurements can be found in the respective subfolders of the laboratory tests (see subfolders in *LAB_campaign*).

In addition, volumetric moisture content values (VWC) were obtained directly from the measurements of the 5TE sensor. This device is equipped with a data logger for data storage. Raw VWC time series were continuously stored with a time resolution of 60 s. VWC time series can be found for each test (see subfolders in *LAB_campaign*).

5.4. POST-PROCESSING

The following parameters were obtained from the combination of parameters obtained by applying standard methods (Table 2).

- Dry bulk density (kg/m^3): $\rho_{dry-bulk} = M_{dry}/V_{wet}$, where M_{dry} is the dry weight of the sample (kg) and V_{wet} is the volume of the wet sample (m^3).
- Wet bulk density (kg/m^3): $\rho_{wet-bulk} = \rho_{dry-bulk} \times (1 + w)$, where w is the mass moisture content (kg/kg).

Furthermore, thermal conductivity and volumetric heat capacity values were derived from the voltage signal on the TP01 sensor thermopile. Following the specifications of the manufacturer (Hukseflux, 2023), a heat pulse must be introduced for three minutes until a stable value of the voltage signal is obtained by the thermopile. Thus, the thermal conductivity (k_t, W/m/ºC) is calculated by dividing the TP01 sensitivity (Section 5.1) by the voltage output difference (ΔU, V), and multiplying by the applied electrical power per meter heating wire (Q, W/m).

$$k_t = \frac{S \cdot Q}{\Delta U} \tag{1}$$

where ΔU is determined by the difference between the voltage output before the heating starts and after heating for three minutes, $\Delta U = U(0) - U(180)$, and Q is determined from the voltage across the heater and taking the heater length (L, m) and electrical resistance (R, ohms) into account, $Q = U_{heater}^2/(R \cdot L)$. A value of Q = 0.934 W/m was set for the measurements.

Volumetric heat capacity (C_v) values were derived from the response time to stepwise heating. Following the specifications of the manufacturer, C_v can be determined during the heat recovery interval after heating. For this purpose, it is required to determine how long it takes to reach 37% of the ΔU. Then, C_v is measured by comparing the TP01 response time to calibration reference conditions.

$$C_v = \frac{k_t}{k} \tag{2}$$

$$k = \frac{k_{ref} \cdot T_{ref}}{T} \tag{3}$$

where k is the thermal diffusivity of the sediment (m^2/s), T is the time to reach the 37% of the ΔU during the heat recovery (s), and k_{ref} and T_{ref} are the reference values of the thermal diffusivity and time to reach 0.37· ΔU under calibration conditions ($k_{ref} = 0.14 \cdot 10^{-6}$ m^2/s; $T_{ref} = 19$ s).

5.5. ADDITIONAL REMARKS

NA

6. DATA AND RESULT FILES ORGANIZATION

The data were organised into three main folders:

- **Laboratory campaign.**

This folder contains the measurements and information of the tests carried out in the laboratory experimental campaign. A subfolder is provided for each test in which the processed temperatures (*Temp_Processed(degC)*), and the raw thermal properties (*TP01*) and VWC (*5TE*) measurements are stored as csv files. In addition, sediment depths conditions and sensor information can be found in *Measure_info.csv* and *Sensor_info.csv*, respectively.

- **Sediment properties.**

Sand, gully pot, stormwater tank and sewer pipe samples were analysed following standards (APHA 1998). Mechanical properties, i.e., mass moisture content, volatile fraction, and densities, are summarized in csv files in the folder: *Standard_methods*. In addition, processed thermal properties and VWC measurements are stored in the folder: *ThermalProp_&_VWC*. The temporal evolution of these properties was measured for each type of sediment. The time reference corresponds to the beginning of the first test (hsed1) for each sediment.

- **Temperature sensor calibration.**

This folder contains the description of the calibration process of the temperature sensors and the resulting coefficients (*Calibration_info.csv*) based on the raw temperature time series from 5 steps in the range of (15-35ºC). Each reference temperature step is stored in a CSV-file. CSV-files contain temperature time series: the first column corresponds to the time and the following columns to the raw temperature measurements. Last column includes the reference temperature from the water bath.

Table 4 summarises the organisation of the data collected in this report.

Table 4. Folders and file organization.

	LAB_CAMPAIGN	Folder
	Sand_hsed1	Subfolder
	Temp_Processed(degC).csv	.csv file
	TP01_220324_171852.csv	.csv file
	TP01_220325_173038.csv	.csv file
	TP01_220326_173448.csv	.csv file
	5TE_220323_173800.csv	.csv file
	Sand_hsed2	Subfolder
	Temp_Processed(degC).csv	.csv file
	TP01_220328_151123.csv	.csv file
	TP01_220329_142340.csv	.csv file
	TP01_220329_175940.csv	.csv file

	5TE_220326_181200.csv	.csv file
	Sand_hsed3	Subfolder
	…	Subfolders
	Sensor_info.csv	.csv file
	Measure_info.csv	.csv file
	SEDIMENT_PROPERTIES	Folder
	Standard_methods	Folder
	APHA_sand.csv	.csv file
	APHA_gully_1.csv	.csv file
	APHA_gully_2.csv	.csv file
	APHA_tank.csv	.csv file
	APHA_sewer_1.csv	.csv file
	APHA_sewer_2.csv	.csv file
	ThermalProp_&_VWC	Folder
	ThermalProp_VWC_sand.csv	.csv file
	ThermalProp_VWC_gully_1.csv	.csv file
	ThermalProp_VWC_gully_2.csv	.csv file
	ThermalProp_VWC_tank.csv	.csv file
	ThermalProp_VWC_sewer_1.csv	.csv file
	ThermalProp_VWC_sewer_2.csv	.csv file
	SENSORS_CALIBRATION	Folder
	Step1_Temp_RawSignal(degC).csv	csv file
	Step2_Temp_RawSignal(degC).csv	csv file
	Step3_Temp_RawSignal(degC).csv	csv file
	Step4_Temp_RawSignal(degC).csv	csv file
	Step5_Temp_RawSignal(degC).csv	csv file
	Calibration_info.csv	.csv file

Figures 6 plot processed temperatures for several laboratory tests measurements.

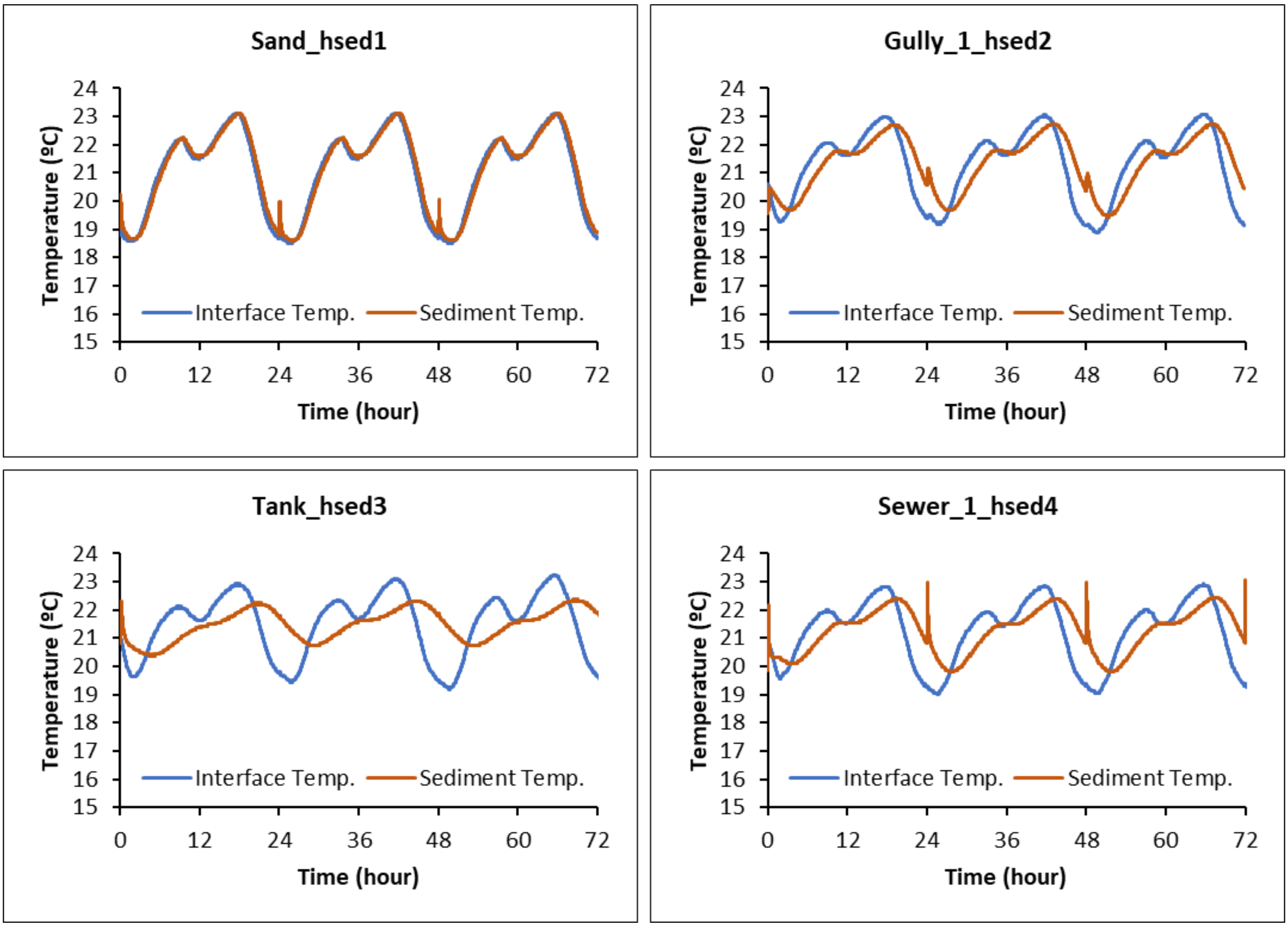

Figure 6. Temperature time series in water-sediment interface (blue line) and sediment-bed (brown line) for tests on sand (hsed1, top-left), gully pot (hsed2, top-right), stormwater tank (hsed3, bottom-left), and sewer pipe (hsed4, bottom-right) sediments.

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9. APPENDICES

9.1. DS18B20 TEMPERATURE SENSOR CALIBRATION

DS18B20 sensors were calibrated by setting 5-step temperatures in the rage of 15-35ºC. For this purpose, all sensors were introduced in the temperature-controlled water bath, and temperatures were measured for 7 minutes with a time resolution of 1 second. Reference temperatures were established from water bath temperatures (Temperature stability: ±0.01ºC). Linear regression equations could be obtained by setting the following equation:

$$T_{\text{reference}} = a \cdot T_{\text{raw}} + b$$

where T_{raw} represents raw temperature measurement (ºC), and a and b are the linear regression coefficients of the DS18B20 calibration. a-coefficients showed values close to 1, as expected, while b-coefficients showed slight oscillations in the offset setting. Table 5 and Figure 7 represent the regression coefficients and lines of the DS18B20 and PT100 sensors, respectively.

Table 5. Regression coefficients of the DS18B20 sensors.

Sensor ID	a	b
LabDS_1603F5	0.99441	0.60816
LabDS_170421	0.99706	0.49065
LabDS_17045F	1.00000	0.31250
LabDS_160420	0.99940	0.44362
LabDS_1603FC	0.99410	0.71020
LabPT_100	0.99101	-1.27957

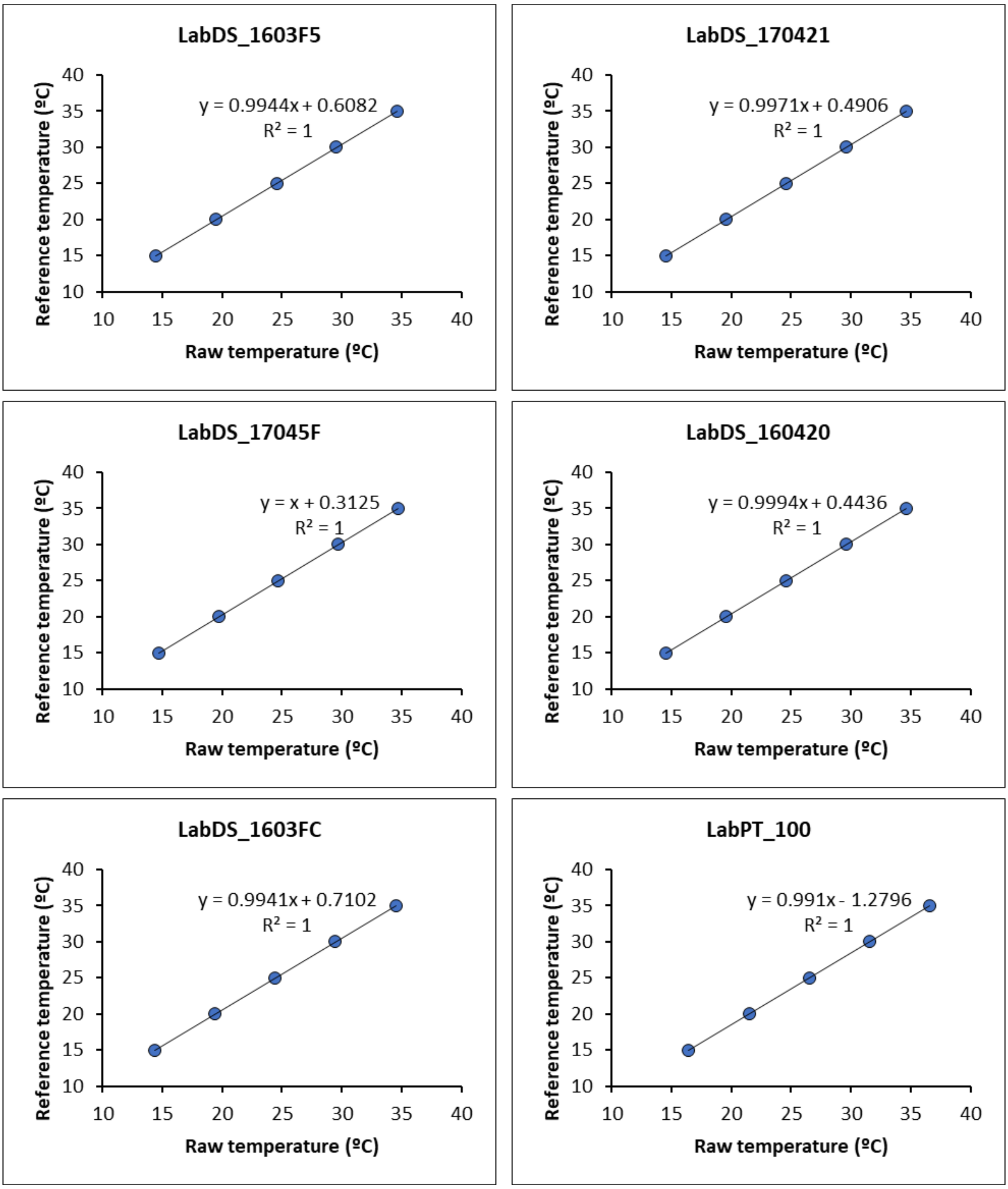

Figure 7. Regression lines obtained from the calibration steps of the DS18B20 and PT100 sensors.