Co-UDlabs

Data Storage Report

Measuring sediment deposits in gully pots from temperature signals

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1. INTRODUCTION

1.1. SCIENTIFIC BACKGROUND

The presence of sediments in urban drainage systems (UDS) has a negative impact on the functioning of UDS. For instance, the resuspension of these sediments may cause substantial pollution of surface waters via combined sewer overflows (CSO). In addition, the persistent sediment accumulation reduces the storage and hydraulic capacity of UDS resulting in an increased risk of flooding. UDS managers spend substantial amount of means and budget to clean out UDS on a regular basis, but there is still a lack of consensus on inspection work frequency (Ertl et al., 2022). One of the main practical issues at present is that there are currently no reliable, and simple-to-execute monitoring methods to obtain information of the location, amount, and composition of sediments in UDS. Recent attempts to monitor sediment bed deposits consisted mostly of single-period measurements that required a high cost of supervision and maintenance, e.g., Lepot et al. (2017), Oms et al. (2003), and Shahsavari et al. (2017). Therefore, sediment monitoring in UDS remains challenging.

The idea behind this research is to use heat transfer processes in UDS 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 application of heat transfer dynamics for measuring sediment accumulation has, to the authors' knowledge, not been explored in the literature so far. Nevertheless, recent studies advanced towards the description of heat transfer processes in UDS infrastructures, such as sewer pipes, especially the fluid-headspace-soil interaction (Abdel-Aal et al., 2021; Figueroa et al., 2021). The current research further extends this analysis by including heat transfer processes regarding the presence of sediment accumulation, like Regueiro-Picallo et al. (2023). Sediment sources are diverse and depend on the UDS infrastructure being analysed. This study focuses on sediment accumulation in gully pots, which occurs mainly because of solid particles settling from surface runoff and wash-off (Rietveld et al., 2020).

1.2. OBJECTIVES

This report presents data collected from lab-scale and field campaigns. The experimental campaigns are framed in the Joint Research Activity 3 (JRA3) within Co-UDlabs Project: "*Improving resilience and sustainability in urban drainage solutions*". 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). Particularly, the aim of these campaigns was to test the application of this methodology in gully pots for measuring sediment build-up. For this purpose, we focused on understanding the heat transfer processes in gully pots in relation to the volume of bed deposits. Thus, the aim of this research is to estimate or at least obtain proof for the presence/absence of sediments by analyzing the differences between the temperature time series measured in the water phase and at the bottom of bed deposits. Results from the experimental campaigns will help to develop new technologies to estimate accumulation in these infrastructures.

The report is structured as follows. The description of the laboratory and field campaigns are described in Section 2 and Section 3, respectively. These two sections include a description of the laboratory model and test procedure, and of the field measurement systems. The subsequent sections describe the measurements performed in both experimental campaigns: temperatures (Section 4), flow (Section 5), sediment level (Section 6), and sediment thermal properties (Section 7). Each section describes the instruments and sensors used, the parameters measured, and how the data were recorded and processed. Section 8 describes the organisation of the data in folders and files. Finally, Section 9 and Section 10 include the bibliographical references and appendices, respectively.

2. LABORATORY EXPERIMENTAL CAMPAIGN

2.1. PHYSICAL MODEL DESCRIPTION

The experimental setup consisted of a 1:1 scaled model gully pot located in the Hydro Hall facilities at Deltares (Delft, The Netherlands). The gully pot model was made of PMMA and the dimensions were 35 × 35 × 101 cm^3. In addition, it had a grated lateral inflow, and a flow outlet opening located 39 cm from the bottom. Further details of the geometry can be found in Rietveld (2021).

The gully pot was placed inside a temperature control tank of dimensions 45 × 84 × 95 cm^3. The outer tank was filled with deionised water and included a temperature control system via a NESLAB RTE-211 water bath (ThermFisher Scientific, The Netherlands). In addition, a system of PVC pipes and connectors led the outflow to a water tank of 550 L which acted as a reservoir and included (i) a defector to force the sedimentation of particles resuspended from the gully pot, (ii) a second temperature control system with a NESLAB ThermoFlex2500 (ThermFisher Scientific, The Netherlands), and (iii) a hydraulic pump with a discharge capacity of 4500 L/h. The setup was operated in a closed loop by pumping the water from the 550 L water tank to the gully pot inlet. Figure 1 summarizes the experimental setup.

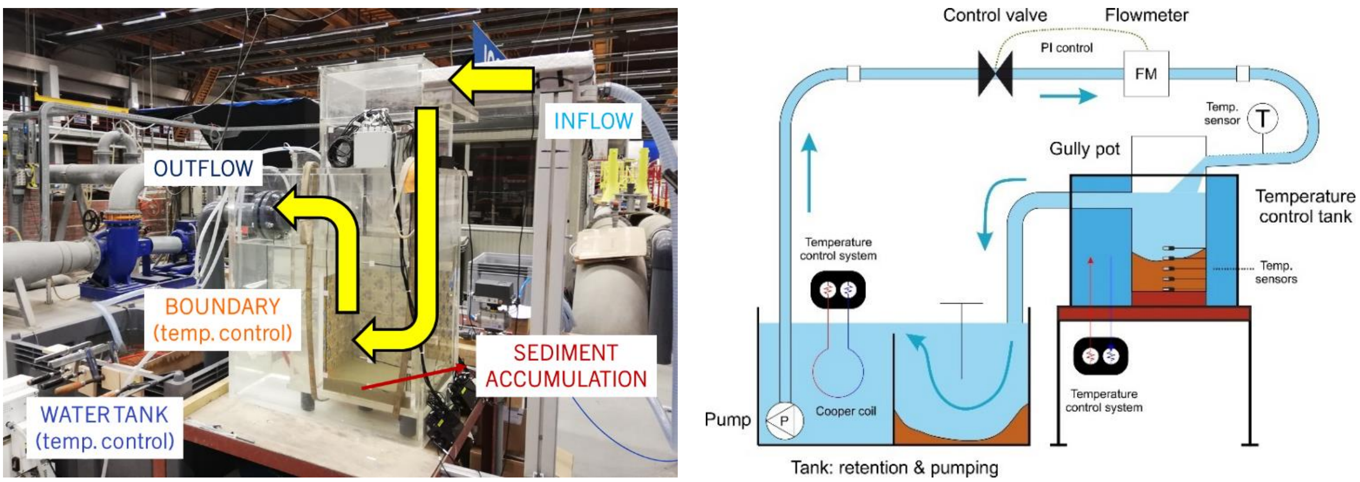


Figure 1. Photo (left) and scheme (right) of the experimental setup.

2.2. EXPERIMENTAL PROCEDURE

The lab-scale experiments replicated the temperature variations in gully pots, which occur because of the mixing of runoff water, pounded water, and sediment bed deposits. Temperature gradients were introduced by setting different temperature setpoints in the control systems, i.e., deionized and 550L water tanks. The tests started by pumping the water to the gully pot inlet once the temperature gradient was stabilised. A PI control system was developed to establish and control the inflow (hydrograph, Figure 2a). The inflow was homogeneously mixed with the pounded water layer in the gully pot without causing significant erosion of the sediment-bed layer. A heat diffusion process was thus initiated through the sediment layer. Once the established hydrograph was completed, the heat recovery phase of the system kept on being measured (Figure 2b).

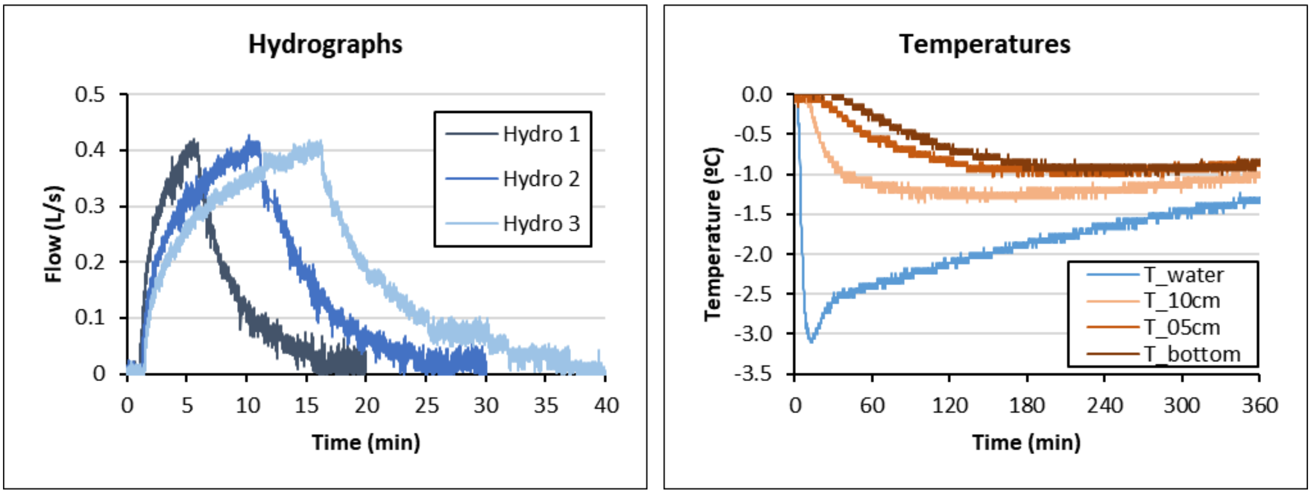


Figure 2. Types of hydrographs (left) and example of temperature measurements in the gully pot (right).

A total of 56 tests were carried out as a result of the combination of the following parameters:

- 5 sediment levels: 5, 10, 15, 20, and 25 cm.
- 3 sediment mixtures: inorganic (sand), organic (gully pot sediments), mix (50% sand and 50% gully pot sediments). Washed sand with a grain size distribution between 0.4 – 0.8 mm was used as inorganic sediments. Furthermore, two gully pot samples were collected from different locations: Deltares (Delft – The Netherlands, sample ID: gullypot_1), and Neeselande (Rotterdam – The Netherlands, sample ID: gullypot_2).
- 3 hydrographs with a peak flow rate of 0.4 L/s at 5 min (hydro1), 10 min (hydro2), and 15 min (hydro3). Only the hydro2 scenario was tested for organic and mixed sediment compounds.
- 2 temperature gradients: -5.5ºC (dT2_neg) and -3.0ºC (dT1_neg). The temperature gradient was obtained as the difference between the water temperature in the 550 L tank and the ponded water inside the gully pot before testing. 6 additional tests were performed for inorganic sediments under positive gradient conditions: 3.0ºC (dT1_pos) y 5.5ºC (dT2_pos).

Reference hydrographs and temperature gradients values were obtained from field measurements (Section 3.1). 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 level (m)	Hydrograph peak (min)	Temperature gradient (ºC)
Sand_05cm_hydro1_dT1_neg	Sand	0.05	5	-2.70
Sand_05cm_hydro2_dT1_neg	Sand	0.05	10	-3.20
Sand_05cm_hydro3_dT1_neg	Sand	0.05	15	-2.85
Sand_05cm_hydro1_dT2_neg	Sand	0.05	5	-5.50
Sand_05cm_hydro2_dT2_neg	Sand	0.05	10	-5.50
Sand_05cm_hydro3_dT2_neg	Sand	0.05	15	-5.55

Sand_10cm_hydro1_dT1_neg	Sand	0.10	5	-3.15
Sand_10cm_hydro2_dT1_neg	Sand	0.10	10	-3.20
Sand_10cm_hydro3_dT1_neg	Sand	0.10	15	-3.20
Sand_10cm_hydro1_dT2_neg	Sand	0.10	5	-5.35
Sand_10cm_hydro2_dT2_neg	Sand	0.10	10	-5.45
Sand_10cm_hydro3_dT2_neg	Sand	0.10	15	-5.40
Sand_15cm_hydro1_dT1_neg	Sand	0.15	5	-3.20
Sand_15cm_hydro2_dT1_neg	Sand	0.15	10	-3.05
Sand_15cm_hydro3_dT1_neg	Sand	0.15	15	-3.05
Sand_15cm_hydro1_dT2_neg	Sand	0.15	5	-5.55
Sand_15cm_hydro2_dT2_neg	Sand	0.15	10	-5.25
Sand_15cm_hydro3_dT2_neg	Sand	0.15	15	-5.25
Sand_20cm_hydro1_dT1_neg	Sand	0.20	5	-3.10
Sand_20cm_hydro2_dT1_neg	Sand	0.20	10	-2.75
Sand_20cm_hydro3_dT1_neg	Sand	0.20	15	-3.15
Sand_20cm_hydro1_dT2_neg	Sand	0.20	5	-5.65
Sand_20cm_hydro2_dT2_neg	Sand	0.20	10	-5.65
Sand_20cm_hydro3_dT2_neg	Sand	0.20	15	-5.65
Sand_25cm_hydro1_dT1_neg	Sand	0.25	5	-2.85
Sand_25cm_hydro2_dT1_neg	Sand	0.25	10	-2.90
Sand_25cm_hydro3_dT1_neg	Sand	0.25	15	-2.80
Sand_25cm_hydro1_dT2_neg	Sand	0.25	5	-5.45
Sand_25cm_hydro2_dT2_neg	Sand	0.25	10	-5.45
Sand_25cm_hydro3_dT2_neg	Sand	0.25	15	-5.50
Sand_05cm_hydro1_dT1_pos	Sand	0.05	5	+3.45
Sand_05cm_hydro2_dT2_pos	Sand	0.05	10	+5.65
Sand_10cm_hydro3_dT2_pos	Sand	0.10	15	+5.00
Sand_15cm_hydro1_dT2_pos	Sand	0.15	5	+5.45
Sand_20cm_hydro2_dT1_pos	Sand	0.20	10	+2.85
Sand_25cm_hydro3_dT1_pos	Sand	0.25	15	+3.30
Gully_05cm_hydro2_dT1_neg	Gully pot	0.05	10	-3.30
Gully_05cm_hydro2_dT2_neg	Gully pot	0.05	10	-4.95
Gully_10cm_hydro2_dT1_neg	Gully pot	0.09	10	-3.00

Gully_10cm_hydro2_dT2_neg	Gully pot	0.09	10	-5.65
Gully_15cm_hydro2_dT1_neg	Gully pot	0.13	10	-3.10
Gully_15cm_hydro2_dT2_neg	Gully pot	0.13	10	-5.70
Gully_20cm_hydro2_dT1_neg	Gully pot	0.19	10	-2.80
Gully_20cm_hydro2_dT2_neg	Gully pot	0.19	10	-5.30
Gully_25cm_hydro2_dT1_neg	Gully pot	0.23	10	-2.85
Gully_25cm_hydro2_dT2_neg	Gully pot	0.23	10	-5.20
Mix_05cm_hydro2_dT1_neg	Mix	0.05	10	-3.00
Mix_05cm_hydro2_dT2_neg	Mix	0.05	10	-5.35
Mix_10cm_hydro2_dT1_neg	Mix	0.10	10	-3.10
Mix_10cm_hydro2_dT2_neg	Mix	0.10	10	-5.50
Mix_15cm_hydro2_dT1_neg	Mix	0.14	10	-2.85
Mix_15cm_hydro2_dT2_neg	Mix	0.14	10	-5.45
Mix_20cm_hydro2_dT1_neg	Mix	0.20	10	-2.80
Mix_20cm_hydro2_dT2_neg	Mix	0.20	10	-5.45
Mix_25cm_hydro2_dT1_neg	Mix	0.25	10	-2.70
Mix_25cm_hydro2_dT2_neg	Mix	0.25	10	-5.45

2.3. SPATIAL AND TEMPORAL REFERENCE SYSTEMS

A coordinate system was set up inside the gully pot to measure the sediment level. The origin of the coordinates was set in one of the lower corners of the gully pot. Regarding the PI control system, a PVC pipe of nominal diameter DN = 32 mm was used to install the flowmeter and the solenoid valve. For this purpose, classic standards were considered by keeping an upstream PVC-pipe section of 5×DN from the flowmeter and a downstream distance of 2×DN to install the solenoid valve.

The tests started when the PI control system was initiated and ended after 3 hours for the configurations with a temperature gradient of 3.0ºC or -3.0ºC, and 6 hours for the gradients of 5.5ºC and -5.5ºC. A relative temporal system to the start of the test was used for data collection. The time resolution of the measurements was as follows:

- <u>Temperatures:</u> a time resolution of 1 s was set during the first hour and 60 s for the rest of the test. We used this time resolution since the greatest temperature changes occurred during the first minutes. Later, tests were set with a uniform time resolution of 5 s because no loss of information on the heat processes occurred.
- <u>Hydrographs:</u> the time resolution for the flow rate measurements was 0.1 s.
- <u>Sediment level:</u> Sediment-bed level measurements were collected before and after each test. For consecutive sand-bed tests in which the sand layer was not changed, the measurement from the previous test was used as the initial condition. Regarding the organic and mix tests, compacting processes were

observed between experiments. For this reason, the sediment level measurements before the tests were used as the initial conditions.

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 level or sediment type (i.e. absence of consolidation or biological processes inducing thermal changes).
- The same calibration parameters of the temperature sensors and PI control system were applied during the entire campaign.

3. FIELD EXPERIMENTAL CAMPAIGN

3.1. FIELD SYSTEM DESCRIPTION

Devices for **MON**itoring **T**emperatures in **SE**diments (MONTSE) were developed for field gully pot measurements. These devices were a simplified version of the one used for laboratory testing. Each device consisted of an IP67 insulated box that contained a temperature measurement and a data collecting system for four sensors and was powered by a battery (3.6 V, 5200 mAh). The boxes were designed to be attached to the underside of the iron gully pot covers by using magnets. As a result, they were not visible to minimise vandalism issues. Three different MONTSE versions were developed.

The first version was designed to measure temperature changes in real gully pots. This version presented two sensors for measuring the air and pounded water temperatures in the gully pots, respectively (Figure 3a). The data from these systems were used as a reference for the design of the experimental campaign in the laboratory. In addition, local rainfall information was available through an automated weather station on Deltares campus (Figure 3b, from the WOW project, UK MetOffice, 2023).

Figure 3. First version for measuring temperature dynamics in real gully pots (left) and weather station at Deltares Campus (right) (MetOffice, 2023).

The second version of MONTSE devices included additional sensors to measure the temperature at the bottom and at 10 cm from the bottom of the gully pots (Figure 4a). In some devices, the air temperature sensor was replaced by one for measuring the soil temperature. In addition, the sensor deployment in the gully pots was improved by using DN 12 mm PVC pipes to rigidize the set up and facilitate the installation in the field. Two sensor orientations were used (Figure 4b). The horizontal sensor orientation was similar to laboratory tests by placing the temperature sensors at the bottom and attached to the walls of the gully pots. The vertical orientation was developed for practical reasons because the gully pot cleaning companies use powerful vacuum cleaners with circular heads that would destroy a horizontal-oriented device, but do not reach the corners of the scupper. Therefore, vertical-oriented devices would safely operate at the gully pot corners.

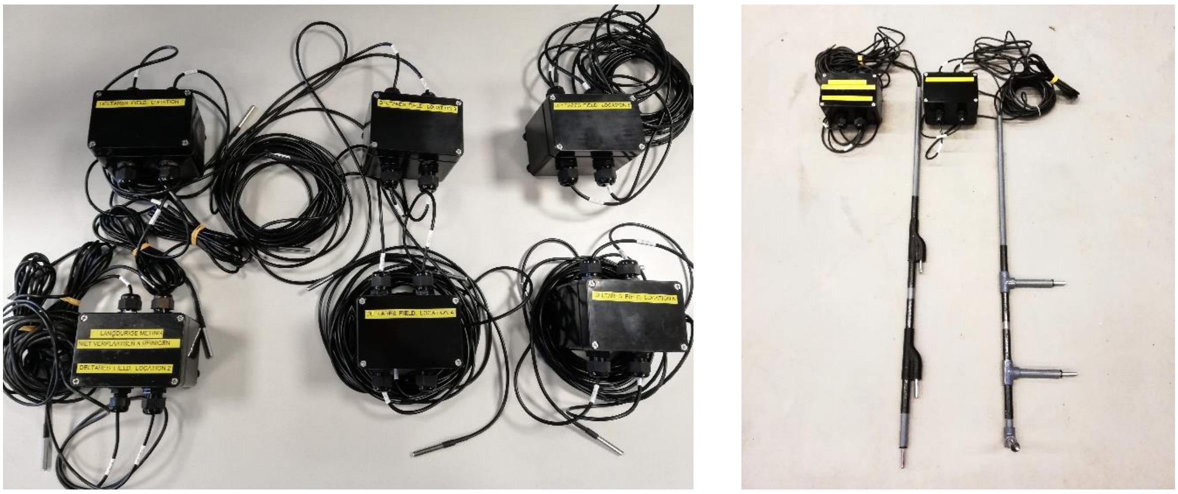


Figure 4. Second version for measuring temperature dynamics in real gully pots (left) and vertical- and horizontal- oriented configurations (right).

Apart from the temperature sensors, the third version included a Dual-Probe Heat-Pulse system. By placing a heater cartridge close to the temperature sensor at the gully pot bottom, sediment thermal properties can be measured in gully pots, similar to Ravazzani (2017). This active heat system showed a high energy consumption Therefore, a more powerful battery (12 V, 1.2 A) was included when compared to the previous versions (Figure 5).

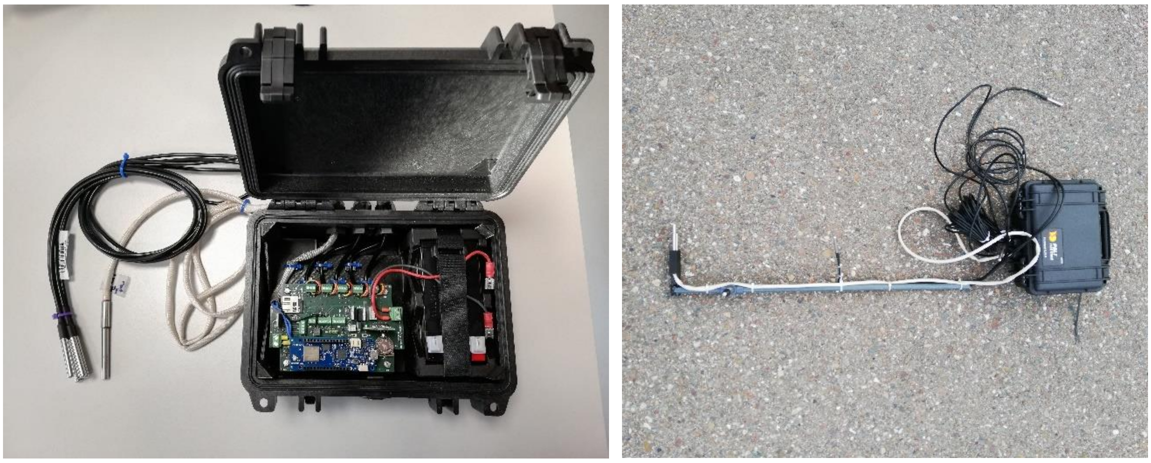


Figure 5. Third version for measuring temperature dynamics in real gully pots (left) and sensor distribution (right).

3.2. SPATIAL AND TEMPORAL REFERENCE SYSTEMS

The bottom of each gully pot was taken as the origin of coordinates like in the experimental laboratory campaign. The first version of MONTSE was installed at two locations at Deltares Campus:

Location ID:	DELTFLD_1

Location coordinates:	51.984627 N, 4.382690 E
General features:	Industrial area, impervious surface, damaged asphalt with nearby garden areas

Pictures:

Figure 6. DELTFLD_1 location.

Location ID:	DELTFLD_2
Location coordinates:	51.985172 N, 4.380112 E
General features:	Industrial area, impervious surface, normal asphalt

Pictures:

Figure 7. DELTFLD_2 location.

For the second version of the MONTSE field devices, 3 locations were selected in South Holland (The Netherlands). 6 temperature monitoring devices were installed (2 per location):

Figure 8. South Holland locations selected for installing the second version of MONTSE (Google Maps, 2023).

- Deltares Campus (Delft)

Location ID:	DELTFLD_1
Location coordinates:	51.984627 N, 4.382690 E
General features:	Industrial area, impervious surface, damaged asphalt
Pictures:  *Figure 9. DELTFLD_1 location.*	

Location ID:	DELTFLD_3
Location coordinates:	51.985045 N, 4.379169 E
General features:	Industrial area, impervious surface, normal asphalt
Pictures:	

Figure 10. DELTFLD_3 location.

- Neeselande (Rotterdam)

Location ID:	ROTTFLD_1
Location coordinates:	51.984989 N, 4.589616 E
General features:	Residential area, impervious surface, brick-paved surface (Dutch clinker bricks)
Pictures:	

Figure 11. ROTTFLD_1 location.

Location ID:	ROTTFLD_2
Location coordinates:	51.985695 N, 4.588685 E
General features:	Residential area, impervious surface, normal asphalt
Pictures:	

Figure 12. ROTTFLD_2 location.

- ABC Westland (The Hague)

Location ID:	HAAGFLD_1
Location coordinates:	52.031935 N, 4.227687 E
General features:	Industrial area, impervious surface, normal asphalt and brick paved sidewalk
Pictures:	

Figure 13. HAAGFLD_1 location.

Location ID:	HAAGFLD_2
Location coordinates:	52.032079 N, 4.227125 E
General features:	Industrial area, impervious surface, normal asphalt, gardened area
Pictures:	

Figure 14. HAAGFLD_2 location.

The third version of MONTSE was tested at Deltares Campus.

Location ID:	DELTFLD_4
Location coordinates:	51.984575 N, 4.381168 E
General features:	Industrial area, impervious surface, normal asphalt, gardened area
Pictures:	

Figure 15. DELTFLD_4 location.

Timestamps were referenced to UTC+0 for the field campaign measurements. Considering the version of MONTSE, the duration of the field measurements was as follows:

- First version: from 19/07/2022 till 23/09/2022
- Second version: from 11/11/2022 till 15/02/2023
- Third version: from 13/01/2023 till 27/01/2023

Temperatures were collected every 60 s for MONTSE versions 1 and 2. This time resolution was set as an agreement to minimise battery consumption and to avoid loss of information of heat transfer processes during rain events. Version 3 required a higher temporal resolution due to the DPHP system. Therefore, 4 states were established:

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

3.3. FIXED PARAMETERS

The following parameters have been assumed to be fixed:

- Mechanical and thermal properties of the sediments were assumed to be constant in each location, regardless of sediment level.
- The same calibration parameters of the temperature sensors were applied during the entire campaign.

4. TEMPERATURE MEASUREMENTS

4.1. 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). In total, 48 DS18B20 sensors, 2 PT100 sensors and 11 Arduino MKRZero boards were used (4 boards in the laboratory test and 7 boards in the field campaign):

- <u>**Laboratory setup:**</u>
  - **DELTLAB_C** board operated using 4 x DS18B20 sensors.
  - **DELTLAB_1** board operated using 7 x DS18B20 sensors.
  - **DELTLAB_2** board operated using 7 x DS18B20 sensors.
  - **DELTLAB_3** board operated using 5 x DS18B20 and 1 x PT100 sensors.

DELTLAB_C was used to measure initial temperatures at the gully pot water layer (GP water), the temperature-controlled outer tank (OT), the temperature-controlled 550L tank (ST), and the room temperature (Air). The boards DELTLAB _1, _2, and _3 were installed to measure the temperatures inside the gully pot, at the inlet, and the room temperature. Inside the gully pot, 4 sensors were placed at the bottom and 2 sensors on the walls every 5 cm from the bottom up to 30 cm. In addition, a sensor was installed in one of the corners close to the gully pot bottom to reproduce the measurements made with the vertical-oriented configuration in the field campaigns. Table 2 summarizes the information on the temperature sensors installed in the laboratory experimental campaign, also included in the file *LAB_CAMPAIGN\LAB_sensor_info.csv*.

Table 2. Temperature sensor information for laboratory test campaign.

Sensor ID	Measure	System	Sensor	Position (*)	Xcoord. (m)	Ycoord. (m)	Zcoord. (m)	Acquisition units
LabDS_013C89	Temp.	DELTLAB_C	DS18B20	GP water	-	-	-	deg.C
LabDS_013CBE	Temp.	DELTLAB_C	DS18B20	OT	-	-	-	deg.C
LabDS_013C28	Temp.	DELTLAB_C	DS18B20	ST	-	-	-	deg.C
LabDS_013C12	Temp.	DELTLAB_C	DS18B20	Air	-	-	-	deg.C
LabDS_0A3CDD	Temp.	DELTLAB_1	DS18B20	GP Bottom	0.090	0.175	0.000	deg.C
LabDS_2A3C38	Temp.	DELTLAB_1	DS18B20	GP Wall	0.175	0.345	0.050	deg.C
LabDS_A53CEB	Temp.	DELTLAB_1	DS18B20	GP Wall	0.005	0.175	0.100	deg.C
LabDS_013C83	Temp.	DELTLAB_1	DS18B20	GP Wall	0.175	0.345	0.150	deg.C
LabDS_573CDD	Temp.	DELTLAB_1	DS18B20	GP Wall	0.005	0.175	0.200	deg.C
LabDS_713CAE	Temp.	DELTLAB_1	DS18B20	GP Wall	0.175	0.345	0.250	deg.C
LabDS_823C47	Temp.	DELTLAB_1	DS18B20	GP Wall	0.005	0.175	0.300	deg.C
LabDS_1D3C43	Temp.	DELTLAB_2	DS18B20	GP Bottom	0.260	0.175	0.000	deg.C
LabDS_423C05	Temp.	DELTLAB_2	DS18B20	GP Wall	0.175	0.005	0.050	deg.C
LabDS_993CF9	Temp.	DELTLAB_2	DS18B20	GP Wall	0.175	0.005	0.150	deg.C
LabDS_A33C65	Temp.	DELTLAB_2	DS18B20	GP Wall	0.170	0.005	0.250	deg.C
LabDS_4F3C07	Temp.	DELTLAB_2	DS18B20	GP Corner	0.005	0.005	0.010	deg.C
LabDS_583C85	Temp.	DELTLAB_2	DS18B20	GP Inflow	-	-	-	deg.C
LabDS_0E3C83	Temp.	DELTLAB_2	DS18B20	Air	-	-	-	deg.C
LabDS_1603FC	Temp.	DELTLAB_3	DS18B20	GP Bottom	0.175	0.175	0.000	deg.C
LabDS_160420	Temp.	DELTLAB_3	DS18B20	GP Wall	0.345	0.175	0.100	deg.C
LabDS_17045F	Temp.	DELTLAB_3	DS18B20	GP Wall	0.345	0.175	0.200	deg.C
LabDS_170421	Temp.	DELTLAB_3	DS18B20	GP Wall	0.345	0.175	0.300	deg.C
LabDS_1603F5	Temp.	DELTLAB_3	DS18B20	GP Wall	0.175	0.005	0.500	deg.C

LabPT_100	Temp.	DELTLAB_3	PT100	GP Bottom	0.180	0.175	0.000	deg.C

(*) GP water: gully pot water layer; GP bottom: gully pot bottom; GP wall: gully pot wall; GP Corner: gully pot corner; OT: gully pot temperature-controlled tank; ST: temperature-controlled 550L tank; Air: room temperature

- **Field campaigns:**
  - **DELTFLD_1** board operated initially using with 2 x DS18B20 sensors for the first version. Later, the system was updated with 4 x DS18B20 sensors for the second version.
  - **DELTFLD_2** board operated using 2 x DS18B20 sensors.
  - **DELTFLD_3** board operated using 4 x DS18B20 sensors.
  - **DELTFLD_4** board operated using 5 x DS18B20 and 1 x PT100 sensors.
  - **ROTTFLD_1** board operated using 4 x DS18B20 sensors.
  - **ROTTFLD_2** board operated using 4 x DS18B20 sensors.
  - **HAAGFLD_1** board operated using 4 x DS18B20 sensors.
  - **HAAGFLD_2** board operated using 4 x DS18B20 sensors.

MONTSE version 1 included DELTFLD_1 and DELTFLD_2 boards for measuring water-temperature dynamics in gully pots. MONTSE version 2 included the updated version of DELTFLD_1, DELTFLD_3, ROTTFLD_1, ROTTFLD_2, HAAGFLD_1, and HAAGFLD_2 for measuring water, sediment and, in some cases, soil temperature dynamics in gully pots. Finally, MONTSE version 3 included DELTFLD_4 board for measuring both temperature dynamics and sediment thermal properties. Table 3 summarizes the information about the temperature sensors in the field campaign, also included in the file *\FIELD_CAMPAIGN\FLD_sensor_info.csv*.

Table 3. Temperature sensor information for the field campaign.

Sensor ID	Measure	Sensor	Location	System	Version	Position / Orientation	Zcoord. (m)	Acquisition units
FldDS_0702FC	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	1	Air / -	-	deg.C
FldDS_130135	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	1	Water / -	-	deg.C
FldDS_02022B	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	2	Water / horizontal	0.35	deg.C
FldDS_193C98	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	2	Wall / horizontal	0.10	deg.C
FldDS_D93CA2	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	2	Bottom / horizontal	0.00	deg.C
FldDS_130135	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_1	2	Soil / vertical	-	deg.C
FldDS_02022B	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_2	1	Air / -	-	deg.C

FldDS_130106	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_2	1	Water / -	-	deg.C
FldDS_0702FC	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_3	2	Water / vertical	0.35	deg.C
FldDS_B23C8B	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_3	2	Wall / vertical	0.10	deg.C
FldDS_B13CC7	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_3	2	Bottom / vertical	0.00	deg.C
FldDS_130106	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_3	2	Soil / vertical	-	deg.C
FldDS_013C79	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_4	3	Water / horizontal	0.35	deg.C
FldDS_013C34	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_4	3	Wall / horizontal	0.10	deg.C
FldDS_013CC5	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_4	3	Bottom / horizontal	0.00	deg.C
FldDS_013C7B	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_4	3	Soil / horizontal	-	deg.C
FldDS_013CB5	Temp.	DS18B20	Deltares (Delft, NL)	DELTFLD_4	3	Air / -	-	deg.C
FldPT_100	Temp.	PT100	Deltares (Delft, NL)	DELTFLD_4	3	Bottom / horizontal	0.00	deg.C
FldDS_013CF5	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_1	2	Water / vertical	0.35	deg.C
FldDS_013C73	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_1	2	Wall / vertical	0.10	deg.C
FldDS_013C9E	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_1	2	Bottom / vertical	0.00	deg.C
FldDS_0000B1	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_1	2	Air / -	-	deg.C
FldDS_0111D8	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_2	2	Water / horizontal	0.35	deg.C
FldDS_013C68	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_2	2	Wall / horizontal	0.10	deg.C
FldDS_013CD1	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_2	2	Bottom / horizontal	0.00	deg.C
FldDS_013C07	Temp.	DS18B20	Neeselande (Rotterdam, NL)	ROTTFLD_2	2	Air / -	-	deg.C

FldDS_013C34	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_1	2	Water / vertical	0.35	deg.C
FldDS_013C49	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_1	2	Wall / vertical	0.10	deg.C
FldDS_013C8F	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_1	2	Bottom / vertical	0.00	deg.C
FldDS_0000E0	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_1	2	Air / -	-	deg.C
FldDS_0000CE	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_2	2	Water / horizontal	0.35	deg.C
FldDS_013CFB	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_2	2	Wall / horizontal	0.10	deg.C
FldDS_013CC5	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_2	2	Bottom / horizontal	0.00	deg.C
FldDS_013CE8	Temp.	DS18B20	ABC Westland (The Hague, NL)	HAAGFLD_2	2	Air / -	-	deg.C

4.2. 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.

4.3. 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 a certified sensor. Data were saved in calibration-corrected formats. Next section summarizes how to introduce the calibrating coefficients.

4.4. POST-PROCESSING

DS18B20 and PT100 sensors were calibrated before the experimental and field campaigns by setting constant temperatures in the water bath, within the temperature range expected to be used in the experiments (10-35ºC). 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 data collected from a certified PT100 sensor, 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. and 10.2. for further details regarding the calibration coefficients and the PT100 certification datasheet, respectively.

4.5. ADDITIONAL REMARKS

NA

5. FLOW MEASUREMENTS

5.1. INSTRUMENTS

The flow measurements were only performed in the laboratory tests. For this purpose, a PI (Proportional-Integral) control system was developed (NI, 2023). The system consisted of a Magnetic Inductive Flowmeter DMH (KOBOLD, USA) and a solenoid valve (Air Torque, Italy) with the aim of regulating the flow rate in each test. Additionally, a SIPART PS2 positioner (SIEMENS, France) with air supply was needed to control the opening and closing system of the solenoid valve. These devices were installed in the rigid PVC pipe (DN 32mm) before the gully pot inlet. The flowmeter was calibrated by the manufacturer, including a certificate test report (not included in this report). The device has an accuracy of ±0.3% of measured value +0.01% of the flowrate at 10 m/s.

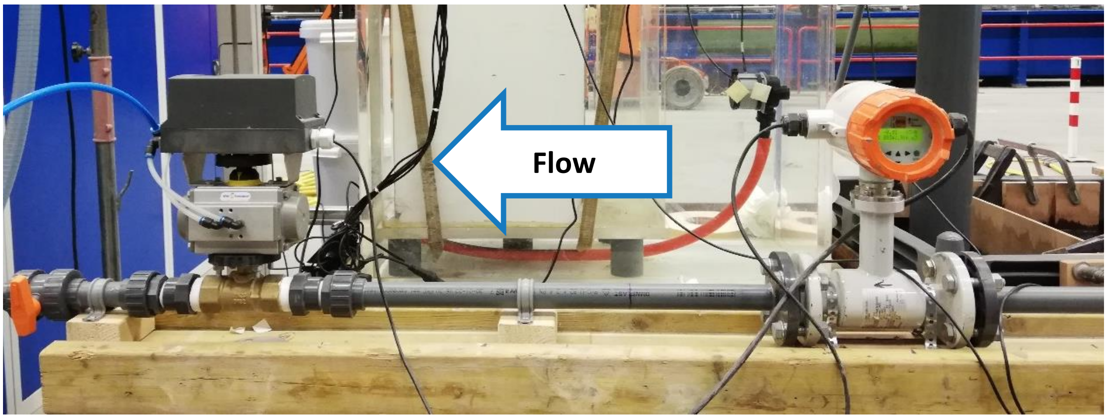


Figure 16. Solenoid valve (left) and flowmeter (right) for the PI control system.

5.2. MEASURED PARAMETERS

Two measurements were obtained with the PI-control system. On the one hand, the flow meter measured the flow rate (L/s), while the solenoid valve measured the opening rate in volts.

5.3. DATA COLLECTION

The PI-control system was implemented as a LabVIEW program running on a PC with an analogue in and output module (IO module). To use the program first a predefined hydrograph must be loaded into the memory, the solenoid valve must be closed, and the pump started. Once the program is running, the LabVIEW program repeats a loop every $\Delta T = 0.1$ sec, with strict timing. Every loop starts by reading the analogue input from the flow meter, using the IO module. A linear function, $Q = 0.973*U - 0.973$, is used to calculate the measured flow, with Q as flow rate in (L/s) and U as voltage in (Volt). This formula is found by fitting a function to the output values on the display of the flowmeter with the output voltages. Then, the program reads the next flow rate setpoint out the memory containing the predefined hydrograph. The PI control algorithm is used to calculate the next voltage output to the solenoid valve, which is displayed by the IO module.

The PI controller was configured to make the system sensitive to flow changes. It was found that the system is responsive and shows no overshot for a proportional gain of 0.15 and integral gain of 0.007.

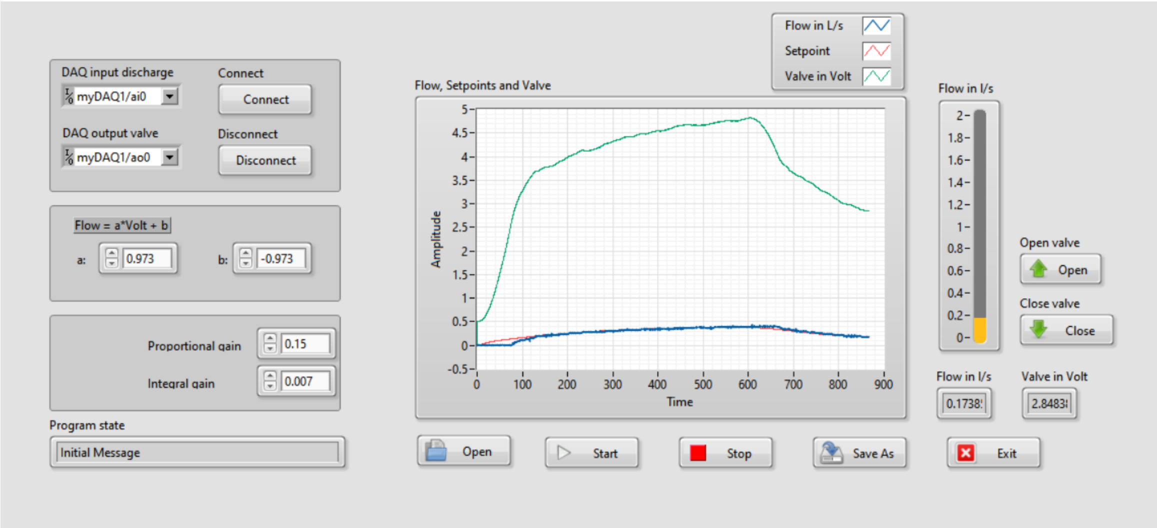


Figure 17. PI control software.

5.4. POST-PROCESSING

Every loop of the program stores the system time, flow setpoint, flow rate and voltage. At the end of the hydrograph this data is stored to a file for later data post-processing.

5.5. ADDITIONAL REMARKS

NA

6. SEDIMENT LEVEL

6.1. INSTRUMENTS

Two techniques were used in the laboratory tests to obtain the level (and from that the deposited depth) of sediments on the bottom. On the one hand, the Structure from Motion (SfM) photogrammetric technique was applied in the tests with inorganic sediments. For this purpose, a GoPro HERO 9 Black camera (GoPro, USA) was used to take underwater images of the sediment bed. Additionally, markers were installed to scale and reference the sediment bed reconstruction (Figure 18, left. Further details in Section 6.4). The tolerance of the SfM measurements was strongly influenced by the coordinates of the targets. The residual errors obtained from the reconstructed model were less than 1 mm in all cases, and the spatial resolution of the point cloud was 2 mm. On the other hand, a ruler was used for the tests with organic and mix sediments because the high turbidity of the water layer inside the gully pot prevented the use of the photogrammetric technique. A tolerance of ± 10 mm was stablished between the single-site measurements and the average sediment level.

A graded rod was used in the real gully pots to obtain sediment level measurements during the field visits (Figure 18, right). This rod was previously used to measure sediment build up in real gully pots (Rietveld, 2021). A tolerance of ± 20 mm was stablished between the single-site measurements and the average sediment level. Sediment depths during the experimental campaign are included in the file *FIELD_CAMPAIGN\FLD_measure_info.csv*.

Figure 18. Targets to perform the scaling and referencing of the sediment-bed 3D reconstruction (left), and graded rod for field measurements (right).

6.2. MEASURED PARAMETERS

The result from SfM technique was the 3D reconstruction of the sediment bed. This provided accurate information on the sediment level at the locations where the temperature sensors were installed. In addition, the variability of the sediment depth could be also measured. Conversely, the sediment level was directly measured in the tests where the ruler and graded rod were applied.

6.3. DATA COLLECTION

An average of 25 photos were taken to perform the 3D reconstruction of the sediment bed with the SfM technique. The photos were taken by submerging the camera in the pounded water of the gully pot. An image overlapping of 60% was set following previous references (Morgan et al., 2017; Naves et al., 2018). The camera configuration was as follows:

- Time-lapse: 5 s/photo.
- Resolution: 5K (5184 x 3888 pixels).
- Field of view (FOV): linear (following the GoPro settings).

The sediment-bed at the end of each test was taken as a reference, which matched the initial sediment-bed at the start of the next test.

Two permanent rulers were installed on gully pot walls for measuring the sediment level for the tests performed with organic and mixed sediments. Under these circumstances, sediment levels were recorded at the beginning and end of each test due to a possible erosion of the sediment bed. Regarding the field measurements with the graded rod, at least 3 measurements were taken at different points of the bed for each gully pot.

6.4. POST-PROCESSING

The 3DF Zephyr free and MeshLab software were used to obtain the 3D reconstruction of the sediment bed. 3DF Zephyr free was used to perform the sparse and dense reconstructions from the images. The result was a textured mesh that reproduces the geometry of the sediment bed (Figure 19). However, real scale and known coordinate system were not available. For this purpose, MeshLab was used to perform the scaling and referencing of the model. At least 4 points of known coordinates must be provided in the model. We used the coordinates of 6 markers on the gully pot wall to obtain a better fit of the 3D reconstruction.

The sediment depth was obtained by averaging the values from the ruler and graded rod measurements.

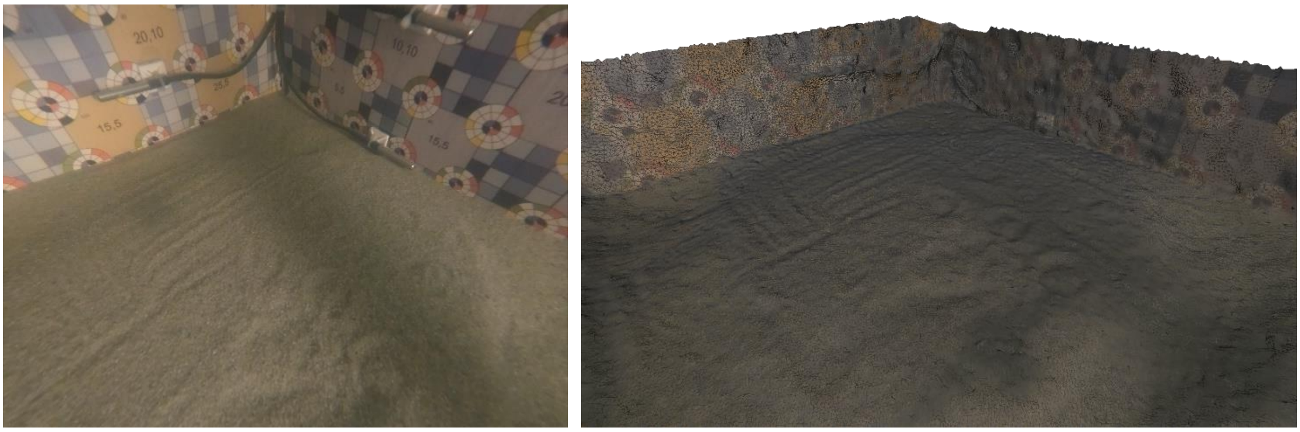


Figure 19. Raw photo (left) and 3D model reconstruction (right).

6.5. ADDITIONAL REMARKS

NA

7. SEDIMENT PROPERTIES ANALYSIS

7.1. INSTRUMENTS

To carry out the analysis of sediment properties (sand, gully pot and mix), 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. Thermal conductivity and volumetric heat capacity measurements 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 = 139.7×10^{-6} V/ºC and uncertainty = $\pm 14.0 \times 10^{-6}$ V/ºC). The volumetric moisture content was measured by using a 5TE sensor (Decagon Devices, USA), which has an accuracy of ± 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.

7.2. 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.

- Thermal conductivity (W/m/ºC)
- Volumetric heat capacity (J/m^3/ºC)

7.3. DATA COLLECTION

Subsamples from Sand, Gully Pot (2 samples), and Mix sediments were analyzed by following several standard methods, which are listed in the following Table 4.

Table 4. Standard methods for sample analysis.

Parameter (sediment property)	Standard method reference
Moisture content	2540G, APHA (1998)
Organic Matter	2540G, APHA (1998)

To obtain the properties of the sediment with the TP01 sensor, a power supply charger (1Volt, 2A) was used to heat the wire as well as a 34401A Digital Multimeter (Keysight, The Netherlands) to measure the voltage on the thermopile sensor. Control and datalogging was performed with an open-source software (GitHub, 2023). Thermal conductivity and volumetric heat capacity values were derived from the voltage signal on the thermopile. In addition, volumetric moisture content values were obtained directly from the measurements of the 5TE sensor. This device is equipped with a data logger for data storage.

7.4. 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).

7.5. ADDITIONAL REMARKS

NA

8. DATA AND RESULT FILES ORGANIZATION

The data were organised into four main folders:

- **Laboratory campaign.**

  This folder contains the measurements and information of the tests carried out in the laboratory experimental campaign. The data for each test was stored in subfolders containing temperature (*Temp_Processed(degC).csv*), flow (*PI_flow.csv*), and sediment level (*Textured_mesh.txt*) measurements. The sub-folders names match the test IDs (Table 1). Temperature CSV-files were compiled for each data collection system, i.e., DELTLAB_C, DELTLAB_1, DELTLAB_2, and DELTLAB_3. Each CSV-file includes the temperature time series. The first column corresponds to the time and the following columns correspond to the temperature measurements of the sensors connected to each system (see Table 1 and Table 2). Flow CSV-files contain the time series of the voltage signal (from the valve), and the flowrate for each test. Finally, point cloud data (x- y- and z- coordinates) of sediment bed are provided in TXT-files for tests performed with sand.

- **Field campaign.**

This folder contains the temperature measurements, the collecting system references and the location information where the MONTSE systems were installed. The name of the files containing the temperature data include the Location ID (Section 3.2). Temperature CSV-files were compiled for each data collection system, i.e., DELTFLD_1, DELTFLD_2, DELTFLD_3, DELTFLD_4, ROTTFLD_1, ROTTFLD_2, HAAGFLD_1 and HAAGFLD_2. Each CSV-file includes the temperature time series. The first column corresponds to the timestamp (UTC+0) and the following columns correspond to the temperature measurements of the sensors connected to each system (see Table 3).

- **Sediment properties.**

The sediment properties were analysed for laboratory and field samples following standards (APHA, 1998). Sand, organic samples (collected in gully pots) and the mixture of sand and organic sediments were analysed. Mechanical properties (mass water content, dry and wet bulk densities, and volatile fraction) are summarized in the folder: *Standard_methods*, including raw data. A CSV-file was compiled for each sediment sample. Thermal properties and volumetric water content measurements from TP01 and 5TE sensors are summarized in CSV-files in the folder: *ThermalProp_&_VWC*. Each CSV-file contains the information of the time at which the measurement was taken relative to the time of sample preparation (first column), the thermal conductivity (second column), volumetric heat capacity (third column), and volumetric water content (forth columns).

- **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 6 steps in the range of (10-35ºC). Each data collection systems presents a sub-folder containing 6 CSV-files that correspond to the temperature steps. 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 certified PT100 sensor.

Table 5 summarises the organisation of the data collected in this report.

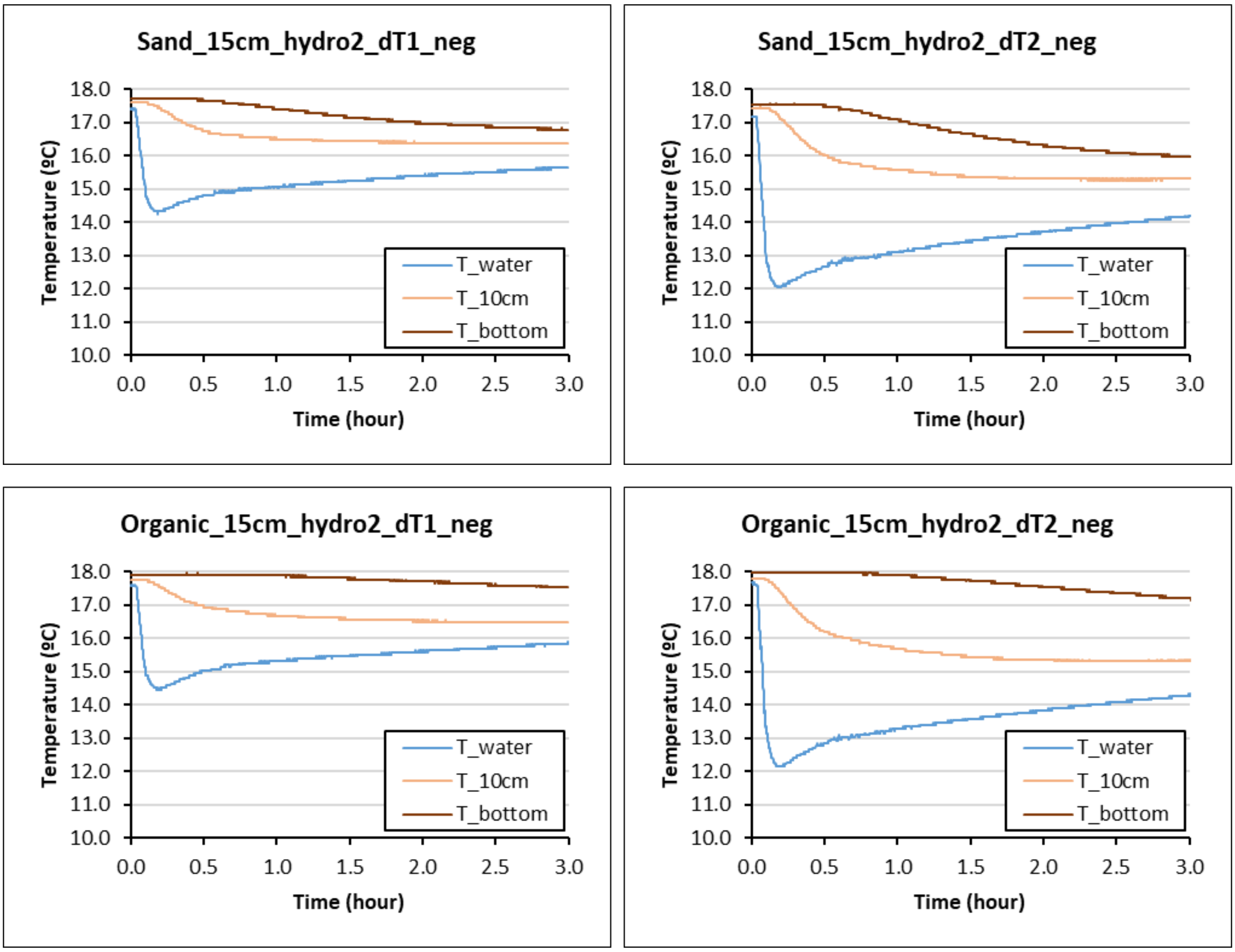
Table 5. Folders and file organization.

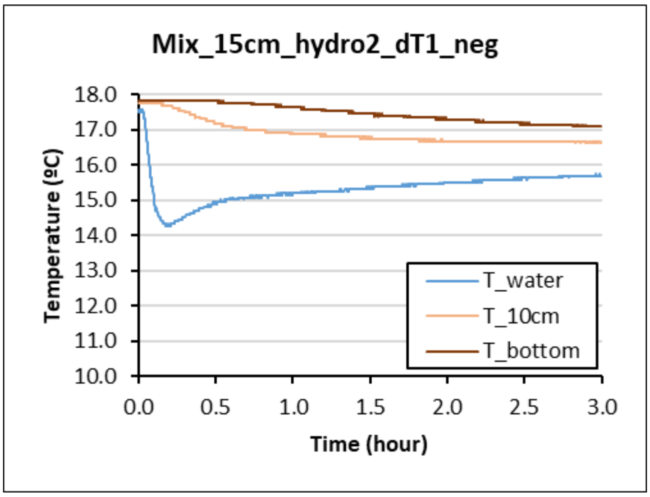
	LAB_CAMPAIGN	Folder
	Sand_05cm_hydro1_dT1_neg	Subfolder
	PI_flow.csv	.csv file
	DELTLAB_1_Temp_Processed(degC).csv	.csv file
	DELTLAB_2_Temp_Processed(degC).csv	.csv file
	DELTLAB_3_Temp_Processed(degC).csv	.csv file
	DELTLAB_C_Temp_Processed(degC).csv	.csv file

	Textured_mesh.txt	.txt file
	Sand_05cm_hydro2_dT1_neg	Subfolder
	Sand_05cm_hydro3_dT1_neg	Subfolder
	…	Subfolders
	LAB_sensor_info.csv	.csv file
	LAB_measure_info.csv	.csv file
	FIELD_CAMPAIGN	Folder
	DELTFLD_1v1_Temp_ Processed(degC).csv	.csv file
	DELTFLD_1v2_Temp_ Processed(degC).csv	.csv file
	DELTFLD_2_Temp_ Processed(degC).csv	.csv file
	…	.csv files
	FLD _sensor_info.csv	.csv file
	FLD_measure_info.csv	.csv file
	SEDIMENT_PROPERTIES	Folder
	Standard_methods	Folder
	APHA_sand.csv	.csv file
	APHA_gullypot_1.csv	.csv file
	APHA_gullypot_2.csv	.csv file
	APHA_mix.csv	.csv file
	Thermal_properties	Folder
	Thermal_prop_sand.csv	.csv file
	…	.csv files
	SENSORS_CALIBRATION	Folder
	DELTLAB_1	Subfolder
	DELTLAB_1_Step1_Temp_RawSignal(degC).csv	.csv file
	DELTLAB_1_Step2_Temp_RawSignal(degC).csv	.csv file
	DELTLAB_1_Step3_Temp_RawSignal(degC).csv	.csv file
	DELTLAB_1_Step4_Temp_RawSignal(degC).csv	.csv file
	DELTLAB_1_Step5_Temp_RawSignal(degC).csv	.csv file
	DELTLAB_1_Step6_Temp_RawSignal(degC).csv	.csv file

	DELTLAB_2	Subfolder
	DELTLAB_3	Subfolder
	…	Subfolders
	Calibration_info.csv	.csv file

Figures 20 and 21 plot processed temperatures for several laboratory tests and field campaign measurements.





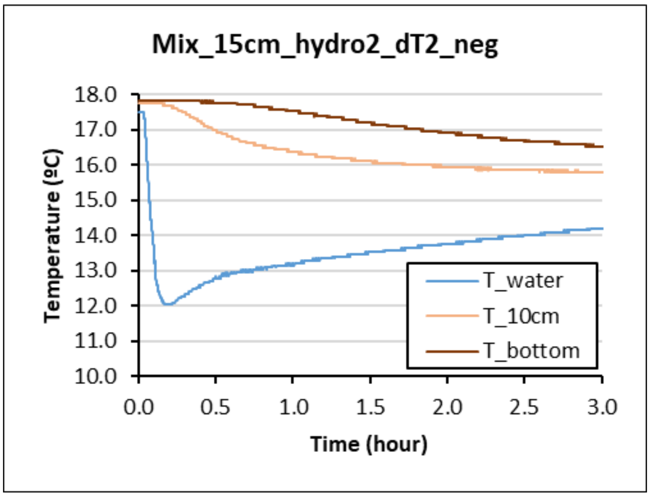
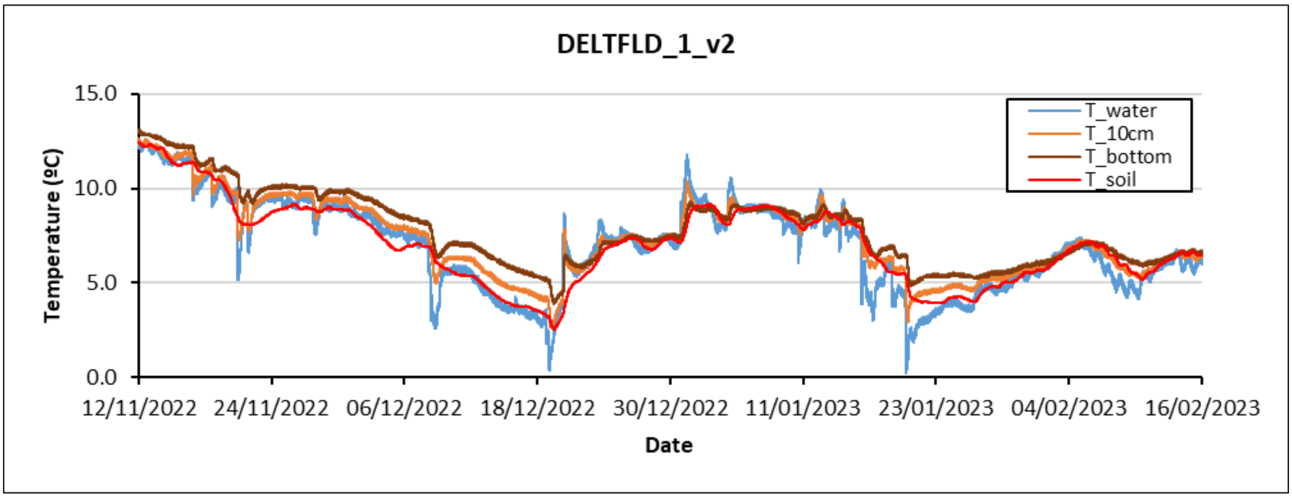


Figure 20. Temperature time series in water and sediment-bed (bottom and 10-cm level) for tests on sand (top), organic (middle) and mix (bottom) sediments; temperature gradients dT1 (left) and dT2 (right); and hydrograph with peak flow at 10 min.



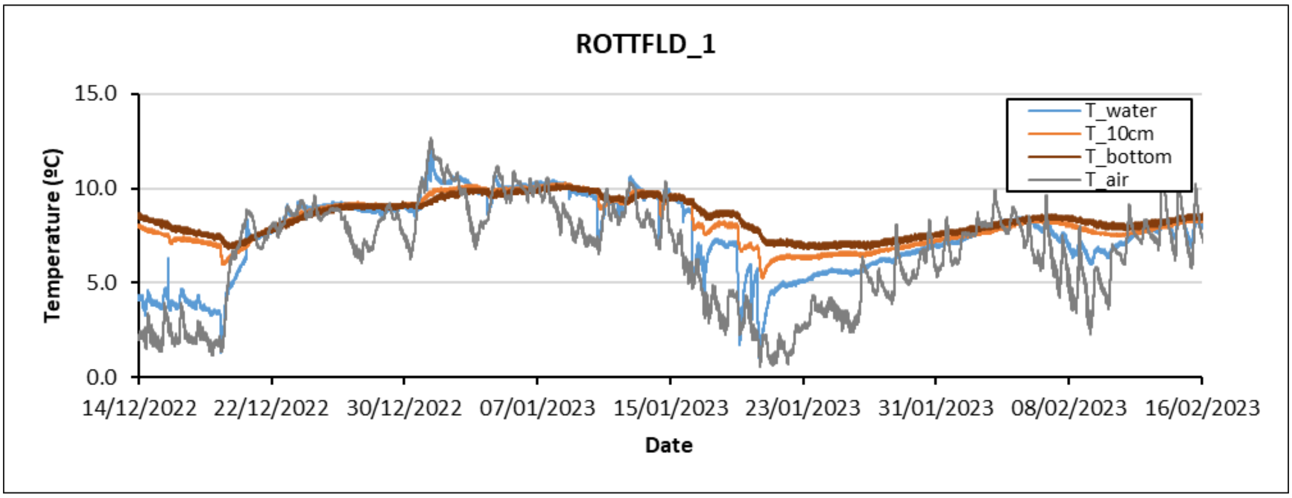


Figure 21. Temperature time series in water, sediment-bed (bottom and 10-cm level), soil and air for field measurements at locations DELTFLD_1 (top) and ROTTFLD_1 (bottom).

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10.APPENDICES

10.1. DS18B20 TEMPERATURE SENSOR CALIBRATION

DS18B20 sensors were calibrated by setting 6-step temperatures in the rage of 10-35ºC. For this purpose, all sensors were introduced in a water control system and temperatures were measured for 5 minutes with a time resolution of 1 second. Temperatures measured by a calibrated PT100 sensor were selected as reference values (see certificate of calibration in Appendix 10.2.). Thus, 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 6 represents the regression coefficients of the DS18B20 sensors.

Table 6. Regression coefficients of the DS18B20 sensors.

Sensor ID	a	b
LabDS_013C89	1.01961	-0.47768
LabDS_013CBE	1.01209	-0.46774
LabDS_013C28	1.01200	-0.56151
LabDS_013C12	1.00135	0.01460
LabDS_0A3CDD	1.00963	-0.23363
LabDS_2A3C38	1.00753	-0.02390
LabDS_A53CEB	1.00427	-0.35620
LabDS_013C83	0.99071	0.45093
LabDS_573CDD	1.00230	0.01314
LabDS_713CAE	1.00377	0.20278
LabDS_823C47	1.00102	0.03797
LabDS_1D3C43	0.98845	0.74467
LabDS_423C05	1.00096	0.06555
LabDS_993CF9	0.99055	0.42027
LabDS_A33C65	1.00153	-0.13814
LabDS_4F3C07	0.99616	0.20858
LabDS_583C85	1.00600	-0.19373
LabDS_0E3C83	0.99728	0.23266

LabDS_1603F5	0.99446	0.40479
LabDS_170421	1.00025	0.28063
LabDS_17045F	1.00204	0.16853
LabDS_160420	0.99906	0.31840
LabDS_1603FC	0.99504	0.54384
LabPT_100	0.99341	-1.37928
FldDS_02022B	1.01133	0.98375
FldDS_193C98	1.00423	0.13112
FldDS_D93CA2	1.01147	-0.11415
FldDS_130135	1.00201	0.58597
FldDS_0702FC	1.00577	0.70753
FldDS_B23C8B	1.00551	-0.33749
FldDS_B13CC7	1.00887	0.02958
FldDS_130106	1.00167	0.36560
FldDS_013C79	1.00184	-0.32929
FldDS_013C34	1.00816	-0.33655
FldDS_013CC5	1.00764	-0.45704
FldDS_013C7B	0.99872	0.09577
FldDS_013CB5	1.00384	-0.31938
FldPT_100	0.99662	-1.25031
FldDS_013CF5	1.00308	-0.34468
FldDS_013C73	1.01176	-0.29409
FldDS_013C9E	0.99831	0.23818
FldDS_0000B1	1.00403	0.01455
FldDS_0111D8	1.01254	-1.48067
FldDS_013C68	1.00926	-0.47426
FldDS_013CD1	0.99479	-0.00184
FldDS_013C07	1.00753	-0.02868
FldDS_013C34	1.00076	0.10386
FldDS_013C49	1.01252	-0.33982
FldDS_013C8F	1.00855	-0.21053
FldDS_0000E0	1.00291	-0.05392
FldDS_0000CE	1.00199	0.07654
FldDS_013CFB	1.00895	-0.18278
FldDS_013CC5	1.00794	-0.29494
FldDS_013CE8	1.01323	-0.26142

10.2. Certificate of calibration

Certificate of Calibration
Fluke Nederland B.V.

Certificate Number:	SA01017782	**Date of Calibration:**	26 Jan 2022
Receive Condition:	DATA ONLY	**Date of Recalibration:**	
Return Condition:	DATA ONLY	**Place of Calibration:**	Eindhoven
Manufacturer:	NOT KNOWN	**Temperature within:**	(23.0 ± 3) °C
Model:	PT100-PROBE	**Humidity within:**	(45 ± 20) %rh
Serial Number:	080104244		
Description:	RESISTANCE TEMPERATURE PROBE		
Procedure:	Manual Procedure 17025		

Customer:	DELTARES
	NL-2629 HD DELFT
Customer Asset ID:	-
RMA Number:	606278506

The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated towards the Raad voor Accreditatie.

The Raad voor Accreditatie is member of the European Co-operation for Accreditation (EA) and is one of the signatories to the EA Multilateral Agreement (MLA) and to the ILAC Mutual Recognition Arrangements (MRA) for the mutual recognition of calibration Certificates. Reproduction of the complete certificate is allowed. Parts of the certificate may only be reproduced with written approval of the calibration laboratory. This certificate is issued provided that neither the Raad voor Accreditatie nor Fluke Nederland B.V. assumes any liability. Fluke Nederland B.V. is accredited by the RvA (Dutch Accreditation Council) based on an assessment against the requirements as laid down in ISO/IEC 17025.

Measurement uncertainties at the time of calibration are given where applicable. They are calculated in accordance with the method described in the Expression of the Uncertainty of Measurement in Calibration (EA-4/02). The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k=2, such that the coverage probability corresponds to approximately 95%. In case a 'n/a' is reported, no expanded uncertainty could be calculated.

This certificate of calibration may contain data that is not covered by the Scope of Accreditation. The unaccredited test points, where applicable, are indicated by the # symbol or confined to clearly marked sections.

Issue Date: 26 Jan 2022

Electronically signed

Authorized By

F.M.J.M. Renders

Certificate of Calibration

Certificate Number: SA01017782

Remarks

- The calibration status found in this certificate on the top of each results page must be interpreted as:

As Found	: Data collected before the unit was adjusted and / or repaired
As Left	: Data collected after the unit has been adjusted and / or repaired
Found / Left	: Data collected without any adjustment and / or repair performed

- The calibration interval (due date) is the responsibility of the end user.
- According to the European norm 'Operation of electrical installations' NEN-EN 50110-1 release 2013 and the Dutch norm NEN 3140 release 2015 paragraph 5.102.12 through 5.102.16, a safety test is not required. Therefore not performed.
- Temperature conversions (if applicable) are performed according to ISO/IEC 60584:2013 for thermocouples, and ISO/IEC 60751:2008 for resistance temperature devices.

Standards and test-equipment used

Inventory No	Model	Serial No
SL1084	1595A-256	B65228
SL1036	5628	2806
SL1095	5901A	5132

Calibration Results
FOUND-LEFT

Certificate no: SA01017782 **Date of Calibration :25 January 2022**

Results:

The table contains the following data:

1. the temperature t_{90} defined according to the *ITS-90*;
2. the at t_{90} belonging resistance value R_{90} according to IEC 60751
3. the measured resistance value R_{uut};
4. the resistance difference R_n-R_{uut}
5. the from R_{UUT} calculated equivalent temperature t_{90c};
6. the difference t_{90}-$t90_c$;
7. the uncertainty in the measured value;
8. the temperature equivalent uncertainty

t_{90}	R_{90}	R_{uut}	$R_{90} - R_{uut}$	t_{90c}	t_{90}-t_{90c}	Uncertainty	
[°C]	[Ω]	[Ω]	[Ω]	[°C]	[°C]	[Ω]	[°C]
0.010	100.0039	100.0021	0.0018	0.005	0.005	0.0070	0.018
29.988	111.6683	111.6630	0.0053	29.974	0.014	0.0070	0.018
75.014	128.9928	128.9736	0.0192	74.964	0.050	0.0069	0.018
99.968	138.4934	138.4640	0.0294	99.891	0.077	0.0068	0.018

Calibration method : The sensor was calibrated with an immersion depth of 230 mm using stirred liquid baths. A Pt25 was used as reference thermometer and a digital multimeter was used to measure all the resistance values.
The calibration was performed in comparison with a standard reference thermometer at increasing calibration temperatures. The sensing current for all resistance measurements was 1 mA.
The temperature scale used is ITS-90.
After the calibration on the highest setting point was completed, the calibration was repeated at 0 °C to check the sensor stability.