Permeable pavement hydraulic performance and clogging experiments using a full-scale urban drainage physical model

DATASET DETAILS

Project acronym	**POREDRAIN**
Project title	Pollution removal characterization and efficiency assessment of filtering sections for sustainable management of urban drainage systems at city scale
Grant Agreement No	RTI2018-094217-B-C33 funded by MICIU/ AEI /10.13039/501100011033/ ERDF "A way to make Europe".

Dataset Information	
Dataset title	Permeable pavement hydraulic performance and clogging experiments using a full-scale urban drainage physical model
Data sources	This dataset includes results from laboratory experiments on the hydraulic performance and long-term clogging of permeable pavement under realistic controlled conditions.
Content	Raw and processed data from water level sensors, flows from two gully pots and the pipe system outlet, TSS and turbidity samples and permeability measurements.
Formats	csv, jpeg.
Volume	72 MB

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Dataset is part of the POREDRAIN project. The project receives funding from the Spanish Ministry of Science, Innovation and Universities under POREDRAIN project RTI2018-094217-B-C33 (MINECO/FEDER-EU). The authors acknowledge also financial support from the European Union under the Horizon 2020 program within a contract for Integrating Activities for Starting Communities (Ref. 101008626)

Abstract

This dataset contains the results from 15 tests conducted used a physical model in the Hydraulic Laboratory of the Centre for Technological Innovation in Construction and Civil Engineering (CITEEC) at the University of A Coruña (Spain).

The objective of the tests is to analyse the hydraulic performance of a porous asphalt layer of the PA-16 type and the impact of clogging on the hydrological behaviour and water quality of the effluent. The porous asphalt was used to retrofit an impervious concrete surface of a 36 m² full-scale street section physical model, which consist of a rainfall simulator placed over the street surface. The behaviour of the porous asphalt layer was assessed by adding surface sediment loads between simulated rainfall events. During rainfall events, ultrasonic sensors (UB500-18GM75-I-V15, Pepperl and Fuchs) were used to measure the rainwater level within the permeable pavement and the flow rates at three discharge points (gully pot 1, gully pot2, and outlet). Additionally, a variable head permeameter was employed to precisely determine the permeability of the test zone. Samples were taken at each of the three discharge points for analysis of total solids and turbidity.

1. Experimental setup

The facility features a 36 m² full-scale street section with a rainfall simulator positioned 2.6 meters above it (Figure 1). The rainfall simulator employs a pressure-compensating irrigation dripper system (PCJ-CNL, Netafim™) integrated into two overlapping pipe circuits. One circuit is equipped with drippers that deliver 1.2 L/h each, while the other has drippers delivering 2 L/h each. With a density of 25 drippers/m², the simulator can achieve three different rainfall intensities of 30, 50, and 80 mm/h when both circuits are activated simultaneously. A more detailed description of the rainfall simulator setup and the rainfall intensity distributions is provided in Naves et al. (2019a).

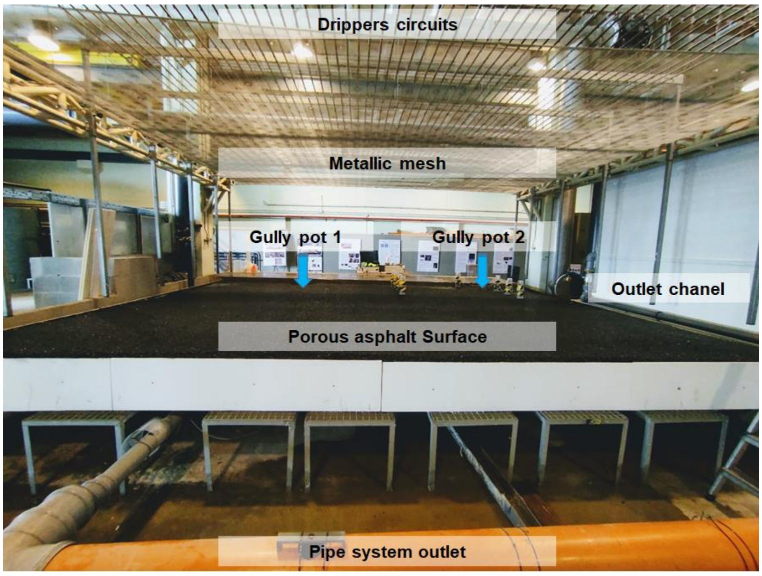


Figure 1. Street section physical model general view

The street surface consists of a tiled sidewalk and a porous asphalt section laid over an impermeable base. Rainwater infiltrating through the porous asphalt is directed into the pipe system via two gully pots (GP1, GP2) positioned along the curb, as well as a lateral outflow channel that conveys the rainwater to a system outlet. The porous asphalt used is of the PA-16 type, containing 4.03% bitumen and 22.6% voids in the mixture.

The porous asphalt surface was constructed over an impervious concrete base (Naves et al., 2020), featuring a transversal slope of approximately 2% up to the sidewalk and a longitudinal slope of 0.5% towards an outflow channel (see Figure 2). Two gully pots, each measuring 0.3 m x 0.3 m, are located 0.02 m from the curb and have a depth of 28 cm. The diameter, length, and slope of the pipes are detailed in Table 1.

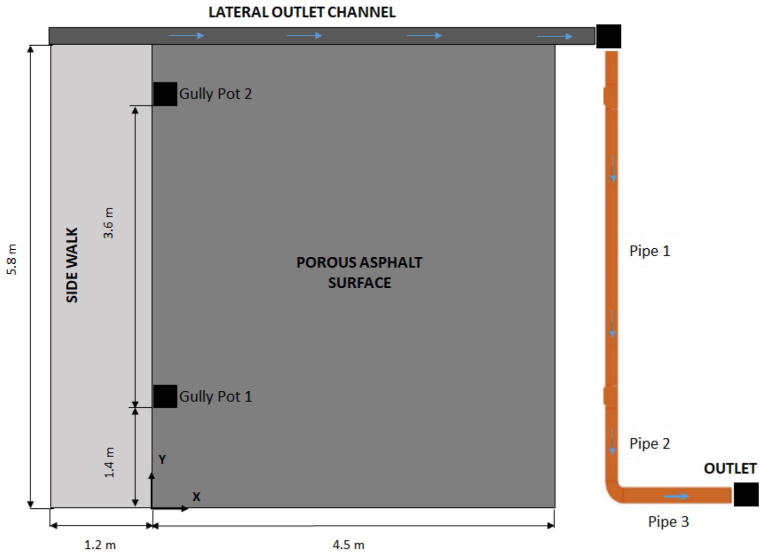


Figure 2. Street section physical model scheme

Table 1. Pipe system geometry

Pipe	Diameter (mm)	Lenght (m)	Slope (%)
1	190	3.72	0.54
2	190	1.23	0.58
3	190	2.93	0.52
Outlet channel	-	6.70	1.42

The mean thickness of the porous asphalt, calculated as 5.7 cm, was determined by measuring the elevation difference between the permeable asphalt and the underlying impermeable surface. Elevation data were collected on a 0.5 m x 0.5 m grid using point measurements relative to a common horizontal laser plane. Further details on the impermeable model surface, a comprehensive description of its physical model geometry, the dripper circuit used to simulate rainfall, and the rain intensity maps can be found in the dataset WASHTREET - Structure from Motion and can be consulted in Naves et al. (2019a, 2019b). The XYZ coordinates obtained can be found in '01_ Thickness_data.zip'. The thickness map of the permeable asphalt physical model is shown in Figure 3.

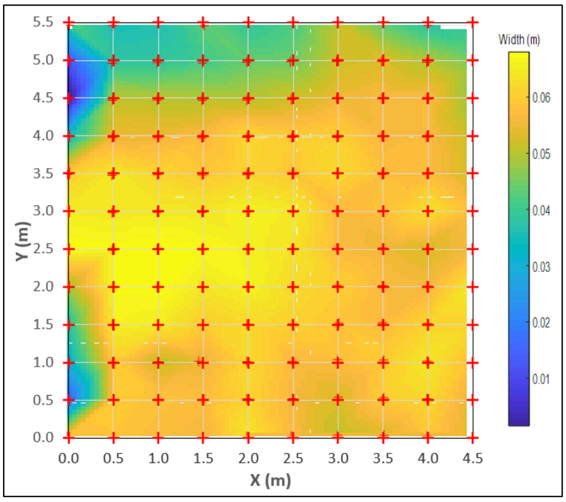


Figure 3. Permeable asphalt width of the physical model obtained in a 0.5 m x 0.5 m grid.

2. Hydraulic experimental procedure

The first set of experiments involves a hydraulic characterization of surface runoff infiltration and the flow generated in the porous asphalt without the effect of pavement clogging (no sediment loading was added to the surface). These experiments simulate constant and homogeneous precipitation at intensities of 30, 50 and 80 mm/h for a duration of 5 minutes. An additional test was conducted to characterize the flow response to a maximum rain intensity of 80 mm/h over 30 min. For this test, online measurements of the water level within the porous asphalt (at 8 control points) and the discharges from the two gully pots and pipe system outlet were recorded from the beginning of the experiment to 30 minutes after the rain stopped.

Files related to hydraulic tests, including information about sensor calibrations at the gully pots, outlet channel, and each of the eight 8 water level sensors (WL1-WL8) placed on the porous asphalt, can be found in the file 02_PP_Hydraulic_Tests.zip. Further details about the location, sensors used, acquisition time, units for each result and permeability measuring points are also presented in 'Measuring_points.csv'. Figure 4 shows the location and ID of the different measuring points.

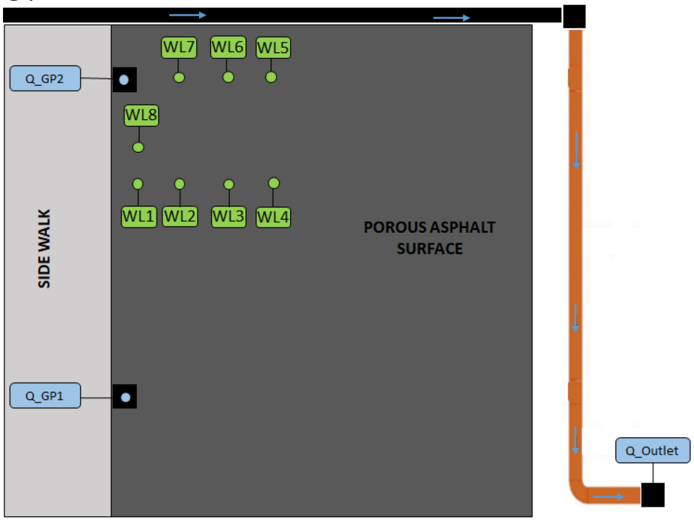


Figure 4. Measuring points in hydraulic tests.

The eight water level checkpoints inside the porous asphalt, along with the water flow through the 2 gully pots and the system outlet, were measured using ultrasonic depth sensors (UB500-18GM75-I-V15, Pepperl and Fuchs). Figure 5 shows images of the sensors installed on the street surface. To ensure the stability of the sensors and the reliability of the signal, custom supports were designed. These supports also protect the water surface from raindrop impacts and were used throughout the entire experiment.

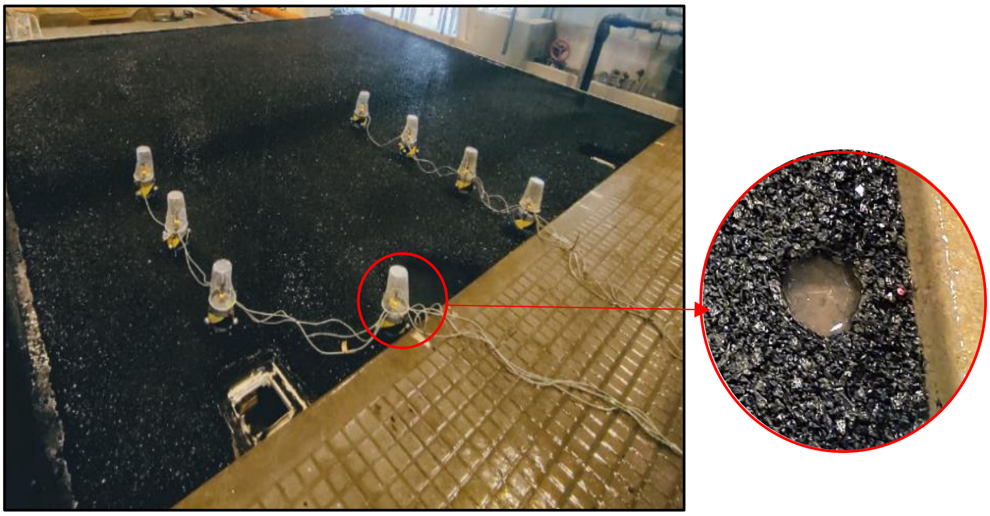


Figure 5. Distance sensors installed on the street surface

A 50 cm x 60 cm sized tank was installed below each gully pot to measure discharges (Figure 6). A similar tank with a V-notch was installed at the pipe system outlet to measure the water from the outflow channel (Figure 7). Due to the runoff flow through the pipe system, the measurement at the outlet provides information on the percentage of water draining to the lateral channel during the water balance test. Pre-calibrated distance sensors (UB500-18GM75-I-V15, Pepperl and Fuchs) were used to measure the flow in all three tanks. Table 2 shows the 4 hydraulic tests performed and their configuration.

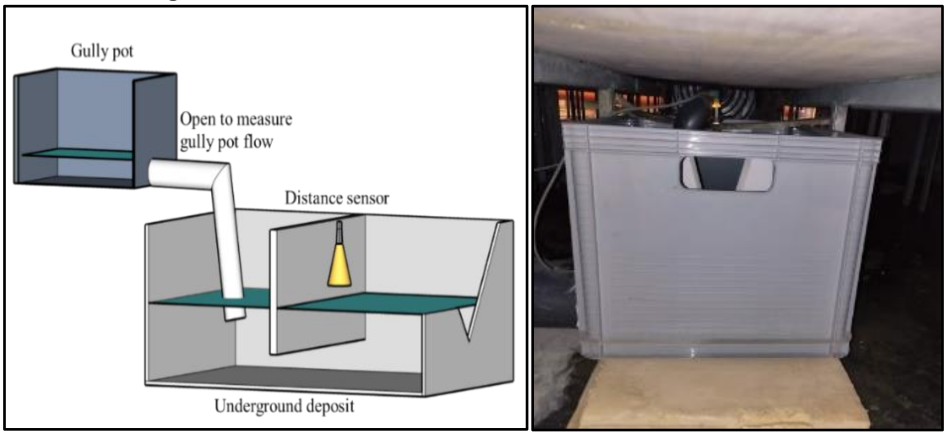


Figure 6. Flow measurement methodology in gully pots GP1 and GP2

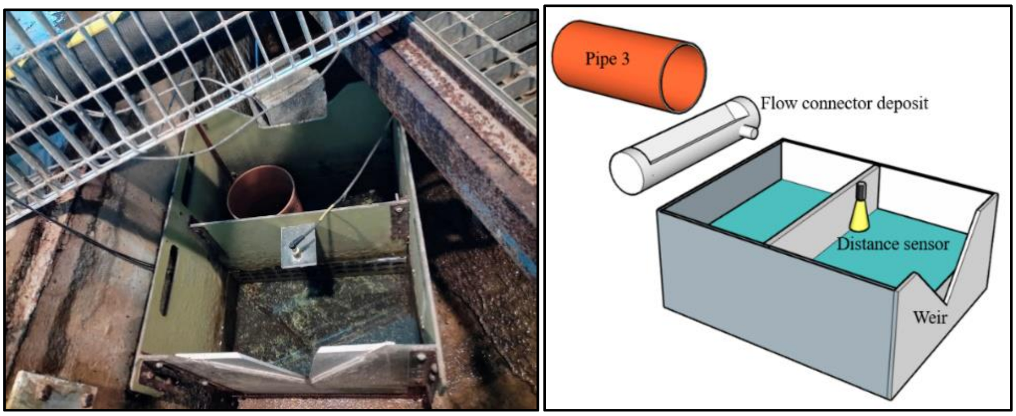


Figure 7. Flow measurement methodology in pipe system outlet.

Table 2. Hydraulic tests.

ID	Rain intensity (mm/h)	Time (minutes)
HY01_30_5	30	5
HY02_50_5	50	5
HY03_80_5	80	5
HY06_80_30	80	30

Finally, to assess the permeability of the porous asphalt, a standardized variable head permeameter was employed in accordance with the Spanish standard NLT-327/00 (CEDEX, 2000). At each test location, three permeability measurements were taken. The permeameter was initially placed at the selected point, and the first measurement (T_0) was used for surface saturation and was therefore not included in the final analysis. The final permeability value was calculated as the average of the subsequent two measurements, T_1 and T_2, adhering strictly to the standardized procedure. The initial permeability values of the porous asphalt layer ranged from 11089 to 37575 mm/h with an average value of 22822.1 mm/h. Detailed permeability data from 24 points was obtained through measurements on a 1.0 m x 1.0 m grid (Figure 8). Data regarding the permeability measurements is included in 'Permeability_csv'.

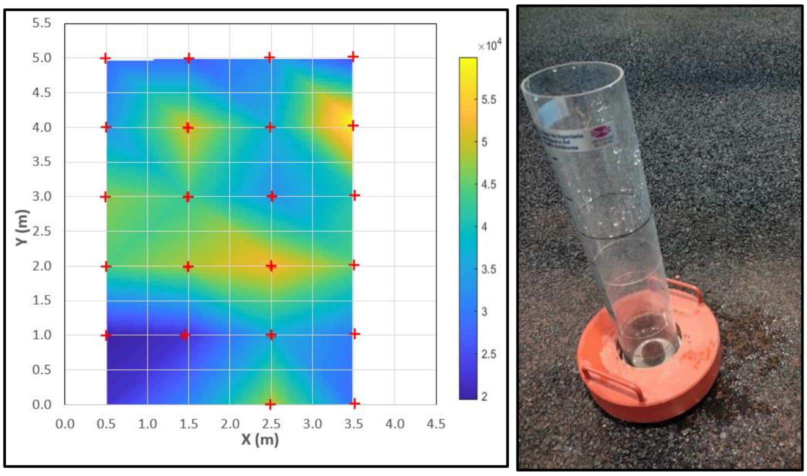


Figure 8. Permeability of the physical model in mm/h

Calibration methodology: Water Level sensors WL1 - WL8

To calibrate the 8 ultrasonic distance sensors and convert the registered voltages to water levels, signal-to-distance calibrations were performed by measuring 4 different distances from each sensor to their horizontal hole-base surface. The calibration equation derived from these measurements was used to transform the signal in volts to depth in millimeters. The distances measured for the calibration of each sensor are shown in Table 3, selected based on the range of values expected during the experiments. Additionally, raw and processed data recorded for 60 second at each distance for each sensor is included in ‘Sensor_Calibration\Calibration_surface_waterlevels\’ (sensors WL1 - WL8).

Table 3. Signal-distance calibration points_mm

Sensor ID	Y cal1	Y cal2	Y cal3	Y cal4
Signal_V	3.7	3.0	2.8	2.4
WL1	148.8	111.2	97.0	75.6
WL2	148.9	112.1	96.1	75.6
WL3	147.4	111.7	95.9	74.9
WL4	148.8	111.5	96.3	75.4
WL5	162.8	118.3	102.8	79.0
WL6	168.4	126.8	105.9	74.7
WL7	175.3	126.9	106.6	77.7
WL8	157.6	118.2	101.9	77.6

Calibration methodology: Flow sensors GP1, GP2 and Outlet

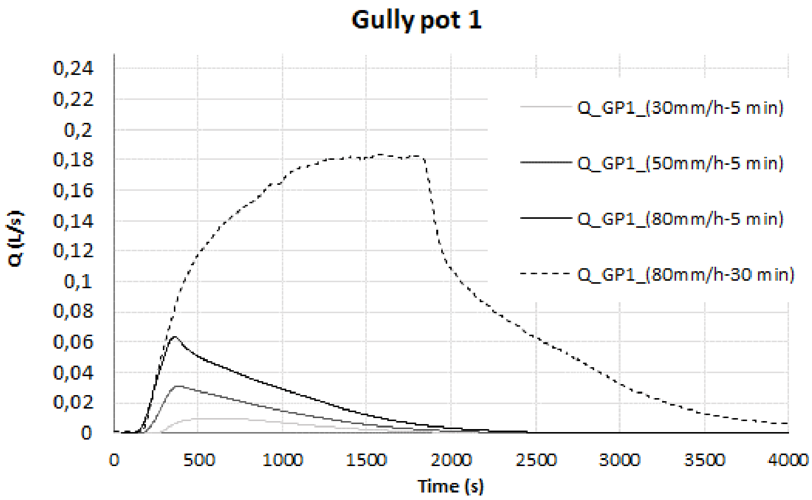
Signal-to-flow calibration was previously performed for sensors Q_GP1, Q_GP2 and Q_Outlet to measure the discharges drained through both gully pots and the lateral outflow channel. Six different steady flows were introduced into each container, and the corresponding signals were recorded. The GP1, GP2 and Outlet v-notch containers have an initial volume, corresponding to the minimum level of the weir, marked as the zero or starting point for each test. Table 4 presents the flows used in the calibration of each sensor. The raw and processed data collected by the sensors over 60 seconds, once the level in the container stabilized for each flow, is included in ‘Sensor_Calibration\Calibration_deposits_flow\’ (sensors Q_GP1, Q_GP2 and Q_Outlet).

Table 4. Signal-flow calibration points (L/s)

		Q_GP2	Q_GP1	Q_Outlet
Calibration 1	Q (L/s)	0,15	0,133	0,23
	Signal (V)	3,31	4,26	2,81
Calibration 2	Q (L/s)	0,07	0,103	0,06
	Signal (V)	3,52	4,40	3,35
Calibration 3	Q (L/s)	0,056	0,052	0,046
	Signal (V)	3,55	4,64	3,56
Calibration 4	Q (L/s)	0,004	0,046	0,036
	Signal (V)	3,80	4,67	3,489
Calibration 5	Q (L/s)	-	0,023	0,022
	Signal (V)	-	4,85	3,59
Calibration 6	Q (L/s)	0,003	0,003	-
	Signal (V)	3,89	5,16	-
Calibration 7	Q (L/s)	0,00	0,00	0,00
	Signal (V)	4,00	5,39	3,90

Finally, a 20-second-wide moving median was applied to the time series to obtain processed results. This means that for each data point in the time series, the median value of the data points within a 20-second window centered on that point was calculated. This technique helps to smooth the data by reducing the impact of short-term fluctuations and noise, providing a clearer view of the underlying trends in the time series. Essentially, it replaces each data point with the median value of its neighboring points within the specified window, improving the overall quality and interpretability of the results.

Figure 9 plot flow results for the three rain intensities considered in the hydraulic characterization (30, 50 and 80 mm/h), and the flow result for the rain intensity of 80 mm/h for 30 minutes, considered as the start point in the clogging test. Figure 10 shows the surface water level results for the rain intensity of 80 mm/h for 30 minutes.



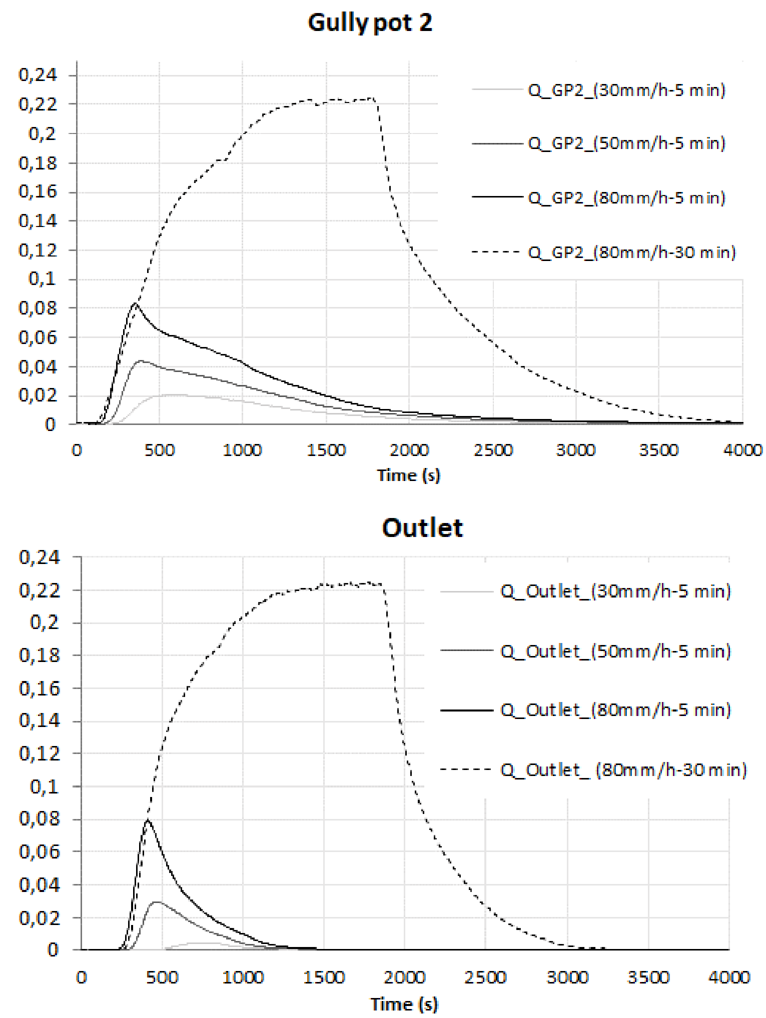


Figure 9. Flow results in pipe system Outlet, GP1 and GP2 for 5 minutes of constant simulated rainfall of 80 mm/h (light grey), 50 mm/h (dark grey) and 30 mm/h (black), and rain intensity of 80 mm/h for 30 minutes (dash line).

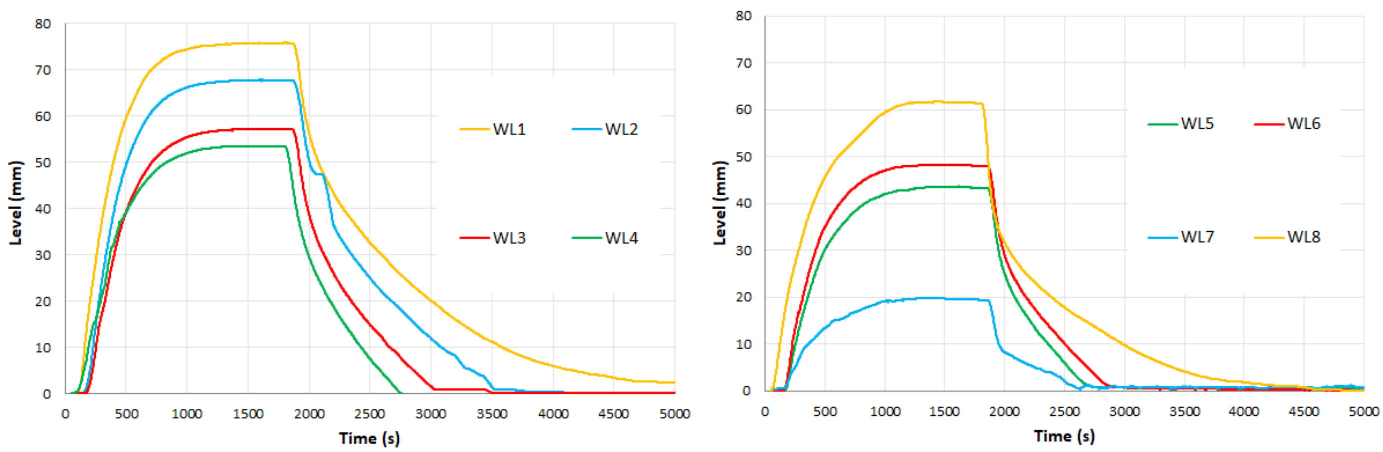


Figure 10. Water lever results for rain intensity of 80 mm/h_30 minutes in the eight control points

2. Clogging tests experimental procedure

To analyze the influence of sediment clogging and evaluate the long-term hydraulic performance of the porous asphalt, 9 tests with sediment loads were conducted The distribution area (5.5 m long and 0.75 m wide strip) was divided into 11 sections, and with the help of a tailored sieve, each sediment load was applied in 6 batches per section to ensure homogeneity along the tested strip. The first test (CT_01) and the last one (CT_11) were carried out without sediment load to measure the zero-sediment conditions, and the recovery conditions after vacuuming. The initial load was 0.5 kg/m^2 (CT_02), increasing up to a maximum load of 5.5 kg/m^2 (CT_10). After each load, a homogeneous and constant rain of 80 mm/h of intensity was simulated for 30 minutes. Table 5 shows all the tests ID and configurations. The data files for the total 11 trials are included in the zip file '03_PP_Clogging_Tests.zip'.

Table 5. Clogging Test ID and configurations

Test ID	Rain intensitie (mm/h)	Sediment load (kg/m^2)	TSS Samples	Turbidity Samples	Permeability	Surface Vacuummed
CT_01	80	0	No	No	Yes	No
CT_02	80	0.5	Yes	Yes	No	No
CT_03	80	1	Yes	Yes	Yes	No
CT_04	80	2	Yes	Yes	Yes	No
CT_05	80	3	Yes	Yes	Yes	No
CT_06	80	3.5	Yes	Yes	No	No
CT_07	80	4	Yes	Yes	Yes	No
CT_08	80	4.5	Yes	Yes	No	No
CT_09	80	5	Yes	Yes	Yes	No
CT_10	80	5.5	Yes	Yes	Yes	No
CT_11	80	<5.5	Yes	Yes	Yes	Yes

The sediment used during the tests was composed of road dust collected from the parking lots of the UDC campus. This sediment represents a realistic graded road deposit dust with a maximum size of 1000 µm and a d50 of 282 µm. It was created by combining the sediment in proportions of 10%, 15%, 20%, 25% and 30%, using sieves of <63, 63, 125, 250 and 500 µm, respectively (Figure 11). The sediment was calcined at 550 ºC to remove organic matter and reduce cohesiveness to a minimum. Detailed particle size distribution (PSD) of the sediment, measured with a laser diffraction particle size analyser (Beckam-Coulter LS I3 320), can be found in the 'SedimentsClasses_PSD.csv' file. The granulometry of the porous asphalt is also included as reference.

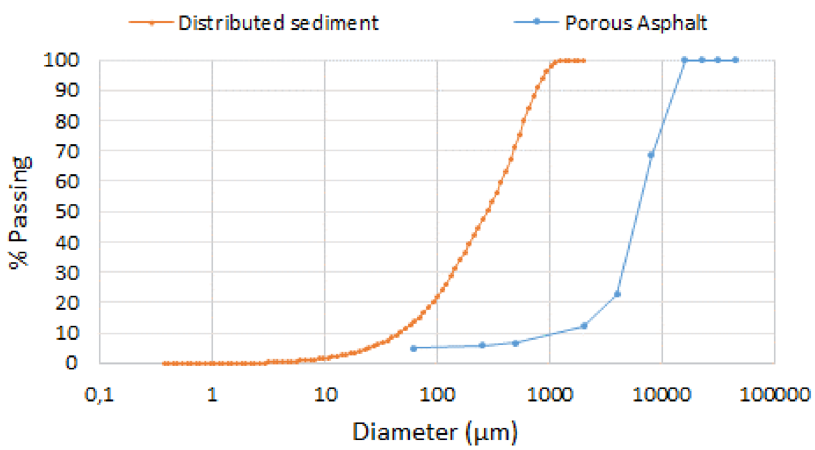


Figure 11. Particle size distribution of the porous asphalt (blue line) and the distributed sediment (orange line)

The same variable head permeameter method used for the initial porous asphalt characterization was also followed to measure the permeability of the porous asphalt for different degrees of clogging during the tests. This was done in accordance with the Spanish standard NLT-327/00 (CEDEX, 2000), which is similar to EN 12697-40 (European Standard, 2005). Six control points were used to monitor the permeability variations caused by the different sediment loads. Measurements were taken at interspersed points and after each kilogram of accumulated sediment load, with three measurements taken each time. Complete measurements at all six control points were only taken at the beginning (without load) and at the end (after vacuuming) to prevent the water pulse generated by the permeameter from excessively rinsing the sediment trapped in the asphalt.

In addition, 9 cm diameter holes have been drilled perpendicular to the test strip to facilitate the measurement of the water level fluctuations within the permeable pavement. There are 4 sensors positioned over the sediment zone (WL1, WL2, WL7, and WL8) and 4 sensors over the zone without sediment (WL3, WL4, WL5, and WL6). Water level measurements were conducted using UB500-18GM75-I-V15 distance sensors from Pepperl and Fuchs.

To analyse total suspended solids (TSS) and turbidity during the simulated rain event, samples were manually collected from the two gully pots and at the end of the outlet channel. Additionally, the discharges from GP1, GP2 and the Outlet of the pipe system were measured following the same methodology as in the hydraulic experiments. Further details including the locations, sensors used, acquisition time and units for each result are provided in 'Measuring_points.csv'

Figure 12 illustrates the location of the sediment test zone with the IDs for different permeability measurement points and the physical model scheme.

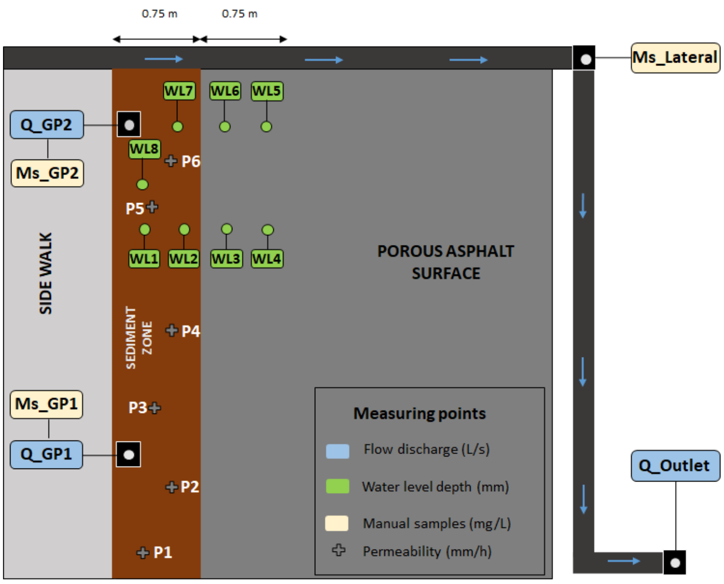


Figure 12. Street section physical model scheme

On average, a total of 60 manual samples were collected in 100 ml container, distributed as follows; 20 at the entrance of GP1, 20 at the entrance of GP2, and 20 at the outlet channel, as detailed in Table 6.

Table 6. Sample collection setup on the timeline

Sample #	Minute	Sec
1	0:03:00	180
2	0:05:00	300
3	0:07:00	420
4	0:09:00	540
5	0:11:00	660
6	0:13:00	780
7	0:15:00	900

8	0:17:00	1020
9	0:19:00	1140
10	0:21:00	1260
11	0:23:00	1380
12	0:25:00	1500
13	0:27:00	1620
14	0:29:00	1740
RAIN STOP	**0:30:00**	**1800**
15	0:31:00	1860
16	0:33:00	1980
17	0:35:00	2100
18	0:37:00	2220
19	0:39:00	2340
20	0:41:00	2460
21	0:43:00	2580

Solids remained in the physical model at the end of the experiment were gathered to conduct a sediment mass balance and assess the long-term performance of the porous asphalt. Firstly, sediment remained over the surface and inside gully pots was collected with an industrial vacuum, to analyse the final distribution of sediments across the area. Furthermore, the laser equipment was also used to obtain the PSD of each collected sample.

Turbidity and TSS values were obtained following the APHA method. To study de distribution of the pollutant associated with the volume of the stormwater effluent in each gully pot and outlet channel, the Event Mean Concentration (EMC) equation was used:

$$EMC = (\Sigma C_t Q_t \Delta t) / (\Sigma Qt\Delta t)$$

where C_t and Q_t are the concentration and flow volume over a discrete time interval (Δt).

PSD data was obtained from the manual samples by a laser coulter particle size analyser (Beckam-Coulter LS I3 320).

3. Data and result files

Each experiment listed in Table 2, conducted to characterize the initial hydraulic conditions of surface runoff infiltration, involved three rainfall intensities (30, 50, and 80 mm/h) with a duration of 5 minutes, as well as a characterization of the maximum intensity (80 mm/h) with a duration of 30 minutes. The following files are included for each experiment, with the time referring to the start of the rainfall:

- 'Flow_RawSignal_V.csv': Raw time series registered by the three distance sensors installed in each container (GP1, GP2 and pipe system Outlet) to measure flow.
- 'WaterLeve_RawSignal_V.csv': Raw time series registered by the 8-distance sensor installed on the surface (WL1 - WL8).
- 'Flow_Processed_Ls.csv': Processed flow time series registered by the three distance sensors installed in each deposit (GP1, GP2 and pipe system Outlet) to measure flow.

- ‘WaterLevel_Processed_mm.csv’: Processed depth time series registered by the 6-distance sensor installed on the surface (WL1- WL8).

Sediment mass collected after the experiments from the different vacuuming areas are provided in a single file (‘MassBalance.csv’). Then, each experiment considered in Table 5 include the following files, referring the time in all cases to the beginning of the rainfall:

- ‘Flow_RawSignal_V.csv’: Raw time series registered by the sensor installed in GP1, GP2 and pipe system outlet containers to measure flow.
- ‘Flow_Processed_Ls.csv’: Processed flow discharge result at GP1, GP2 and pipe system outlet.
- ‘Depths_RawSignal_V.csv’: Raw time series registered by the 8 distance sensor installed on the asphalt surface (WL1-WL8).
- ‘Depth_Processed_mm.csv’: Processed depths results for sensors WL1-WL8.
- ‘TSSsamples.csv’: Collection time time and TSS concentration value for gully pots (TSS GP1 and TSS GP2) and outlet (TSS Outlet) manual samples.
- ‘Turbidity.csv’: Collection time and Turbidity value for gully pots (FTU GP1 and FTU GP2) and outlet (FTU Outlet) manual samples.
- ‘PSD_MassB (folder)’: PSD of the different masses collected for the final mass balance named as ‘PSD_MassB_Measuring_points.csv’

The plots in Figure 13 show the TSS and turbidity results for rain intensities of 80mm/h during each test. Figure 14 shows mass balance and granulometry for each measuring point.

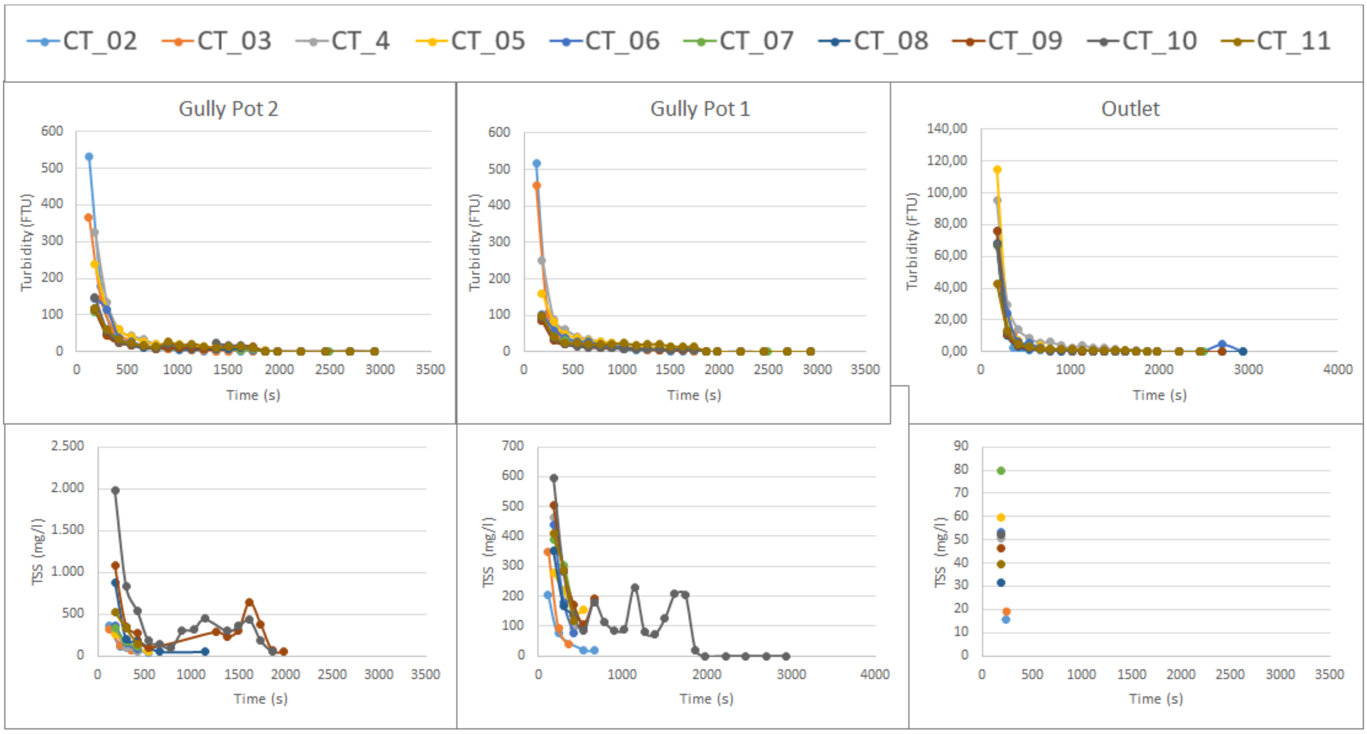


Figure 13. Total suspended solids (TSS) and Turbidity (FTU) results in both gully pots and in the pipe system outlet for the rain intensity of 80 mm/h.

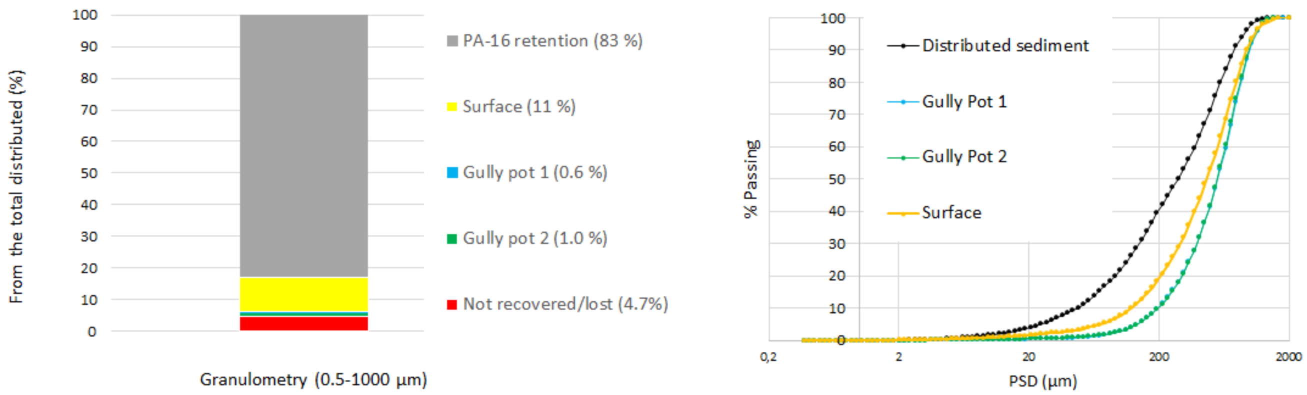


Figure 14. Mass balance and particle size distribution of the sediment recovered after vacuuming

Photos and videos about the porous asphalt installation process are provided in '04_Multimedia files'.

4. References

Naves, J., Anta, J., Suárez, J. et al. Hydraulic, wash-off and sediment transport experiments in a full-scale urban drainage physical model. Sci Data 7, 44 (2020). https://doi.org/10.1038/s41597-020-0384-z

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