Flood
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Determination of paving permeability - VUBA

Aura Innovation Centre

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Led by:
UNIVERSITY OF HULL | ENERGY AND ENVIRONMENT INSTITUTE

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This report summarises the design and use of a permeameter to determine the permeability of two kinds of paving, then the formulation of a numerical groundwater flow model to investigate the effects of different permeability pavements on runoff in a generic street.

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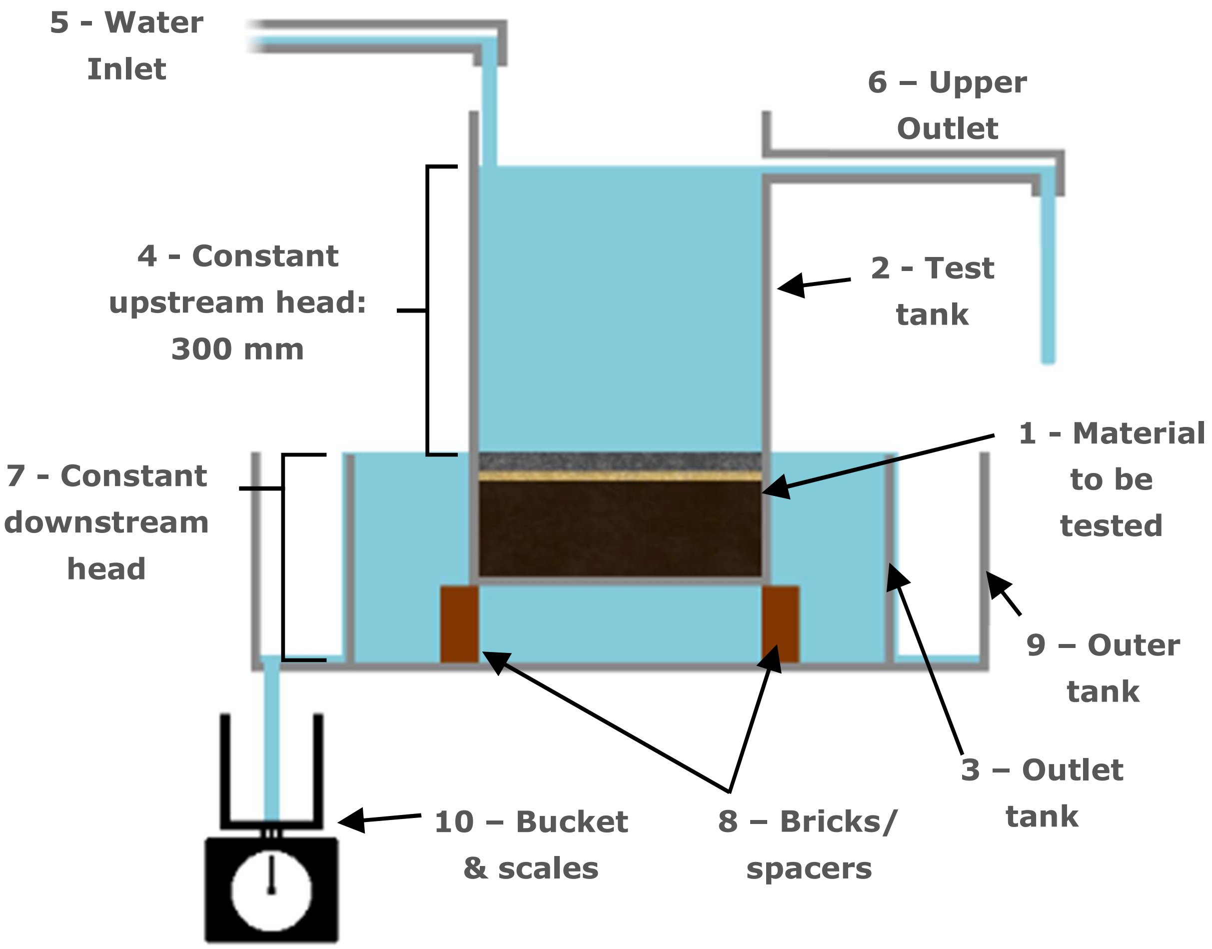
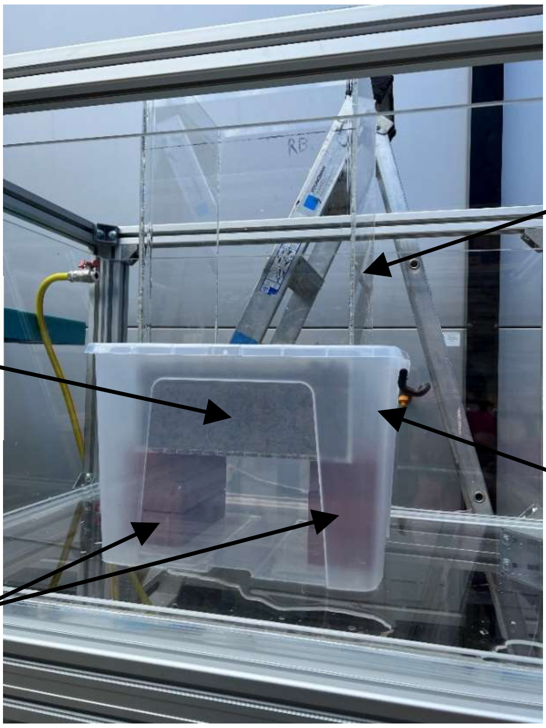
1 Physical Modelling



1.1 Setup

The test rig consists of an inner test tank to hold water above the material sample, an outlet tank to hold the downstream water level, and an outer tank to capture the outflow so that it can be measured. This setup was based on the BS EN 12697-19:2020, corresponding to Bituminous mixtures – Test Methods, specifically Part 19: Permeability of specimen.



1 - Material to be tested

2 - Test tank

3 – Outlet tank

5 - Water Inlet

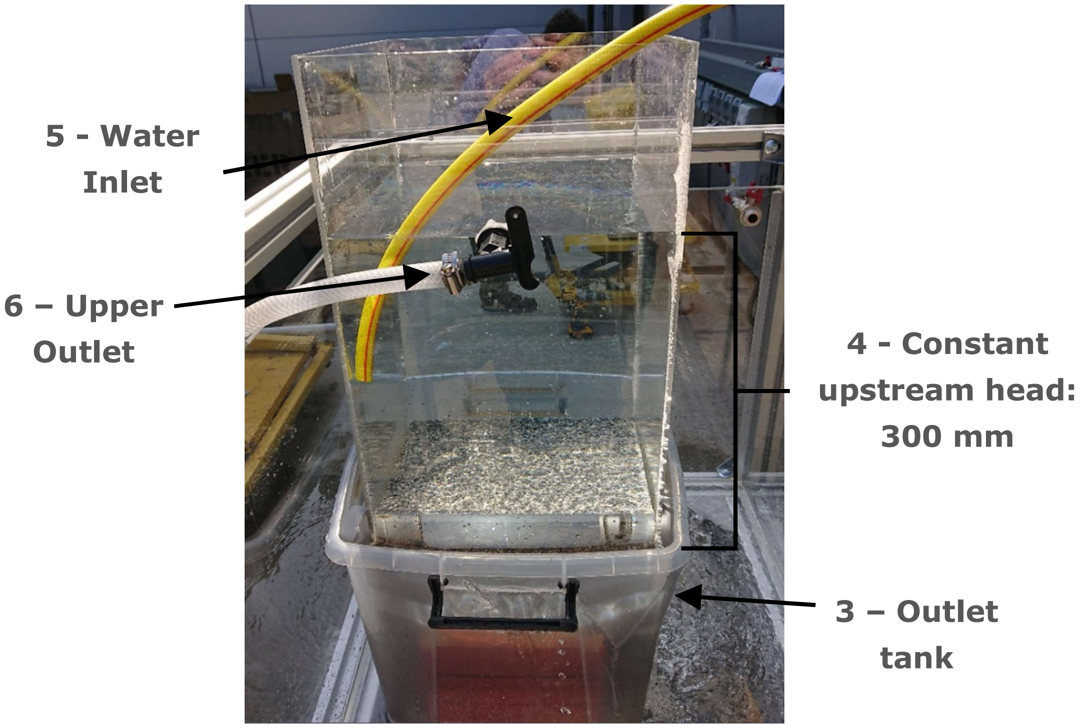
2 - Test tank

9 – Outer tank

To test the permeability of the sample material (1), a constant hydraulic head is needed. This is created by the difference between two water levels – the level of water above the sample material in the test tank (2) and the level of water in the outlet tank (3), which the test tank sits in. The upstream level (4) is held at 300 mm above the top surface of the sample material by constantly running water into the test tank from a hosepipe (5) and allowing excess to run out by an outlet (6) drilled in the side of the test tank 300 mm above the sample's upper surface. The lower level (7) is maintained by filling the outlet tank (3) to full and allowing excess water to overflow the top of it, and should be made to align with the top surface of the sample material by lifting the test tank up on bricks or other waterproof spacers (8) which should be positioned such that they cover as few of the perforations in the bottom of the test tank (2) as possible. Water that runs out of the outlet tank (3) is collected in an outer tank (9) with a hole or tap in the bottom, and measured using a bucket and set of scales (10).

For this setup, it was found to be important that: -

- The water inlet (5) has sufficient flow rate to exceed what flows through the sample and so be able to fill the test tank.
- The tap or hole in the bottom of the outer tank is big enough to quickly drain all of the water entering the outer tank



1.2 Testing method

1. The pavement material to be tested is assembled in the bottom of the test tank.
2. The test tank is lifted into the outlet tank, and the test rig is setup as shown above,
3. The water is run into the top of the test tank to fill the lower and upper tanks to the required levels. Once the levels are reached, the inlet flow can be lowered to just enough to hold the top level. During this time, water is allowed to flow freely out of the outer tank.
4. Flow through the rig is maintained for 10 minutes to saturate the sample material.
5. Before each test, the bucket is weighed to determine its dry mass. It is then placed under the outlet of the outer tank to collect all the water flowing through the system, and a timer is started. After a given amount of time (usually 30 or 60 seconds) the bucket is removed, and weighed again, and its filled mass is determined
6. This test is repeated multiple times per sample material to improve the accuracy of the final result.

7. To calculate permeability, flow rate needs to be calculated from the mass of water and measurement time: -

$$\boldsymbol{Q = \frac{m_{flilled} - m_{dry}}{\rho\, t}}$$

$\boldsymbol{Q}$ = flow rate (m^3 s^1)

$\boldsymbol{m_{flilled}}$ = Bucket mas when filled (kg)

$\boldsymbol{m_{dry}}$ = Bucket mass when empty (kg)

$\boldsymbol{\rho}$ = density of water (kg m^3; assumed = 1)

$\boldsymbol{t}$ = Time to fill bucket

Next, permeability is calculated from the flow rate:-

$$\boldsymbol{K_z = \frac{Ql}{hA}}$$

$\boldsymbol{K_z}$ = Permeability (m s^1)

$\boldsymbol{Q}$ = flow rate (m^3 s^1)

$\boldsymbol{h}$ = Height difference between upper and lower water levels (m; = 0.3 in this setup)

$\boldsymbol{l}$ = Thickness of sample material (m)

$\boldsymbol{A}$ = Area of sample (m2; = 0.3 x 0.3 =0.09 m in this setup)

1.3 Results

For each pavement type, the above test was repeated 10 times and the mean result was calculated: -

Pavement type	Mean calculated permeability (m/s)	Standard Deviation	SD as %
Block Paving	1.05×10^{-4}	1.692×10^{-6}	1.61
Resin Bound Permeable	1.98×10^{-3}	5.239×10^{-5}	2.65

BS EN 12697 states that the permeability is typically between 0.5×10^{-3} m/s and 3.5×10^{-3} m/s, when testing porous asphalt. This value only corresponds to the bituminous mixture related permeability, and does not consider any sub-base requirements, or consequences of installed permeability.

In conclusion, these experiments indicate that a typical Vuba Resin-Bound product, when tested against an archetypical block paving installation, with corresponding sub base formations, exhibits a measured vertical permeability coefficient of approximately 19 times that of traditional block paving.

2 Numerical modelling

2.1 Model Setup

A numerical model was created in USGS Modflow 6.3, a widely used, open-source, groundwater flow model made by the U.S. Geological survey. To represent a street, the model had a size of 20 x 200 m, and was simulated with a grid resolution of 1m. Vertically, the model was split into 8 layers, the top most of which was 0.15 m and represented the pavement and support material tested above. Below this, each layer was 1.5 times the thickness as the last (a measure that helped to maintain model stability), and so a total depth of 7.875 m was modelled.

The permeability of the top layer material was set to the value found in section 1 for each type of paving. Lower levels had a permeability of 1×10^{-5} m s^{-1}. 10 minutes after the start of the model, ~37.5mm of rainfall fell over 35 minutes, with a peak rainfall of 90 mm/hour. This represents a period of intense rainfall for the UK, but is still below the highest rainfall intensity recorded (80 mm over 30 minutes; see Met Office 2023) The model was capable of simulating the percolation of the rainfall through the upper, unsaturated layers of ground and the flow of the water after it reaches the water table, but was not able to simulate surface flows of water. Any water that did not percolate into the pavement was removed from the model immediately, effectively modelling a street where an efficient drainage system quickly removes surface water.

To evaluate the pavement’s response to the rainfall event, the volume of water rejected form the ground surface, as well as the flow rate of water leaving the model by groundwater flow through the model boundaries was logged.

2.2 Results

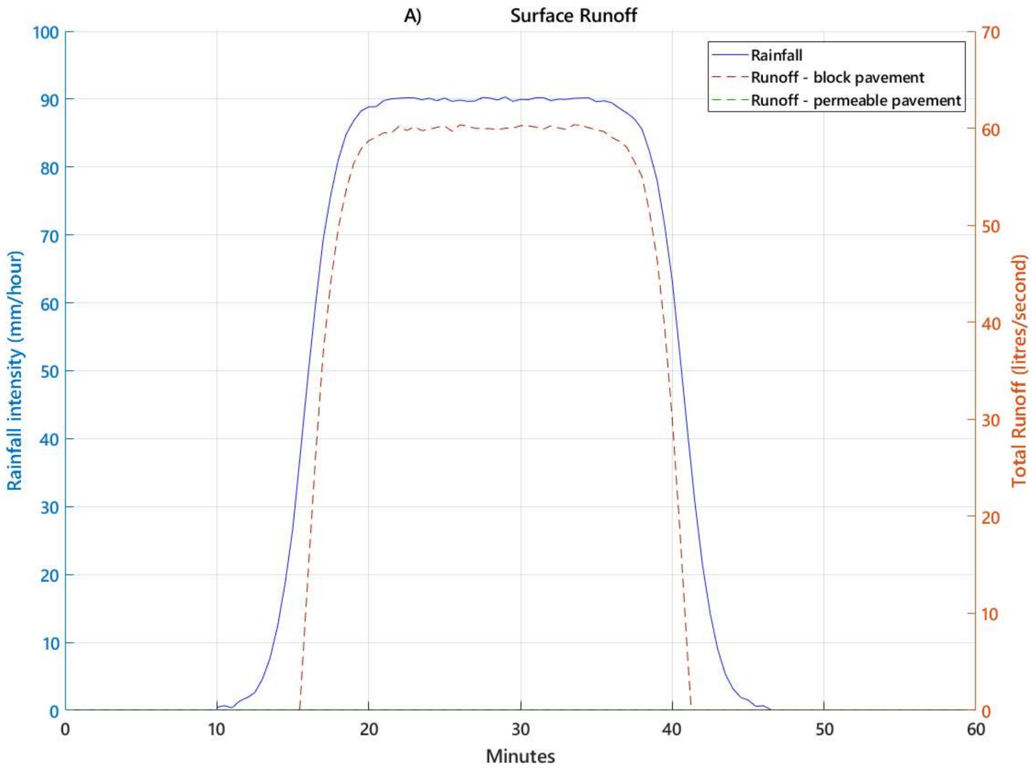


Figure 1: *Hydrograph of total runoff from the model, plotted alongside rainfall intensity.*

During the rainfall event, the block pavement caused a total of 82,000 litres of runoff to be rejected from the top surface of the pavement, at a maximum rate of c. 60 l/second (see Figure 1). The permeable pavement caused no runoff in this simulation, as all rainfall was able to percolate into the ground.

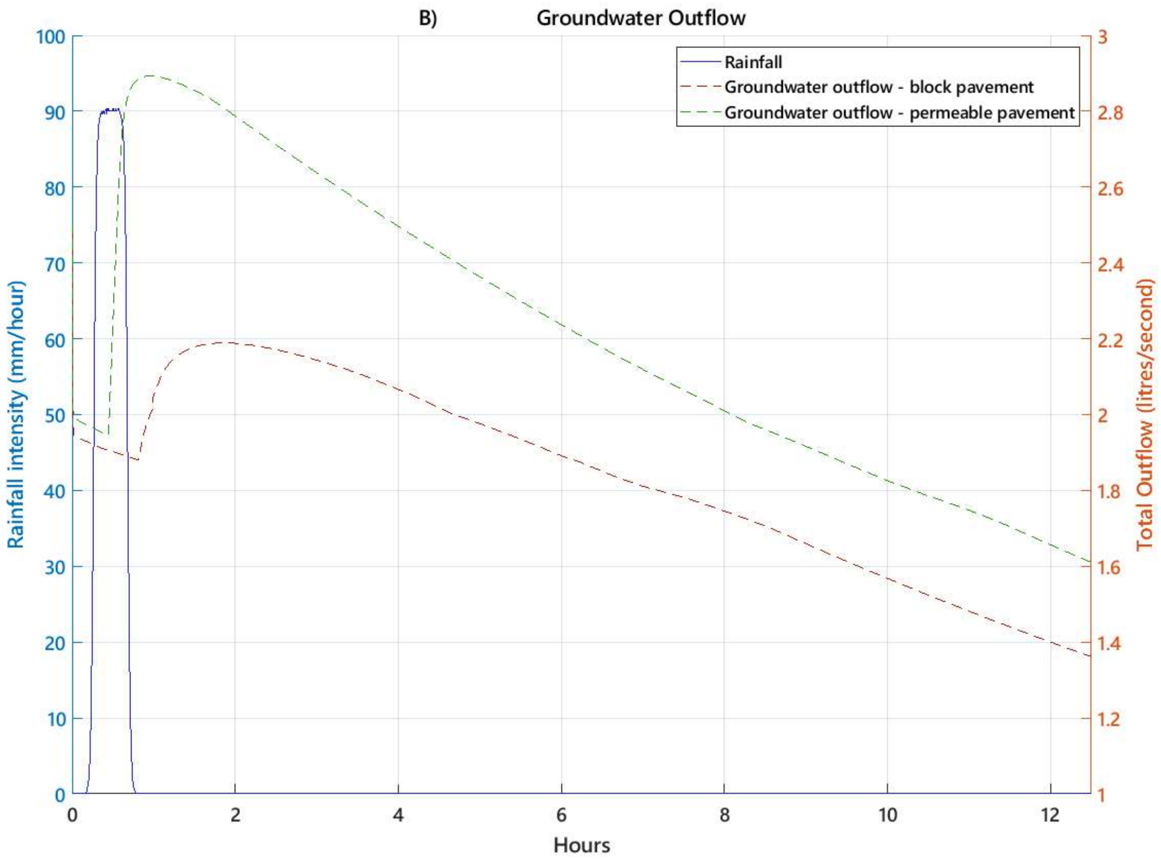


Figure 2: *Graph of total groundwater outflow from the model, plotted alongside rainfall intensity.*

Figure 2 shows that permeable pavement generates a higher groundwater flow from the boundaries of the model. This is expected due to faster infiltration through the pavement resulting in more rainfall reaching the groundwater (or subsurface drains if these where present). Note that this model assumes that all runoff is immediately captured and removed by surface drains. If this wasn’t the case, rainfall could be stored on the surface as puddles, then percolate slowly into the groundwater after the rainfall event, potentially leading to a longer, low peak in groundwater outflow for the block pavement.

3 References

Met Office, 2023, UK climate extremes (rainfall); https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-extremes - accessed 20/06/2023

Flood Innovation Centre
Aura Innovation Centre
Bridgehead Business Park,
Meadow Rd, Hessle, UK. HU13 0GD

01482 464700
floodinnovation.co.uk

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