Hydraulic performance of full flowing perforated pipe underdrains surrounded by loose laid aggregate

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Introduction

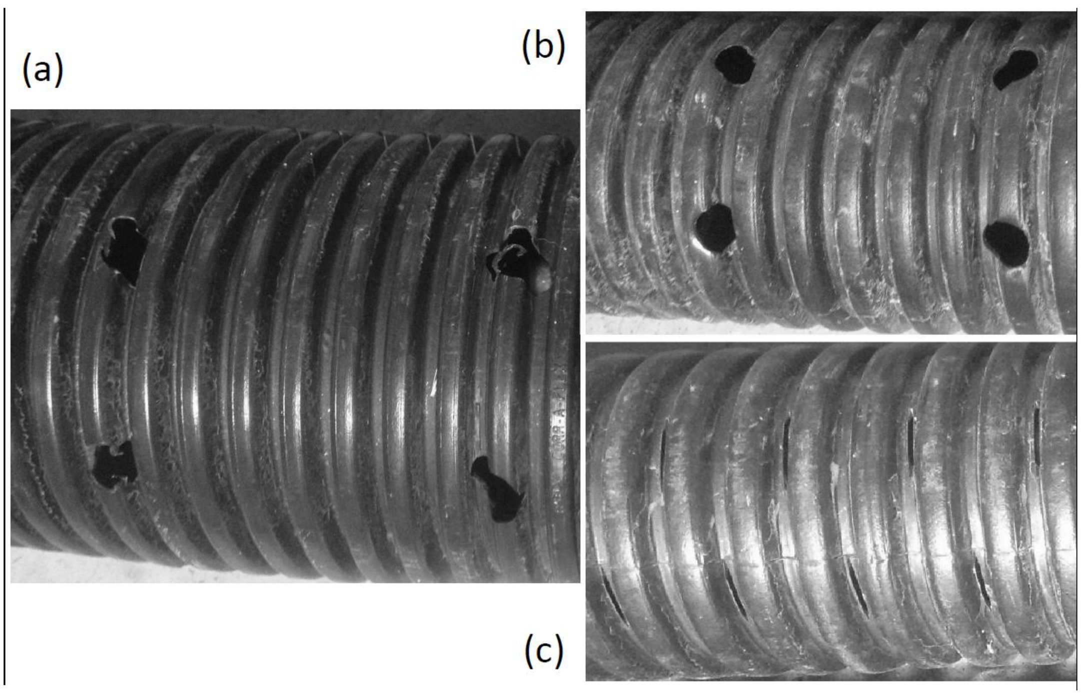
Low Impact Development (LID) Best Management Practices (BMPs) are becoming increasingly popular. Many of these BMPs work to increase the infiltration of runoff into the underlying soil. However, some BMPs, including porous pavements and infiltration trenches, sometimes need additional sub-surface drainage to comply with local drawdown regulations or to prevent the trench or pavement filling with runoff leading to water percolating up to the surface. Unfortunately, there is very little information available on how these drains perform. The goal of this research is to aid engineers by developing stage – discharge relationships for a range of commonly available perforated pipes.

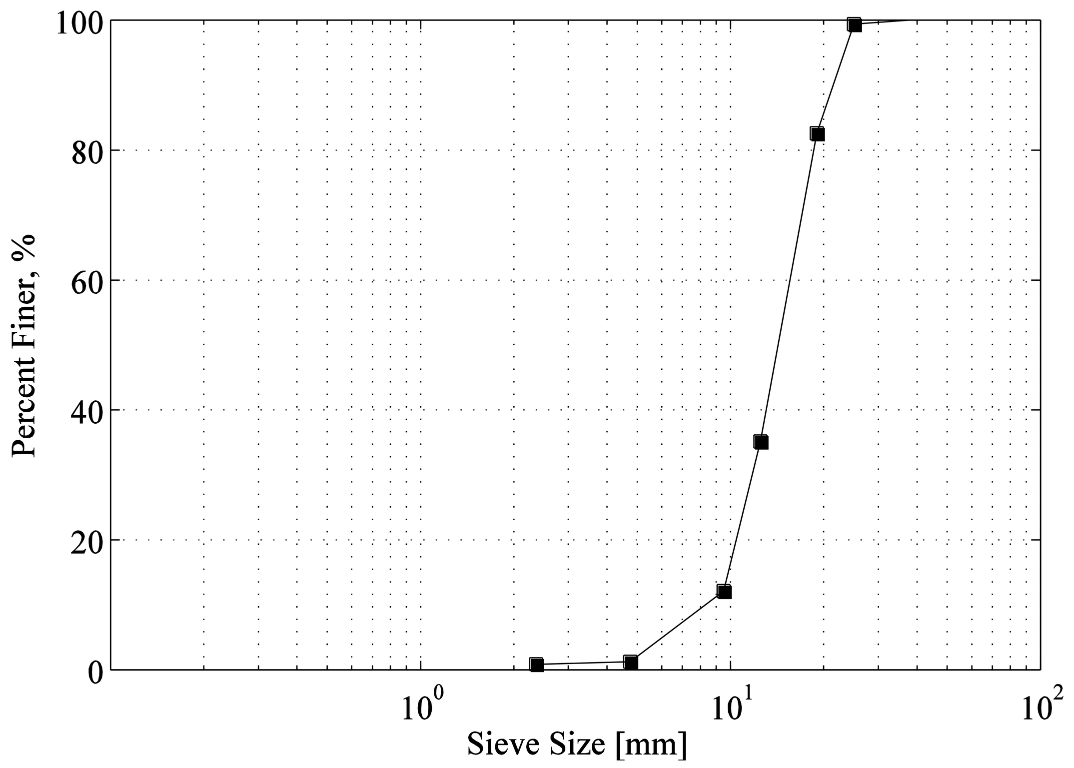
Experimental setup

We conducted a series of full scale lab experiments to establish the stage-discharge relationship for three commonly used perforated pipes.

The flume used had a 3 m test section. The inflow was controlled by 2 pumps with variable frequency drives and the flow rate was measured by 2 v-notch weirs. The pressure was measured along the pipe using piezometer tubes.

Three different, commonly available, perforated pipes were tested (a) 15.2 cm (6”) leached, (b) 10.2 cm (4”) leached, and (c) 10.2 cm (4”) perforated. Three separate 3 m samples of each pipe were tested. Both the aggregate depth and water depth were varied in the tests.

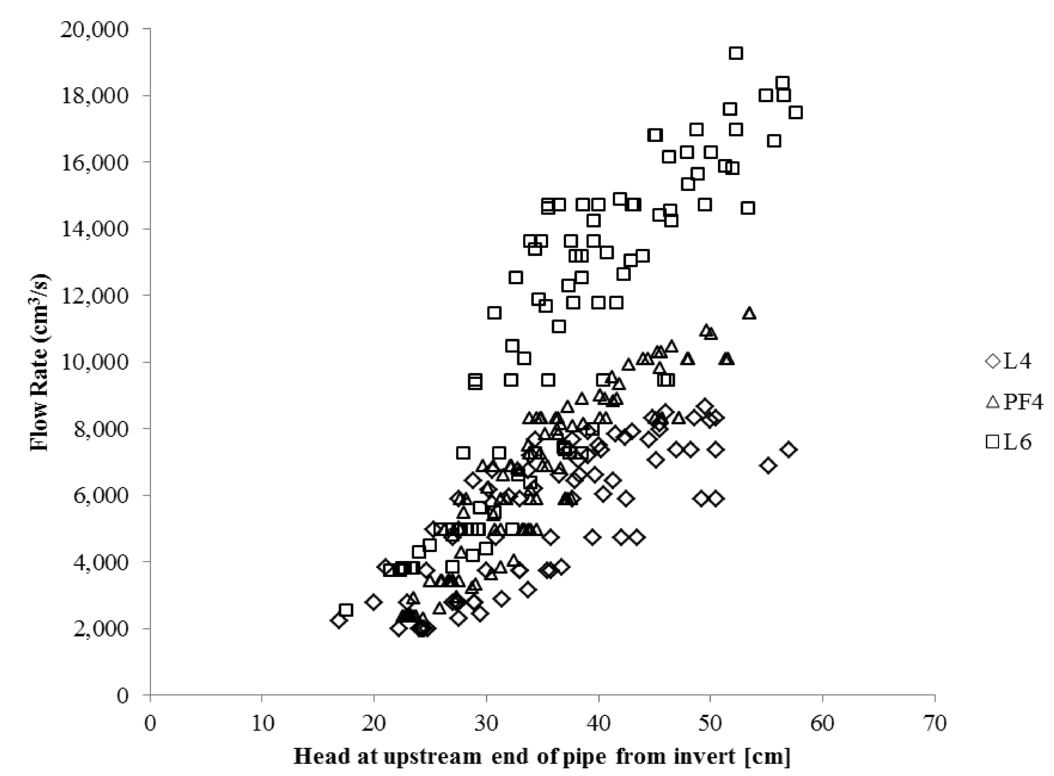


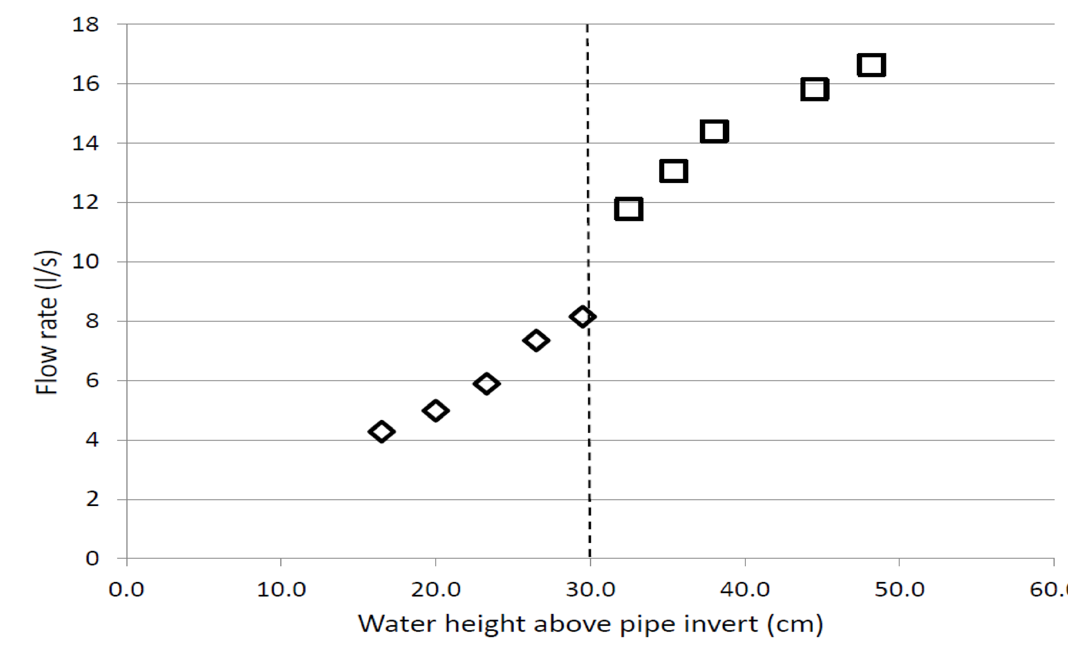


The pipes were laid in a bed of No. 57 stone (size gradation shown to left). The bed thickness varied from 7 cm for the 15.2 cm pipe to 11 cm for the 10.2 cm pipes. The depth of aggregate above the pipe ranged from 0-31 cm. For each test the water was turned on and allowed to run until the water surface level was steady.

Results

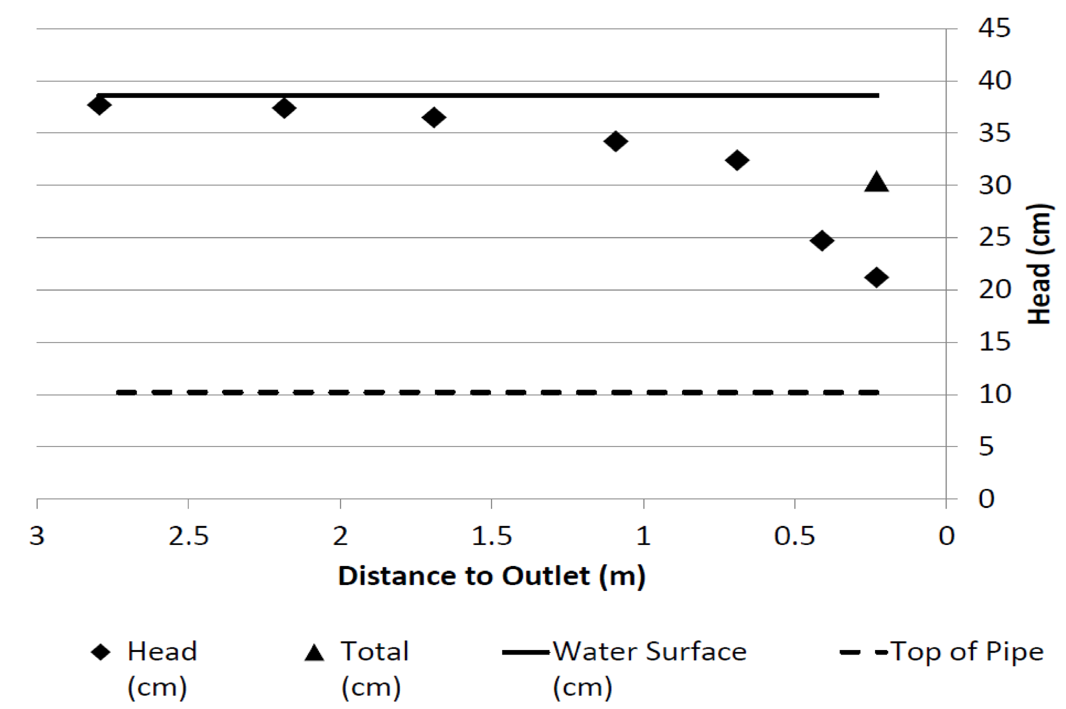
A total of 87 separate tests were conducted. The figure shows the flow rate measured versus the head over the invert. Multiple flow regimes were observed including the pipe running partially full at the outlet, and cases where the water surface was below the top of the aggregate and sloped down toward the outlet.

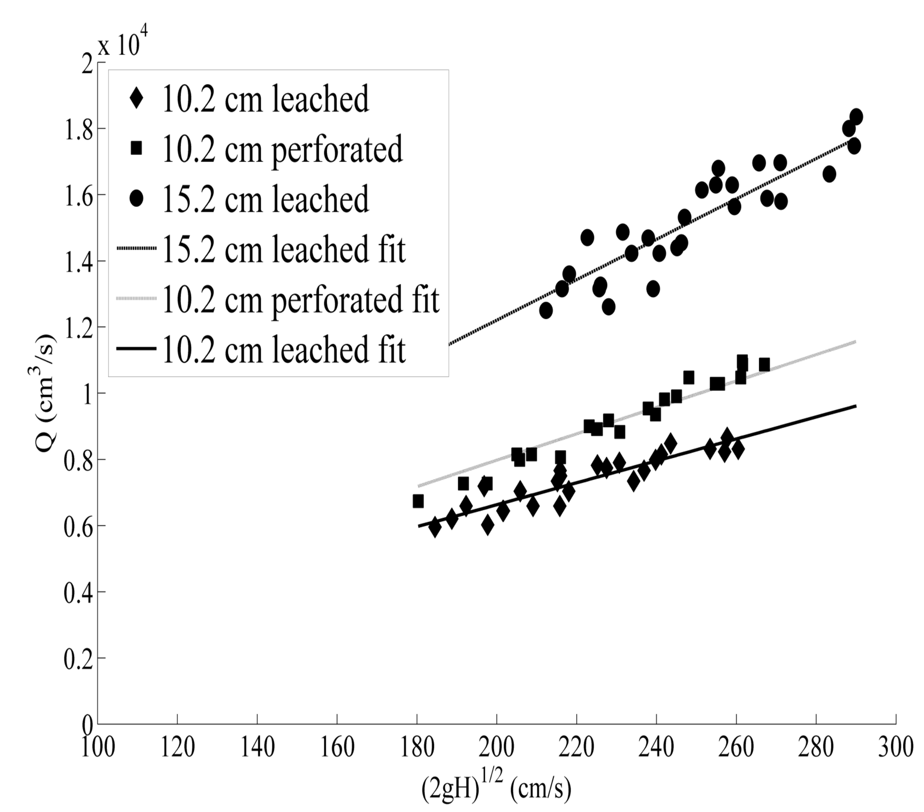




This figure shows the stage-discharge relationship for a 15.2 cm leached pipe with 15 cm of aggregate cover. There is a clear change in behavior when the water surface moves above the aggregate layer. The remaining results only consider this case.

Pressure measurements in the pipes indicate that the bulk of the head loss in the pipe occurs in the last meter. Therefore, it is likely that the bulk of the inflow into the pipe occurs in this region. If so, adding additional pipe length beyond a few meters will not improve performance.





Flow rates for all cases where the pipe is running full and the aggregate bed is below the water surface are plotted versus $(2gH)^{1/2}$. The data for each pipe falls on a straight line indicating that the pipe can be modeled as an orifice. That is

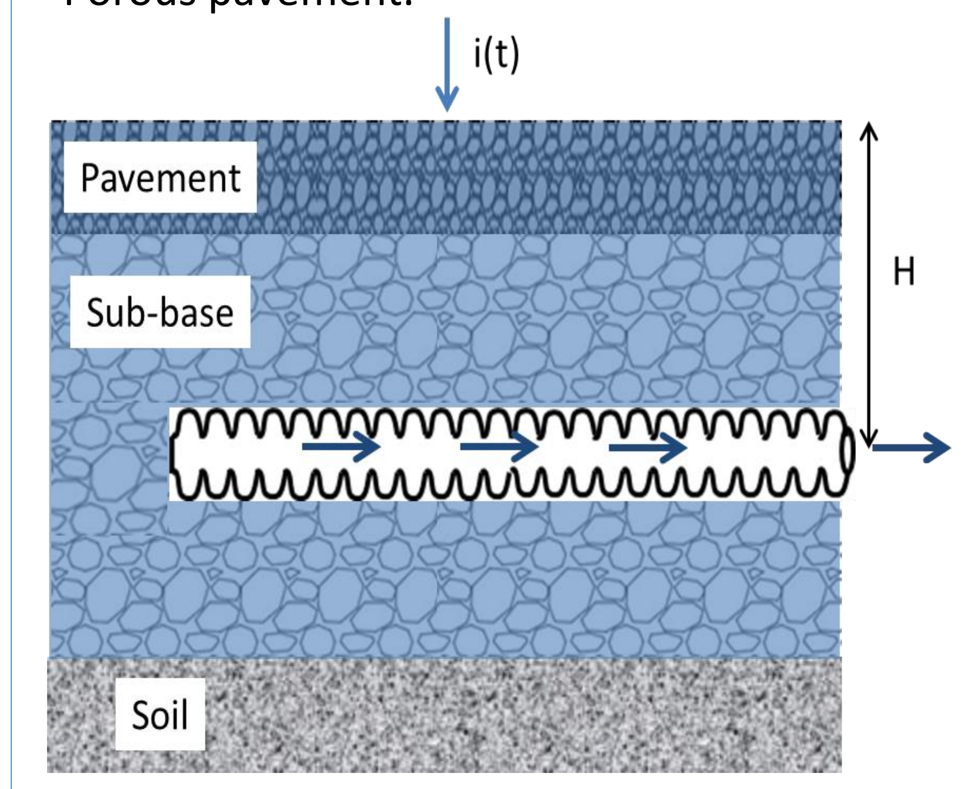
$$Q = C_D A_o \sqrt{2gH}. \qquad (1)$$

The orifice discharge coefficients are: 10.2 cm Perforated $C_D = 0.49$, 10.2 cm Leached $C_D = 0.41$, and 15.2 cm Leached $C_D = 0.34$.

Applications

The results can be used for sizing and locating perforated pipe underdrains for porous pavements. Porous pavements reduce runoff, enhance infiltration and can improve water quality. However, when installed over low infiltration capacity soils, porous pavements sometimes require a subsurface drain to prevent the rain water percolating up to the pavement surface.

The image to the right is Centennial Blvd. on the campus of Clemson University. The pavement in the foreground is porous whereas the pavement in the background is a regular impervious asphalt. Note the lack of surface runoff on the Porous pavement.



The location of any given size perforated pipe underdrain can be calculated using the orifice equation (1) and the discharge coefficients established in our tests. To avoid the rainfall filling the sub-base and percolating back to the surface, the discharge out of the pipe must equal the rainfall intensity times the pavement area. Therefore, the depth (H) of the pipe centerline below the pavement surface can be calculated from:

$$Q_{max} = i_{max} A_{pave.} = C_D A_{pipe} \sqrt{2gH} \qquad (2)$$

Future Work

We are planning to extend this research experimentally and numerically to:

1. Experimentally examine the partially full outflow case
2. Test different aggregate covers with different porosity and hydraulic conductivity
3. Develop a computational model for the experimental setup
4. Conduct a computational parametric study that examines the influence of pipe length, trench width, pipe diameter, wall inlet area, and aggregate depth, on the discharge coefficient for the pipe running full case.

References

Murphy, P., Kaye, N. B., & Khan, A. A. (2014) “Hydraulic performance of aggregate beds with perforated pipe underdrains flowing full.” *A.S.C.E. Journal of Irrigation & Drainage Engineering* **140**(8), 04014023-1-7.