Numerical Model For Hydraulic Performance Of A Perforated Pipe Under-drain Surrounded By Loose Aggregate

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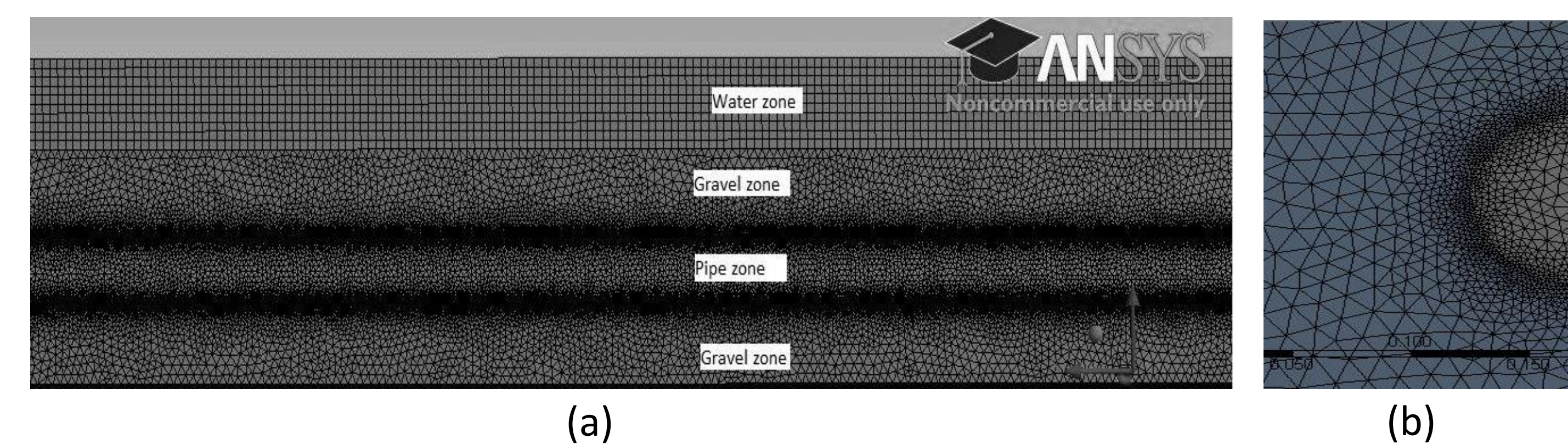
Introduction

Urbanization significantly alters the hydrological cycle, leading to reduced infiltration, increased flooding, and reduced water quality. Proper management of storm-water runoff is necessary to mitigate these undesired impacts. The use of Best Management Practices (BMP) and Low Impact Development (LID) is becoming more common day by day for this purpose and perforated pipes are one of the main components of these LIDs and BMPs. This poster presents results from a CFD model that combines both porous media flow and pipe flow. The model was developed in ANSYS FLUENT to examine the hydraulic behavior (stage-discharge relationship) of a porous pipe shrouded in loose aggregate for use as an underdrain in storm water management. The model was validated against the experimental data of Murphy et al. (2014) and was then used to undertake a detailed parametric study of porous pipe underdrain performance.

Methodology

A detailed 3D model has been made and solved using the ANSYS workbench and **ANSYS FLUENT** v 14.0 respectively. There were three cell zones in every model; pipe, aggregate and water. The aggregate zone was designated as a porous packed bed zone.
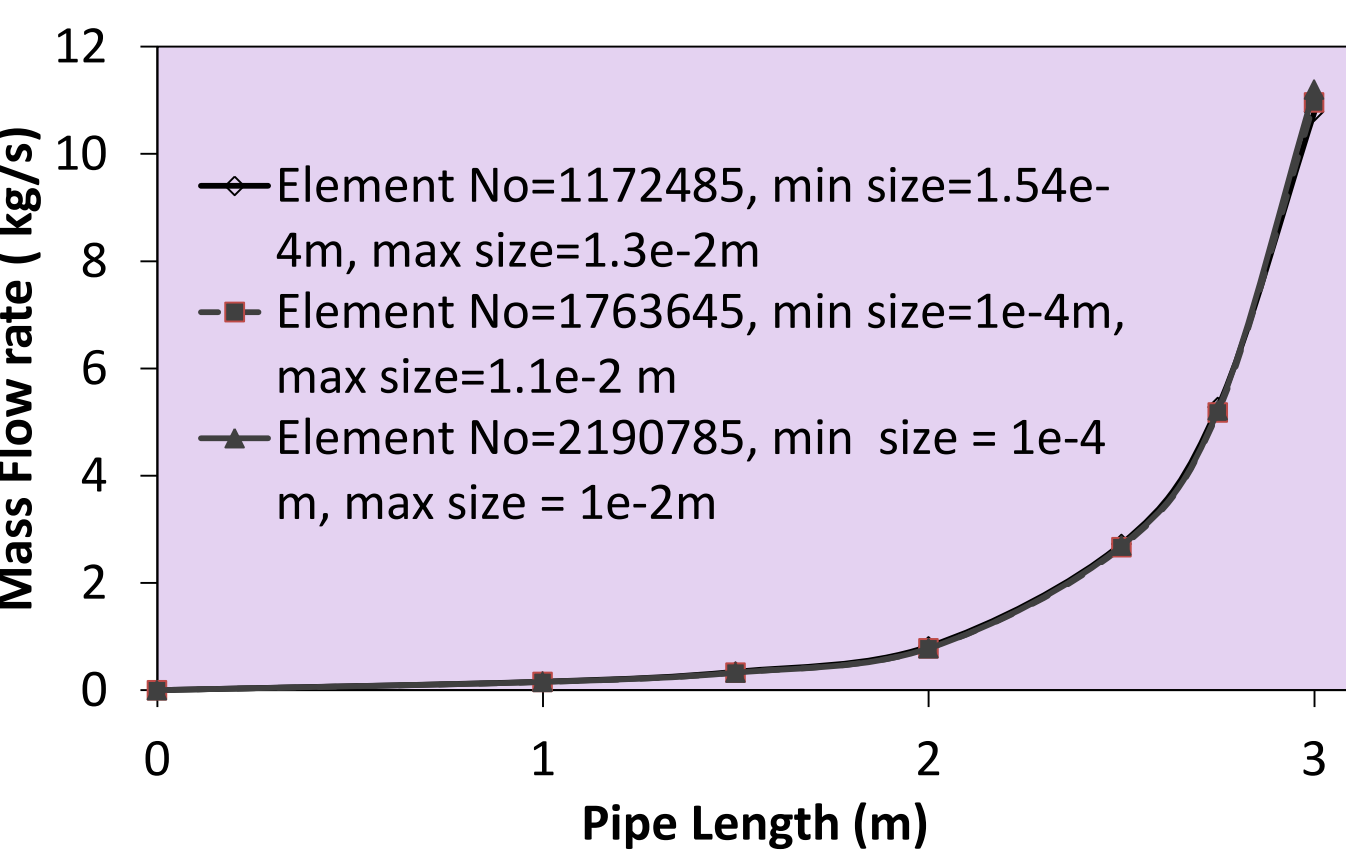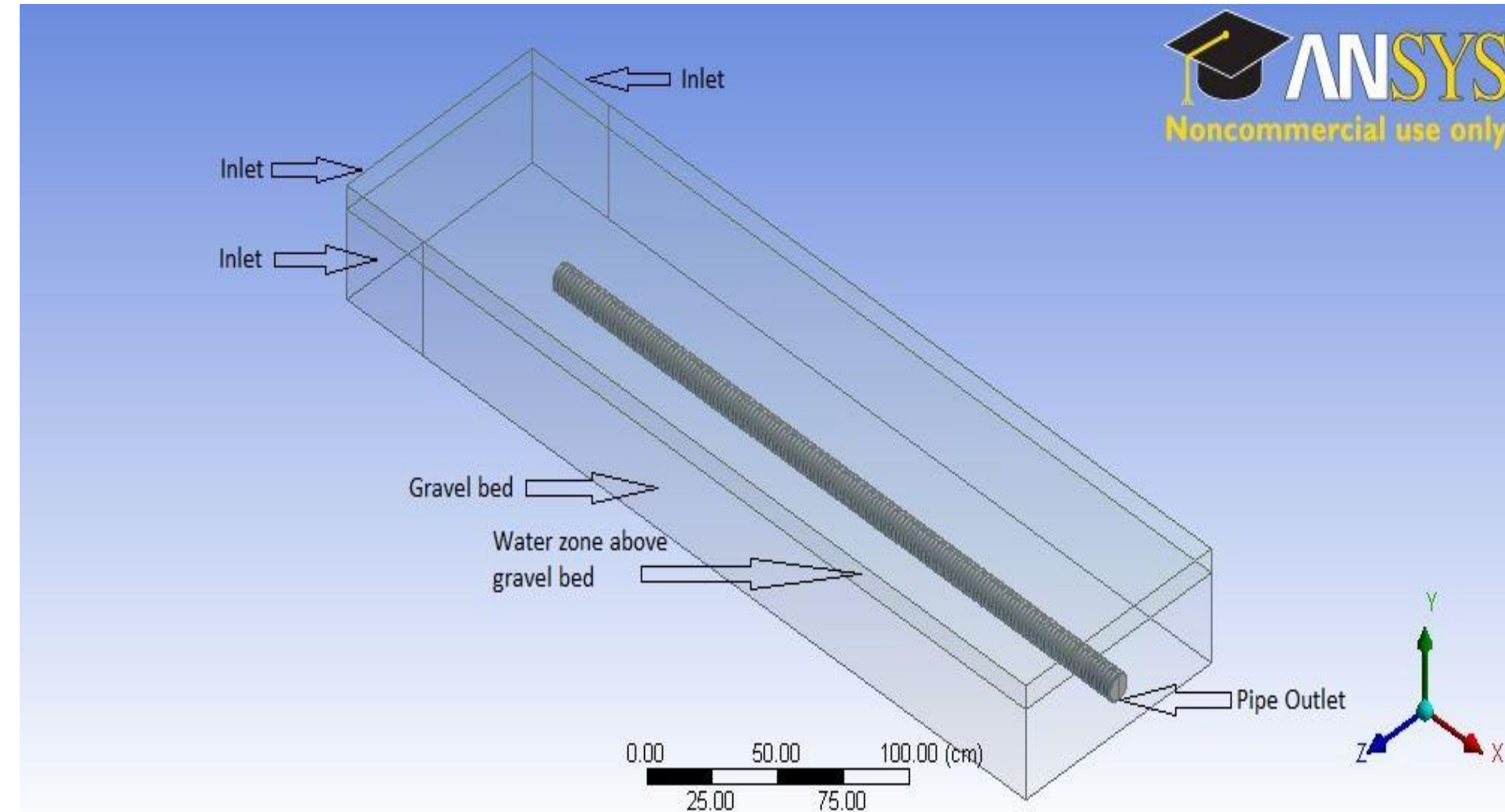

From a mesh sensitivity analysis, it was found that the optimum minimum size of the element is 1.54e-4 m and the maximum face size is 1.3e-2 m. Figures below show the mesh along mid plane (a) and a close view along a cross section of the model (b) respectively.

Element No=1172485, min size=1.54e-4m, max size=1.3e-2m
Element No=1763645, min size=1e-4m, max size=1.1e-2 m
Element No=2190785, min size = 1e-4 m, max size = 1e-2m

(a) (b)

The figure on the right shows the different boundary conditions using different colors.

The following solution methods were used in developing the model.
- Pressure–velocity coupling : SIMPLE
- Momentum, turbulent kinetic energy and turbulent dissipation rate discretization: Second Order Spatial
- Moment discretization: Second Order Upwind Scheme
- Time : Transient
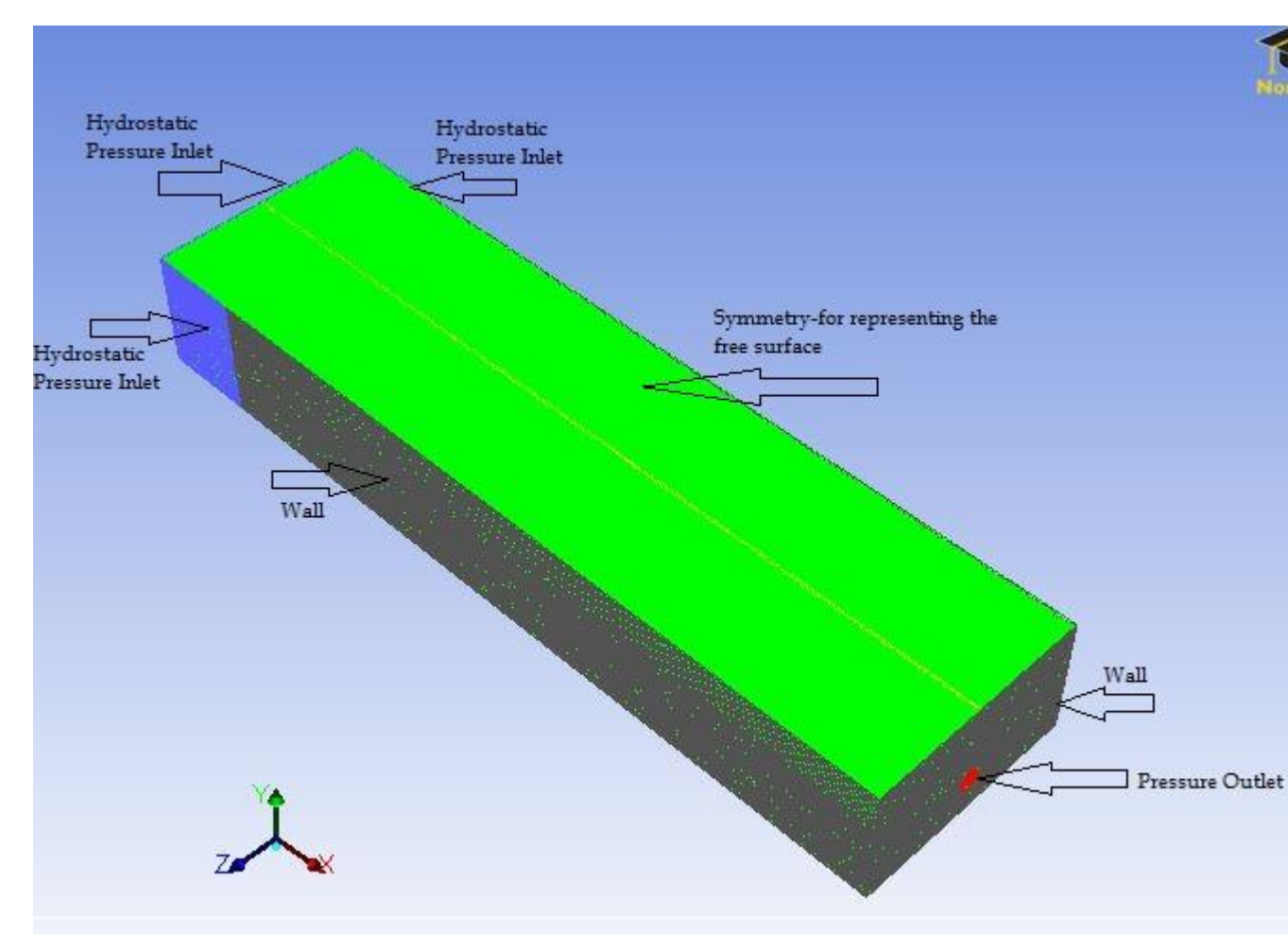
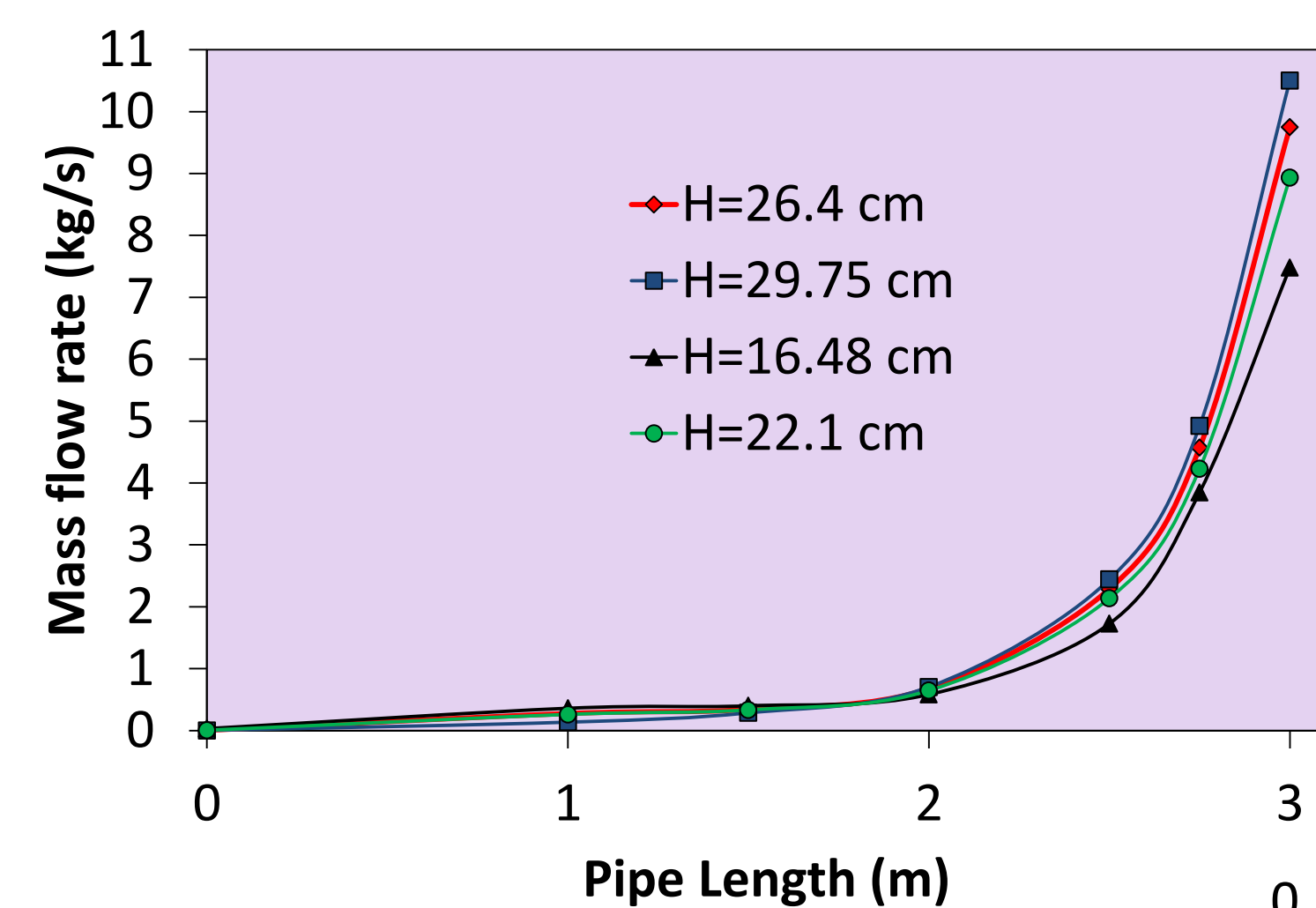The Palmetto Cluster at Clemson University was used for all these large scale simulations.

Results
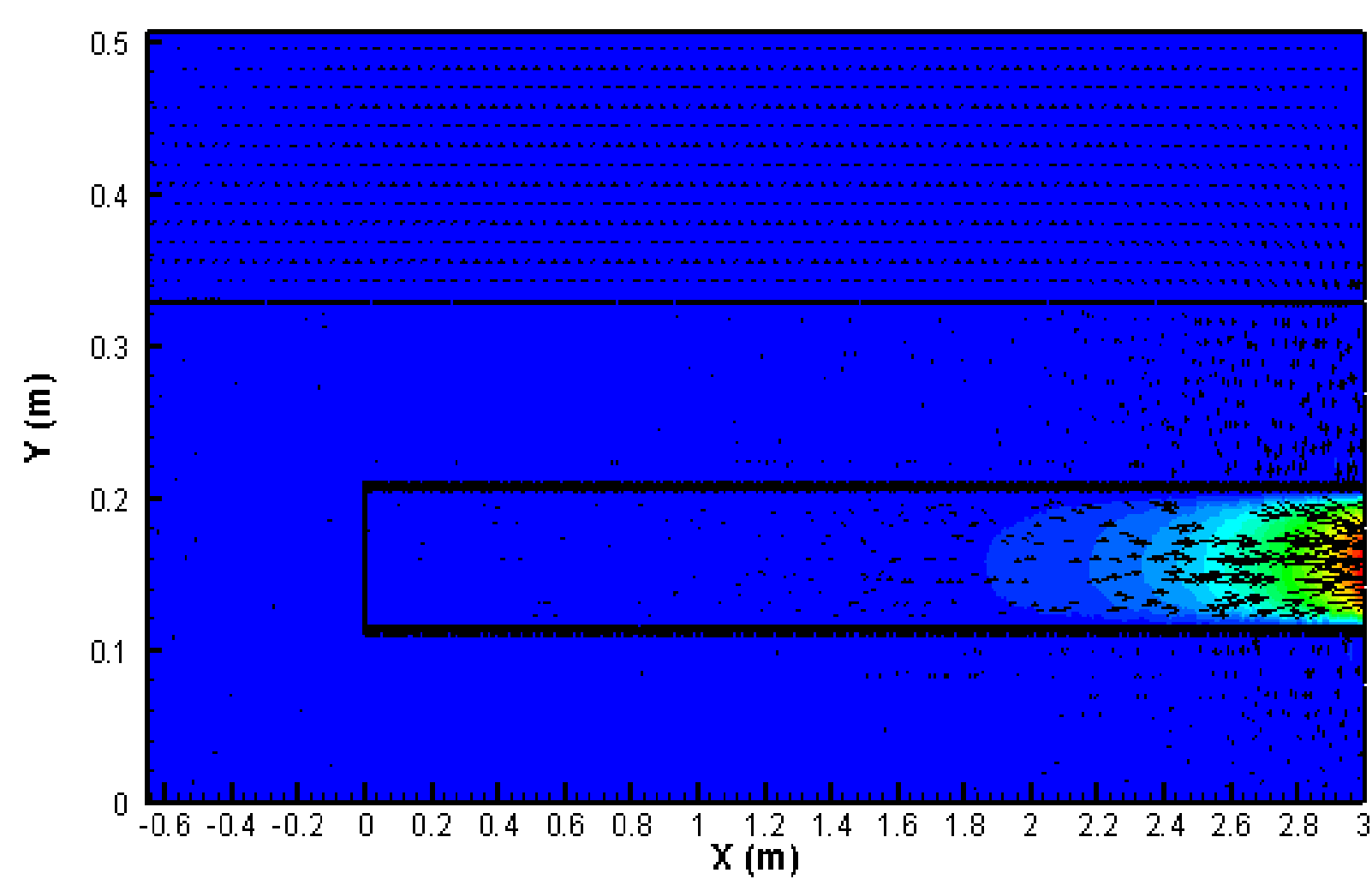
✓ When the water surface is above the top of the aggregate, water flows along the water surface and then down through the aggregate.

✓ The aggregate flow is mostly vertical, which is consistent with prior experimental results.

The CFD model constantly over predicted the mass flow rate through the pipe.

✓ The difference between the CFD model and experimental results was on average 10.6% (upper figure to right).
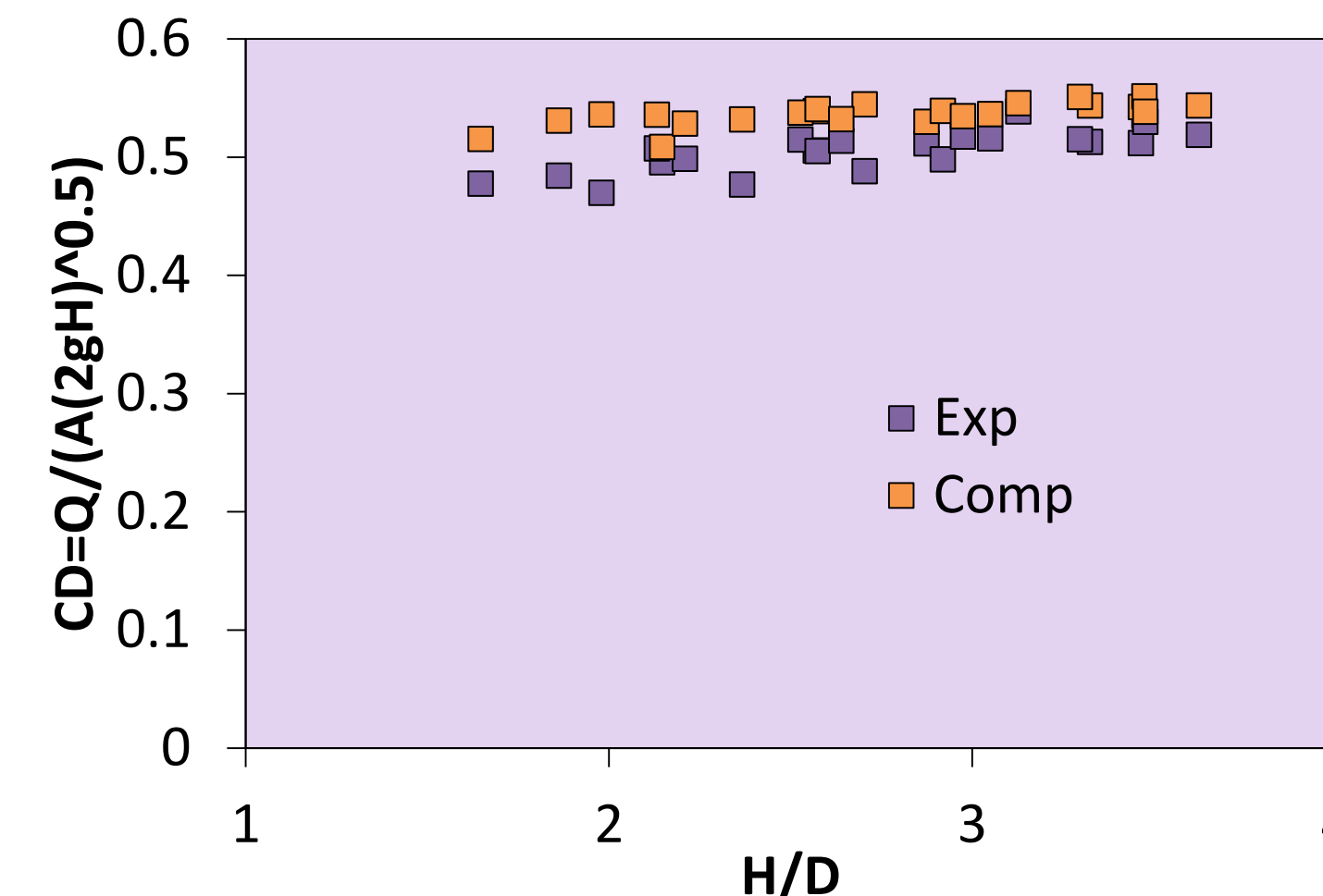
One possible explanation for this consistent over prediction is that the CFD model does not account for individual pieces of aggregate blocking holes in the pipe sidewall. To correct for this, the wall inlet area was reduced by multiplying it by the aggregate porosity. That is,

$$A_{inlet-corrected} = \phi_{aggregate} A_{inlet}.$$

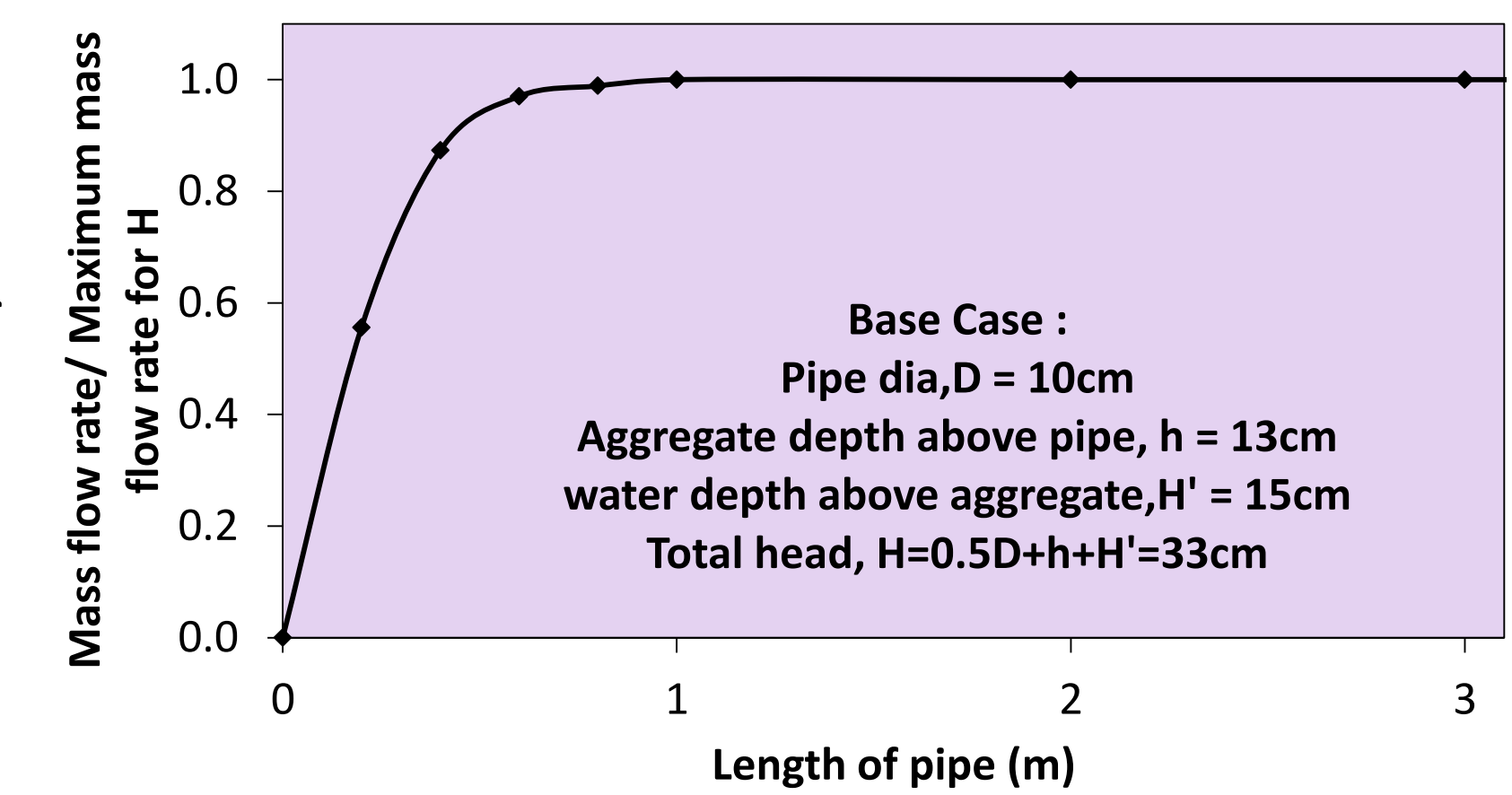✓ This reduced the average error to just 6% (lower figure to right).

✓ The mass flow rate is quite small at the upstream end of the pipe with the bulk of the water entering the pipe in the final meter before the outlet.

A non-dimensional plot of $C_D = \frac{Q}{A\sqrt{2gH}}$ vs. $\frac{H}{D}$ for both experimental and computational data is shown on the right.

✓ Experimental C_D is 0.492 from Murphy et al. (2014).
✓ Computational C_D is 0.53

Parametric Study

A parametric study was undertaken to examine the impact of pipe length, total head, trench width, pipe diameter, and pipe wall inlet area on the hydraulic performance of porous pipes. In all cases the domain length was 10 m.

Results indicate that for a given pipe and trench configuration, the discharge increases with pipe length up to a critical length of typically just over 1 m. Beyond this critical length, there is no increase in the outlet flow rate with further increases in the pipe length.

Base Case :
Pipe dia,D = 10cm
Aggregate depth above pipe, h = 13cm
water depth above aggregate,H' = 15cm
Total head, H=0.5D+h+H'=33cm

✓ There is little performance to be gained by having porous pipe drains that are longer than about 1 m.
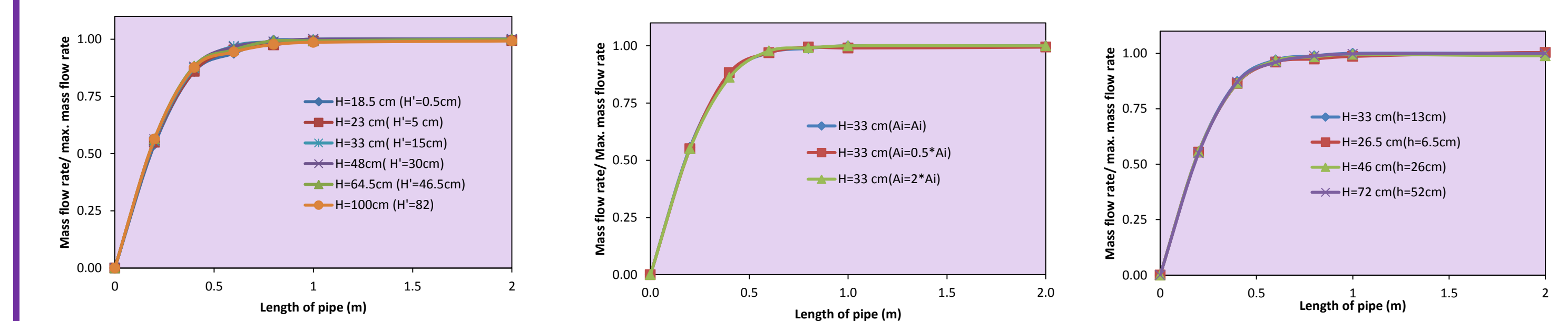
✓ The critical length is insensitive to changes in (from top left) total head over the pipe (H), wall inlet area (Ai), depth of aggregate (h), pipe diameter (D), and channel width (W).
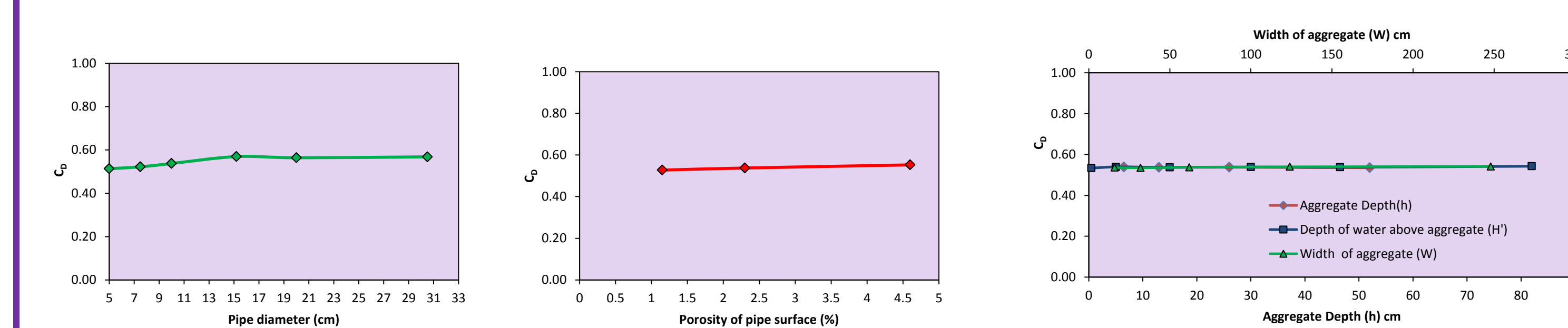
✓ C_D doesn't vary with H, Ai, W, and h.
✓ If the pipe diameter increases, C_D increases a bit up to a certain point and then becomes constant.

Applications

- This developed model can be used for design and analysis of different LIDs and BMPs for any practical range of parameters.
- The parametric study shows that for draining stormwater, using several parallel pipes instead of a single long pipe of the same diameter and total length will provide better performance.

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.