Lysimeters

1 Introduction

This steady state SEEP/W example illustrates how to model a lysimeter from construction of the model to interpretation of the results. Lysimeters are used to measure flow through caps and liners, but their correct design is critical to their ability to function under field conditions. If they are not specifically designed for each case, considering material properties, likely flow conditions, and physical dimensions, they are likely to not provide useful field data.

A lysimeter is a physical container (i.e., shallow pan, barrel, cup etc.) that is installed at depth within a soil profile and is designed to collect water that has percolated vertically through the soil. At regular intervals, the water that has entered the lysimeter is measured, and the amount of water collected over a given time frame is interpreted to be equal to the infiltration rate that has occurred through the surrounding soil profile. The measured infiltration rate can then be used to evaluate situations such as the effectiveness of an engineered soil cover system or to predict the movement of contaminants with time.

Because a lysimeter is buried at depth, it is not possible to visually evaluate and witness its performance. Interpretation of performance depends entirely on having an understanding of the processes involved and the properties that control flow. In the past, questions were raised about the effectiveness and reliability of shallow pan lysimeters in particular as appropriate monitoring devices. The use of a finite element model is instrumental in learning more about how a lysimeter works and in helping understand the dominant processes involved, ensuring that future designs are effective.

When a lysimeter is installed in the ground, it should be backfilled with the same soil as the surrounding material.

2 Feature highlights

GeoStudio feature highlights include:

- Steady state flow
- Interface lines as barriers to flow
- Multiple files in a single analysis

3 Geometry and boundary conditions

The image in Figure 3-1 below is the overall geometry of the model with regions, points, and lines shown. The mesh and boundary conditions are turned off in this view. The model is set up to consider 2 different lysimeter designs: a shallow option, and a deeper option. Geometry lines have been drawn to represent the walls and base of the lysimeter, and they are assigned either a “none” material model to make them impermeable to flow, or the sand material model to make them part of the “waste”.

The model is set up with six analyses: three consider low, average, and high surface fluxes for the shallow lysimeter; and three consider the same flux conditions on the deeper lysimeter. The flow rates at the ground surface are assumed net surface flow after evaporation and transpiration, and are constant over all time for the steady state analyses. The three flow rates are 1e-3, 1e-4 and 1e-5 m/day.

The base boundary condition is a Head = 0 condition. Because the model left hand corner is located at coordinates X=0, Y=0, this boundary condition means the water table is just touching the lower left corner. As the bottom slope rises to the right, the pressure condition is assume negative, hydrostatic because H = 0, P = -y along the slope.

The lysimeter is a device that captures flow inside its volume so that it can be measured. The collection of water can be manual, by pumping from a vertical pipe, or lateral to a tipping bucket rain gauge device via piping installed into the slope. In either case, a seepage review boundary condition must represent the exit point of water from the inside of the lysimeter. The boundary location in these models is a small distance up from the base of the lysimeter. This means that as soon as the bottom few inches are saturated, water will start to leave the lysimeter through the review boundary node. If the lysimeter dries out, the review node will not become a source for water in the finite element solution.

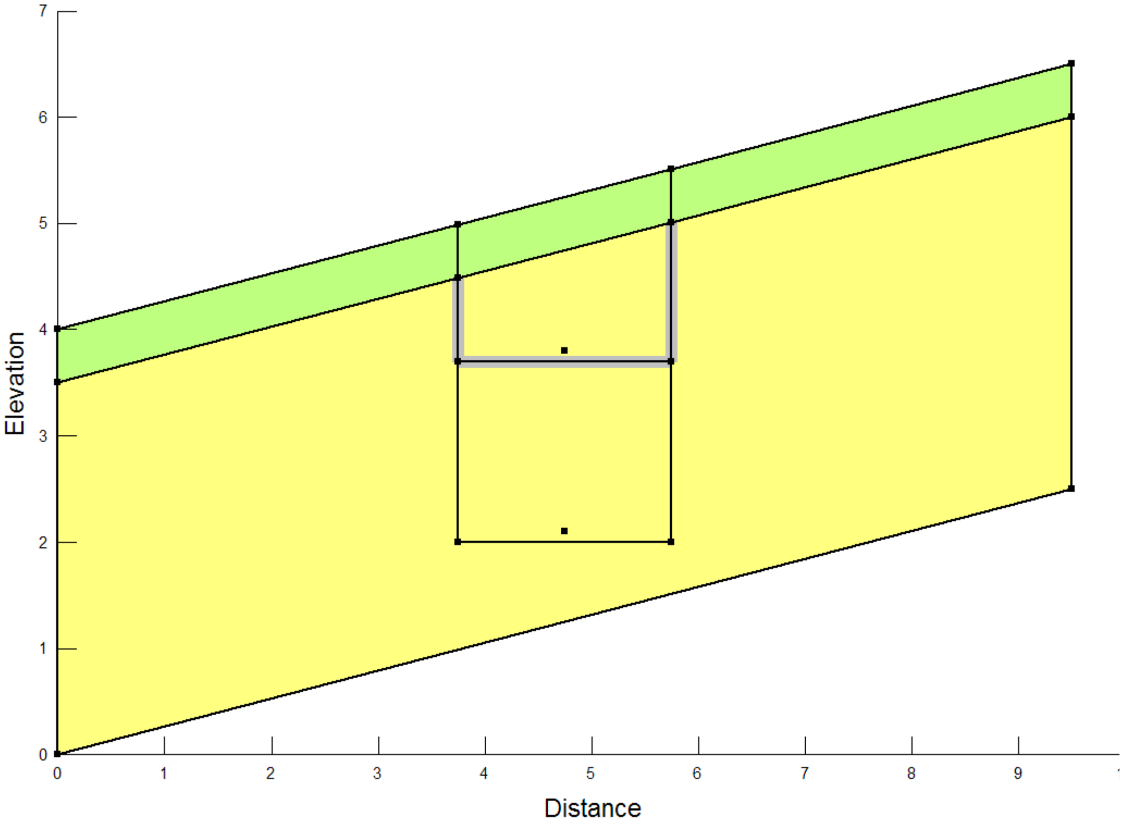


Figure 3-1 Geometry common to all analyses

This geometry was created by first drawing a soil region for the yellow waste material. A surface region mesh was then applied to represent the cap material. Next, the Draw Lines command was used to outline the lysimeter. The Draw Mesh Properties command was then used to specify the finite element size inside the soil, and to specify that an interface element of thickness 0.05m was to be applied to the lysimeter lines. The thickness is not critical to the solution in this case, as the material assigned to the interface is a “none” material, which means it is excluded from the solution of the equations. More information on drawing interface elements is available in the chapter on Geometry and Meshing in the GeoStudio2007 Engineering Methodology books (eg., SEEP/W, VADOSE/W).

The two images below show a close-up of the lysimeter design and boundary conditions for the shallow and deep walled cases. You can see that the depth of lysimeter is changed simply by changing the material assigned to the interface elements. In these views, you can also see the location of the drain point boundary condition.

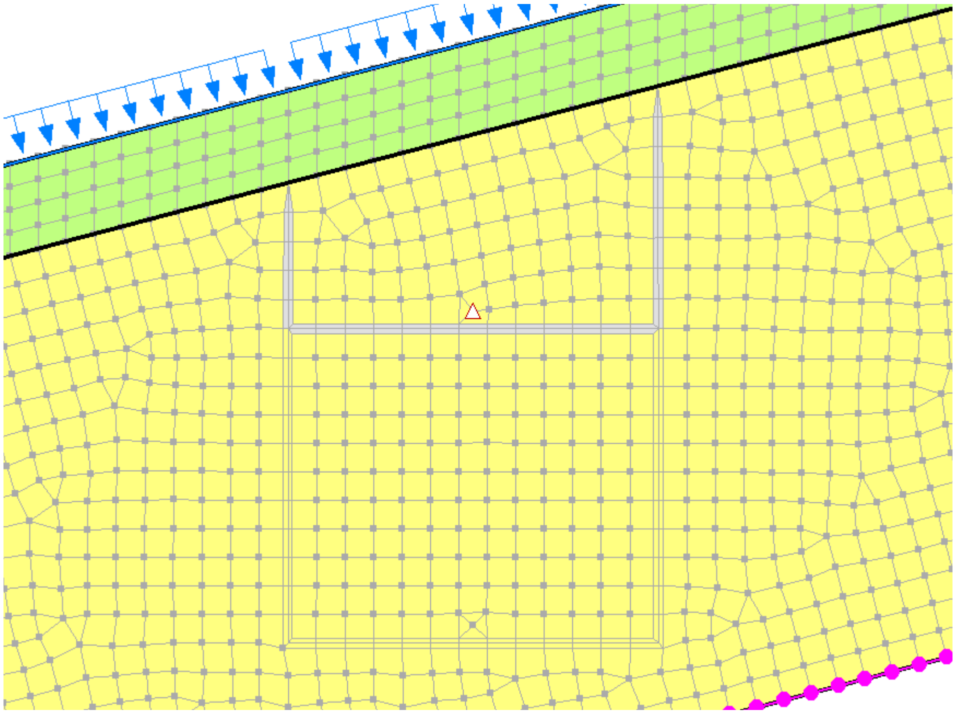


Figure 3-2 For analyses with shallow lysimeter

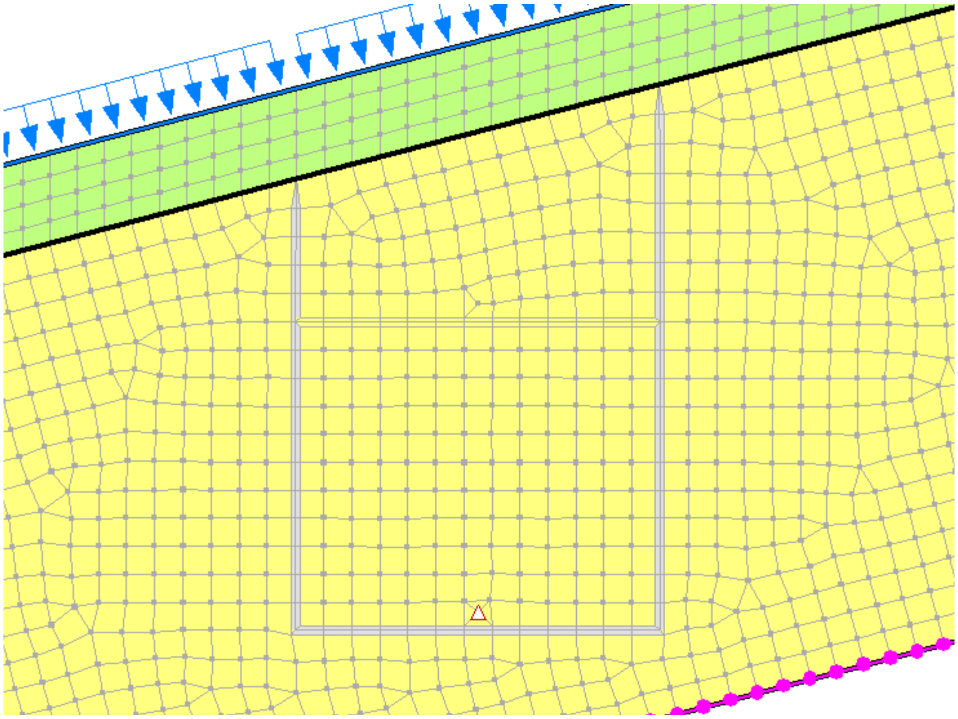
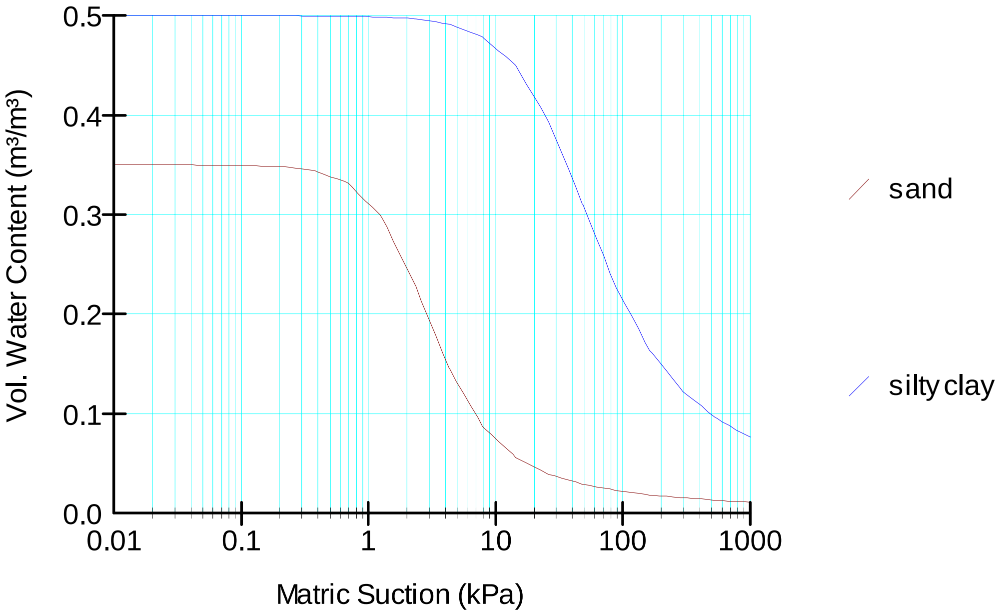
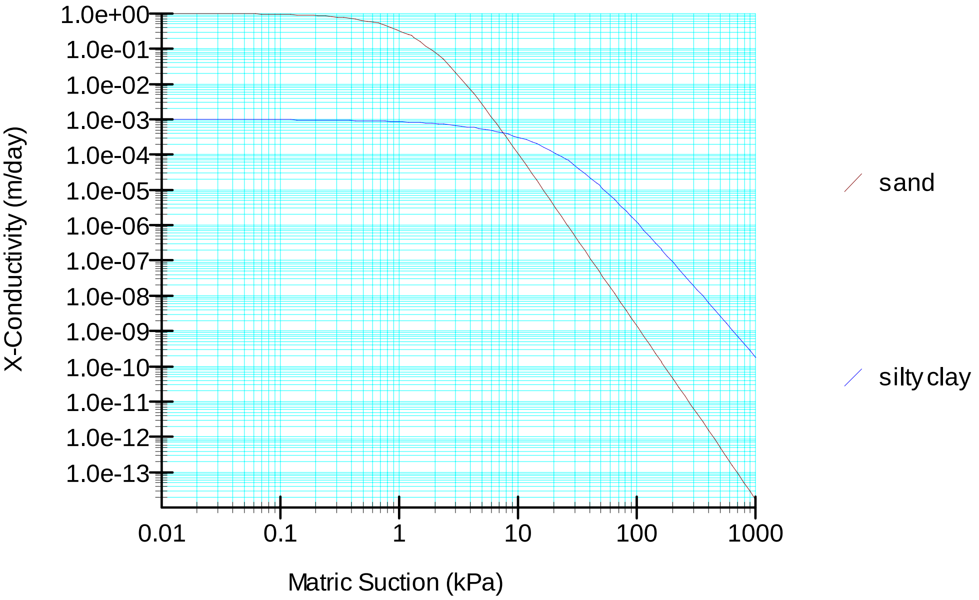


Figure 3-3 For analyses with deeper lysimeter

4 Material properties

The material models are set up to simulate a silty clay cap material over a sandy waste material. The functions are from internal sample functions in SEEP/W, and are shown below.





5 Discussion of results

The key to designing a lysimeter that is going to work as intended, is to adjust the geometry of the lysimeter so that there is no positive gradient existing at the top of the lysimeter that will draw water out of the container. In other words, given an assumed range of infiltration rates and the hydraulic properties of the soil, the same equilibrium pressure condition must be established within the confines of the lysimeter that exists outside the lysimeter. The image in Figure 5-1 shows how a shallow pan lysimeter will not function correctly. There is an obvious difference in pressures inside and outside the pan. When this is the case, bypass flow will occur, as shown in Figure 5-2.

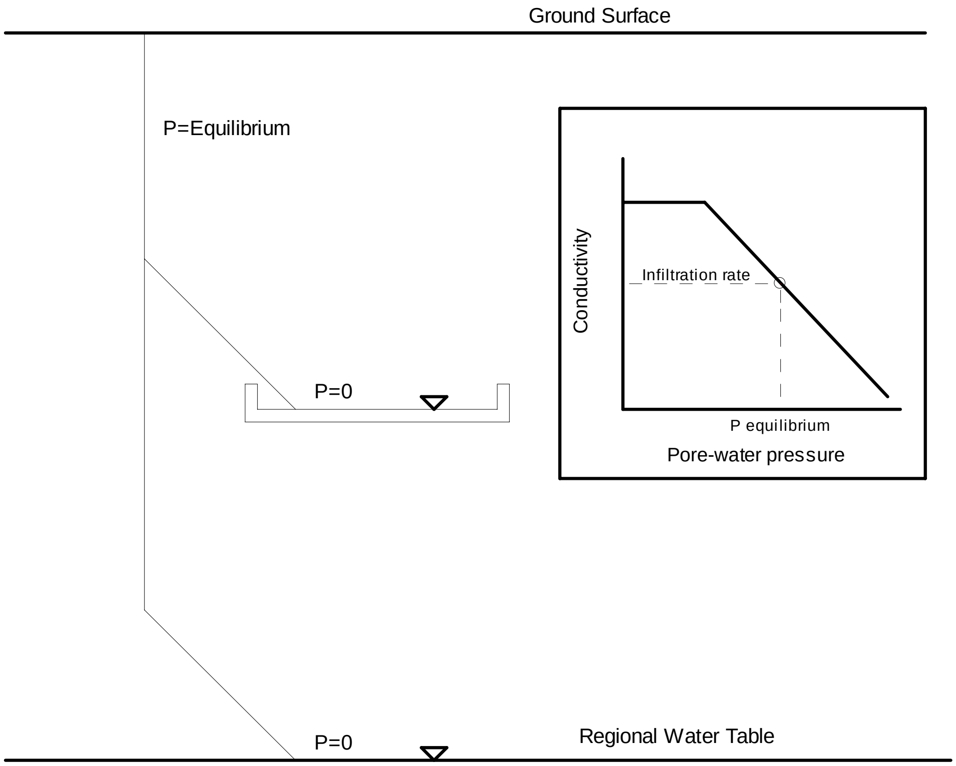


Figure 5-1 Pressure profiles within and around lysimeter

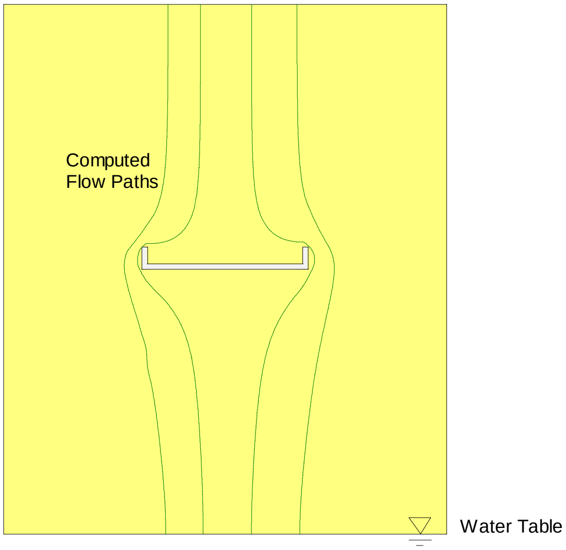
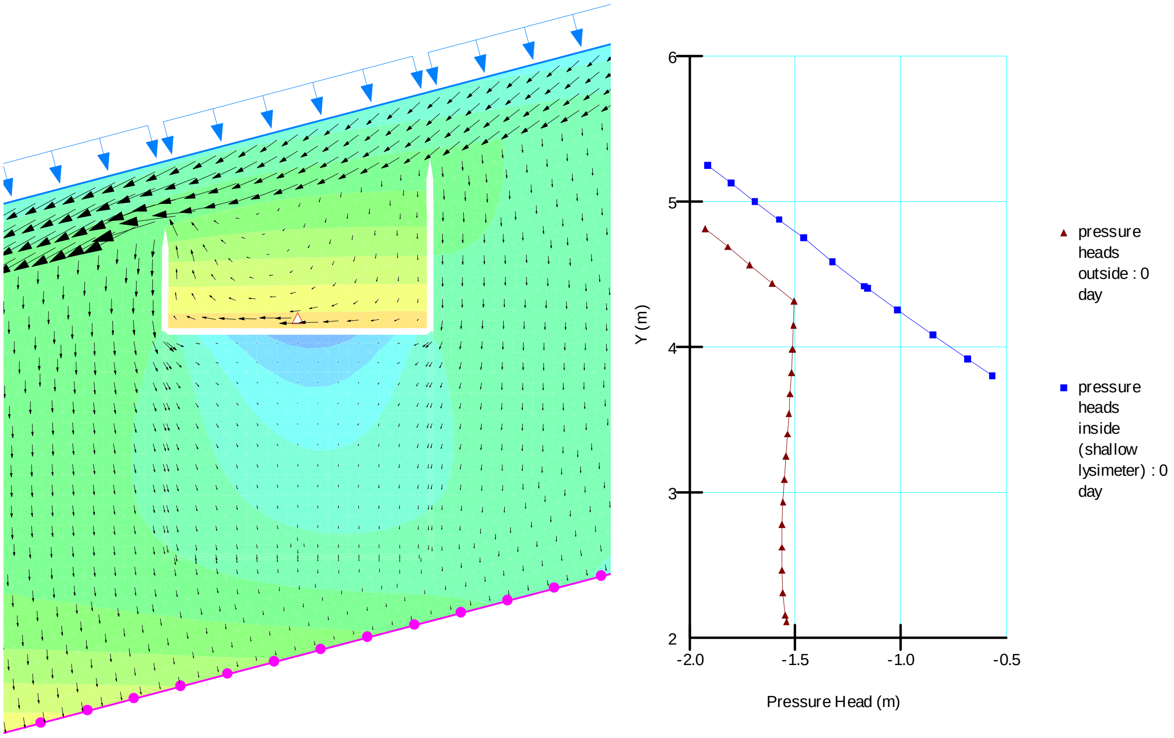


Figure 5-2 Bypass flow, non functioning lysimeter

Let us now consider the results of the six analyses in this example file. First, we consider the shallow buried lysimeter for the three flow cases.

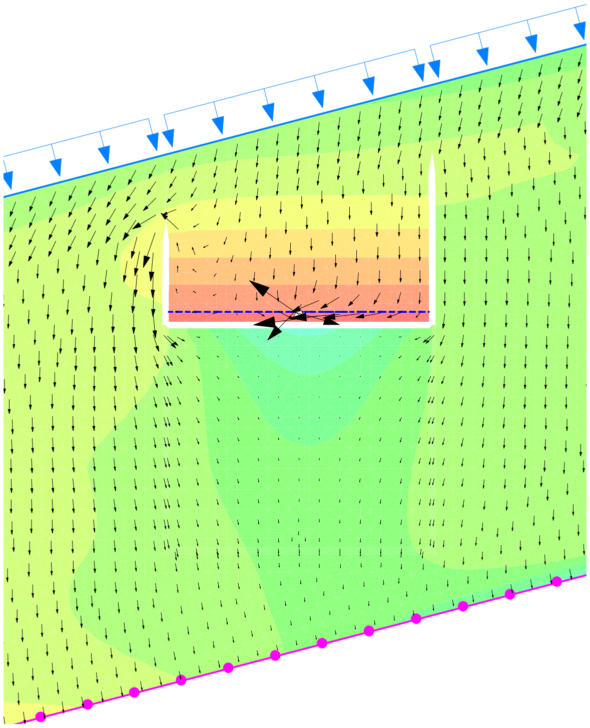
Analysis: Shallow low flux

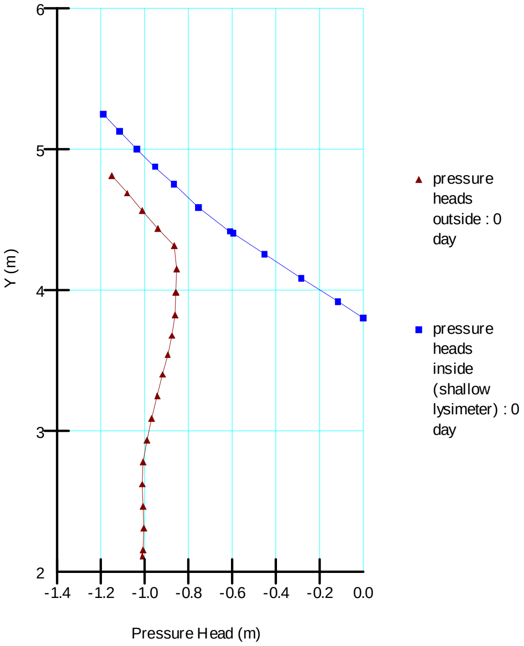
This image shows the flow regime and pressure profiles within and external to the lysimeter for the low flow case. There is obvious bypass flow and different pressures within and external to the lysimeter. There is wicking up and around the left edge, and there is no drainage out the drain node, as positive pressures never develop to cause a seepage review condition that will lead to collection from the base of the lysimeter.



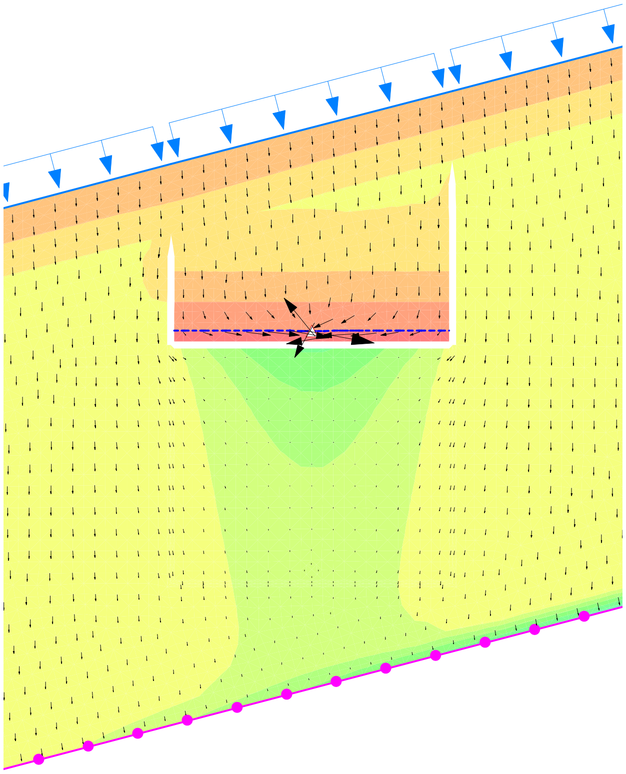
Analysis: Shallow ave flux

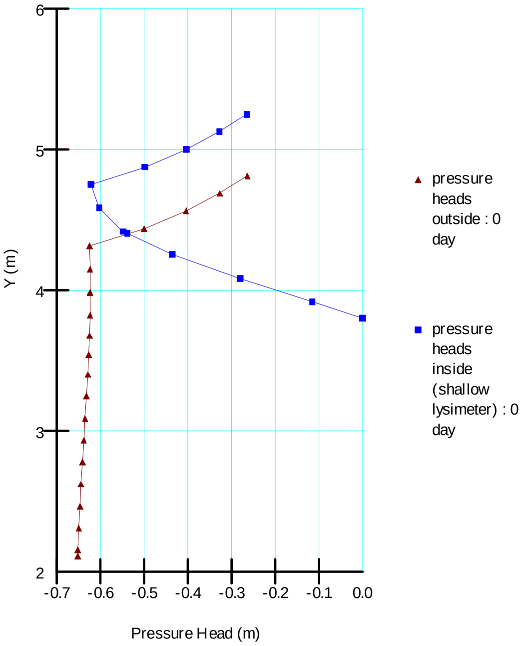
The following images show better performance, in that there is some collection of water from the base of the lysimeter. However, if you look carefully, there is still some wicking of flow up the left side and the pressure profiles are clearly not common. This design will appear to work, but will underestimate the actual flow passing the base of the cap.





Analysis: Shallow higher flux



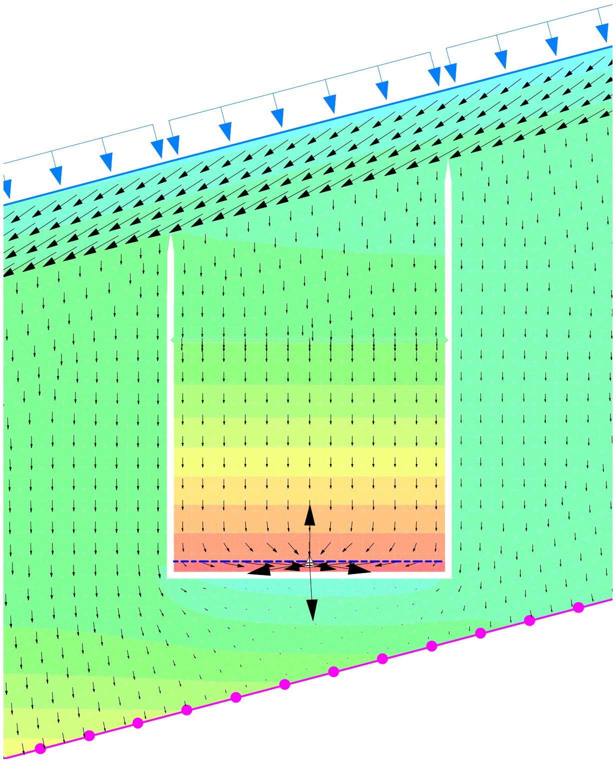


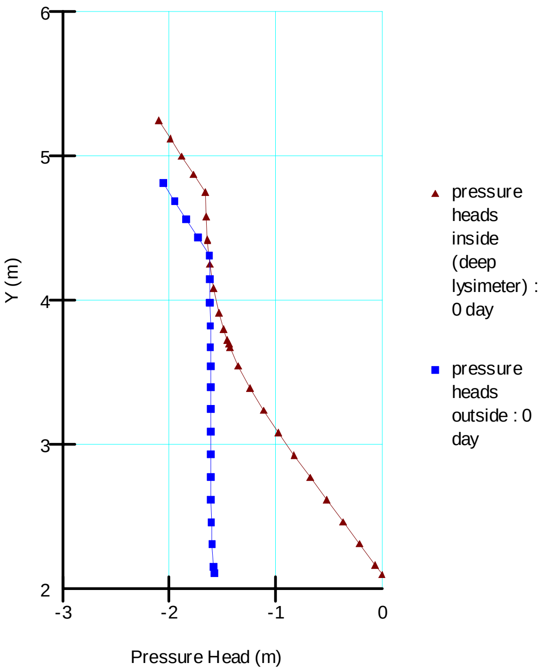
The previous images show even better performance for the highest flow case when you consider the pressure contours and flow arrows on the left. There is clearly no upward flow within the lysimeter and the pressure profiles are converging. These pressure profiles are taken in the center of the lysimeter and on the outside left side. You can see from the color contours that on the inside, left of the lysimeter, there is still a difference in pressure relative to the outside.

Overall, the shallow wall lysimeter is not performing adequately for the anticipated range of infiltrations applied to the ground surface. The reason for the failure is the that the walls of the lysimeter are not high enough to allow the pressures within the contained area to dissipate with elevation above the drain. Now let us consider the deep wall lysimeters.

Analysis: deeper low flux

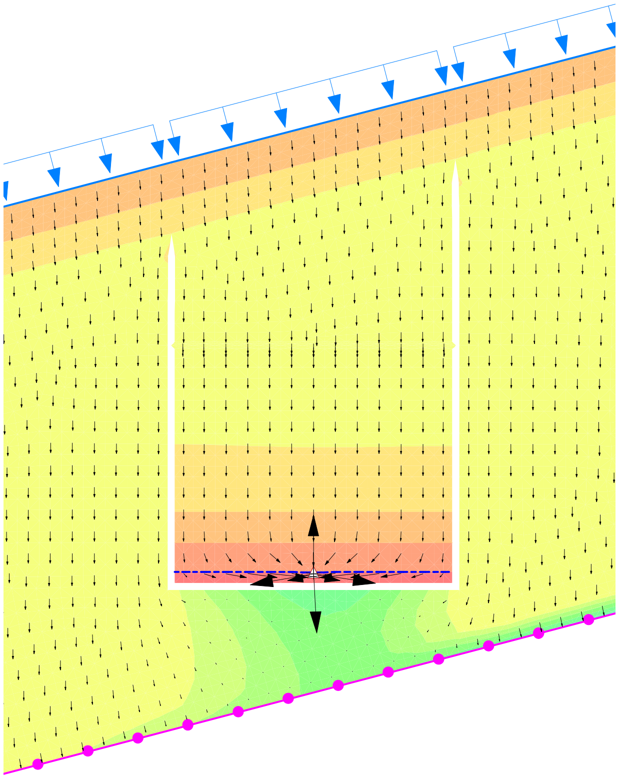
The deep wall lysimeter with the lower flux rate shows no upward wicking of water, and the contour colors within and external to the lysimeter appear to match quite well. The pressure profile graphs show that there is clearly a small zone where the pressures are the same, which means the gradients (and therefore flow) are the same.

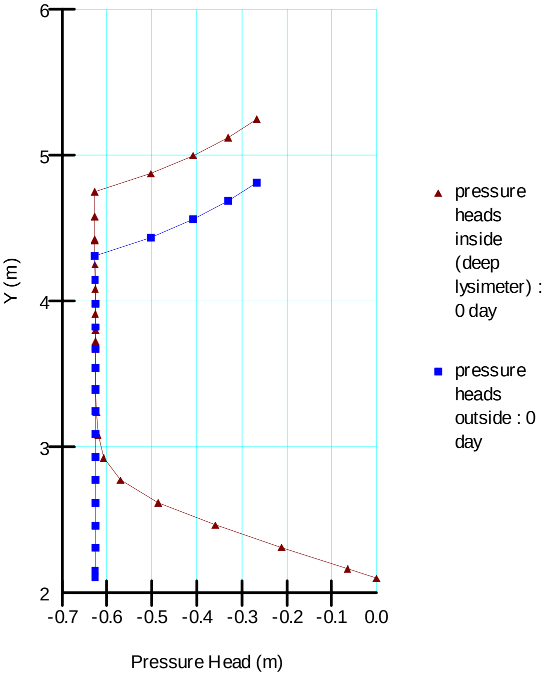




Analysis: deeper higher flux

The final two images below are for the higher flux rate and the deeper walled lysimeter. The average case is not discussed here, but is available for review in the GeoStudio file. If the low flux rate and high flux rate designs are satisfactory, then the lyismeter should function for the anticipated range of field conditions and soil properties.





Clearly, the lysimeter is functioning as intended. The flow vectors, contour color, and pressure profiles all indicate the hydraulic conditions within and external to the lysimeter match. All collected water volumes can be measured and divided by the cross-sectional area of the lysimeter to arrive at a unit flux rate for flow percolating through the base of the cap.