GeoStudio Example File
The behavior of lysimeters

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Introduction

There are many key processes involved in the flow regime of unsaturated soil systems. Understanding and measuring these processes are important in design of infrastructure, as well as understanding potential transport processes that may occur, such as at waste rock dumps or tailings ponds. Lysimeters are devices that are designed to measure the net percolation of water through an unsaturated zone. These lysimeters are often buried, for example, below clay-lined containment systems to monitor the performance of the liner. The intent is to collect the water that percolates through the liner and measure the volume of water through a system that drains into a nearby collection station.

The design of lysimeters requires careful consideration to ensure that the device will collect representative data on the drainage processes occurring in the material of interest. For example, the height of the side walls is a key consideration that may influence the performance of the lysimeter. The objective of this example is to illustrate the potential issues that can arise when using lysimeters to monitor unsaturated flow systems.

Background

Bews et al. (1997) installed two soil covers at a field site in North Queensland, Australia at the Kidston Gold Mine. These soil covers required instrumentation, including lysimeters, to monitor moisture conditions and net percolation rates through the soil covers and into the underlying waste rock material. The use of lysimeters results in an elevated water table within the lysimeter that is not representative of field conditions. This leads to a change in the flow behavior of the soil and waste rock, leading to unrealistic infiltration rates being reported to the monitoring equipment of the lysimeter. To ensure that the net percolation rate is captured accurately, the design of the lysimeter must ensure that the negative pore-water pressure or matric suction inside and outside of the lysimeter wall at the top of the lysimeter must be the same (A_1=A_2, Figure 1). This ensures that no hydraulic gradient exists in the soil that can lead to water to be diverted either away from the lysimeter or into the lysimster (i_{A1-A2}=0).

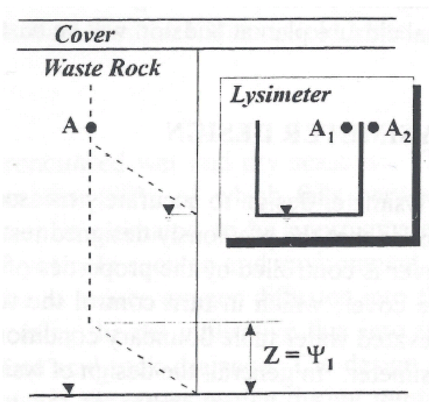

Figure 1. Cross-section of matric suction profile within and outside of the lysimeter walls (Bews et al. 1997).

In order to prevent these unrealistic results, Bews et al. (1997) conducted numerical modeling to determine the best design variables for the lysimeter prior to installation into the field. The numerical modeling included five design variables that were modified throughout 36 steady-state simulations. These design variables were the depth of the lysimeter, the lysimeter wall height and diameter, the lysimeter material, and the infiltration rate from the soil cover. For the purpose of this example, only the wall height of the lysimeter design and hydraulic conductivities of the soil cover and lysimeter backfill are varied to simulate the influence of the lysimeter on flow behavior.

Numerical Simulation

Figure 2 shows the model configuration of a clay layer overlying 6 m of sand. There is a water table present at depth in the sand below the lysimeter installation. The assumption is that there is sufficient water on the clay surface so that the pore-water pressure remains zero at all times. Advantage can be taken of symmetry in this case to reduce the file sizes and computing time. Only the left half of the problem is used in the analysis.

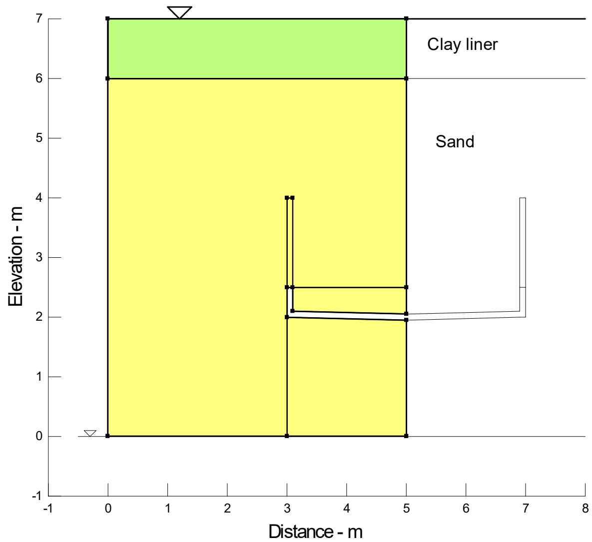

Figure 2. Problem configuration.

The intent is to model both a shallow pan and a deep pan in the lysimeter design. This has been done by creating regions to represent the varying wall heights and adding or removing the material properties from the appropriate regions for each analysis.

Four steady-state water transfer analyses are included in the Analysis Tree of the GeoStudio Project (Figure 3). The first three analyses use a shallow pan only, with varying hydraulic conductivity functions for the clay liner. The fourth analysis uses the deep pan scenario with the lowest hydraulic conductivity function for the clay liner.

Figure 3. Analysis tree of the GeoStudio Project.

The assumed zero pressure condition at the surface of the clay liner is simulated using the pressure head boundary condition set to 0 m. The same boundary condition was also applied to the bottom boundary of the domain to represent a water table. Water can potentially exit the lysimeter pan at the center, where there would typically be a drainage system attached for monitoring purposes. It is, consequently, flagged as a Potential Seepage Point by applying this special boundary condition to the node at the top centre of the lysimeter pan. This means that if the pore-water pressure at this point becomes positive, water will then drain from the pan. If the pore-water pressure remains negative, however, the flow at this point will remain at zero (e.g., Q = 0 m^3/sec)

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The volumetric water content (VWC) functions were defined using the internal sample material types for clay and sand materials, with saturated water contents of 0.5 and 0.35, respectively (Figure 4). The coefficient of volume compressibility was set to 1 x 10^{-4} and 5 x 10^{-4} 1/kPa for the clay and sand materials, respectively.

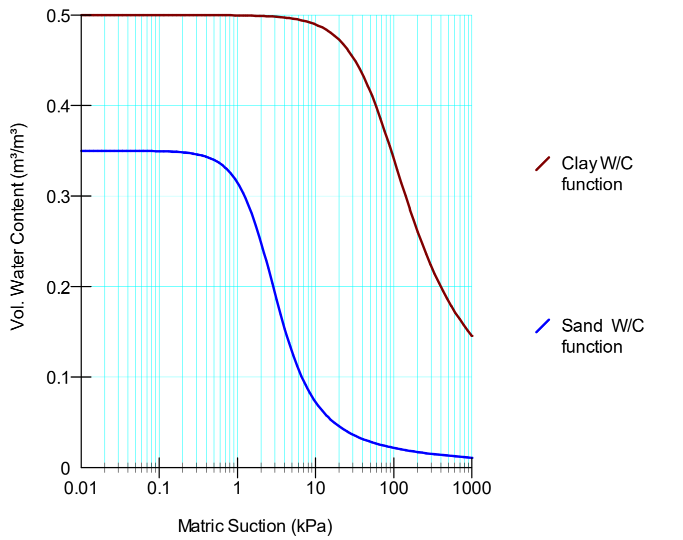

Figure 4. Volumetric water content functions for the clay liner and sand materials.

The internal estimation functions were used to also define the hydraulic conductivity functions (Figure 5). The van Genuchten method was used for all materials with the clay or sand volumetric water content function. The rate of net percolation can be controlled by changing the hydraulic conductivity of the clay. Three functions were created for the clay liner to illustrate this, with a high, medium, and low saturated hydraulic conductivity set to 1 x 10^{-5}, 1 x 10^{-6} and 1 x 10^{-7} m/sec, respectively. The sand hydraulic conductivity function was defined using a saturated hydraulic conductivity of 0.01 m/sec.

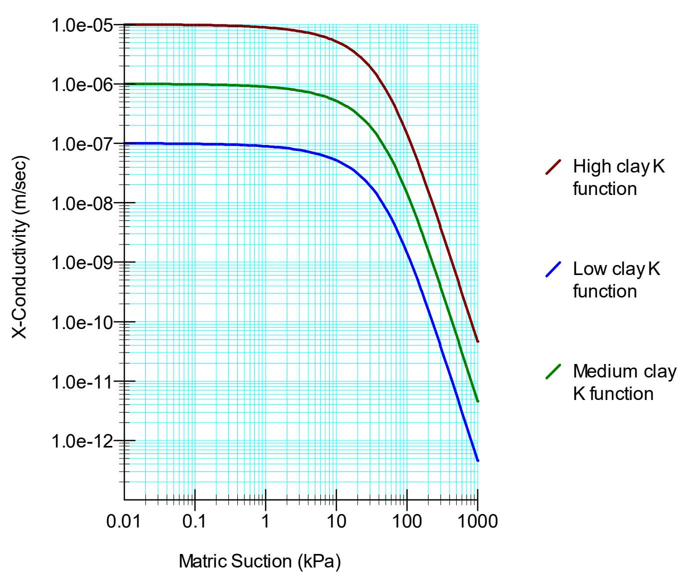

Figure 5. Hydraulic conductivity functions for the three clay liner and sand materials.

The global element mesh size was set to 0.2 m for all of the analyses. A finer discretization of approximately half the global element size was used on the region within the shallow pan and above the potential seepage face.

Obtaining a converged solution for these analyses can be difficult. It takes many iterations and the minimum under-relaxation rate needs to be set at 0.01, as highlighted in Figure 6.

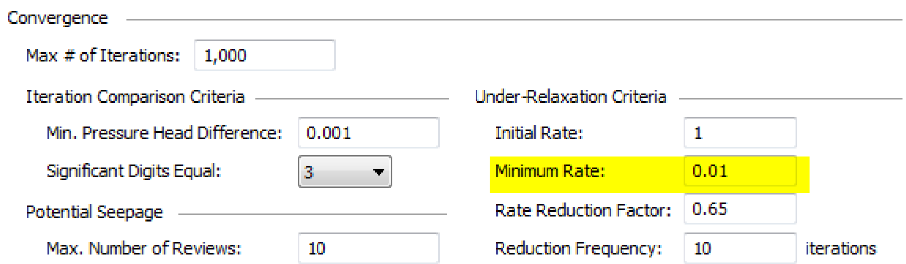

Figure 6. Convergence parameters used in the lysimeter analyses.

Results and Discussion

The resulting pore-water pressure contours, flow paths and velocity vectors for the shallow pan analyses with high, medium, and low hydraulic conductivity functions for the clay liners are shown in Figure 7, Figure 8 and Figure 9, respectively. As indicated by the figures, the shallow pan works well when the hydraulic conductivity of the clay liner is higher, as water moves through the sand, into the pan, and directly into the outlet. As the clay liner hydraulic conductivity decreases, however, the water begins to spill over the shallow pan, forcing water to be diverted away from the outlet.

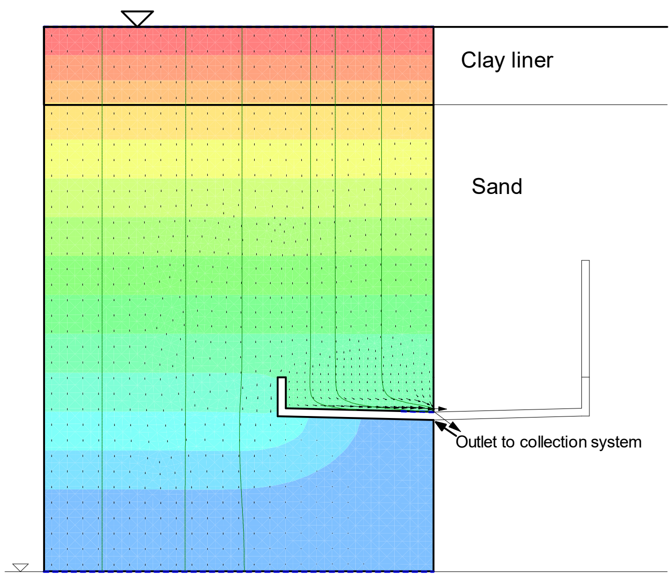

Figure 7. Shallow pan with high clay liner hydraulic conductivity.

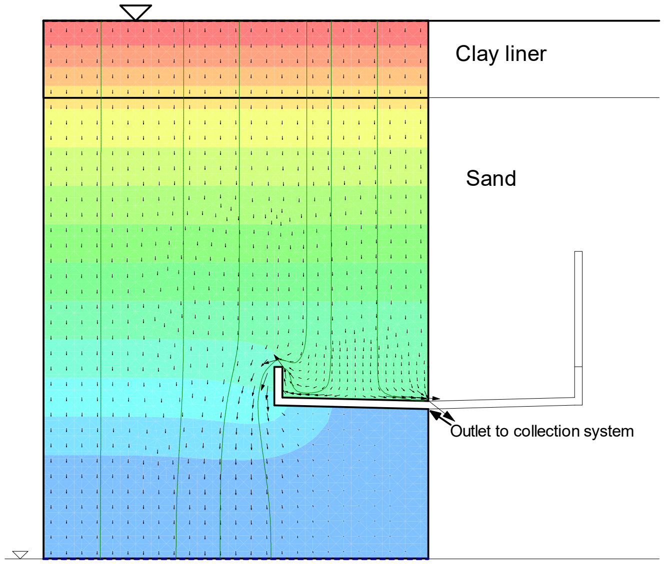

Figure 8. Shallow pan with medium clay liner hydraulic conductivity.

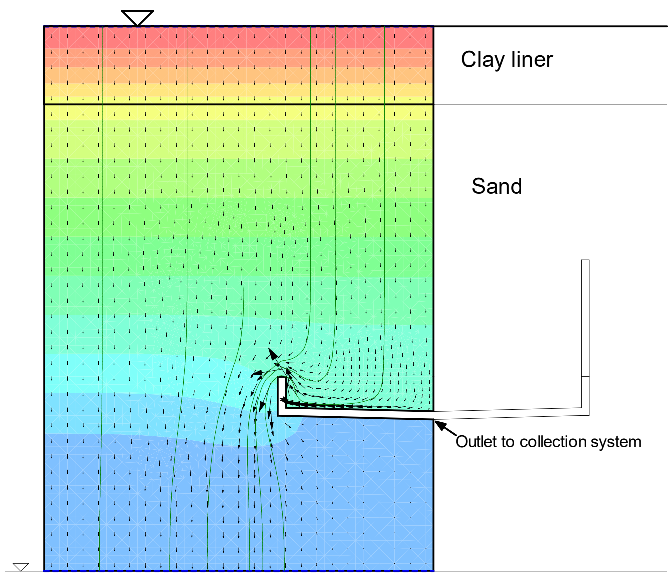

Figure 9. Shallow pan with low clay liner hydraulic conductivity.

When interpreting these results, it is useful to remember that water flow always goes from a high **total** head (*h*) to a lower total head. It is not, necessarily, the pore-water pressure difference, but the total head difference. Consider the total head at the outlet and at the inner corner of the pan rim in Table 1. With the high percolation obtained with the higher hydraulic conductivity of the clay liner, *h* is higher on the rim than at the outlet. Therefore, the water will flow towards the outlet. With the low percolation rate, it is the reverse – *h* is less on the rim than at the outlet; therefore, the water will flow outwards and over the rim.

Table 1. Total head measurements at the pan rim and outlet.

Analysis Name	Total head - top of rim (m)	Total head – at outlet (m)
Shallow pan – high K	2.08	2.05
Shallow pan – low K	1.80	1.84

The resulting pore-water pressure contours, flow paths and velocity vectors for the deep lysimeter pan and the clay liner with low hydraulic conductivity are shown in Figure 10. Here, the water is collected and diverted to the outlet a similar manner as the low pan with high hydraulic conductivity in the clay liner.

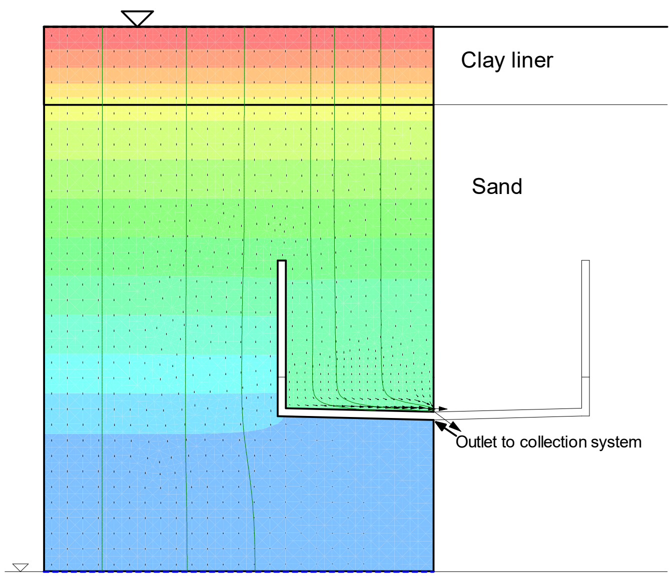

Figure 10. Deep pan with low hydraulic conductivity in the clay liner.

To gain a deeper understanding of the water transfer results in each of the above examples, the water rate along the bottom of the clay liner directly above the lysimeter pan and collected at the outlet is graphed. The subdomain was chosen by dragging an area over the clay liner region directly above the area of the lysimeter pan (Figure 11). The nodal locations were chosen using the geometry object and choosing the line along the bottom of the clay liner. The node at the water outlet at the centre of the lysimeter pan was used as the location for the second water rate graph. The resulting net percolation rates for each location are shown in Table 2. Similar to what was illustrated in the above figures, the performance of the shallow pan lysimeter design decreases as the hydraulic conductivity of the clay liner decreases. When the deep pan lysimeter design replaces the shallow pan in the low hydraulic conductivity scenario, the lysimeter performance returns, ensuring that the appropriate infiltration rate is collected.

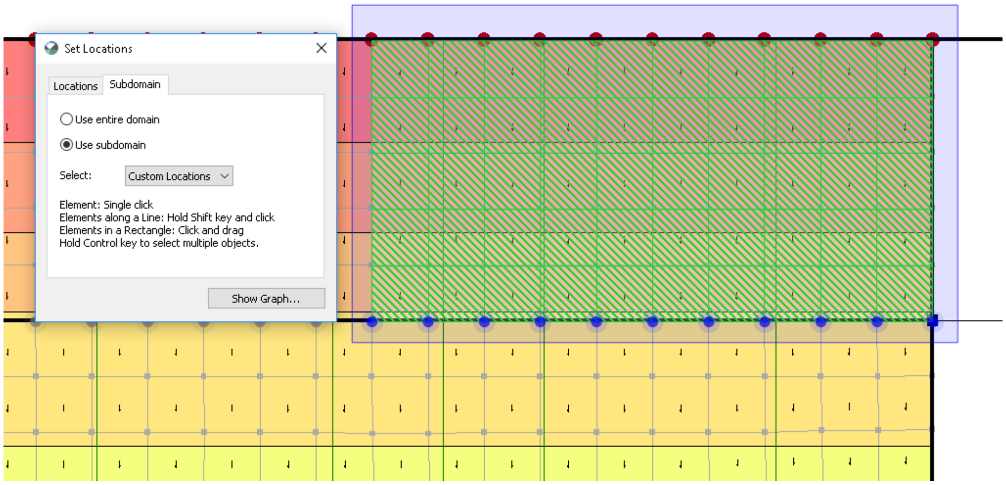

Figure 11. Subdomain and nodal locations for the water rate graphs.

Table 2. Comparison of the net percolation rates measured at the clay liner and lysimeter outlet.

Analysis Name	Net percolation from clay liner (m^3/sec)	Net percolation measured at outlet (m^3/sec)
Shallow pan – high K	2.54×10^{-5}	2.33×10^{-5}
Shallow pan – medium K	2.80×10^{-6}	1.32×10^{-6}
Shallow pan – low K	3.12×10^{-7}	~0
Deep pan	3.12×10^{-7}	3.03×10^{-7}

Summary and Conclusions

Clay liners are typically used to decrease the amount of water flowing through the liner to underlying material and, ultimately, to an underlying water table. To accomplish this, the objective of a clay liner is to use as low a hydraulic conductivity as possible. In order to measure the most representative net percolation rate using lysimeters, it must be for the low percolation rate that a lysimeter is designed. One way to improve the performance of a lysimeter under very low percolation rates is to increase the height of the side walls. In this illustrative example, increasing the wall height by 1.5 m ensures that all of the liner-leakage is collected by the lysimeter.

The key to designing a lysimeter is to ensure that the total head is the same inside and outside of the lysimeter near the top rim. The second issue in the design is the type of material inside the lysimeter. The favorable result depicted in these analyses is achieved because the material inside the lysimeter is the same as the surrounding native soil.

References

Bews, B.E., Barbour, S.L., Wilson, G.W. and O'Kane, M.A. (1997). *The Design of Lysimeters for a Low Flux Cover System over Acid Generating Waste Rock*, Proceedings – 50th Canadian Geotechnical Conference, Ottawa, Ontario, Canada, pp. 26 – 33.