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GeoStudio Example File
Mineral heap leaching

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Introduction

Heap leaching is a mining process to extract minerals from the ore by sprinkling a leach solution on a pile (heap) of ore. As the leaching solution percolates through the ore, the minerals are dissolved and then later are extracted from the leachate collected at the base of the heap. This process is conceptually depicted in Figure 1.

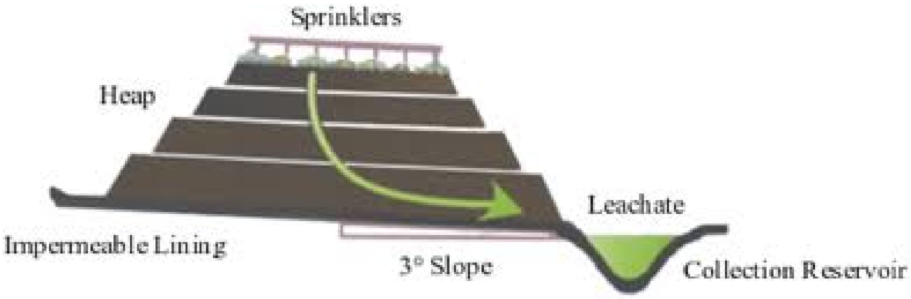

Figure 1. Illustration of heap leaching (public web image).

The placement of the ore can result in segregation and stratification of layers with different textures. This variability in texture influences the flow paths of the leaching solution and has an effect on the amount of the leaching solution retained or released by the ore as the application rate changes. The objective of this example is to illustrate how SEEP/W can be used to study the processes observed in heap leaching.

Numerical Simulation

The one-dimensional domain used in this example is 8 m in height and consists of 5 regions that can be used to simulate different layering scenarios (Figure 2).

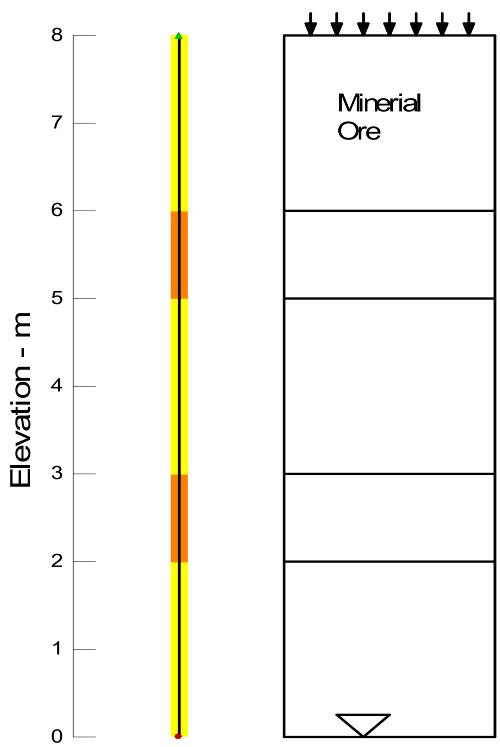

Figure 2. Problem configuration.

A total of 5 steady-state water transfer analyses were completed, with 2 transient water transfer analyses also included as child analyses to two of the homogeneous steady-state analyses (Figure 2). The first three analyses simulate homogeneous columns with varying leaching rates. The first analysis uses a very low rate that would be representative of a natural rainfall without leaching. The second and third analyses include both steady-state and transient analyses that vary the leaching rate from low to high and high to low with time. The last two analyses consider steady-state flow regimes when two 1 m layers become either a coarser or finer material compared to the previously homogeneous material.

Figure 3. Analysis Tree for the GeoStudio Project.

At the base of the column, it is assumed that there will be sufficient leaching solution present so that the pore-water pressure remains at zero. At the top node of the column, a total flux rate (Q) is specified to simulate the application of the leaching solution. For the "Initial; no leaching" analysis, the Q boundary condition is assumed to represent natural rainfall to simulate the steady-state conditions when no leaching is occurring ($Q = 1x10^{-8}$ m^3/sec). The low and high leaching rates have been set to $3x10^{-7}$ m^3/sec and $3x10^{-6}$ m^3/sec, respectively.

For illustrative purposes, the main, homogeneous material is considered to be a silty sand. The volumetric water content (VWC) function uses the silty sand sample function in SEEP/W with a saturated water content of 0.5 (Figure 3). The VWC function is then used to estimate the K-function, with a saturated hydraulic conductivity (K_{sat}) of $5x10^{-6}$ m/sec (Figure 4).

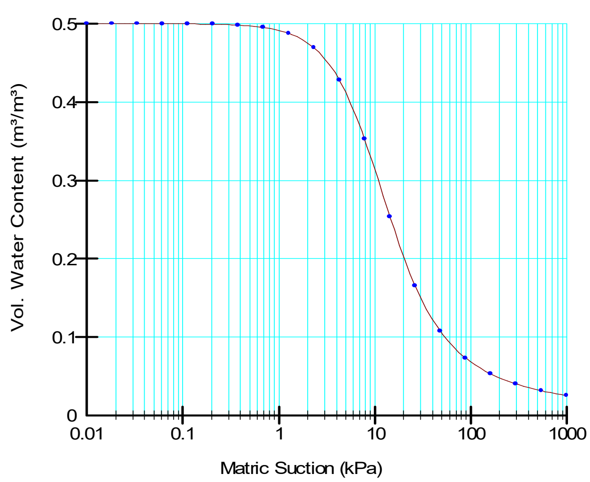

Figure 4. Volumetric water content function of the silty sand material.

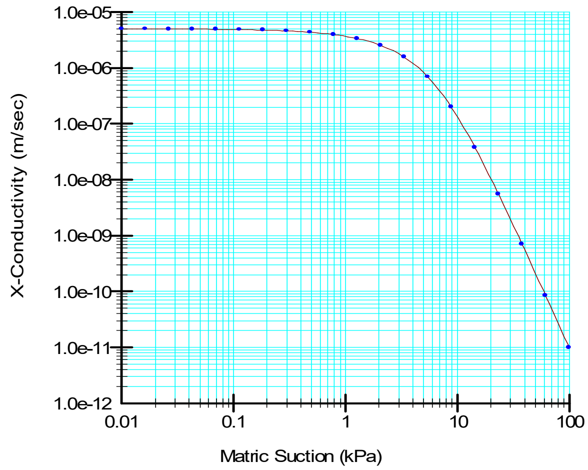

Figure 5. Hydraulic conductivity function of the silty sand material.

To examine the effect of stratification, two analyses use layers of either a coarse or fine material. The coarse layers are defined using a sand sample type both of the VWC and hydraulic conductivity functions, with the saturated water content set to 0.4 (Figure 6) and the K_{sat} set to $1x10^{-5}$ m/sec (Figure 7). The finer layers are defined using the same VWC function as the silty sand, with a K_{sat} of $2.5x10^{-6}$ m/sec.

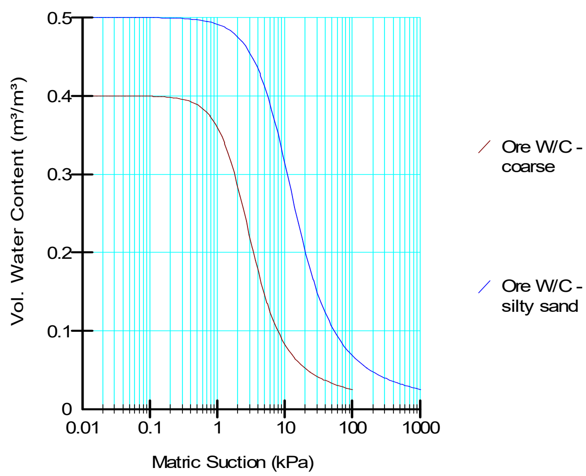

Figure 6. Comparison of volumetric water content functions for coarse and silty sand materials.

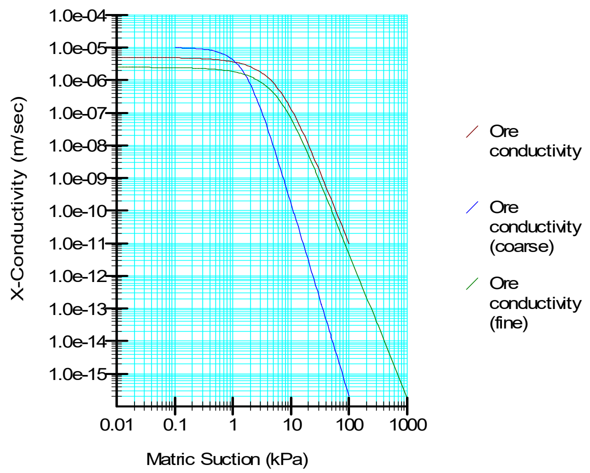

Figure 7. Hydraulic conductivity functions for all materials.

The first transient analysis uses the pore-water pressure profile from the steady-state analysis of the homogeneous column with a low leaching rate. The transient analysis has the high leaching rate assigned to the top node. The simulation is set to a total duration of 4 days, with 15 time steps that increase exponentially from an initial time step size of 1 hour. The second transient analysis uses the homogeneous steady-state analysis with a high leaching rate as the Parent analysis. In this second case, the top boundary condition is changed to the low leaching rate at the start of the transient analysis. The total duration is set to 10 days, with 15 time steps that increase exponentially from an initial time step of 1 hour. The global element size was set to 0.02 m.

Results and Discussion

The pore-water pressure profile for the “Initial; no leaching” analysis is shown in Figure 8. At the base of the column, the pore-water pressure is negatively hydrostatic, but then becomes constant at a pore-water pressure of approximately -20 kPa.

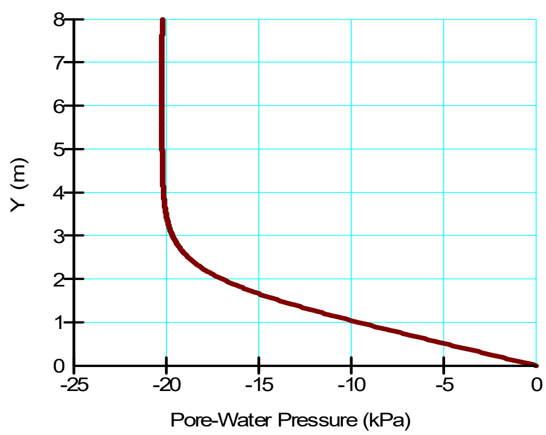

Figure 8. Pore-water pressure profile with natural rainfall.

Where the profile is vertical, the hydraulic gradient (i) is unity (1.0). The flow rate (q) can then be calculated using:

$$q = Ki \quad \text{Equation 1}$$

This indicates that the flow rate is equal to the hydraulic conductivity (K) when the gradient is equal to 1. The hydraulic conductivity is, consequently, equal to the infiltration rate. The corresponding *K* falls on the K-function at a matric suction of 20 kPa (Figure 9) or a pore-water pressure of -20 kPa. This relationship between the hydraulic conductivity, the infiltration rate and the corresponding suction is an important concept to understand when interpreting infiltration analyses. This will become more evident in the subsequent analyses below.

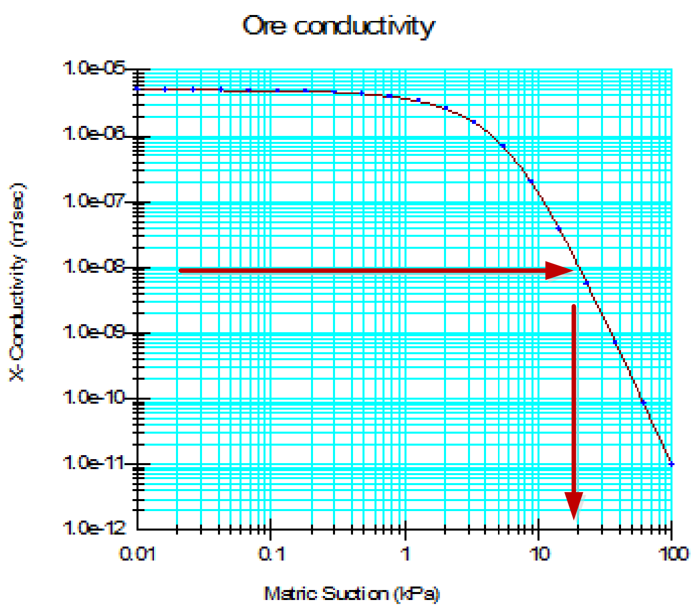

Figure 9. Conductivity equal to infiltration rate and corresponding suction.

Figure 10 shows the pore-water pressure profiles for the homogeneous, steady-state analyses, while Figure 11 shows the corresponding volumetric water content profiles. The higher leaching rate results in higher pore-water pressure profiles, or higher water content, when compared to both the low leaching rate and the natural rainfall rate.

The area between the two VWC curves for the high and low leaching rates in Figure 11 becomes important when changing the rate. The area between the curves represents the volume to be stored or drained depending on the direction of the rate change.

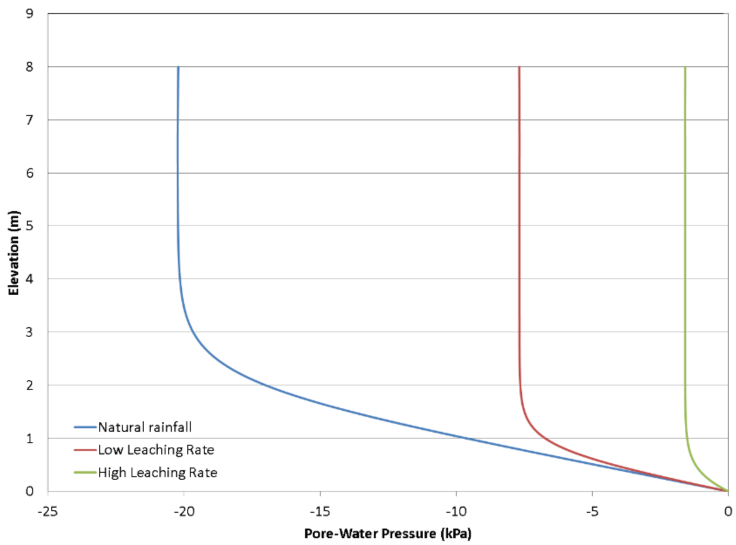

Figure 10. Pore-water pressure profiles for all homogeneous, steady-state analyses.

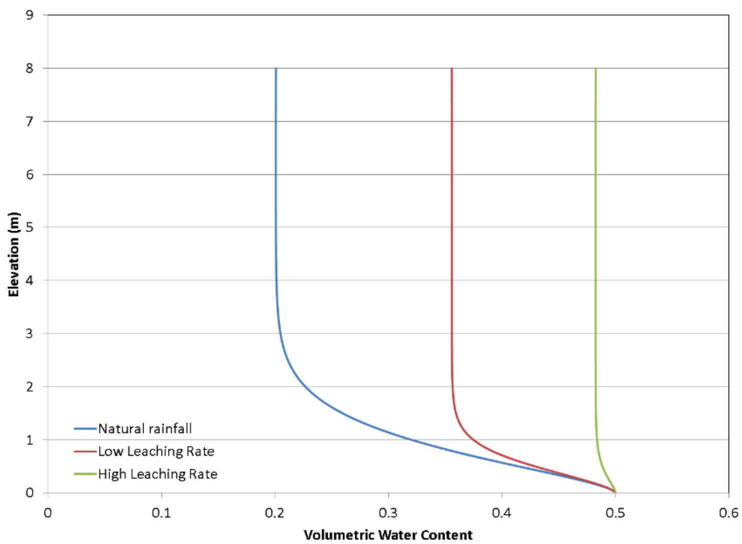

Figure 11. Volumetric water content profiles for all homogeneous, steady-state analyses.

Figure 12 shows the water content profiles when switching the leaching rate from low to high in the first transient analysis. The solution is approaching the steady-state conditions after about 4 days (345,600 sec). Figure 13 shows the water content profiles when decreasing the leaching rate from high to low in the second transient analysis. After 10 days (864,000 sec), the situation has not yet reached steady-state conditions. This reveals that wetting-up a profile is much faster than draining the solution that has already been stored in the ore. The reason for this is the changing hydraulic conductivity. During the wetting-up process, the conductivity increases as the pore-water pressure decreases; or, conversely, the conductivity diminishes as the ore drains and the suction increases.

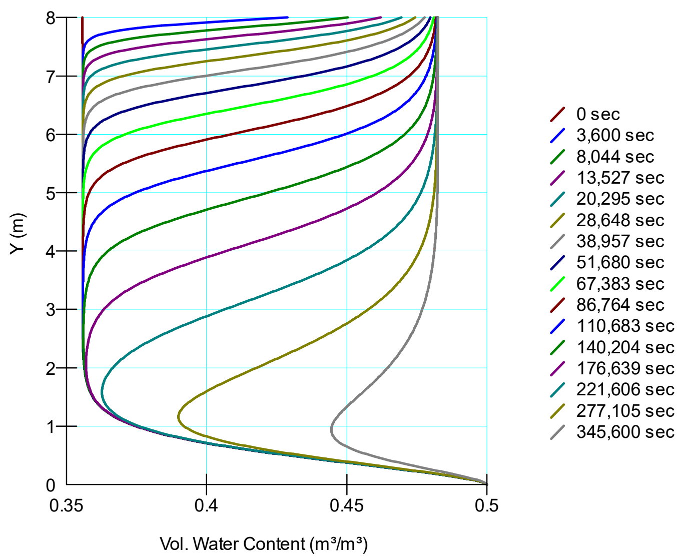

Figure 12. Water content profile with time after increasing the leaching rate.

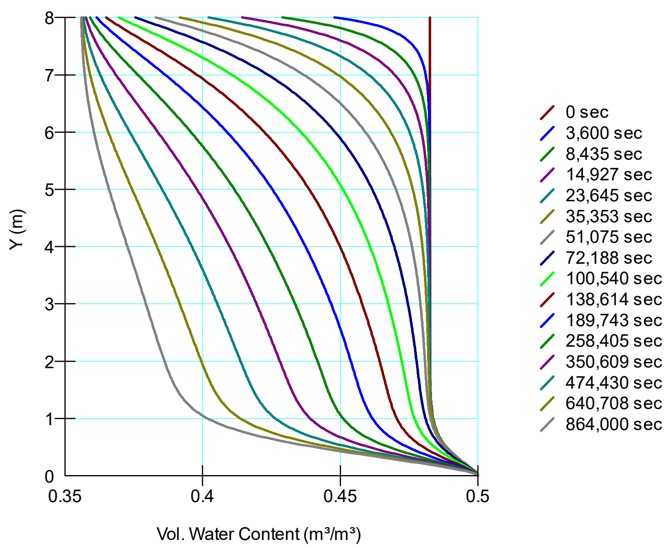

Figure 13. Water content profile with time after decreasing the leaching rate.

The implication for operating a heap-leach operation is that the amount of leachate that will arrive at the collection point will vary with time and depends on the amount of leaching solution stored or drained from the ore. When changing the leaching rate, there may be lengthy periods of time when the leachate collection amount differs from the application rate.

Now, we will discuss the results when the 1 m lines within the column in Figure 2 are assigned different materials. If the layers are coarser than the original homogeneous ore, then the water content profile under a low leaching rate could be as depicted in Figure 14. Referring back to Figure 11, the water content is around 0.35. With the coarser layers present, the water content is as high as 0.45 at the base of the main ore matrix. Then, with distance upwards to the top of the ore layers, the water content tends to go back to the homogeneous case (0.35). The implication is that more leaching solution could be stored inside the ore with the coarser layers present.

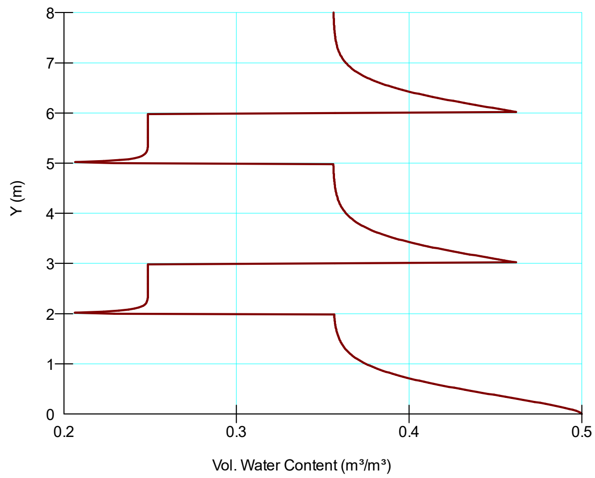

Figure 14. Water content profile with coarse layers present under a low leaching rate.

Conversely, if there are finer layers present with a lower hydraulic conductivity, it is possible that there may be some flooded zones, as illustrated by the positive pore-pressures in Figure 15.

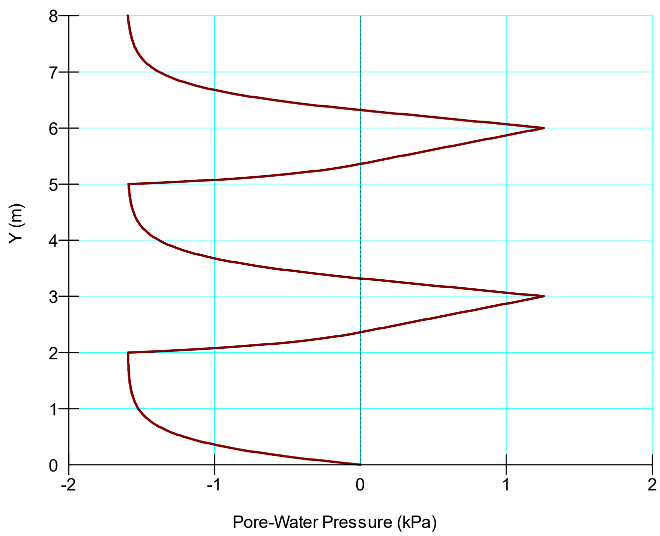

Figure 15. Pore-water pressure profile with fine layers present under a high leaching rate.

Summary and Conclusion

The objective of this example was to illustrate the ability of SEEP/W to simulate the flow regime of a one-dimensional column within a mineral heap. Various leaching rates and material layers were simulated. The resulting volumetric water content or pore-water pressure profiles could be visualized to show the flow regime and patterns experienced under the varying conditions.