GeoStudio Example File

Groundwater Flow in Small Drainage Basins

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Introduction

The presence of small drainage basins can have a significant effect on the overall hydrogeological patterns of a landscape. Understanding the potential influence of these small basins can be important for understanding field observations in geotechnical and hydrogeological investigations. Toth (1963) investigated an area in Central Alberta, Canada that consists of a number of small drainage basins, valleys, and water sheds. This illustrative example explores the influence of a small drainage basin with varying hydraulic properties on the regional and local groundwater flow patterns of a landscape similar to that investigated by Toth (1963). Specifically, the use of polygonal regions, flows paths, flux vectors, and water transfer contour options in GeoStudio are illustrated.

Background

Toth (1963) developed a mathematical model of a landscape in Central Alberta, Canada to gain an understanding of the influence of small drainage basins on groundwater flow patterns. The area consisted of four main creeks, with a series of valleys and watersheds that were spaced equally along the landscape. According to groundwater levels observed within various monitoring wells along the landscape surface, a hinge-like seasonal fluctuation was observed between the groundwater divide and the main stream.

Toth (1963) determined that high permeability lenses existed within the landscape and these lenses had a distorting effect on the original homogeneous potential flow paths. For simplicity, ellipsoid lenses were used in the numerical model because it was expected that they would provide a reasonable two-dimensional estimation of the overall groundwater flow patterns (Figure 1). The lens characteristics (i.e. length, permeability, etc.) were varied to determine the potential disturbance on the overall groundwater flow patterns.

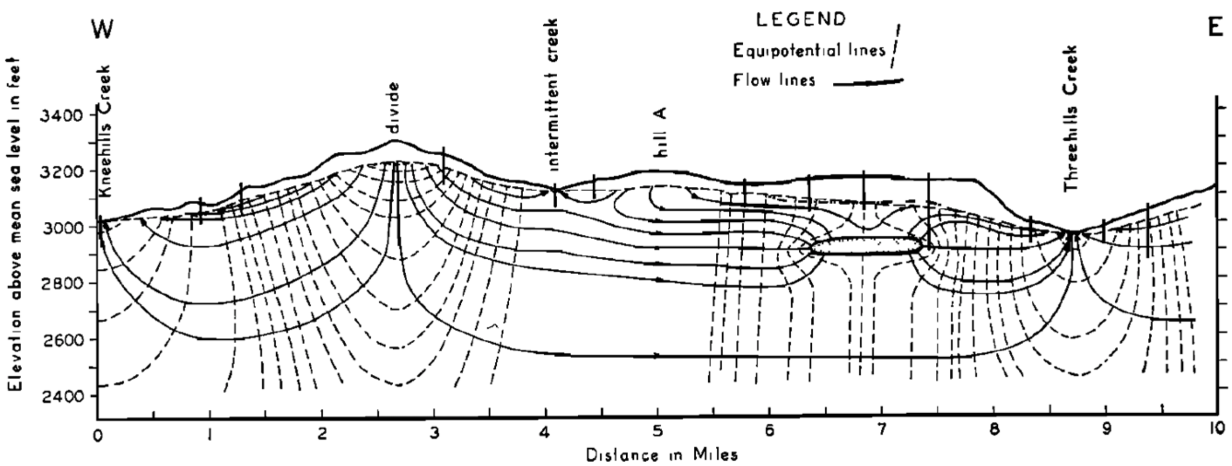

Figure 1. Influence of a highly permeable lens on a regional groundwater flow system (Toth, 1963).

Toth (1963) concluded that the flow system was unconfined and symmetrical relative to the middle of the groundwater divide and valley bottom. It was also concluded that the material was heterogeneous with minor local flow systems present within topographic irregularities along the slope. Lastly, the mathematical model was able to demonstrate the effect of ellipsoidal lenses of high permeability on the overall flow systems.

Numerical Simulation

Four steady-state analyses have been developed to simulate the influence of an ellipsoidal lens with varying hydraulic characteristics on the overall groundwater flow system of a simplified regional system. The domain is based loosely on the mathematical model developed by Toth (1963) and is approximately 1220 m wide and 250 m high (Figure 2). The water transfer analyses are all individual analyses that are not linked to a Parent (Figure 3). The lens was defined using a polygonal floating region drawn over-top of the primary region (Figure 4). A material was applied to the polygon for the first three cases, while no material was assigned in Case 4 to imply a perfectly impermeable lens.

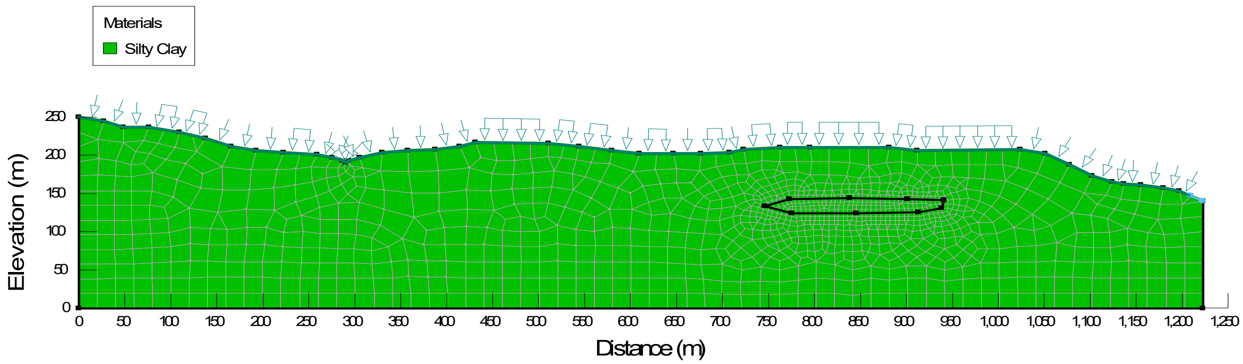

Figure 2. Problem configuration for Case 1.

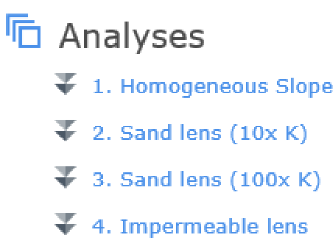

Figure 3. Analysis Tree for the Project.

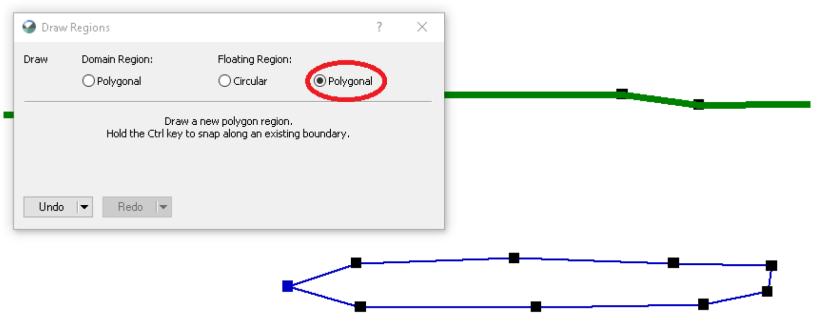

Figure 4. Definition of the lens using a polygonal floating region.

The first analysis (Case 1) represents a homogeneous slope. Cases 2 and 3 explore the potential of a higher permeability lens, where the hydraulic conductivity within the lens increases by 10 and 100 times the original surrounding hydraulic conductivity, respectively. The last case considers the potential of a perfectly impermeable lens by simply removing the material from the lens region.

The volumetric water content functions representing the homogeneous soil and sand lens materials were estimated using a silty clay and sand sample function with a saturated water content of 0.4 and 0.25, respectively (Figure 5). The hydraulic conductivity function for the silty clay was estimated using a saturated hydraulic conductivity of 1 x 10^{-6} m/sec and a residual water content of 0.04 (Figure 6). The hydraulic conductivity functions of the sand lenses in Case 2 and Case 3 used a saturated hydraulic conductivity of 1 x 10^{-5} and 1 x 10^{-4} m/sec, respectively, with a residual water content of 0.04.

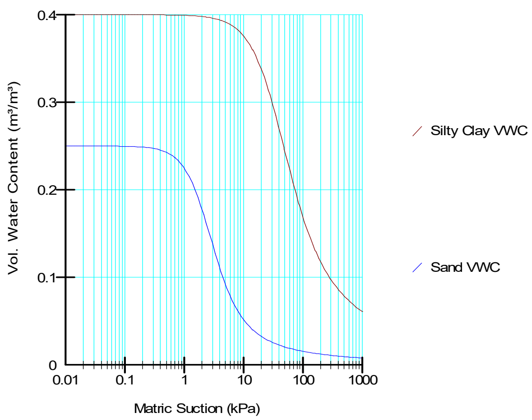

Figure 5. Volumetric water content functions.

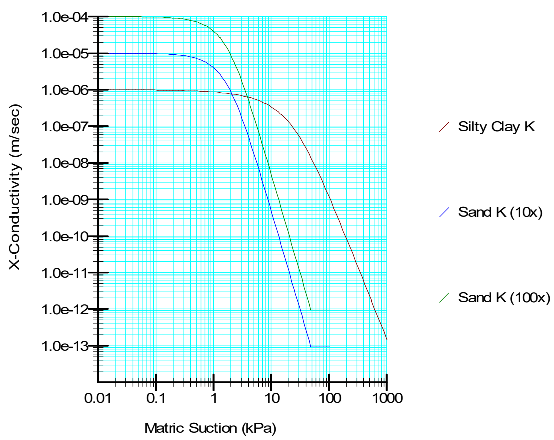

Figure 6. Hydraulic conductivity functions.

The creek at the valley bottom was modeled using a constant head boundary condition of 147 m. A water flux boundary (*q*) condition was applied to the remaining ground surface with an estimated annual rainfall rate of 450 mm/year (1.43 x 10^{-8} m/sec). The potential seepage face review option is activated on the flux boundary such that discharge locations can develop if needed. The left, right and bottom boundary of the domain were assumed to be no flow boundaries. The global element size for the domain was set to 20 m, with the polygonal opening refined to a ratio of a quarter of the global element size, or 5 m.

Results and Discussion

The resulting pore-water pressure contours and flow paths for the homogeneous case are shown in Figure 7. The regional flow paths indicate that water flow is primarily from the upper recharge zones to the valley creek. A small discharge zone in the upland depression does create a local flow system where an intermittent creek was noted by Toth (1963). This local flow system does create some hinge-like behavior in some of the regional flow paths, but water is still able to flow from the main recharge zone in the uplands to the main discharge zone within the lower valley.

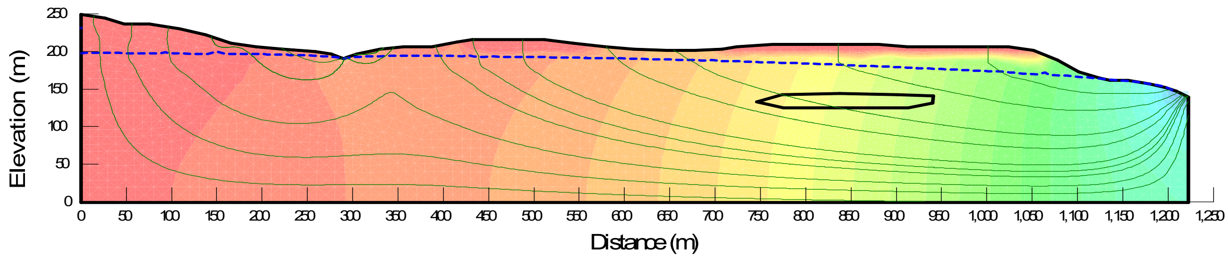

Figure 7. Total head contours and flow paths for Case 1.

The total head contours and flux vectors are indicative of a homogeneous, isotropic material below the water table surface (Figure 8). Water movement is nearly horizontal beneath the water table to the valley discharge zone. There is no change in the flow path due to the sand lens because the polygonal floating region uses the same material as the adjacent region.

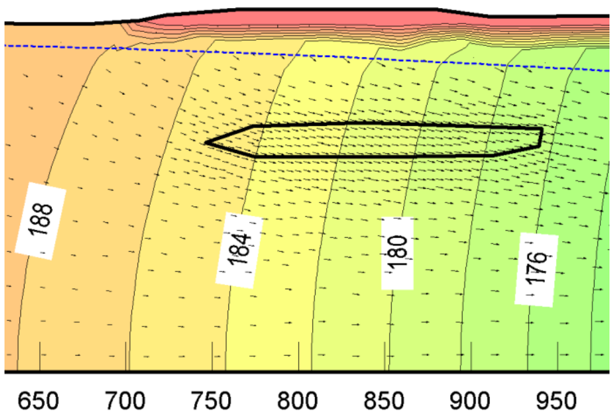

Figure 8. Flux vectors and total head contours near the lens location in Case 1.

The hinge-like behavior in the flow paths near the valley discharge zone start to develop in Case 2, in which the lens was changed to the sand material with a hydraulic conductivity one order-of-magnitude larger than the surrounding silty clay (Figure 9). The groundwater also begins to be pulled from the local system that develops in the depression along the upper slope. The hinge-like behavior experienced in the regional flow paths below this discharge zone is also diminished.

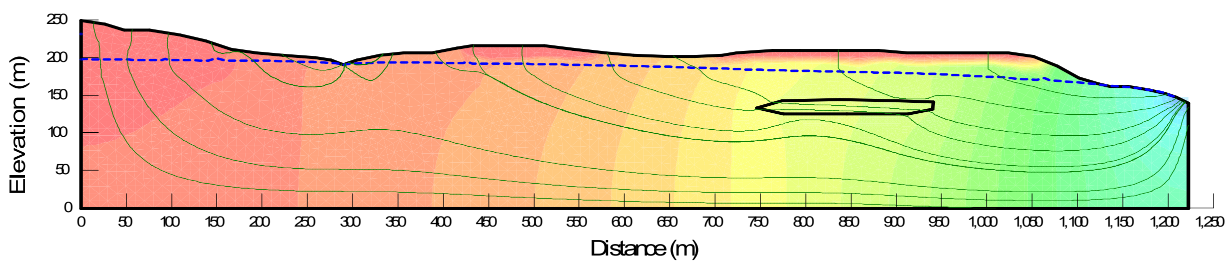

Figure 9. Total head contours and flow paths for Case 2.

These effects are even more exaggerated when the hydraulic conductivity of the sand lens is increased two orders-of-magnitude compared to the silty clay. More of the regional groundwater flow is diverted through the highly permeable sand lens (Figure 10). The shape of the total head contours and flow paths also indicate that the focused flow through the sand lens is decreasing the total head experienced at the upland side of the lens (Figure 11). Figure 12 presents the total head across the sand lens. As the conductivity of the lens increases, the total head at the upstream side decreases and the gradient across the lens decreases.

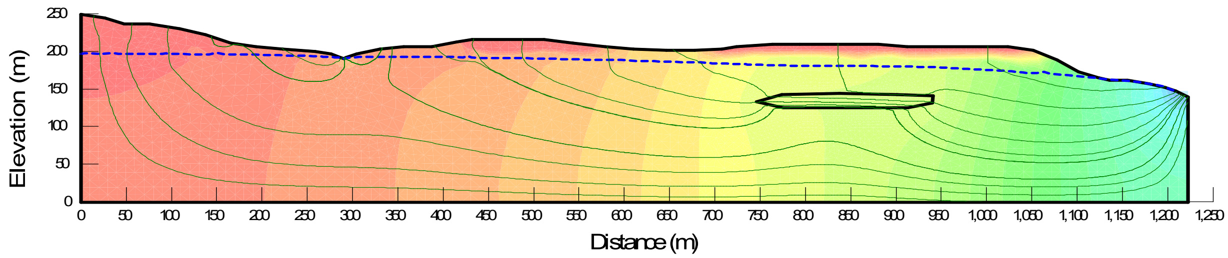

Figure 10. Total head contours and flow paths for case 3.

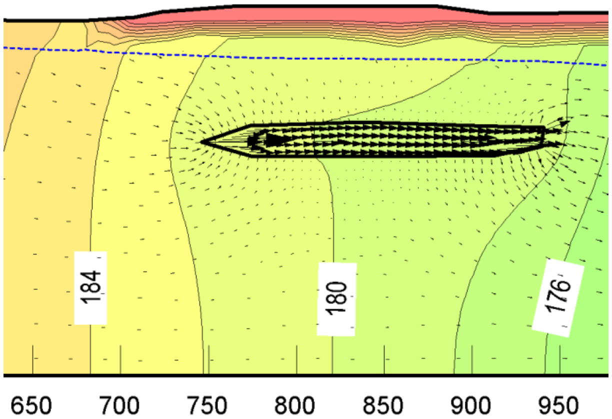

Figure 11. Flux vectors and total head contours near the lens location in Case 3.

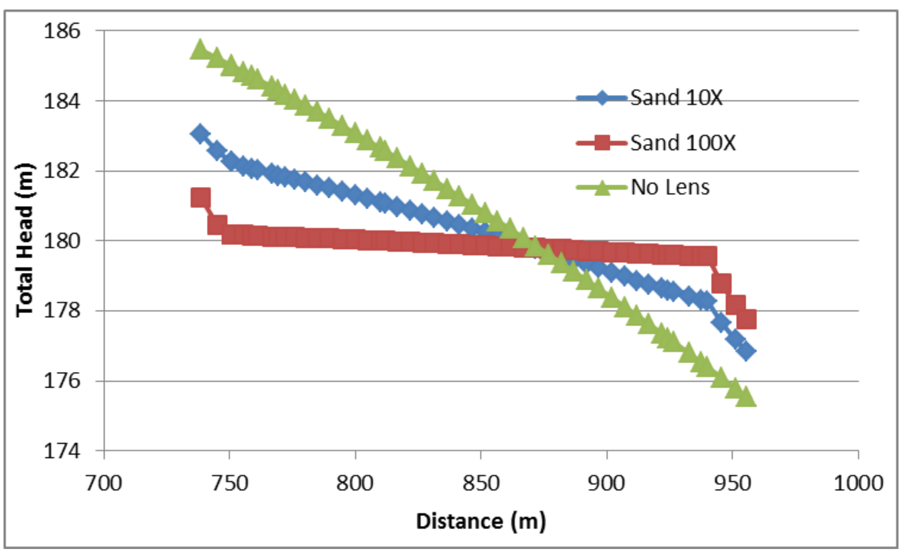

Figure 12. Total head profiles across the sand lense for Case 2 and 3.

In Case 4, the groundwater must divert around the impermeable lens (Figure 12). This increases the influence of the small local groundwater system on the regional flow paths, as more water is forced to discharge the local discharge zone instead of flowing to the valley creek. Figure 13 shows the change in the total head contours and flux vectors as the flow is diverted either below or above the impermeable lens, leading to a higher total head being observed at the both sides of the lens.

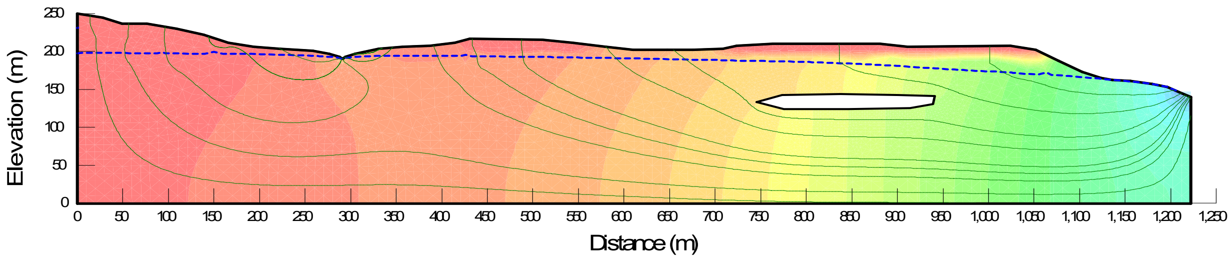

Figure 13. Total head contours and flow paths for case 4.

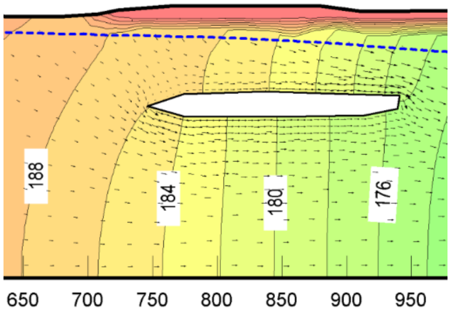

Figure 14. Total head contours and flux vectors for Case 4.

Summary and Conclusions

This example illustrated the use of a polygonal opening within a soil domain to help gain an understanding of the influence of a soil lens with varying hydraulic characteristics on the overall groundwater flow system of a regional system. The analyses were based on a mathematical model conducted by Toth (1963) for a region in Central Alberta, Canada.

References

Tóth, J. 1962. A theory of groundwater motion in small drainage basins in Central Alberta, Canada. Journal of Geophysical Research 67 (11): 4375-4387.