GeoStudio Example File
Groundwater whirls

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Introduction

Spiraling groundwater flow, or groundwater whirls, can occur in layered aquifers with different anisotropy. The whirls are mostly of the same scale as the layer thickness while the number of whirls depends on the number of layers. The flow patterns in real world aquifers, with complex stratifications, most likely result from the superposition of whirls at different scales. The practical implication of groundwater whirls is that water is exchanged between aquifer layers. A process that may have significant impact on contaminant transport. Several studies have focused on groundwater whirls in layered aquifers (Hemker et al., 2004; Meesters et al., 2004; Hemker and Bakker, 2006). In this example, the groundwater whirls in a confined aquifer with blocks of varying anisotropy are compared to those reported in one of these seminal papers.

Numerical Simulation

Figure 1 shows the problem configuration in which two 150-meter-long, 20-meter-wide, 10-meter-high anisotropic blocks lie at the center of a 200-meter-long, 70-meter-wide, 20 meter-thick, homogeneous, box-shaped, aquifer. The general flow direction is lengthwise (due north) and makes a 45° angle with either of the major principal directions of the orthogonal horizontal hydraulic conductivity tensor in the anisotropy blocks. Stated otherwise, the dip direction is 315° (clockwise positive from north) in the top (light orange) block and 45° in the bottom (dark orange) block.

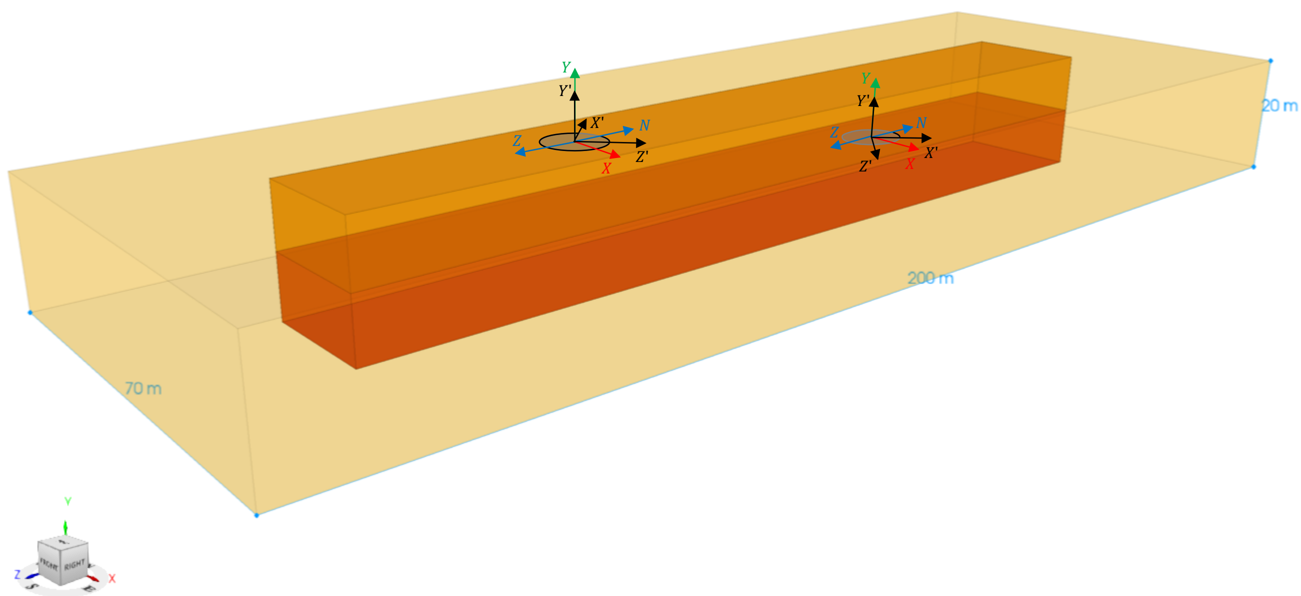

Figure 1. Problem configuration.

The hydraulic conductivity of the homogeneous portion of the aquifer is assumed equal to one meter per day while that of the anisotropic blocks is assumed equal to one meter per day along the x'-axis ($K_{x'}$) and y'-axis ($K_{y'}$), and one-tenth of a meter per day along the z'-axis ($K_{z'}$). The western and eastern sides of the aquifer are considered impervious while the southern and northern sides are pervious with total head boundary conditions that differ by one meter. It must be emphasized that the difference in total head influences total head, pore-water pressure head, flux and rate, but not flow paths and flow lines. The mesh consists of 299691 nodes and 280000 hexahedral elements.

Results and Discussion

Figure 2 and 3 show the total head contours in the aquifer in perspective and plan view, respectively. The anisotropy of the blocks results in small indentations in the contours as water flows into/out of the upper and lower blocks in opposite directions. The contours deviate by approximately ten degrees clockwise from east in the upper block and ten degrees counterclockwise in the lower block. The flow rate through the aquifer is equal to 6.19 m^3/day, which is in close agreement with that reported in Hemker et al. (2004) and Diersch (2014).

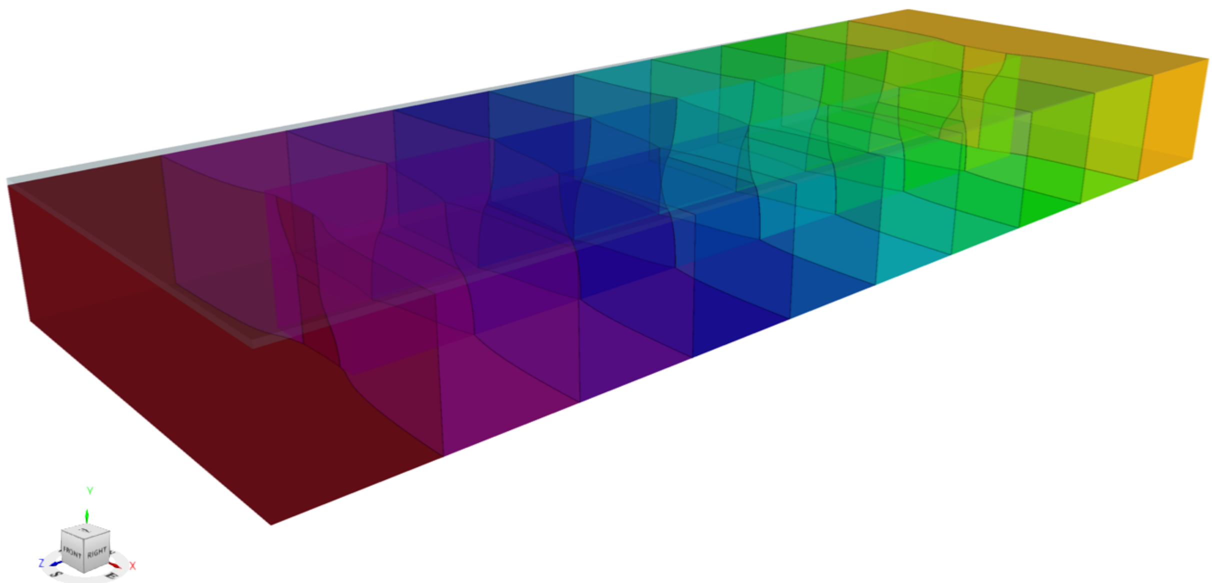

Figure 2. Water total head contours – Perspective view with transparency.

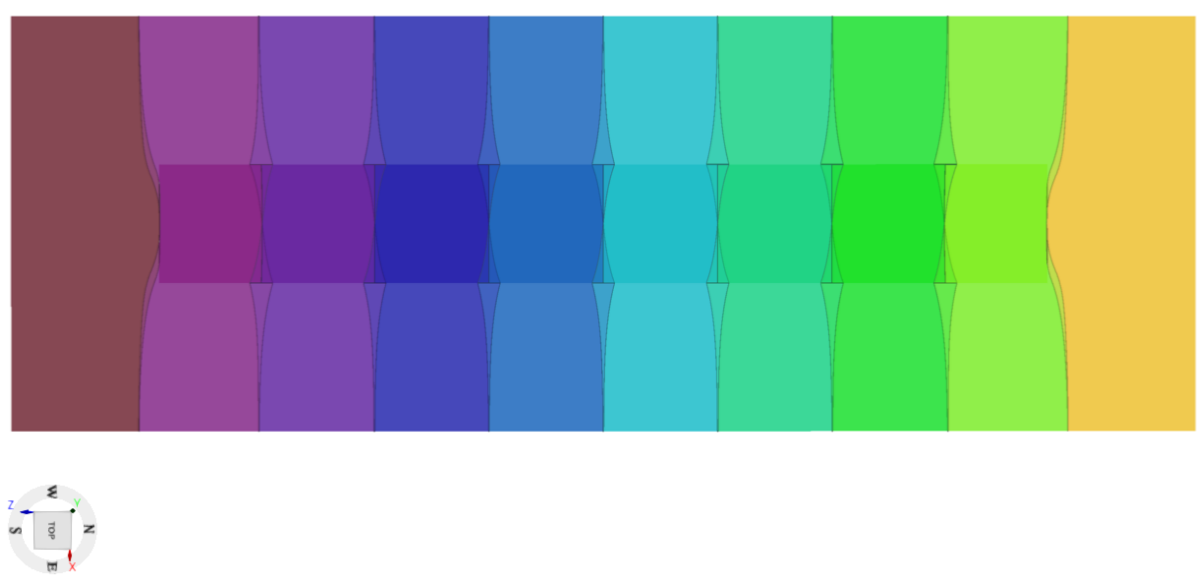

Figure 3. Water total head contours – Plan view with transparency.

GeoStudio Example – Groundwater whirls

Figure 4 shows five flow paths starting in the middle of the southern boundary at depths of one, three, five, seven, and nine meters. The flow paths, which exhibit a characteristic whirl-like pattern, were generated using the GeoStudio scripting API in combination with the script available through the Learning Management System. Figure 5 shows the flow paths, now numbered one to five, in plan, face, and side view. The first flow path passes through the upper block and remains in the upper portion of the aquifer while the other flow paths pass through both the upper and lower blocks. The third, fourth, and fifth flow paths, which start nearest to the interface between the blocks, repeatedly cross the interface and exhibit a pronounced swirling pattern. A close look at the face view reveals concentric flow paths that travel out of the upper block, down through the isotropic portion of the aquifer, into the bottom block, up through the isotropic portion of the aquifer, and back into the upper block. The number of revolutions increases as the starting point of the flow path nears the interface. The flow paths are in close agreement with the flow paths (in black) found in Diersch (2014). The discrepancies are ascribed to differences in mesh density.

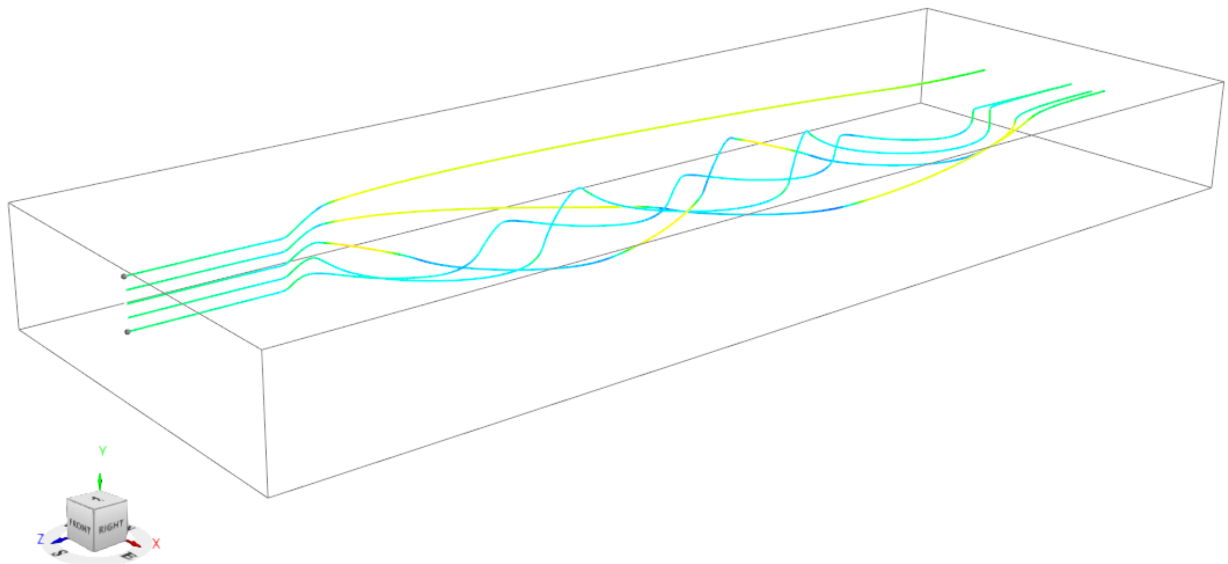

Figure 4. Flow lines – Perspective view.

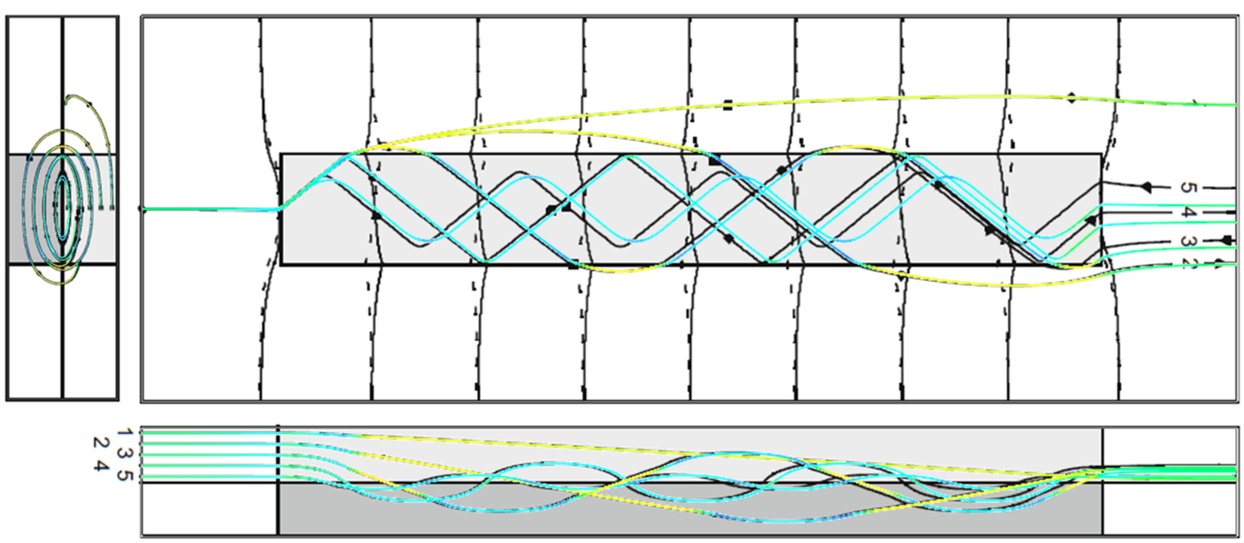

Figure 5. Flow lines – Plan, face, and side view.

Summary and Conclusions

The objective of this example was to demonstrate the capability of simulating groundwater whirls within a confined aquifer with blocks exhibiting varying degrees of anisotropy. The results clearly highlighted that anisotropy exerts a significant and non-negligible influence on groundwater flow behavior. Both the computed flow rate and the resulting flow paths were closely aligned with those reported in a seminal paper on groundwater whirls, thereby validating the software's effectiveness in modeling complex anisotropic aquifer systems.

References

Diersch, H.-J.G. 2014. FEFLOW: Finite element modeling of flow, mass and heat transport in porous and fractured media. Springer.

Hemker, K., and Bakker, 2006. Analytical solutions for whirling groundwater flows in two-dimensional heterogeneous anisotropic aquifers. Water Resources Research, 42(12): W12419.

Hemker, K., van den Berg, E., and Bakker, M. 2004. Ground water whirls. Groundwater, 42(2): 234-242.

Meesters, A.G.C.A., Hemker, C.J., and van den Berg, E.H. 2004. An approximate analytical solution for well flow in anisotropic layered aquifer systems. Journal of Hydrology, 296(1-4): 241-253.