Exercise – Effect of Fractures on Groundwater Flow Patterns

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Context: This activity was developed for a short-course for professionals and I have not yet used it in my undergraduate class. I have used TopoDrive in other lab exercises and the user-interface is straight-forward enough for students to quickly master. I believe the exercise can easily be adapted as an undergraduate lab exercise as long as they are given some background on the difference between characteristic fracture patterns for crystalline and sedimentary rocks.

Goal: Conduct simple numerical experiments to gain a better understanding of the effect of fractures on groundwater flow patterns.

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References:

Hsieh, P.A., 2001. *TopoDrive and ParticleFlo – Two Computer Models for Simulation and Visualization of Ground-water Flow and Transport of Fluid Particles in Two Dimensions*: U.S.G.S. Open File Report 01-286, 30 pg.

Web page: (public domain software and users' manual)

http://water.usgs.gov/nrp/gwsoftware/tdpf/tdpf.html

Note there are downloads available for Windows operating systems as well as a Java applet for a web browser that will work for Windows or UNIX systems. There is no download for Macintosh operating systems.

Introduction:

Paul Hsieh, of the USGS, has developed two (relatively easy-to-use) computer models for 2-D simulation and visualization of groundwater flow (TopoDrive) and transport of fluid particles (ParticleFlow). We're going to use TopoDrive to explore the effects of fracture heterogeneities on groundwater flow and transport.

Simulations

We'll first simulate a small regional flow system that is approximately 1 km in length.

•Use Start menu to set up the model domain.

Model domain length	1,000 meters
Vertical Exaggeration	1.0

Simulation 1: ***Sloping Water table in a homogeneous, isotropic aquifer***

We're first going to simulate flow in a homogeneous, isotropic aquifer with a hydraulic conductivity of 1×10^{-7} m/sec.

•*Water Table*

Click the "Water Table" button to bring up the Water Table Dialog Box, which provides a reminder to draw the water table from left to right.

•*Mesh*

# Columns	100
# Rows	50

•*Assign properties*

-Click the "Properties" button to bring up the Properties Dialog Box.

-We'll use the "isotropic" option.

-Five sets of hydraulic conductivity (m/s) and porosity (%) values are available for assignment to model elements. Each set is represented by a color. Default values are initially provided, but users may alter any or all of these values in the edit boxes.

-Select a set of hydraulic conductivity and porosity values by clicking the color icon. The selected icon is indicated by a thick black frame.

-Draw a polygon to enclose those elements to which the selected property values will be

assigned. A polygon is drawn by clicking at its vertices. To finish drawing the polygon, double click the last vertex.
-The elements enclosed by the polygon are filled with the color that was selected in the dialog box. In our first simulation we will use a hydraulic conductivity of $1x10^{-7}$ m/sec (which is the red box).

•Compute head (use 30 contour intervals)

•For Flow
Use the "Flow path tracking option".
Flow paths are added by clicking in the model domain. It's good to try and get a relatively regular vertical spacing of flow lines.

•For Animation
This steps shows the evolution of the flow paths defined above. You need to specify the amount of time that is equal to 1 second of animation. A good starting point is often to set 1 second (of animation time) equal to 3650 days (10 years). I typically leave the animation smoothness at the default value.

You start the animation by clicking anywhere within the model domain. You can also pause the animation by clicking anywhere within the model domain. To restart the animation, once again, click within the model domain.

Note: Due to the low hydraulic conductivity value, this simulation will take several minutes to run.

In the space below, draw the resulting animation and note the range of travel times (i.e, when the first and last particles reach the water table). If you would like to print a copy of your simulation, you may do so using the print tab. If your machine is connected to a printer, you can print to a hard copy. Alternatively, you could print to a pdf file or do a screen capture if your instructor wants you to turn in copies of your simulations.

Range of travel times: ____

Simulation 2: ***Sloping Water table in granite***

Now we're going to rerun the same model but include some fractures that might be typical in a region with granitic bedrock. We'll assign our "fractures" a hydraulic conductivity that is 4 orders of magnitude greater than "background" K ($K=10^{-3}$ m/sec for the fractures, $K=10^{-7}$ m/sec for the granite).

In the space below, draw some fractures that might be typical in granitic bedrock.

Now, go back to your model and click on the properties box. Choose a hydraulic conductivity of 10^{-3} m/sec (blue box) and use the mouse to draw in a fracture pattern similar to the one you drew in the above box. It takes awhile to get the hang of drawing thin, fracture-like heterogeneities. If you don't like what you've drawn, just go back to the properties option, pick the option for 10^{-7} m/sec (red) and fill-in the whole area. Then try again to draw your fractures.

Once you have a fracture pattern that you are happy with, rerun the model by calculating the heads and running the resulting animation. Draw the resulting flow lines on the above diagram (or print your results to a printer or a file). What's the range of travel times (i.e, when the first and last particles reach the water table)?

Range of travel times: ____

Summarize the effects of "granitic" fractures on the flow system.

Simulation 3: ***Sloping Water table in fractured sedimentary rock***

Now we're going to create a model that might be typical of fractured sedimentary rock. We'll probably want to change our "background" K to a slightly higher value and we'll want to change our pattern of fracture heterogeneities to something more typical of a fractured sedimentary sequence.

In the space below, draw some fractures that might be typical in sedimentary bedrock.

Again, go back to your model and click on the properties box. Change the background hydraulic conductivity to something more representative of sedimentary bedrock aquifers and then fill in the entire model domain with this value. I work on a fractured dolomite aquifer and a reasonable background hydraulic conductivity for that aquifer is 3×10^{-6} m/sec.

Run the model using your background hydraulic conductivity by calculating the heads and running the resulting animation. Note the range of travel times for particles to reach the water table.
Range of travel times: ____

Now, go back to the properties menu and choose a hydraulic conductivity value that is 3 to 4 orders of magnitude higher than your background value (you might need to edit the default values). Then, use the mouse to draw in a fracture pattern similar to the one you drew in the above box.

Once you have a fracture pattern that you are happy with, rerun the model by calculating the heads and running the resulting animation. Draw the resulting flow lines on the above diagram (or print your results to a printer or file). What's the range of travel times (i.e, when the first and last particles reach the water table)?

Range of travel times: ____

Summarize the effects of “sedimentary” fractures on the flow system.