# Computer Exercise: TopoDrive

## Objectives

1. Review the concept of topography-driven flow.
2. Examine the effects of landform and geological heterogeneity.

## Groundwater flow equation

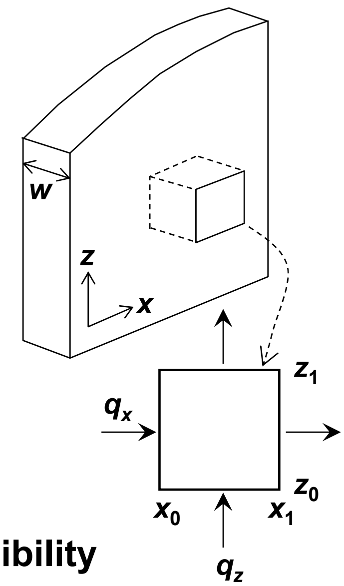
Slice of aquifer with thickness $w$ (m)

Net flow in $x$-direction ($m^3\ s^{-1}$):
= $[q_x(x_0) - q_x(x_1)] \times$ (cross-sectional area)

Net flow in $z$-direction ($m^3\ s^{-1}$):
= $[q_z(z_0) - q_z(z_1)] \times$ (cross-sectional area)

The rate of storage change in the box ($m^3\ s^{-1}$):
= $S_s \times \Delta h/\Delta t \times$ (box volume)

$S_s$ ($m^{-1}$): specific storage $\propto$ material compressibility






Mass balance of the box is given by:

(net flow)$_x$ + (net flow)$_z$ = rate of storage change

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t}$$

The transient flow equation was 'applied' to GW problems by Theis (1935) and rigorously derived by Jacob (1940).

$\rightarrow$ See a historical note by Bredehoeft (2008, *Hydrogeol. J.*, 16:5-9).

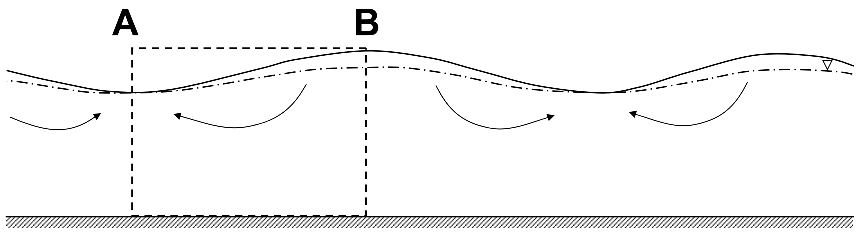
When 'average' flow is considered, the short term storage change becomes negligible $\rightarrow$ steady-state flow equation.

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = 0$$

This partial differential equation can be solved with appropriate boundary conditions to calculate hydraulic head distribution in a vertical cross section.

# Boundary conditions for flow equation

**Suppose a cross section of undulating terrain underlain by relatively impermeable bedrock. The shape of the water table resembles that of the land surface.**



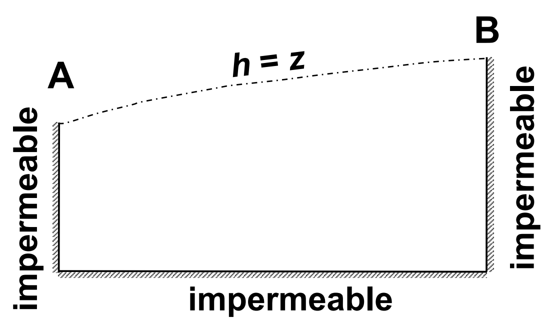

**Flow lines symmetrically converge at A and diverge at B.**
**→ A and B are considered impermeable boundaries.**

**The water table is commonly treated as the top boundary of the saturated region. To set a boundary condition at the water table (WT), recall that:**

$$h = z + \psi \quad \text{and} \quad \psi = 0 \text{ at WT} \quad \rightarrow \quad h = z \text{ at WT}$$



**The boundary conditions shown in the figure will be used in the following exercises.**

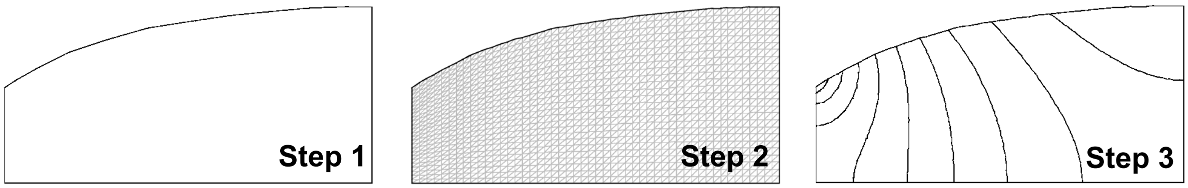


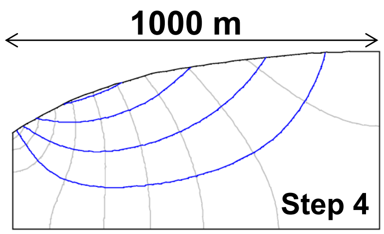
## TopoDrive program

**TopoDrive is a public-domain program written by Paul Hsieh at US Geological Survey** (http://water.usgs.gov/nrp/gwsoftware/tdpf/tdpf.html).

**Let's become familiar with the program by generating the famous Hubbert** (1940, *J. Geol.*, 48: 785-944) **section.**

→ **Step-by-step instruction on computers.**




**Questions:**

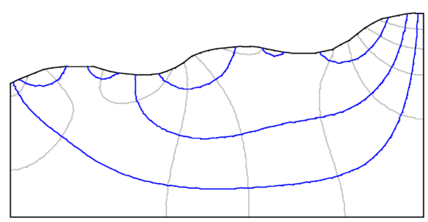
**Where does groundwater recharge occur?**

**How about discharge?**



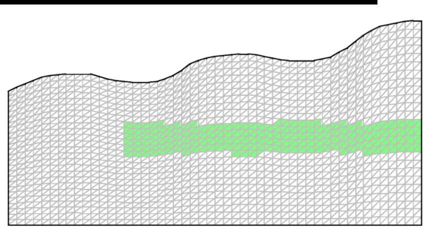
## Effects of undulating topography

**Can you identify local and regional flow systems?**

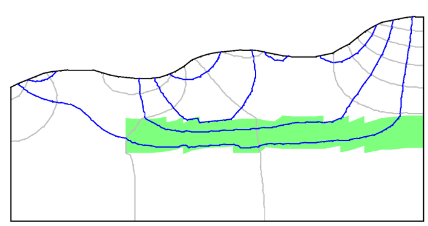


**This concept was developed by Tóth** (1963. *J. Geophys. Res*., 68: 4795).

## Effects of high-*K* layer



**Insert a layer with $K = 10^{-4}$ m/s.**

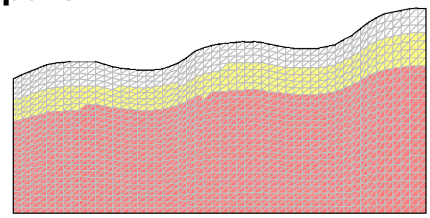


**What are the effects of high-conductivity layer?**

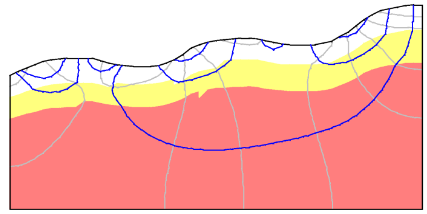
**This concept was studied by Freeze and Witherspoon** (1967, *Water Resour. Res*., 3: 623-634)

## Effects of decreasing *K*

**Hydraulic conductivity of geological materials generally decreases with depth. This is related to the development of fractures and macropores near the surface or higher degree of compaction at depths.**



**Add a middle layer ($K = 3 \times 10^{-6}$) and bottom layer ($K = 10^{-6}$).**

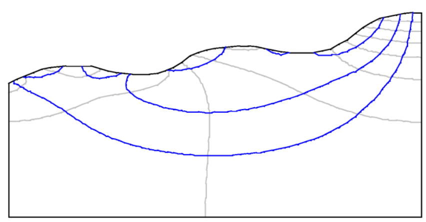


**Run an animation and examine the 'activeness' of local and regional flow systems.**



## Effects of anisotropic *K*

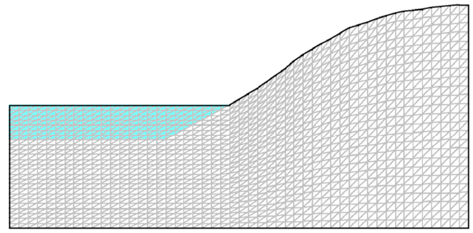
**Remove the middle and bottom layers. Specify $K_x = 10^{-5}$ and $K_z = 2 \times 10^{-6}$ m s$^{-1}$.**



**What are the angles between flowlines and equipotential lines? Flow paths are shallower compared to the isotropic case. Why?**

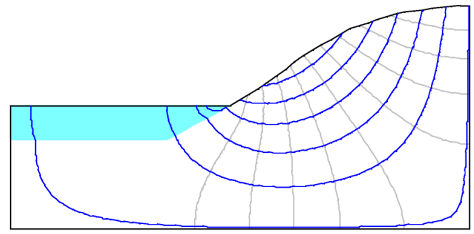
## GW-Lake interaction

**We can represent a lake in TopoDrive by a zone with very high *K*.**



**Set up a cross section with a lake represented by $K$ = 0.01 m $s^{-1}$.**

**Flow lines are denser near the shore, indicating higher discharge flux along the shore.**



**While this explains general spatial trends of lake-bottom seepage flux, in reality, the flux distribution is much more complex due to geological heterogeneity.**
**→ Explore this further by yourself.**