HWRS 582 – Groundwater modeling

HM2 - Challenge

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1) Show, based on the flux with horizontal distance from a constant head boundary, that the model is steady-state. Repeat this for a homogeneous and for a heterogeneous column for which zones of different K are placed in series with the direction of flow. Note that the best way to do this is to take the values from the .list file into Excel, combine them with the K values from the .bcf file, and calculate the flux at each point. Keep in mind that heads are calculated at the center of a cell (a node) and the K values are defined over each cell.

Answer: Following the definition of steady-state, we have that the total flux entering and going out of each cell must be the same. In our case, I calculated the flow in the horizontal and vertical direction, finding that they are almost the same (Fig. 1 and 2) which proves that the model did the right calculations. However, probably in the horizontal direction, the model required more iterations to have the same value. Figure 3 shows the gradient as surface and contour, which is linear in the same way as the spreadsheet we used the last week.

Flux ->

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
2		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
3		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
4		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
5		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
6		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
7		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
8		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
9		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
10		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
11		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
12		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
13		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
14		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
15		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
16		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
17		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
18		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
19		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
20		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
21		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
22		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
23		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
24		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1
25		-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.0	-2.1	-2.1

Figure 1. Horizontal flux in each cell. 1 layer (Amplificated 1000 times)

Flux î

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1																									
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 2. Vertical flux in each cell. 1 layer (Amplificated 1000 times)

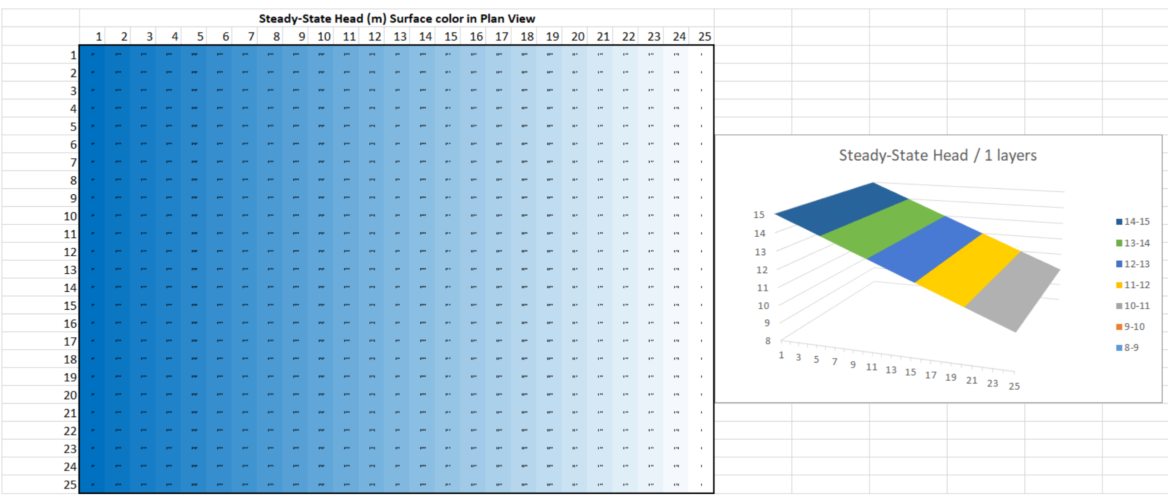

Figure 3. Surface Water head and 3D representation. 1 layer.

In the case of the heterogeneous (2 layers), I calculated the same figures, finding that the horizontal flux (Fig. 4) has similar values but do not the same. Another problem for that differences could be the decimal values used to solve the water head. Apparently, 2 decimals are not enough when you work with high hydraulic conductivities. In the vertical flux (Fig. 5), I had newly a constant value of zero.

Flux ->

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
2		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
3		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
4		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
5		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
6		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
7		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
8		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
9		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
10		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
11		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
12		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
13		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
14		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
15		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
16		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
17		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
18		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
19		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
20		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
21		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
22		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
23		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
24		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4
25		-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4	-1.4	-1.4	-1.4	-1.5	-1.4	-1.4

Figure 4. Horizontal flux in each cell. 2 layers (Amplificated 1000 times)

Flux î

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1																									
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 5. Vertical flux in each cell. 2 layers (Amplificated 1000 times)

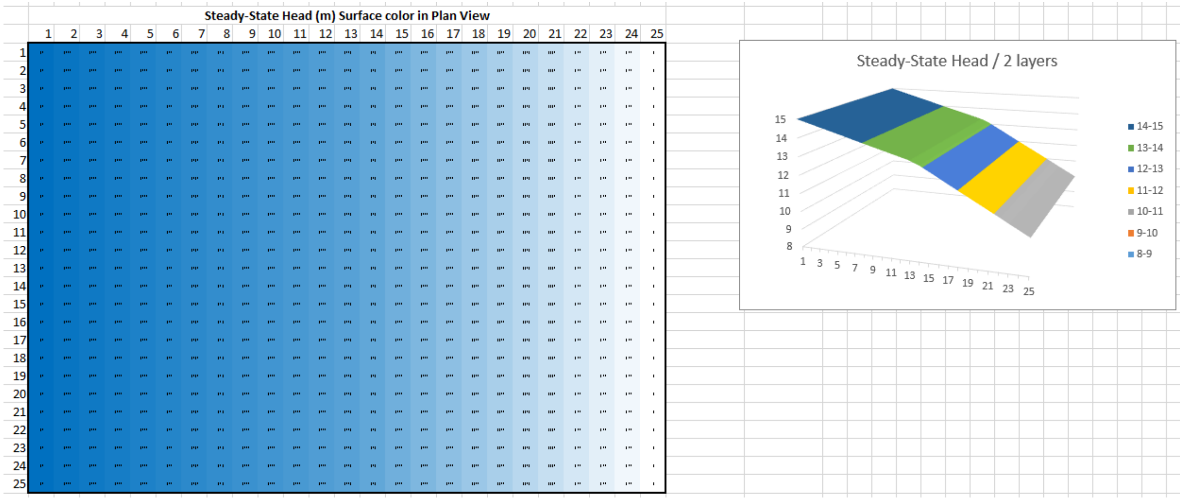

Figure 6. Surface Water head and 3D representation. 2 layers.

2) Show the steady-state head contour in plan view for the heterogeneous (zones in series) condition. Use this plot to defend a contention that flow is 1D. Then, drawing on your Excel assignment, use the results to explain WHY the equivalent hydraulic conductivity, Keq, is closer to the lower of the two K values.

Answers: Figure 7 shows that all the color sections are completely vertical. That means that the flux must be horizontal given that flow lines are always perpendicular to the equipotential lines. Additional, figures 2 and 5 presents zero flux in the vertical direction which confirms that the dimensionality of the problem is 1D.

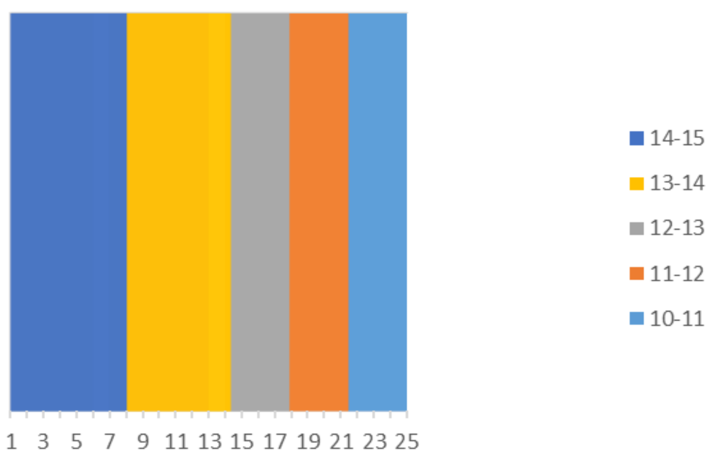

Figure 7. Steady-state head with 2 layers.

The last figure shows that the higher energy loss in the right section, which has the lower hydraulic conductivity (0.5 m/day). In fact, the first layer only required 1.69 m of energy. The other 3.31m is lost in the layer with lower conductivity. Given that Keq can be understood as the more representative conductivity, Keq will be controlled by the lower conductivity. Another, example of the same situation happens when you try to characterize the average speed in a race. If a person did walking and biking in the same race, the average speed will be controlled by the mode in which more distance was done by the person.

3) Build a model based on a homogeneous domain with a square region of lower K in the middle of the domain. What can you learn based on your explanation of what controls the effective K for a 1D flow system now that you are applying it to a 2D system? What do you think the Keq of this entire system would be compared to the high and low K values? Explain why it is much more difficult to develop a direct solution for this 2D system than it was for a 1D system (including the zones placed in series).

Answers: In this situation, we must apply another concept to understand the water behavior. I call the concept of laziness; water always takes the easiest path flow between 2 points. In other words, water always moves to minimize the total energy used, therefore if the water has the chance to take an easy path it will always take it. In our exercise, water has the chance to move in both directions (in homework 1, we imposed one direction), therefore the water that faces the region with low conductivity will prefer to change the direction and move through a region with high conductivity because that requires less energy. In conclusion, the Keq will be like the conductivity where more water is moving through. In our example, the average flux at the end of the modeling (right side) for the homogeneous conductivity was $2.1x10^{-3}$ m/d. In the case with 2 layers in series, the average flux was $1.4x10^{-3}$ m/d, and in the case, with the inclusion, the average flux was $2.0x10^{-3}$ m/d. That shows us that the system with the inclusion is more similar to the homogeneous than the case in series.

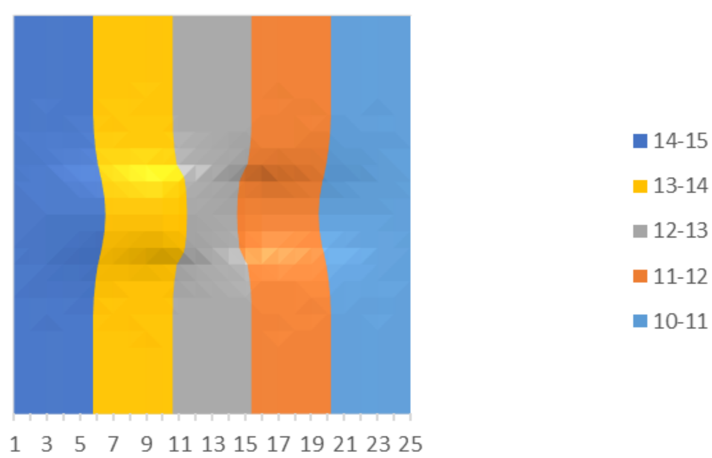

Figure 8. Steady-state head with a square region of low conductivity.

In this case, the estimation of the Keq is more complicated because the quantification of the energy used requires the length used for particle, which depends on the disposition of the inclusion.

Discussion Points

4) What is MODFLOW? What is a MODFLOW? What is a MODFLOW package? What is a MODFLOW input package?

Answer: MODFLOW is a groundwater model. A MODFLOW is a specific developed model. A MODFLOW package is a subroutine that adds a specific characteristic to the model. A MODFLOW input package is a subroutine that helps to incorporate the input in a model.

5) What is meant by model dimensionality?

Answer: MODFLOW is a 3D model, however, each problem can have a different number of dimensions that control the flow. For example, a well has flow in 3 dimensions but if you use a cylindric coordinate system you can characterize the flow just using 2 dimensions. The same happens with the first 2 exercises done in the challenge, they can be reduced to just one dimension.

6) Why might parameters be defined in zones?

Answers: The geology could change between different regions in a catchment which affects the hydraulic conductivity.

7) If you want to establish purely horizontal flow, what (specifically) should be defined as constant along the constant head boundaries?

Answer: Given that water moves between different energy levels, we must define a constant water head vertically, this way we are not imposing a gradient in the vertical direction.

8) What is an equipotential? Assuming that the medium is isotropic (why?) and that flow is horizontal, how can you track the path of a water particle through the domain?

Answer: Equipotential is a line with equal energy. Anisotropic could be a problem if you are using only one cell to deal with that because the flux is in 3D and you will be visualizing it in 2D. In the case you are using multiples layers to create a discretization on the vertical component, you will have a surface for the equipotential and you could apply the concept that path flow is always perpendicular to the equipotential (line or surface).

9) For steady state conditions, there are equivalent Type I and Type II boundary conditions. What would the Type II boundary condition be that would result in the same equipotential for the first model? What is the value of the constant flux? What about the second model? What are the values of the constant flux on the left and right boundaries? What is fundamentally different about the equivalent Type II boundary for the third model compared to the first two?

Answer: When you impose a water head (Type I) as a boundary condition, that imposes indirectly a flux in the system. Therefore, if you impose the resulting flux as a boundary condition (Type II), you will have as result the same difference in the water head. That shows that the relationship between water Head and flux is not bidirectional, because the different combinations of water head can produce the same flux (the relationship is between delta H and flux). For that reason, if you need to apply a type II condition you must have at least one type I defined in the system. In the case of the homogenous model, if we impose the constant flux on one side and the water head on the other, we will have the same answer. The same happens with the 2-layer model. In the case of the inclusion, the flux is not constant in the boundaries however is we apply this variable flux as a boundary condition and the water head in the other, we could rebuild the results.

Final thoughts: A good understanding of type I and II is fundamental for any modeler, so probably more explanation about that will be useful. Especially if the explanation goes with a simple analogy. For example, a slice is a good one. When you define the top and the bottom of the slice, you are defining how fast you will go at the end. However, if I tell you only the speed that I want, could you define the elevation of the slice? It could on the ground or at the top of a building, the result in speed is the same.