Groundwater modelling

Module 7 WSE - HI River basin modelling

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Contents

1. Model of unconfined aquifer

Q2

In the original model introduce a second pumping well at location of cell (5, 15). Using trial and error estimate the maximum total pumping rate (from both wells at locations (15,15) and (5,15)), that is larger than the single pumping rate at cell (15,15) in the original model estimated at 1110 m3/day, still ensuring that no water is pumped from any of the boundaries. Explain your answers and support them with whatever results you find appropriate, such as water balance, groundwater head distribution, particle tracking

Ideally, if there is no inflow from any of the boundaries, the inflow will all come from the infiltration, whose charge has a maximum value – 3200m^3/d.

$$\mathrm{B} \times \mathrm{L} \times \mathrm{I} = 2000 \times 2000 \times 0.0008 = 3200 m^3/\mathrm{d} \tag{1}$$

That means the maximum total pumping rate cannot exceed 3200m^3/d. Since the two wells are almost symmetrical in topography, their weights for the influence of the boundary are nearly the same. In order to ensure the sum maximum, their rate should be assumed equally first, and then some fine-tuning is performed by observing the results.

Both abstraction rate start from 600m^3/d, and then gradually increase in steps of 100 m^3/d until the moment when the western constant head boundary changes. Next, modify the step interval and continue modelling until not meeting the requirements.

Table 1. The boundary results in different cases

Case	Well (5,15)	Well (15,15)	western boundary	eastern boundary
1	0	1110	9.83E-02	0.00E+00
2	600	600	0.00E+00	0.00E+00
3	700	700	0.00E+00	0.00E+00
4	800	800	3.04E+01	0.00E+00
5	720	720	0.00E+00	0.00E+00
6	730	730	0.00E+00	0.00E+00
7	740	740	1.37E+00	0.00E+00

In Case 7, part of the well (5, 15) water is pumped from the western boundary. In contrast, the wells in case 6 do not have any flow from the boundaries. Thus, we choose Case 6 for further research, plotting the groundwater head distribution graph.

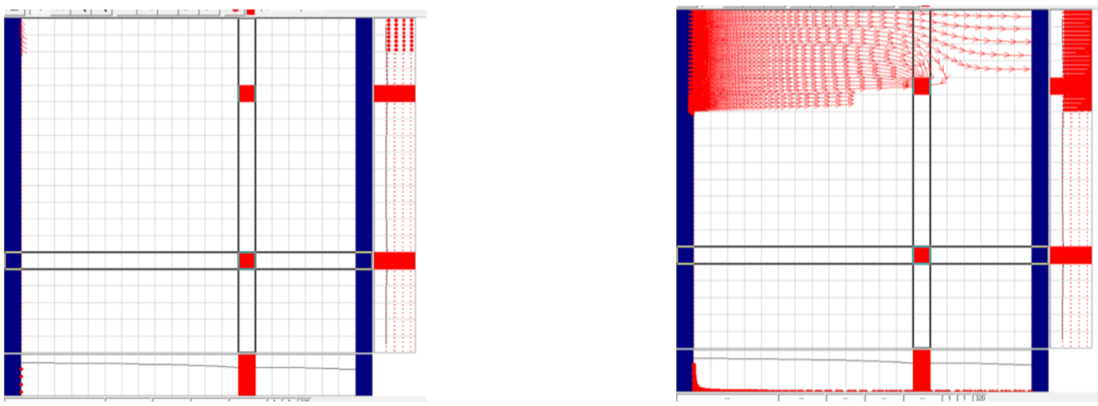


Figure 1. The particle tracking results of case 6 and 7

In the graph, the hydraulic gradient close to the upstream is a bit not parallel to the boundary line. Under the same hydraulic gradient, the value of the north point is smaller compared to the south point, that is, the water level drops relatively quickly compared to the south.

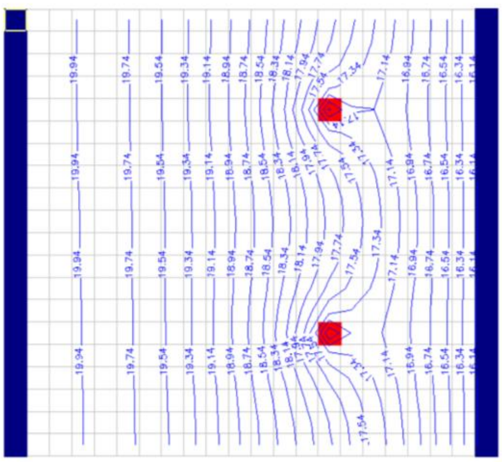
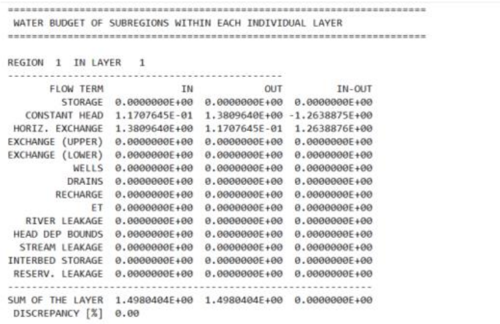


Figure 2. The groundwater head distribution results

In the end, some fine-tuning is acted in steps of 5 m^3/s, reducing the Well (5, 15) value and growing the Well (15, 15) value. Using the trial and error, the final result needs to meet three conditions:

The constant head from the upstream boundary is slightly larger than 0; the hydraulic gradient close to the upstream is basically parallel to the borderline; the particles from the western boundary appear, but without reaching the well.



WATER BUDGET OF SUBREGIONS WITHIN EACH INDIVIDUAL LAYER

REGION 1 IN LAYER 1

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
CONSTANT HEAD	1.1707645E-01	1.3809640E+00	-1.2638875E+00
HORIZ. EXCHANGE	1.3809640E+00	1.1707645E-01	1.2638876E+00
EXCHANGE (UPPER)	0.0000000E+00	0.0000000E+00	0.0000000E+00
EXCHANGE (LOWER)	0.0000000E+00	0.0000000E+00	0.0000000E+00
WELLS	0.0000000E+00	0.0000000E+00	0.0000000E+00
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
RESERV. LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
SUM OF THE LAYER	1.4980404E+00	1.4980404E+00	0.0000000E+00
DISCREPANCY [%]	0.00		

Figure 3. The water balance of the final case

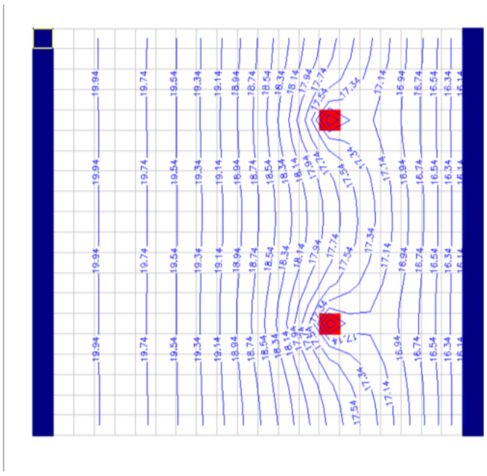


Figure 4. The groundwater head distribution of the final case

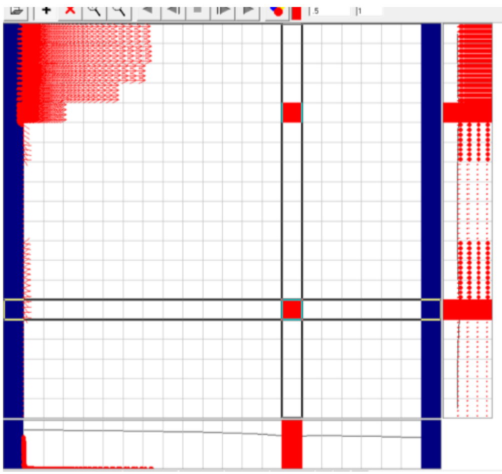


Figure 5. The particle tracking of the final case

For further increase of the rate, the well will start obtaining water from the western boundary. Therefore, the well (5, 15) and (15, 15) results are determined to be 705 m^3/s and 805 m^3/s respectively.

2. Model of a polluted aquifer

Note: In the report and the course, the model has some mistakes. Since the Wells inflow is not equal to 3500 but 3850 (the initial conditions).

Q6

Suppose that the natural recharge to this aquifer is 50% smaller. Explain the differences in water balance components compared to the original model (think about the changes in groundwater heads). Will the polluted zone be larger or smaller than in the original model? Support your answer with results in terms of appropriate particle tracking analysis results.

Table 2. The water balance in original case

FROM TERM	IN	OUT
WELLS	3500	13700
RECHARGE	4448	0
RIVER LEAKAGE	5786	34
SUM	13734	13734

Table 3. The water balance in changing case

FROM TERM	IN	OUT
WELLS	3500	13700
RECHARGE	2223	0
RIVER LEAKAGE	7980	4
SUM	13704	13704

The water balance table indicates the natural recharge from precipitation reduces to half compared to the original model from 4448 m^3/d to 2223 m^3/d. Next, the river leakage provides more inflow to the aquifer layer from 5786 m^3/d to 7980 m^3/d. In the meantime, less outflow from the model is via the river leakage (from 34 m^3/d to 4 m^3/d). Instead of 13704 m^3/d as in the original model to total inflow is now 13734 m^3/d (a bit change).

For the inflow growth of river leakage, we can get the answer through the groundwater head distribution. The reduction in infiltration reduces the water head of the entire catchment. Thus, at the upstream location of the tributary, more cells show higher head in the aquifer than the water head in the river (see figure below). It can be concluded that there is more flow of water from the river to the catchment as inflow, and there is less flow as outflow.

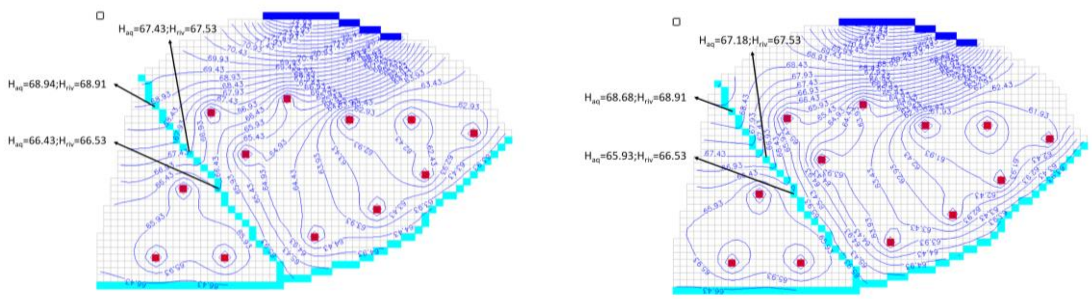


Figure 6. Two groundwater head distributions (original and changing case)

The polluted zone will be larger than in the original model. In order to determine the exact zone that is polluted, we pump forward tracking particles from the southern river. The final particle tracking result introducing a line to distinguish the zone is then used to delineate the polluted zone. In the original model, we ignore a bit of particles reaching well No.10. In contrast, this part occupies a large area in the polluted area, which should be excluded from future pumping. Next, in the southwest corner, the contaminated area expands to the north.

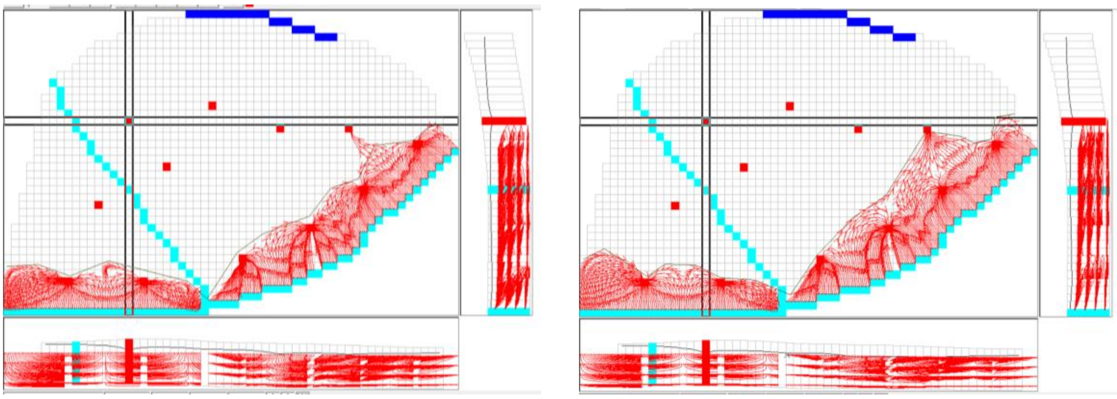


Figure 7. The polluted zone in particle tracking (original and changing case)

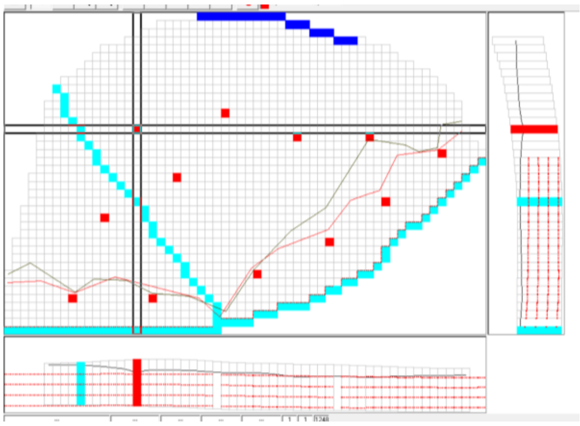


Figure 8. The polluted zones' comparison between the two cases

Q9

In the second version of the model, after the wells close to the southern river have been switched off, and the Well No.10 has been reduced to 1500 m3/day pumping rate, the total available water for water supply has been significantly reduced (from 13,500 to 6000 m3/day). Can you introduce new wells that will pump total additional water of as close as possible to 2,000 m3/day, while still not taking any water from the polluted zone of the aquifer? Use as small number of wells as possible, with a maximum of five additional wells. You can modify (reduce) the pumping rate of most critical Well No 10 (on the east), but the total pumping rate should be increased by as close as possible to 2000 m3/day, i.e should be equal to 8000 m3/day. Present the new well configuration indicating the pumping rate of each well. Provide support for the solution that you have found (confirming that you have provided additional water without pumping any polluted water) with water balance and particle tracking results.

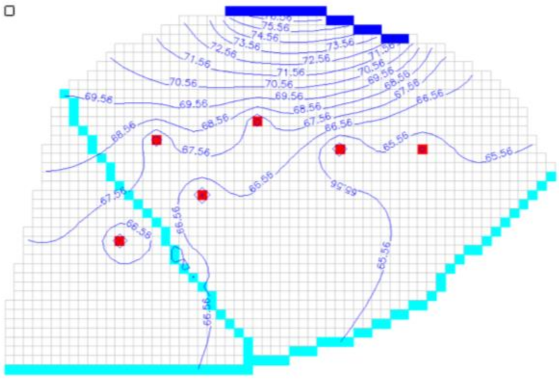


Figure 9. The groundwater head distribution of original model

WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
CONSTANT HEAD	0.0000000E+00	0.0000000E+00	0.0000000E+00
WELLS	3.5000000E+03	6.0000000E+03	-2.5000000E+03
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	4.4475000E+03	0.0000000E+00	4.4475000E+03
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	8.8868533E+01	2.0363680E+03	-1.9474994E+03
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
RESERV. LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
SUM	8.0363687E+03	8.0363682E+03	4.8828125E-04
DISCREPANCY [%]	0.00		

Figure 10. The water balance of the original model

The water balance for this case shows to increase the 2000 m^3/s water pumping. In order to achieve this task, we should improve the inflow ability and weak outflow in river leakage. Thus, in the next drilling process, several wells need to be distributed on both sides of the river.

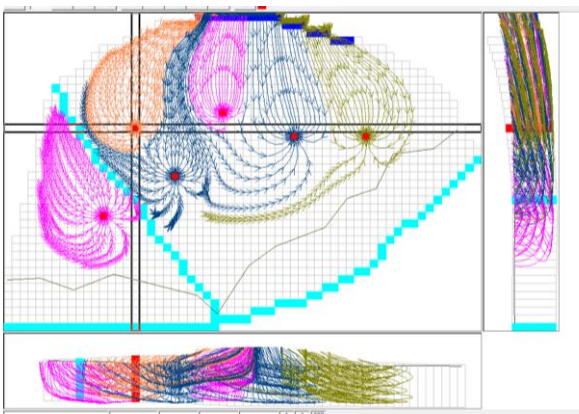


Figure 11. The particle tracking of the original model

The particle tracking result indicates that the current wells take water from the tributary or the northern boundary. First, almost northern inflow from the neighbouring aquifer (represented by injection wells) is pumped by the wells. We can set a new well close to this part taking water from there so that W5, W11 have to absorb water from the tributary instead of the northern boundary. Also, we need to avoid W3, W11 and W10 take water from the polluted zone. Second, we find there is few water from the downstream of the tributary flowing to the wells. Thus, we need to build some wells so that the entire wells can take more water from the tributary, especially the downstream of the tributary. In other words, these new wells will prompt W3, W4, and W5 to divert water from the tributary.

In summary, we initially assume three new wells, two on each side of the tributary and one close to the northern inflow. Through trial and error, the specific case is as follows:

Table 4. The well designing scheme

Well	Coordinate	Supply
W10	(16,46)	900
W13	(16,7)	750
W14	(11,11)	900
W15	(5,29)	950

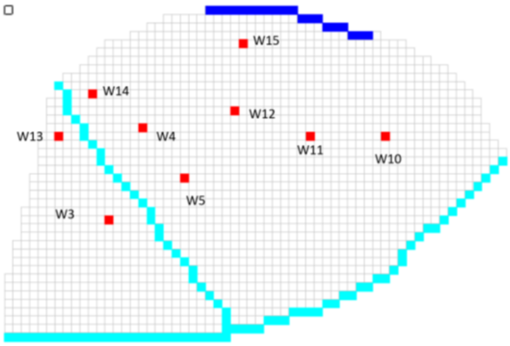


Figure 12. The specific well designing scheme

W13 and W14 absorb mostly water from the upstream of the tributary, and W15 mainly absorbs water from the northern boundary. This design maximizes the flow of tributary water into the wells. Meanwhile, the particle tracking shape of W5 and W11 changes dramatically.

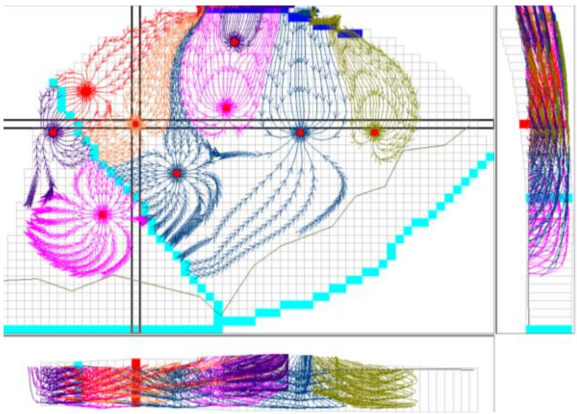


Figure 13. The particle tracking of the modified model

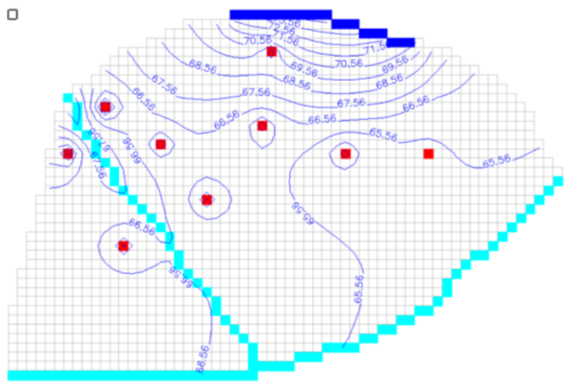
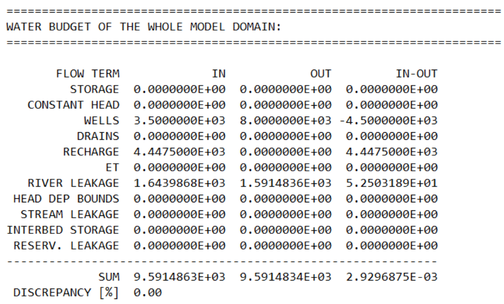


Figure 14. The groundwater distribution of the modified model

The water balance shows the inflow increasing (from 9m^3/s to 1644m^3/s) and outflow decreasing (from 2036 to 1591) in river leakage, which can explain how the well pumping ability improves. Most of the added water comes from the inflow in river leakage, located in the upstream of the tributary. As the pumping of the whole catchment increases, the groundwater level goes down, so the outflow from the river leakage declines.



WATER BUDGET OF THE WHOLE MODEL DOMAIN:

FLOW TERM	IN	OUT	IN-OUT
STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
CONSTANT HEAD	0.0000000E+00	0.0000000E+00	0.0000000E+00
WELLS	3.5000000E+03	8.0000000E+03	-4.5000000E+03
DRAINS	0.0000000E+00	0.0000000E+00	0.0000000E+00
RECHARGE	4.4475000E+03	0.0000000E+00	4.4475000E+03
ET	0.0000000E+00	0.0000000E+00	0.0000000E+00
RIVER LEAKAGE	1.6439868E+03	1.5914836E+03	5.2503189E+01
HEAD DEP BOUNDS	0.0000000E+00	0.0000000E+00	0.0000000E+00
STREAM LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
INTERBED STORAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
RESERV. LEAKAGE	0.0000000E+00	0.0000000E+00	0.0000000E+00
SUM	9.5914863E+03	9.5914834E+03	2.9296875E-03
DISCREPANCY [%]	0.00		

Figure 15. The water balance of the modified model

3. Profile model – flow under a dam

Q10

In Model a) reduce the hydraulic conductivity of the aquifer below the dam from 1 m/day to 0.2 m/day. Present analysis of the obtained results in terms of head distribution under the dam, flow under the dam and uplift force (per unit width). Explain the differences compared to the original Model a). Use whatever results you find appropriate in your explanations.

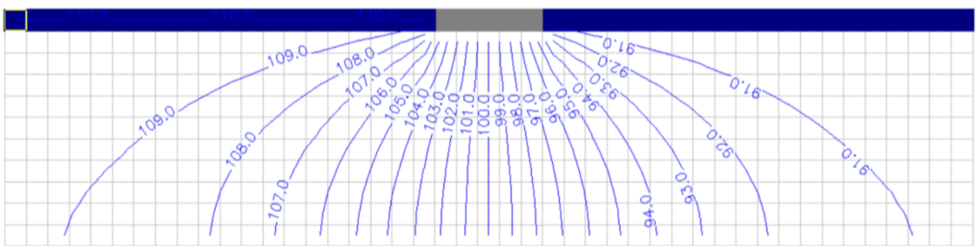


Figure 16. The groundwater head distribution of the original model

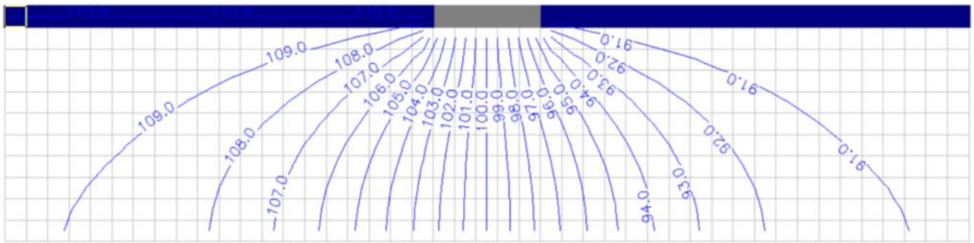


Figure 17. The groundwater head distribution of the modified model

The aquifer distribution is the same in the equipotential and values. The upstream and downstream are 110 m^3/d and 90 m^3/d respectively. The groundwater head distribution is symmetric along the centre line of the dam (100m^3/d). From upstream to downstream, the head distribution is from sparse to dense till the centre, and then the groundwater head is gradually sparse till the downstream.

The original model's total constant flow under the dam is 12.9 m^3/d (per unit width). When we assign 0.2 m^3/d, the overall constant flow is 2.57 m^3/d (per unit width). Since less hydraulic conductivity means less fluid transmit through pore spaces and fractures in the presence of an applied hydraulic gradient. However, this does not affect the distribution of the groundwater head in this case.

The total uplift force is calculated by using the following formulas:

$$H = Z + \frac{P}{\rho G} \tag{2}$$

This total groundwater head can convert into this equation:

$$P = (H - Z) \times Pg \tag{3}$$

Force for each cell is calculated as:

$$F = P \times A = P \times (w \times b) = 5P \tag{4}$$

The total force is sum of all five force calculated for the five cells below the dam.

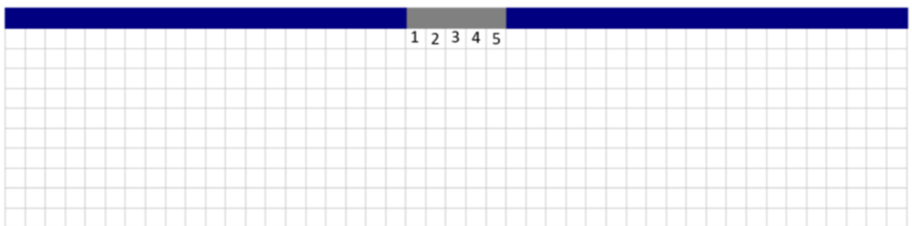


Figure 18. The five cells' location

Table 5. The uplift force calculation

Cell	1	2	3	4	5	
H	104.2	102	100	98	95.8	Total force
H-Z	19.2	17	15	13	10.8	
P (Pa)	188352	166770	147150	127530	105948	
Force (MN)	0.94	0.83	0.74	0.64	0.53	3.68

Both total force is the same value – 3.68MN (per unit width), since their head distributions are the same.