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Effect of Injection/ Pumping Wells on Pollution Transport in Groundwater

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الملخص:

تتعرض المياه الجوفية للتلوث بسبب أنشطة الإنسان المختلفة فى مجالات الصناعة والزراعة والصرف الصحى وهناك عدد من الطرق والإحتياطات التى يمكن أن تستخدم لوقف انتشار وانتقال الملوثات مع المياه الجوفية فى حالة حدوث التلوث ومن هذه الطرق حقن التربة لتقليل النفاذية أو إنشاء حوائط طينية فى داخل الأرض أو احتواء هيدروديناميكى للملوثات فى موقعها باستعمال آبار الحقن أو الضخ فإنها تستعمل فى شفط المياه الملوثة أو حصر الملوث فى مكان محدد ومنعه من الإنتقال إلى أماكن أخرى وقد تم فى هذا البحث دراسة الخواص الهيدروليكية وتأثيرها على فاعلية بعض هذه الطرق وذلك بالإستعانة بالنمذجة العددية باستعمال النموذج العددى MT3D وقد شملت الدراسة معدل الحقن أو الضخ للآبار وطول المصفاة ومكانها بالإضافة إلى عدد الآبار المستعملة وبينت النتائج أن نقص معدل الضخ أو الحقن وكذلك تقليل عدد الآبار يساعد على زيادة انتشار الملوث وظهر أيضا أن تغيير طول المصفاة فى آبار الحقن ليس ذو تأثير فعال مثل الحال فى آبار الضخ وأما تغيير عدد آبار الضخ يكون ذو فاعلية أكثر عنه فى حالة آبار الحقن.

Abstract

The natural quality of groundwater tends to be degraded by activities of man including industry, agriculture and waste water. There are several alternatives to prevent migration and spread of pollution in groundwater. Some alternatives are physical such as grouting, or slurry walls. Others could be hydrodynamic containment by injection or pumping wells. Injection wells are used to confine a pollutant in place or dilute its concentration by injecting clean water in the aquifer. Pumping wells are used to discharge the pollutant out of the groundwater reservoir or act as interceptors for a containment. In this research, the hydraulic characteristics and behavior of the hydrodynamic methods are investigated by using numerical simulation. The numerical model MT3D has been used in this investigation. The injection/pumping rate , length of screen and its layer and number of wells are considered.

Results has shown that decreasing the rate or the number of the injection/ pumping wells permits more pollution spread. Changing the screen length of the injection well is not effective in preventing the pollution spread in the long term concern. Changing the number of the pumping wells has more effect on a containment spread more than the case of injection wells.

1. Background

Hydrodynamic control for containing containments in place by injection wells, or removing them from the ground by discharge wells are considered effective methods to prevent contamination spread in a hydrogeological system (Rogoshewski and others, 1983). With pumping, there is always the problem of what to do with the contaminated water removed from the ground of necessity, on site treatment is required before injecting the water to the subsurface or releasing it to surface water bodies (Knox and others 1984). Injection wells could be used to dilute the groundwater pollution by injection clean water or be used as interceptors for diverting the flow direction. Guevara (2.015) and Bogan (2004) show that number of injection or withdrawal wells and the pumping/ injectionrates would be minimized through a proper choice of wells location and the distance between wells . This could be achieved through good understanding of the problem and implementing successful design for the controlling system in each specific site.

In this paper, investigation of injection and pumping wells is performed and discussed. The numerical models MT3D and MOFLOW have been employed. Change of injection/ pumping rate, depth and position of screen and distribution of wells around the pollution source are considered. The results has shown that less rate or number of The injection/pumping wells permits more pollution spread. Changing screen length and position of wells has slight effect on containing the pollution in place.

2. The Hypothetical Zone of Study

The hypothetical zone of study is square in shape with dimensions 800m by 800m. It has been divided into a grid of 100.00 cells (100 cells by 100 cells). The studied region covers a phreatic aquifer with 28m total depth. The aquifer is assumed to have four layers. Each layer is homogeneous and isotropic with hydraulic conductivity of 10 m/day and specific yield 0.2 Dispersivity is taken 500 m^2/day without considering sorption and decay. Groundwater flow takes place from the left to the right boundaries under the effect of specified head boundarieswith values 29 and 26 m , respectively. A pollution source is assumed in the first aquifer at the cell of intersection of the row number 41 and the column number 24. The source has concentration of 300 PPM.

3. Description of the Used Model

MT3D is a computer model for simulating a contaminant transport in groundwater system in either two or three dimension. The model uses a mixed Eulerian- Lagrangian approach in the solution of the adjective-dispersive-reactive equation. The model is used in conjuction with the flow one, MODFLOW. Both models are developed by the U. S.

Geological Survey (McDonald and Harbaugh, 1988). They are three-dimensional finite-difference models. MT3D retrieves the hydraulic heads, the velocity distribution, and the various flow sink/source terms saved by the flow model, and employ them to determine

concentration of a single miscible contaminant in groundwater under the effect of the enforced boundary conditions considering advection, dispersion, source/sink mixing, or chemical reactions. The computer program of the MT3D transport model is written in the standard FORTRAN 77 language.

The equation of solute transport in porous medium which is a partial differential one (Bear, 1972 and 1979; and Van Genuchten, 2005) is given as:

$$\frac{\partial}{\partial X_i}\left(D_{ij}\frac{\partial C}{\partial X_j}\right) - \frac{\partial}{\partial X_i}(CV_i) + \frac{q_s}{n}(C - C_s) + \sum_{k=1}^{N} R_K = \frac{\partial C}{\partial t} \qquad (1)$$

Where,

$$V_i = -\frac{K_{ij}}{n}\frac{\partial h}{\partial X_j} \text{i , j = 1 , 2 and 3} \qquad (2)$$

C = C(X, Y, t) = pollutant concentration [M/L^3],

V_i =V_i(X, Y, t) = seepage or average pore water velocity in direction x_i[L/T],

D_{ij}= D_{ij}(X, Y, t)= dispersion coefficient tensor [L^2/T],

n = n (x/y) = effective porosity [L],

K_{ij}= K_{ij}(x/y) = hydraulic conductivity tensor [L/T],

q_s = = Volumetric flux per unit volume representing sources

(positive) and sinks (negatives) [T^{-1}],

C_s = = concentration of the sources / the sinks [ML^{-3}],

x_i = Cartesian coordinates,

t = time[T], and

$\sum_{k=1}^{N} R_K$= adsorption and decay by chemical reaction terms [ML^{-3}L^{-1}],

Then, the components of the tensor, D_{ij} , in a system of three-dimensional Cartesian coordinates are obtained through the transformation of coordinates formula

$$D_{xx} = \alpha_L \frac{V_y^2}{|V|} + \alpha_T \frac{V_x^2}{|V|} + \alpha_T \frac{V_z^2}{|V|} \qquad (3)$$

$$D_{yy} = \alpha_L \frac{V_y^2}{|V|} + \alpha_T \frac{V_x^2}{|V|} + \alpha_T \frac{V_z^2}{|V|} \qquad (4)$$

$$D_{zz} = \alpha_L \frac{V_z^2}{|V|} + \alpha_T \frac{V_x^2}{|V|} + \alpha_T \frac{V_y^2}{|V|} \qquad (5)$$

$$D_{xy} = D_{yx} = (\alpha_L - \alpha_T)\frac{V_x V_y}{|V|} \qquad (6)$$

$$D_{xz} = D_{zx} = (\alpha_L - \alpha_T)\frac{V_x V_z}{|V|} \qquad (7)$$

$$D_{yz} = D_{zy} = (\alpha_L - \alpha_T)\frac{V_y V_z}{|V|} \qquad (8)$$

Where,

α_L = the longitudinal dispersivity [L] ;

α_T = the transverse dispersivity [L] ; and

$$V = (\boldsymbol{V_x^2} + \boldsymbol{V_y^2} + \boldsymbol{V_z^2})^2$$

Vx , Vy and Vz are the components of the velocity vector along X, Y, and Z .

4. Injection Wells

Injection wells have been studied considering the effect of the injection rate, the screen length , and the number of wells on a contaminant spread.

a. Injection Rate

Four injection wells feeding clean water into the groundwater reservoir are assumed around the pollution source. The wells screen is fully penetrating the four layers of the aquifer. The injection rate is taken 600 m^3/day for each well. The resulting equipotential lines and the concentration lines in PPM are presented in Figure (I). It is shown that the pollution spread is contained in a limited zone between the wells due to the effect of the clean water injected by the four surrounding wells. The diameter of spread circle is about 100 m when the injection rate is reduced to 300 m^3/day, more spread of the pollution takes place in the aquifer as shown in Figure (2). Diameter of the resulting spread zone around the pollution source increases to reach about 350 m.

b. Layer of Screen

The case of having wells with injection rate 300 m^3/day has been repeated with a screen length of only 10 m penetrating the lowest layer of the aquifer. Figure (3) shows the results in the form of equi-concentration lines of the pollutant, in the first layer. Slight increase in the concentration can be noticed when comparing the results with the ones shown in Figure (2). This slight increase is related to having the injection screen away in the fourth layer.

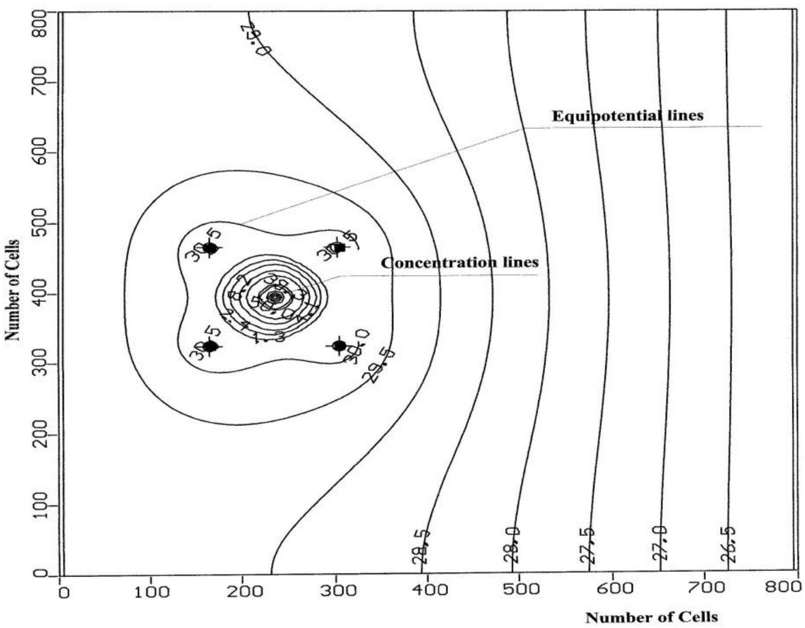

Figure (1): Concentration lines in plan view having four injection wells of clean water with rate 700 m^3/day

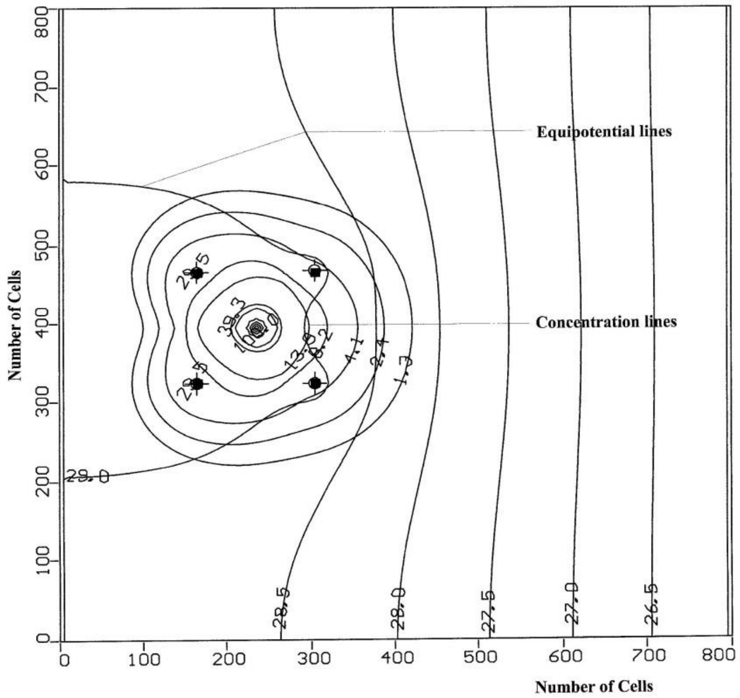

Figure (2) Concentration in plan having four recharging wells of clean water with rate 350 m3/day

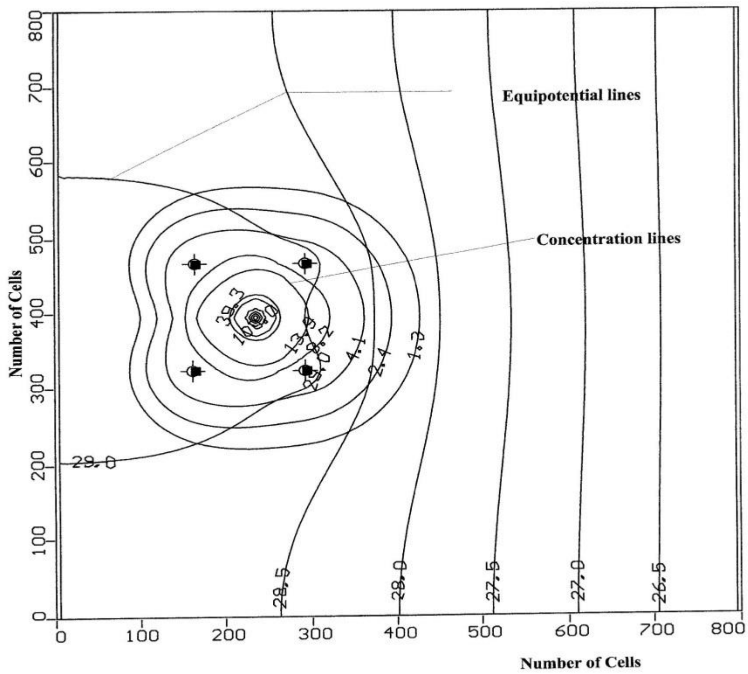

Figure (3): Concentration in plan having four injection wells of clean water with rate 350 m3/day and screen in the lower 10 m of the well

c. Effect of the Number of Injection Wells

When the number of the injection wells has been reduced to be two upstream once, more pollution spread has taken place downstream the contaminant source as shown in Figure (4). The increase of the pollution zone is noticed when it is compared with the corresponding one in Figure (2) that has the same conditions but only with four injection wells.

5. Pumping Wells as Interceptors

Investigation of hydraulics of a contaminant withdrawal by pumping wells as interceptors is performed and discussed in the following section. The studied hydraulic characteristics include the pumping rate, the depth and the number of wells.

a. Pumping Rate

Four pumping wells are assumed around the pollution source to keep the contaminant in place and prevent its spread through the aquifer. The wells are assumed having screens which are fully penetrating the aquifer with pumping rate of 600 m^3/day. The resulting equipotential lines and the equi-concentration lines in PMM are presented in Figure (5). it is shown that the polluted zone is contained between the four wells. When the pumping rate is reduced to 300 m^3/day, the wells has become not capable, any more, of preventing spread of the pollution zone which has extended outside the wells as shown in Figure (6).

b. Well Depth

The case of having wells of pumping rate 300 m^3/day has been repeated with a screen length of 10 m that penetrates only the lower part of the aquifer. The corresponding concentration in the first layer is shown in Figure (7). The Figure shows more pollution (compared with the results of the fully penetrating wells shown in Figure (6)) is taking place in the first layer because the discharging screen is far in the lowest (fourth) layer.

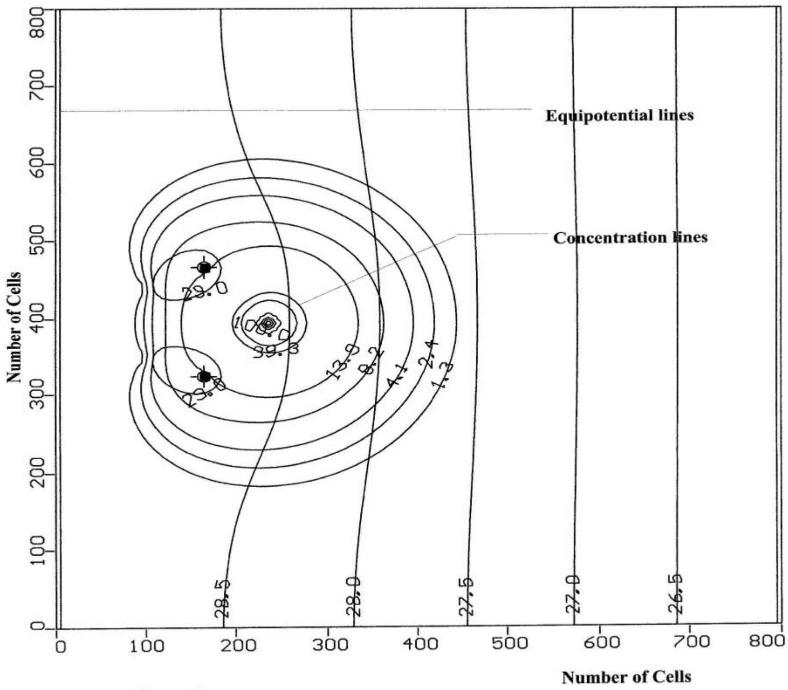

Figure (4): Concentration in plan view having two injection wells of clean water with rate 350 m^3/day

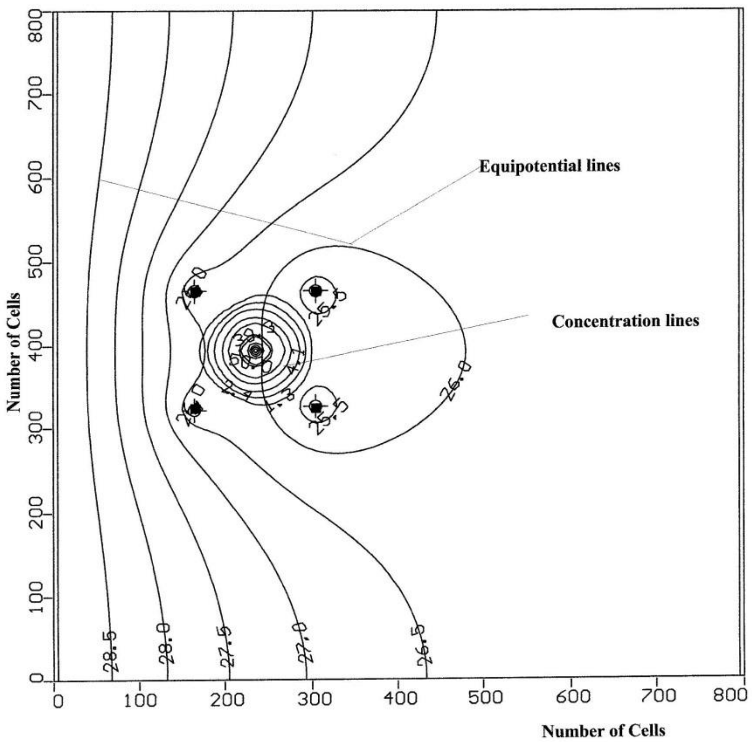

Figure (5): Concentration in plan view having four pumping with rate 700 m^3/day

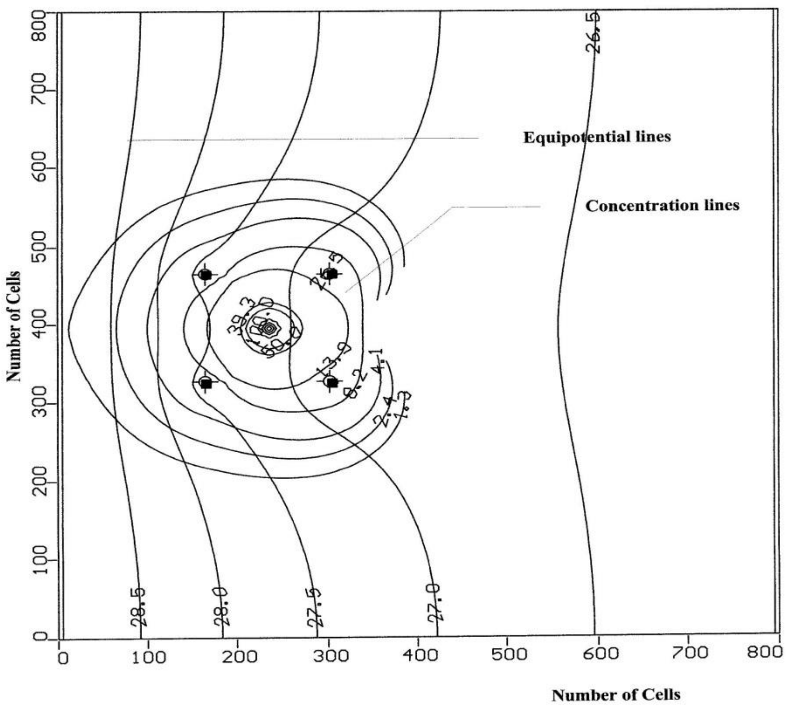

Figure (6): Concentration in plan view having four pumping with rate 350 m^3/day

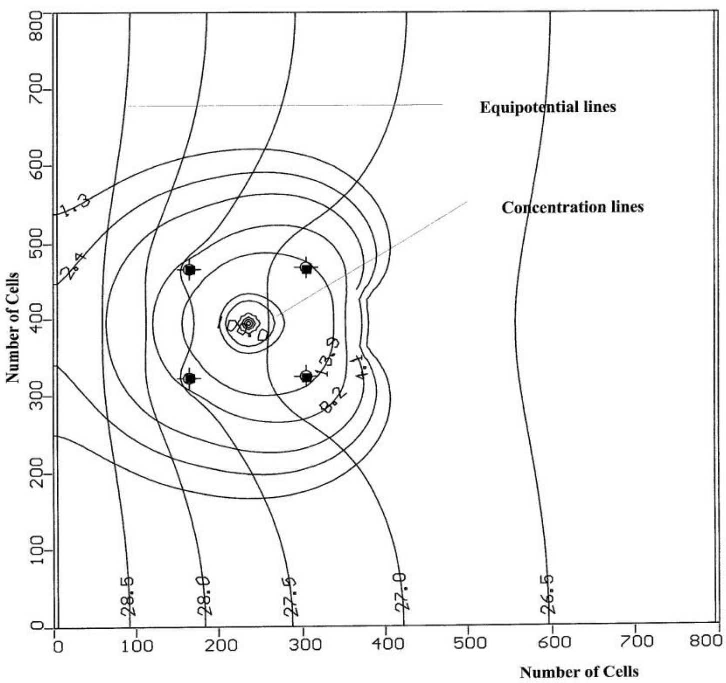

Figure (7): Concentration in plan having four pumping wells with rate 350 m^3/day and screen in the lower 10 m of the well

c. Number Wells

The number of discharging wells are reduced to two downstream one: in Figure (8) and then to one well in Figure (9) .Results show increase in the pollution Spread on comparing with the results shown in Figure (6) .

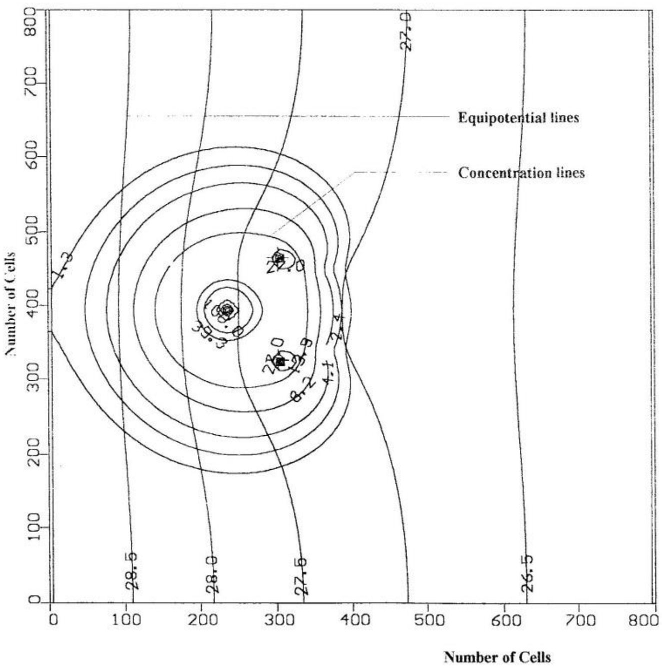

Figure (8): Concentration lines in a plan view having two pumping wells with rate 350 m^3/day

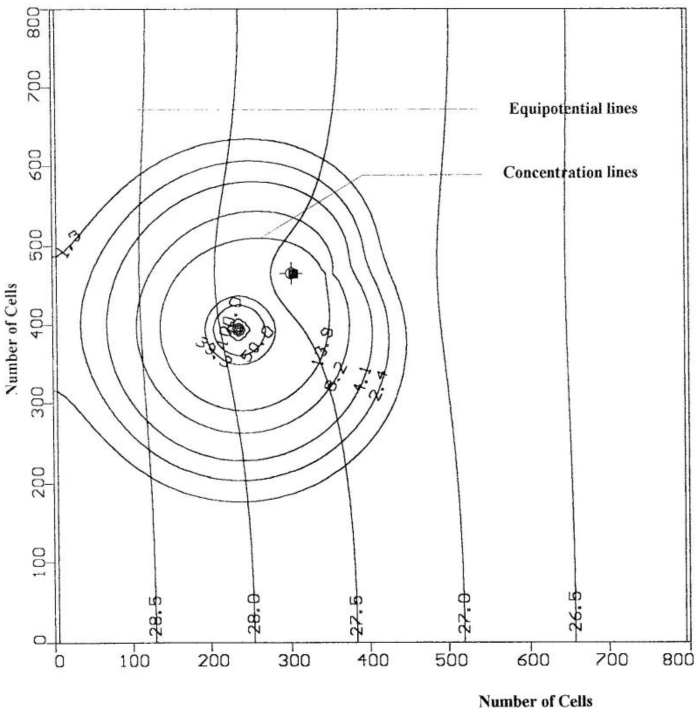

Figure (8): Concentration lines in a plan view having one pumping wells with rate 350 m^3/day

6. Conclusion

The current study helps in understanding the hydraulic behavior of the hydrodynamic Containment of a contaminant in groundwater for the sake of achieving successful design of controlling systems .The main findings of the study includes the following points **:**

1.Hydrodynamic control of the pollution spread by using injection or pumping wells is an effective method.

2. Decreasing the rate or the number of the injection wells/pumping wells permits more pollution spread.

3. Changing the screen length of the injection well is not effective in preventing the pollution spread in the long term concern.

4. The effect of changing the screen length of the pumping wells on the pollution spread is more than that of injection ones.

5.Changing the number of the pumping wells has more effect on a contaminant spread

More than the case of injection wells.

6. The present investigation attracts the attention of the decision makers to the main

factors that should be considered in the design of real applications. it is clear that the injection/pumping rates as well as the number of wells should be studied well in each specific site for designing a successful hydrodynamic system .

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