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APPLIED STUDY OF ARTIFICIAL RECHARGE OF GROUND WATER ON BENGHAZI'S VALLEY

دراسة تطبيقية علي التغذية الصناعية للمياه الجوفية (وادي بنغازي)

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ملخص

إن عملية التغذية الصناعية للمياه الجوفية هي إحدى الحلول المهمة للحفاظ على المياه الزائدة في مناطق معينة في الجماهيرية الليبية وبالتالي حسن إدارة هذه المياه خلال المواسم المختلفة. و في هذا البحث تم استخدام طريقة الفروق المتناهية لحل المعادلات التفاضلية لحركة المياه الجوفية تحت أحواض التغذية وحساب قيم ارتفاع مناسيب المياه. كذلك تم تطبيق النموذج الرياضي المعد على منطقة مختارة من الجماهيرية (وادي بنغازي) و دراسة شكل المرتفع المائي (النتوء المحدب) تحت حوض التغذية مع تغيير بعض القيم الهيدرولوجية. و قد لوحظ ان معدل الترشيح ومساحة حوض التغذية هما عاملان مهمان في تحديد شكل المرتفع المائي و كذلك معامل التخزين الذي له تأثير كبير حيث أنه يمثل مقياس لكمية الماء المخزون في المكمن المائي المحصور. كما أن معامل النفاذية يتناسب عكسيا مع المرتفع المائي ومنها يمكن تحديد إمكانية استخدام المكمن في التغذية الصناعية.

ABSTRACT

The artificial recharge of ground water is an important solution to store the excess water and manage it by applying good methods. The finite difference method was used to solve the differential equations of the ground water flow and to find the water levels under the recharge basin. The mathematical model was applied on Banghazi's Valley and the water mound was studied under different hydrological conditions. It was clear that the recharge rate and basin area were considered two important factors to form water mound. Also, storage coefficient represented the quantity of storage ground water in the confined aquifers. The permeability of the aquifer confined the ability to use the aquifer for storing water.

INTRODUCTION

Rain is an important water source in some areas of Libya Gamaheriya so. one of the suitable methods to use it. is the recharging process for ground water. Because of the high water consumption in the different uses. the discharge from the ground water aquifers was noticed to be increased by large rates. In Trapulse region. through the period from 1960 to 1990. there was a severe depression in ground water levels about 5.0 ms. As a result of that. the intrusion of sea water was increased and caused a high concentration rate of salt water (7000 part in million) which represented a very high rate compared with the permissible international rate. So. it is important to find the solutions to balance the use of the ground water. One of these solutions is the artificial ground water recharge which has many useful purposes. to reduce the depression of ground water levels, besides improving the quality of the storage ground water and thus to manage the surface water from season to another.

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The main objective of this research is to investigate the hydrological changes that occurred to the ground water levels in an artificial recharge site in one of Gamahirya regions "Benghâzi's Valley". Also, the present research includes a construction of a mathematical model leading towards analytical solutions for the artificial ground water recharge.

ARTIFICIAL GROUND WATER RECHARGE

The artificial recharge of ground water started in nineteen century, then it was developed in this century especially in Holland, Sewed, Germany, France, USA and other countries. The water networks in many cities greatly depend on different techniques to recharge the ground water, which supply these networks by water used in many purposes. The artificial recharging of ground water is the operation to increase the seepage and the natural infiltration of rainfall or the surface run-off through soil layers and keeps the ground water in suitable aquifers.

The most important arms of the artificial ground water recharge are summarized as follows: -

- Increase the storage capacity of ground water,
- Stop or decrease the increasing depression on ground water levels,
- Store the excess run-off from rainfall, floods and excess water from rivers and torrents,
- Protect the ground water aquifers from the intrusion action of the sea water by rising the ground water table, then the interface between the salt-water and fresh water depression,
- Avoid or stop the soil collapse,
- Use the recharge basins as natural filters to treat the reused water, and
- Keep the ground water as an economic source without any depression in the quality and the quantity.

The rainfall is usually the main source to recharge the ground water, but if there is no rainfall in the region, we can get the surface water from other areas through pipelines or open channels. Sometimes, the wastewater can be used again after a good treatment to be suitable for recharging ground water.

There are many methods used to recharge the ground water but the famous methods are, 1- Water-Spreading including several methods as, recharge-basin method, stream-channel method, furrow method, flooding method and digging method,

2- Injection well methods.

THEORETICAL APPROACH

The finite difference method was used as one of the numerical methods to solve the two-dimensional flow through soil and to calculate the water head at the choosing points for the non-homogenous aquifer having an irregular boundary.

To find the head from the finite difference grid for a homogenous, isotropic, unconfined aquifer, the following equations were used; (see Fig.(1) and Fig.(2)).

In (x) direction: -

$$T\left[\frac{h_{i+1,j}^{t+\frac{\Delta t}{2}}-2h_{i,j}^{t+\frac{\Delta t}{2}}+h_{i-1,j}^{t+\frac{\Delta t}{2}}}{(\Delta y)^2}\right]+T\left[\frac{h_{i,j+1}^{t}-2h_{i,j}^{t}+h_{i,j-1}^{t}}{(\Delta x)^2}\right]=\frac{S}{\left(\frac{\Delta t}{2}\right)}\left[h_{i,j}^{t+\frac{\Delta t}{2}}-h_{i,j}^{t}\right] \quad (1)$$

In (y) direction:-

$$T\left[\frac{h_{i+1,j}^{t+\frac{\Delta t}{2}}-2h_{i,j}^{t+\frac{\Delta t}{2}}+h_{i-1,j}^{t+\frac{\Delta t}{2}}}{(\Delta y)^2}\right]+T\left[\frac{h_{i,j+1}^{t+\Delta t}-2h_{i,j}^{t+\Delta t}+h_{i,j-1}^{t+\Delta t}}{(\Delta x)^2}\right]=\frac{S}{\left(\frac{\Delta t}{2}\right)}\left[h_{i,j}^{t+\Delta t}-h_{i,j}^{t+\frac{\Delta t}{2}}\right] \quad (2)$$

in which:

S: is the aquifer storage coefficient,

T: is the transmissivity, and

h: is the water head.

For non-homogenous aquifer, one can't apply a steady flow exactly but try to use some methods to calculate the drawdown at any point. In general case of two-dimensional flow, it was considered that, the hydrologic conductivity (K), storage coefficient (S) and the recharge sources were constants for the grid of constant distances (dx = dy). At any time (t) every grid has a different values of recharge sources.

In the case of unconfined aquifer the non-linear equations were converted to linear equation by assuming a constant aquifer thickness with variable time. The horizontal bottom of the aquifer was taken as a datum, see Fig.(3). so. at datum h = b. where b is the saturated thickness of aquifer between any two points.

Refer to Fig.(3), the discharge ($q_{i-1/2,j}$) was calculated in (i) direction from point (i-1 , j) to point (i , j) using Darcy's equation, as follows:

$$q_{i-\frac{1}{2},j} = K_{i-1,j}\,\Delta x_{i-1,j}\,b'_{i-\frac{1}{2},j}\,\frac{\left[h_{i-1,j} - h_{i-\frac{1}{2},j}\right]^{t+\Delta t}}{\frac{\Delta y_{i-1,j}}{2}} \qquad (3)$$

and,

$$q_{i-\frac{1}{2},j} = K_{i,j}\,\Delta x_{i,j}\,b'_{i-\frac{1}{2},j}\,\frac{\left[h_{i-\frac{1}{2},j} - h_{i,j}\right]^{t+\Delta t}}{\frac{\Delta y_{i,j}}{2}} \qquad (4)$$

by solving eq.(3) and eq.(4) to find h, then:

$$\therefore Q_{i-\frac{1}{2},j} = \left\{\frac{\Delta y_{i,j}}{2K_{i,j}\,\Delta x_{i,j}\,b'_{i-\frac{1}{2},j}} + \frac{\Delta y_{i-1,j}}{2K_{i-1,j}\,\Delta x_{i-1,j}\,b'_{i-\frac{1}{2},j}}\right\}^{-1}\left(h_{i-1,j} - h_{i,j}\right)^{t+\Delta t} \qquad (5)$$

which can be written as,

$$Q_{i-\frac{1}{2},j} = C'_{i,j}\left(h_{i-1,j} - h_{i,j}\right)^{t+\Delta t} \qquad (6)$$

Also:

$$Q_{i+\frac{1}{2},j} = D'_{i,j}\left(h_{i,j} - h_{i-1,j}\right)^{t+\Delta t} \qquad (7)$$

Consequently. the flow equations in i direction can be written as follow.

$$Q_{i,j-\frac{1}{2}} = A'_{i,j}\left(h_{i,j-1} - h_{i,j}\right)^{t+\Delta t} \qquad (8)$$

$$Q_{i,j+\frac{1}{2}} = B'_{i,j}\left(h_{i,j} - h_{i,j-1}\right)^{t+\Delta t} \qquad (9)$$

where

$$C^t_{i,j} = \left[\frac{\Delta y_{i,j}}{2K_{i,j}\,\Delta x_{i,j}\,b^t_{i-\frac{1}{2},j}} + \frac{\Delta y_{i-1,j}}{2K_{i-1,j}\,\Delta x_{i-1,j}\,b^t_{i-\frac{1}{2},j}} \right]^{-1} \quad (10)$$

$$D^t_{i,j} = \left[\frac{\Delta y_{i,j}}{2K_{i,j}\,\Delta x_{i,j}\,b^t_{i+\frac{1}{2},j}} + \frac{\Delta y_{i+1,j}}{2K_{i+1,j}\,\Delta x_{i+1,j}\,b^t_{i+\frac{1}{2},j}} \right]^{-1} \quad (11)$$

$$A^t_{i,j} = \left[\frac{\Delta x_{i,j}}{2K_{i,j}\,\Delta y_{i,j}\,b^t_{i,j-\frac{1}{2}}} + \frac{\Delta x_{i,j-1}}{2K_{i,j-1}\,\Delta y_{i,j-1}\,b^t_{i,j-\frac{1}{2}}} \right]^{-1} \quad (12)$$

$$B^t_{i,j} = \left[\frac{\Delta x_{i,j}}{2K_{i,j}\,\Delta y_{i,j}\,b^t_{i,j+\frac{1}{2}}} + \frac{\Delta x_{i,j+1}}{2K_{i,j+1}\,\Delta y_{i,j+1}\,b^t_{i,j+\frac{1}{2}}} \right]^{-1} \quad (13)$$

Then the change rate in volume of storage ground water at point (i, j) can be expressed as follows:

$$\frac{\Delta V_{i,j}}{\Delta t} = S_{i,j}\,\Delta x_{i,j}\,\Delta y_{i,j} \left[\frac{h^{t+\Delta t}_{i,j} - h^t_{i,j}}{\Delta t} \right] \quad (14)$$

or

$$\frac{\Delta V_{i,j}}{\Delta t} = E^t_{i,j} \left[\frac{h^{t+\Delta t}_{i,j} - h^t_{i,j}}{\Delta t} \right] \quad (15)$$

where $Q^t_{i,j}$ is the external recharge source of ground water.

By Appling the principle of mass equilibrium at point (i, j)

The summation of inflow = the summation of outflow

$$A^t_{i,j} h^{t+\Delta t}_{i,j-1} + B^t_{i,j} h^{t+\Delta t}_{i,j+1} + C^t_{i,j} h^{t+\Delta t}_{i-1,j} + D^t_{i,j} h^{t+\Delta t}_{i+1,j} - (A_{i,j} + B_{i,j} + C_{i,j} + D_{i,j} + E_{i,j})^t h^{t+\Delta t}_{i,j} = Q^t_{i,j} - E^t_{i,j} h^t_{i,j} \quad (16)$$

and in a matrix form

$$[COEF]^t \; [h]^{t+\Delta t} = [Q - E\,h]^t \qquad (17)$$

For the confined aquifer, the value of $b'_{i,j-\frac{1}{2}}$ is considered constant with changing of time and for the unconfined aquifer; this value equals the layer thickness at the beginning of pumping.

By applying the initial conditions for the grid,

No. of equations = No. of unknowns = (NR – 2) x (NC – 2)

In which:

NR: number of rows in the matrix, and

NC: number of columns in the matrix.

Then, the matrix was formed and solved to find the drawdown at any point.

A computer programming (Fortran 88) was prepared using the finite difference method to analyze the ground water flow through the aquifer (Study model). The program was used to calculate the ground water levels under the different natural and artificial hydrological changes. The Flow chart for program that named GRWATER is shown in Fig. (4).

DESCRIPTION OF THE BENGHAZI'S VALLEY

The ground water is the main source in this region in addition to a little amount of treatment of seawater. The rainfall ranges from 100 to 500 mm/year (El-Gabal El-Akdar). This rain is still little and there are several dams used to collect it and to protect many regions from floods through down the mountain. In this region, sometimes rain cause a run-off of 10 to 20 mm that helped in recharging the ground water but the useful quantity depends on many factors like, texture and natural of surface layer, topography, grass, soil type, ground slope, ...etc. Because of the big amount of losses due to evaporation (about 2.0 m/year) so, it is recommended to save water by recharging it to the ground water aquifer by constructing small basins in high drainage areas to flow the water through valleys during the periods of rains.

There were three regions which were considered as water sources in the study area, the first is **Benghazi's Valley**; which was partially recharged from rains of Marg and El-Abyar and also from drainage water of Katera Valley after filtration. The second is located at **North Benghazi's Valley**; it extends from Seedy Kalefa in the north and it was provided by the infiltrated water from the top of the hill and the drainage flow inside the valley. The third is the **South Benghazi's Valley (Silloq Valley)**; it was recharged by infiltration and flowing drainage water from Wadi El-Ahmar and Wadi El-Bab.

Generally, much hydrological information like rains, evaporation, run-off, infiltration, water consumption, ...etc., for these valleys were collected from Soil and Water Company and some reports were established by hydrologic consultants. The collected information of Benghazi's Valleys and the surrounded regions that in share in providing water, gave initial predictions of the water sources and the effect of increasing ground water discharge. The region is considered semi-dry and the average annual rainfall from 150 mm/year at Saluq to about 500 mm/year at El-Gabal El-Akdar and excess rainfall in winter from 18 mm to 85 mm in Marg.

The permeability of the ground water aquifer (k) in Benghazi's Valley ranges from $1.5 * 10^{-5}$ to $16 * 10^{-3}$ m/sec., the storage coefficient (S) ranges from $4.4 * 10^{-3}$ to $4.6 * 10^{-3}$ and the specific yield of wells ranges between 0.1 to 100 lit/sec. There are about 900 wells in Benghazi's valley, 320 wells were constructed manually to be used for some small farms and the remain wells were constructed by many technical methods to face the excess needs for irrigation, industry and drinking needs.

MATHEMATICAL MODELING: -

Since the hydrological parameters have a wide range of values. The data analysis became essential to show the effect of the hydrological input parameters on the modeling results. The following parameters were used for the sensitivity analysis:

- The recharge rate (q) ranged from 0.50 to 1.50 ft/day
- Area of recharge basin (a) ranged from 100 to 10000 ft^2
- Permeability (K) ranged from 22.55 to 2255 ft/day
- Storage Coefficient (S) ranged from 0.0001 to 0.10

A mathematical model was developed to simulate the water mound due to recharge in a 2-D ground water flow system. The model solved the ground water problem using the finite difference approximation and the corresponding algebraic equations were solved using iteration method. Water table elevations underneath the recharge basin due to recharging were calculated and incorporated in the mathematical model. Water table elevations (water mound) underneath recharge basin were shown in figures (5) to (9), and they were drawn versus the distance which was measured from center of recharge basin to a distance of 50.0 ft.

Figure (5) shows the relationship between the water levels and the distance due to time increment of 2, 4, 6, 8 and 10 days. Also, Fig.(6) shows an example of an isometric projection of water table elevations underneath the recharge basin. For three values of storage coefficient (S) of 0.00010, 0.0010 and 0.10, Fig.(7) was drawn and showed the effect of this factor on the water table elevations. Also, the values of the other variables were taken as following: The area of recharge basin (a) of 100, 1000, 10000 ft^2, the permeability (K) of 22.55, 2255 ft/day and the recharge rate (q) of 0.50, 1.00 and 1.50 ft/day; Also, the relationships between the water levels and the distance for the mentioned values were drawn in figures (8 , 9 and 10).

CONCLUSIONS AND RECOMMENDATIONS: -

Sometimes, it is very useful to use the artificial recharge as a good method to storage and manage the ground water. Water table elevations underneath the recharge basin due to the artificial recharge in a chosen area in Benghazi's Valley, were simulated using the ground water mathematical model prepared herein to represent the 2-D flow system and the following conclusions could be introduced: -

1-The mathematical model can be used to give a good primary indication about the possibility to use the ground water aquifer in the artificial recharging.

2-This mathematical model can be used for many different wide ranges of boundary hydrological conditions. It can be applied on non-homogenous aquifers and also, in studying the field artificial recharge in large ground water aquifers.

3- It was noticed that, if the water mound level underneath the recharge basin was high, the ground water aquifer was considered unfavorable for recharging.

4- From the drawn figures it was clear that :

I- The recharge rate and basin area were considered two important factors in the formation of water mound. The increasing of basin area, the flatter slope of water mound was taken into consideration too. Also, the

- increasing of the recharge rate leaded to a big slope of water mound underneath the recharge basin had pronounced effect. So, it is better to choose a recharge basin, which has a moderate area to give suitable slope and ground water levels within reach.

II- The storage coefficient caused a big effect in the formation of water mound underneath the recharge basin and it represented the quantity of storage ground water in the confined aquifers.

III- The permeability of the aquifer was inversely proportional to the water table elevations. So, a high permeability of aquifer caused a lower water mound. On the contrary, if the aquifer has a low permeability, it will be unsuitable for recharging as the water holding capacity is relatively high.

It is recommended to use the mathematical model to choose the suitable sites for artificial recharge of ground water because it is easy to input different values and ranges of hydrological variables for many ground water aquifers. Also, the accurate field measurements are required to give a good simulation. It is also fruitful to simplify the mathematical model to be used in many water management projects.

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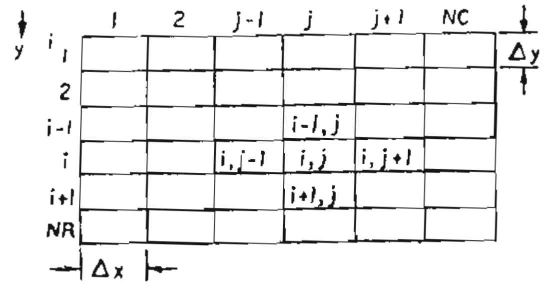

Fig. (1) Finite Difference Network for Unconfined Aquifer.

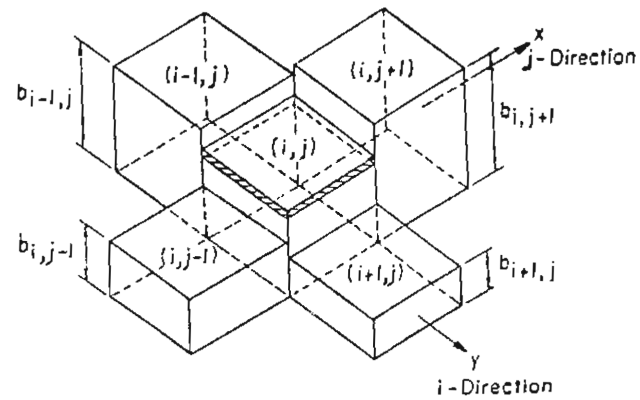

Fig. (2) Finite Difference Network in Two-Dimensional Flow (Eckhardt and Sunada, 1975).

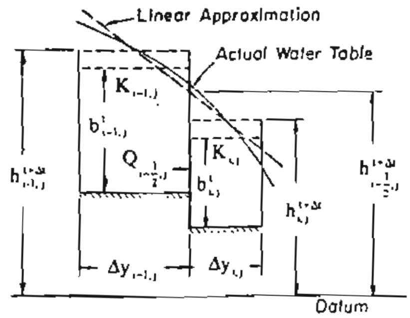

Fig. (3) The transition Between Nodes in the Network.

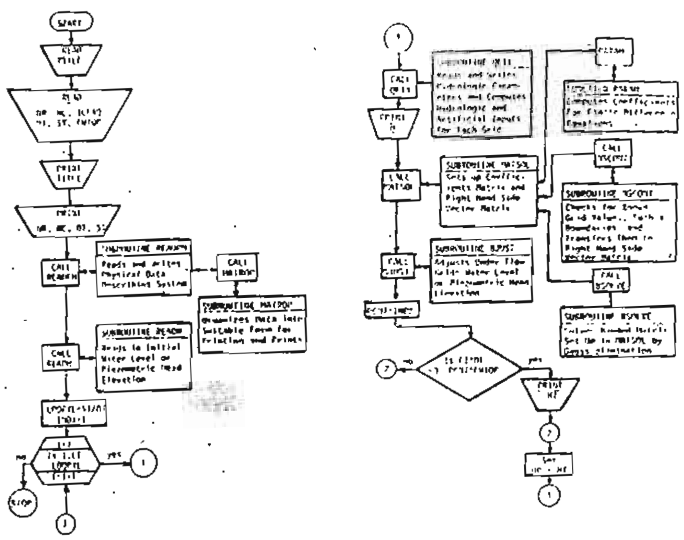

Fig. (4) Flow Chart for Program GRWATER.

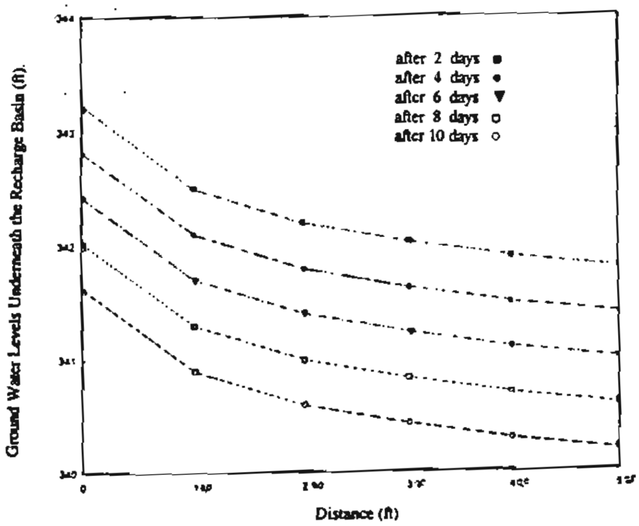

Fig. (5) Water Levels Underneath the Basin During Different Intervals

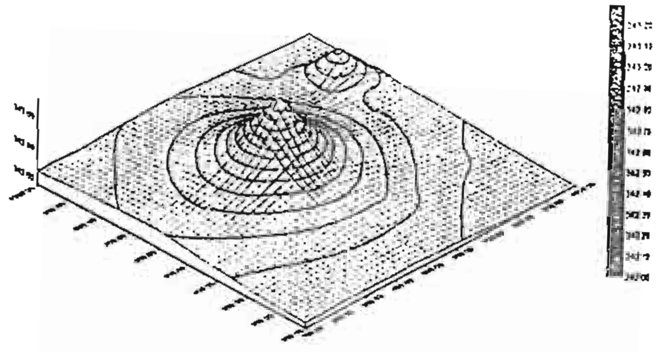

Fig. (6) Isometry of Water Mound Underneath the Recharge Basin.

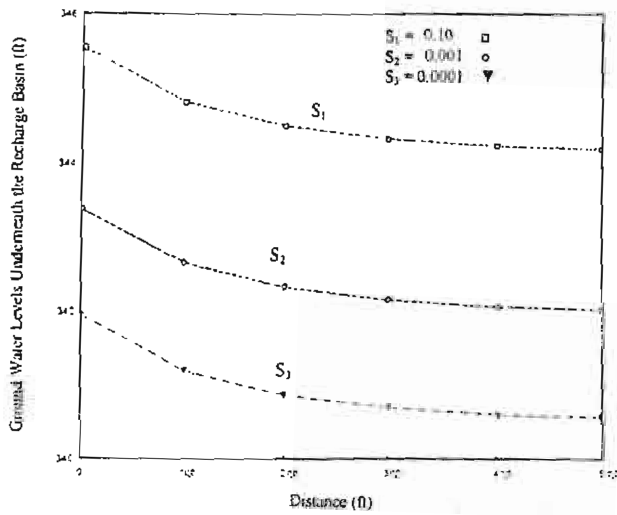

Fig (7) Effect of Storage Coefficient on the Water Levels Underneath the Basin.

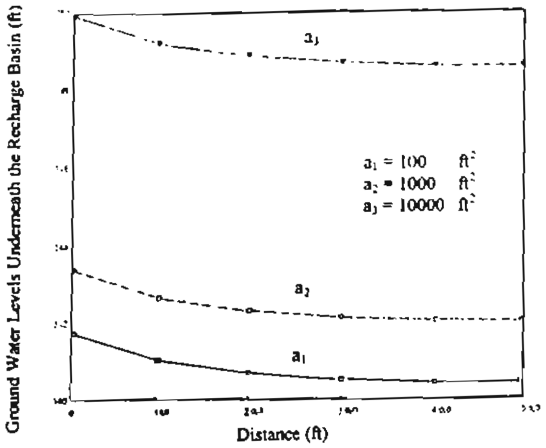

Fig (8) Effect of Recharge Basin Area on the Water Levels Underneath the Basin

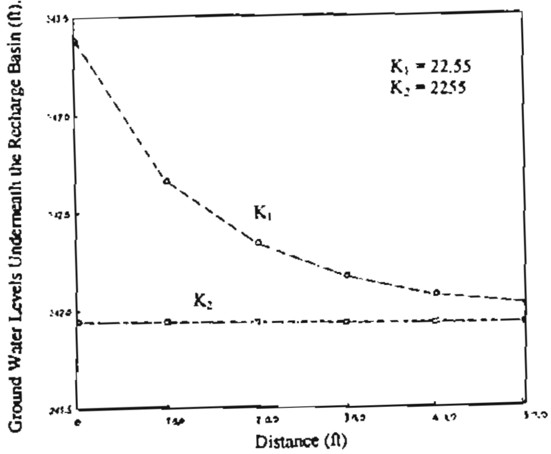

Fig. (9) Effect of Permeability on the Water Levels Underneath the Basin.

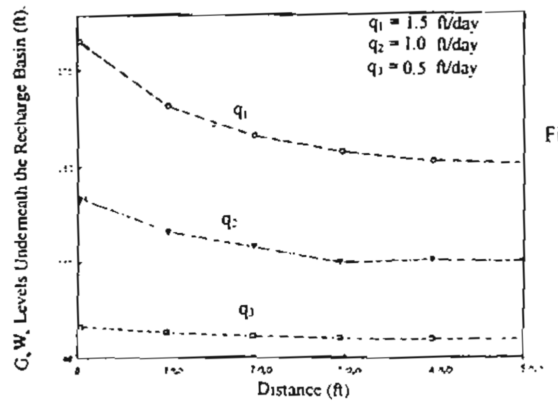

Fig. (10) Effect of Recharge Rate on the Water Levels Underneath the Basin.