A COST EFFECTIVE DESIGN OF A MULTIPLE WELL SYSTEM FOR USE IN THE WADI EL-NATRUN AREA

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ABSTRACT

Huge losses in the groundwater resources in the Wadi-El-Natrun depression are occurring due to the evaporation from lakes and evapotranspiration from vegetation cover and the high water table near the lakes. The use of a multiple well system would intercept the inflow towards the lakes. This scheme would lower the water level in the lakes and the adjacent areas. A cost effective study procedure has been developed in order to find out the optimum well number, capacity and spacing of the well system at Wadi El-Natrun area.

NOTATION

CR total annual cost of individual capital investments.
CRF capital recovery factor.
hw water depth in the well.
H_o original water depth in the aquifer.
i interest rate per year.
I slope of a crossflow
I_c well casing cost.
I_d well drilling cost.
I_{ds} distribution cost.
I_m mobilization cost.
I_n investment cost of an equipment.
I_s well screening cost.
I_w water supply cost.
K coefficient of permeability.
ne economic life of an equipment in years.
Q well discharge.
r_w well radius.
TDH total dynamic head.

INTRODUCTION

The Wadi-El Natrun depression receiving special attention from Water Development Agencies because of its potential as a groundwater resource [9] and [3]. Referring to the piezometric map of the West Delta area (see Figure (1)) and according to [2], [9], and [4], it can be concluded that the groundwater in Wadi El-Natrun is fed mainly from seepage of the Nile Delta and West Nubaria *area. The hydraulic gradient of the crossflow* towards the depression is about 2.5 m/km. The reason for the local *steep gradient of the water table is mainly due to* the high rate of evaporation from El-Natrun lakes which act as a natural discharging area.

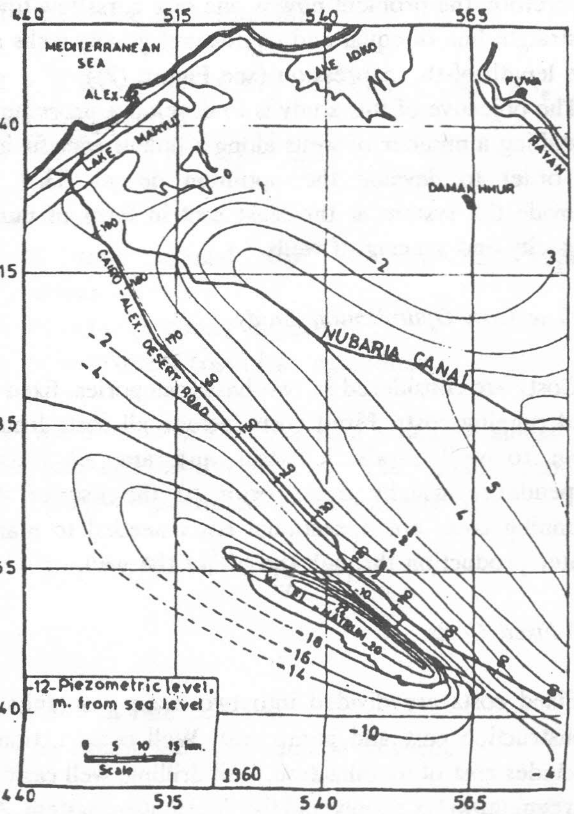

Figure 1. Piezometric map for the West Delta aquifer (after the Author (4)).

According to [4], the estimated losses in the groundwater resources in Wadi El-Natrun due to evaporation from lakes and evaporation from vegetation cover and the high water table level near the lakes are about 59 x10^6 m^3 / year. This leads to be consideration of the proposal to lower the water table level by pumping from deep wells in order to reduce the losses from the groundwater resources. Lowering the water table in this way provides additional quantities of groundwater, which can be used for reclaiming new areas in and around the depression. Furthermore, it will help to keep the salts away from the ground surface and the root zone in the lowlands of the depression and, accordingly, improve the soil quality and crop production. Since the salinity of the groundwater near the lakes is high [5], it will appropriate to drill the well system in the northeastern part of the depression and parallel to the Cairo-Alexandria road.

Since Wadi El-Natrun is more or less oblong in shape, its length being normal to the direction of flow (Fig 1), a reasonable way of arranging the wells is to use a straight row of equally spaced deep wells all placed along the depression length normal to the direction of the crossflow. Therefore, the problem now is one of a corssflow towards a straight line of equal and equidistant gravity wells along the length of the depression (see Figure (2)).

The objective of this study is to develop a procedure for installing a number of wells along a line of specific length in order to develop the optimum design. That is to provide the system at the least cost in term of number, capacity and spacing of wells.

2. *The Cost Optimization Study*

Costs are considered in two basic categories, fixed costs and running costs. Fixed costs include all costs from test hole to well production test and are all a capital expenditure usually made prior to the use of water. Running costs are operational costs needed to maintain water production through the life of the well.

2.1 Fixed Costs

Fixed costs are divided into two main cost units, well construction cost and pump cost. Well construction cost includes cost of mobilization, well drilling, well casing and screening, water supply and the distribution system. Actual cost estimates for actual cases can be obtained only from well drillers and pump suppliers. REGWA (General Company for Research and Ground Water) drilled many wells in Wadi El-Natrun. Therefore, their prices for drilling water wells are taken as guides in this study [7]. However, the prices used in the present study are not to be taken as absolute figures, they are merely indicative of the parameters to be considered in such an analysis.

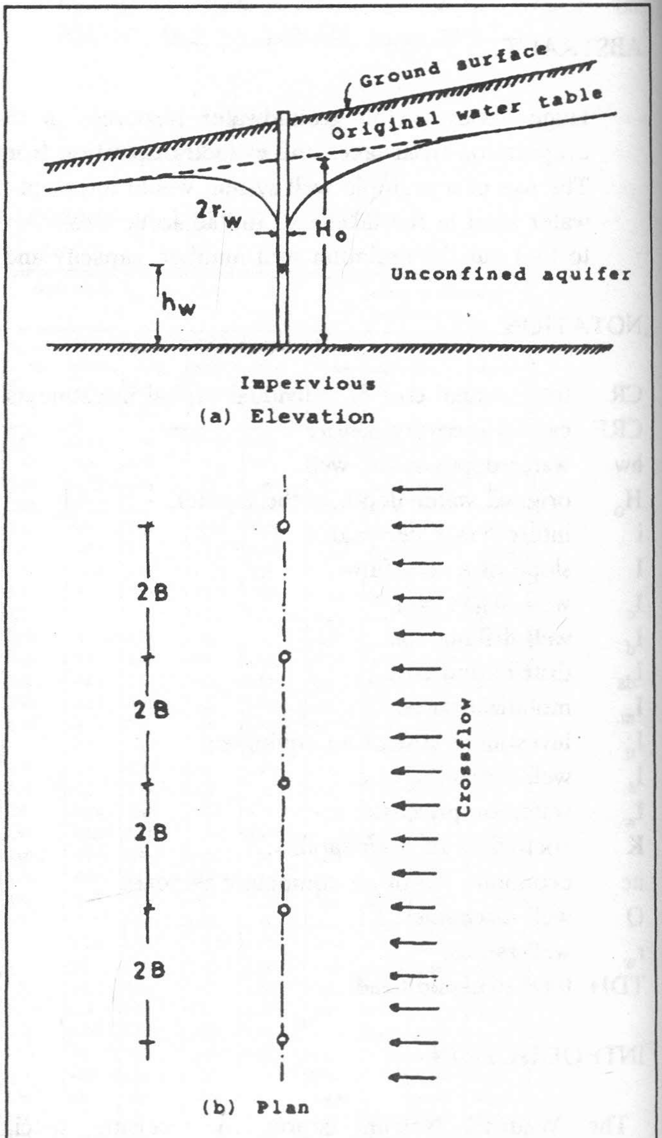

Figure 2. Crossflow towards a straight line of fully penetrating gravity wells.

a. Mobilization

Mobilization costs for drilling wells at a site depend on the drilling equipment, the number of wells and the site accessibility. The following relationship is suggested to estimate the mobilization cost for drilling the well system in Wadi El-Natrun:

$$I_m = 1000 [1 + 0.3 (n-1)] \quad (1)$$

I_m = mobilization costs in Egyptian pounds (L.E.)
n = number of wells in the site (n > 1)

b. Well Drilling

The well drilling cost, I_d, depends on the type of drilling equipments, local drilling technique, geological conditions, and depth, size and number of wells. For the purpose of this study the cost of drilling a well is taken to be L.E. 100.0 per meter of the total depth of the well.

c. Well Casing

The well casing cost, I_c includes the supply and installation of the well casing. The investment cost of well casing will be taken to be L.E. 120.0 per meter of the casing length.

d. Well Screening

According to the Author [7], the screen length for Wadi El-Natrun wells can be determined by

$$I_s = 170 Q \quad (2)$$

where:

I_s = screen length in meters
Q = well discharge in m^3/sec.
The investment cost of the well screening is taken to be at about L.E. 140.0 per meter length of the screen.

e. Supply of Water for Drilling

Since water for the drilling operation is rather costly to obtain in the area, a cost of L.E. 500.0 per well is estimated to cover the cost of water supply, I_w.

f. Distribution System

The cost of the distribution system, I_{ds}, is extremely variable and no average cost can be developed. They include costs of pipelines, connections, valves and possibly tanks to store the excess pumped water. Thus, it would not be unreasonable for these costs to average L.E. 5000.0 per well.

g. Pumps

Centrifugal pumps are recommended for use in the well system st Wadi El-Natrun. The expected price on site of such type of pumps, I_p, is about L.E. 30,000 per unit per well. This price includes the costs of well housing, control system, supply and installation of the pump.

2.2 Annual Cost

Cost effective analysis generally involves determining costs over a considerable period of time. Thus, in order to compare two non-uniform series of money disbursements, it is necessary somehow to make them comparable.
Fixed costs are reduced to an annual cost by application of a capital recovery factor. This factor is dependent upon the interest rate applicable and service life of the equipment. Thus, the annual cost of different investment can be estimated as follows [8]:

$$CR = (CRF_1 \times I_1 + CRF_2 \times I_2 + ... + CRF_n \times I_n + 0.03 \sum I_1 + I_2 + ... I_2 \quad (3)$$

where:
CR = total annual cost of individual capital investments.
CRF = capital recovery factory.
I_n = investment cost of an equipment.

3 % of the investment sum has been added for annual tax assessments and insurance costs. The capital recovery factor, CRF, is represented by the formula [1]

$$CRF = i (1 + i)^{ne} / ((1 + i)^{ne} -1) \quad (4)$$

where

i = interest rate per year
ne = economic life of equipment in years.

A reasonable average economical life of 30 years is considered for the well system and an economical life 10 years is assumed for the pump. Since the current rate of interest is about 15 %, the capital recovery factors for the wells and pumps are 0.152 and 0.199 respectively.

2.3 Running Costs

Running costs are all costs associated with the normal operation of the well system. The principle cost units are energy cost, operation cost, maintenance and service costs.

a. Energy Cost

Energy cost is directly proportional to the product of discharge rate, total head and operating time. In Wadi El-Natrun the annual electricity requirement cost for a group of wells is given by [7]

$$EC = 1.44 \; TDH \; Q \qquad (5)$$

EC = annual cost of electricity in pounds.
TDH = total dynamic head in metre.
Q = pump discharge in cubic meter per hour.

b. Maintenance Cost

The maintenance cost of the system includes the maintenance cost of wells and pumps as well as the maintenance cost of the distribution system. Since annual maintenance cost, I_{mc}, is time and use dependent, it would be reasonable for this cost to be 10 % of the total annual cost of both the fixed and running costs.

c. Service cost

Service cost of the well system, I_{sc}, includes costs of administration, labour, paid vacation and other miscellaneous cost. An average value of the annual investment service cost, I_{sc}, is assumed to be about 5 % of the sum annual cost of both fixed and running costs.

3. Application to Wadi El-Natrun Area

For the purpose of this study, the yield of the well system is considered equal to the losses in groundwater resources due to evaporation from both lakes and areas with high water table surrounding the lakes. The well system will be assumed to fully penetrate the aquifer. Referring to the hydrogeological data of the aquifer in the northeastern part of the depression [3], the input data requirements for the cost analysis of the well system can be summarized as follows:

1. The hydraulic conductivity (K) = 10 m/ day
2. The crossflow slope (I) = 2.5 x 10^{-3}
3. Average saturated thickness of the aquifer (H_o) = 40.0 m.
4. Average static head from the ground level to the static level of water = 40.0 m
5. Total depth of well = 80.00 m.
6. Pumping rate of the well system = 59x10^6 m^3/year = 1.87 m^3/sec.
7. Well radius = 30 cm.
8. Total length of the depression = 50.0 Km.

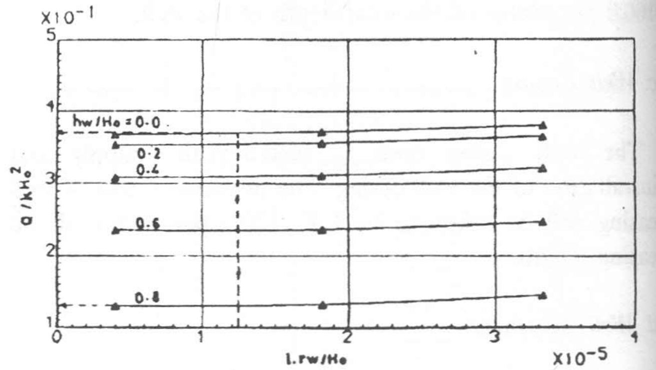

Figure 3. Curves for determining the discharge from a gravity well in a crossflow (after the Author (6)).

3.1 Fixed Cost

Figure (3) shows the relationship between well discharge, Q and crossflow slope, I, for different well drawdown in the well, h_W, as obtained by the Author [6] using the finite element method. The term $I.r_w/H_o$ would amount value of 1.88 x 10^{-5} and for the extreme values of drawdown h_w/Ho = 0.80 and 0.0, the corresponding minimum and maximum discharge from a well will be 0.025 and 0.069 m^3/sec respectively. Thus, the corresponding maximum number of wells will be about 1.87/0.025 ≈ 75 wells, while the minimum number will be 1.87/0.069 ≈ 27 wells. Therefore, the optimum number of well should lie somwhere between 27 and 75 and, accordingly, the wells cost analysis will be carried out for different number of wells (30, 40 50, 60, 70, 75).

Table (1) shows the relationship between well fixed cost analysis steps as encountered earlier in section 2.1. Using Equation (3), the total fixed annual cost of the well system can be obtained as indicated in row 14.

Table 1. Annual fixed cost of the well system*.

Well No. (n)	30	40	50	60	70	75
Q (m^3/sec/well)	0.062	0.047	0.037	0.031	0.027	0.025
H_w (m)	8.0	22.4	26.0	29.2	31.5	32.0
Is (m)	10.5	8.0	6.3	5.25	4.6	4.25
Ic (m)	70.5	73.0	74.7	75.8	76.4	76.8
Im (ponds)	9.7	12.7	15.7	18.7	21.7	23.2
Id (pounds)	240.0	320.0	400.0	480.0	560.0	600.0
Is (pounds)	44.6	44.6	44.6	44.6	44.6	44.6
Ic (pounds)	235.8	350.4	448.2	542.8	641.8	691.2
Iw (pounds)	15.0	20.0	25.0	30.0	35.0	37.5
Ids (pounds)	150.0	200.0	250.0	300.0	350.0	375.0
Wells Construction (pounds)	642.8	853.0	1065.1	1277.0	1488.0	1594
Ip (pounds)	810.0	1080.0	1350.0	1620.0	1890.0	2025
Total annual fixed cost (pounds)	320.5	403.0	503.0	603.4	7004.0	754.0

* Costs in thousands of Egyptian pounds.

Table 2. Total annual cost of the well system*.

Row No.	Wells No. (n)	30	40	50	60	70	75
1	Q (m^3/h/well)	223.2	169.2	133.2	111.6	97.2	90.0
2	TDH(m)	88.0	72.16	68.2	64.7	62.1	61.6
3	EC (pounds)	848.52	703.27	654.07	623.85	608.9	598.8
4	Total annual fixed cost Pounds)	302.5	403.00	503.00	603.40	704.0	754.00
5	Imc + Isc (pounds)	172.9	166.0	173.0	185.0	196.0	202.0
6	Total running cost (pounds) (3) + (5)	1021.1	869	826.5	809.0	804.0	800.0
7	Total annual cost (poinds) (4) + (6)	1324.0	1272.0	1330.0	1412.0	1508.0	1554.

* Costs in thouthands of Egyptian pounds.

3.2 Running Cost

Table (2) contains a summary of the running cost analysis. For clarity, it will be helpful to present the contents of rows 4, 6 and 7 graphically as shown in Figure. (4). Curves A and B represent the annual fixed and running costs respectively, while curve C represents the total annual cost of the well system. It can be seen from curves A and B that the annual fixed cost increases whereas the running cost decreases as the number of wells increases.

Referring to curve C, it may be noted that as the number of wells increases the total annual cost decreases until the cost of adding wells starts to increase. At this points the decreasing cost is reversed and an increase in the total annual cost is obtained. This point gives the minimum costs as shown in Figure (4) and, accordingly, the corresponding economical number of wells is evidently 41 wells. This number corresponds to a well discharge of about 1.87/41 ≈ 0.046 m^3/sec or 166 m^3/h, and water depth in the well of about 23 m as obtained from Figure (3). The corresponding screen length is about 8.0 m. Since the wells are equally spaced the depression length, the corresponding well spacing is about 50,000/41≈1220 m.

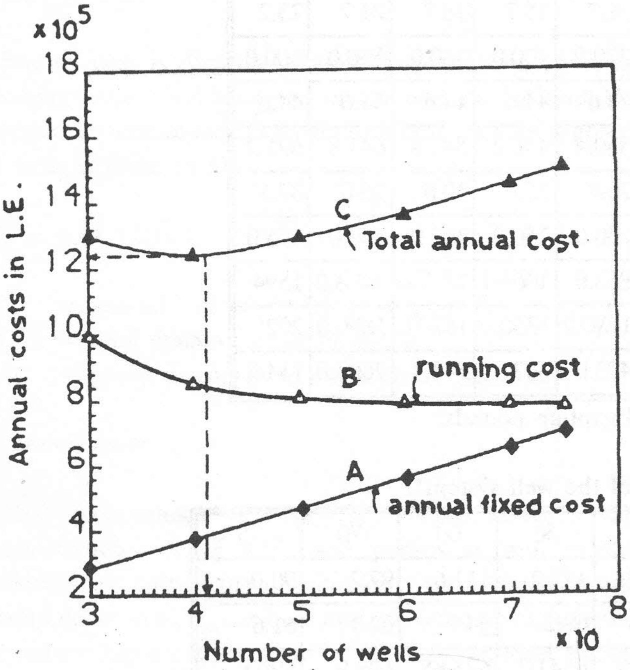

Figure 4. The optium wells number at the Wadi El-Natrun area.

It may be noted from Figure (4) that the corresponding annual fixed and running costs of the optimum number of wells are about 30 % and 70 % of the total annual cost respectively.

CONCLUSIONS

A cost effective study procedure has been developed in order to find out the optimum well number, capacity and spacing of a straight row of equally spaced wells at the Wadi El-Natrun area. Some of the prices used in this study have been based on the actual figures obtained from REGWA. It has been concluded that the annual fixed cost (cost of well construction and pumps) increases as the well number increases, whereas the annual running cost (cost of pumping, maintenance and service) decreases. The optimum well number, based on the minimum total cost of the well system, is found to be 41. The corresponding well capacity, water depth in the well and well spacing are about 166 m^3/h, 23 m and 1220 m respectively.

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