OPTIMAL DESIGN OF WELL POINT SYSTEM FOR DEWATERING

A DISSERTATION

submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the Dissertation entitled " **OPTIMAL DESIGN OF WELL-POINT SYSTEM FOR DEWATERING** " is being submitted in partial fulfillment of the requirements for the award of the Degree of Master of Engineering in Water Resources Development, Indian Institute of Technology, Roorkee , is an authentic record of my own work carried out from July,17, 2001 to December, 2001 under the supervision of Dr. G.C. Mishra, Professor, WRDTC, and Dr. M.L. Kansal, Associate Professor, WRDTC, Indian Institute of Technology, Roorkee.

The matter embodied in this Dissertation has not submitted by me for the award of any other degree.

Dated : December 09, 2001

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This is to certify that the above statements made by the candidate are correct to the best of our knowledge and belief.

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SYNOPSIS

The most important input parameters for selecting and designing a dewatering system are the height of the ground water above the base of excavation and the permeability of the ground surrounding the excavation. Depending upon the capacity of the machine, the manpower and time available the excavation work proceeds at certain rate.

The design of dewatering system starts with estimation of the inflow quantities. In addition to knowing the permeability of the formation, the depth and plan dimension of the excavation must be known. Duration of dewatering as it relates to power consumption, operating and maintenance cost, installation cost, discharge facility usage cost are important for determining which is the most economical set up. Then selection of a system that will perform economically for the parameters and constraints set forth can be accomplished. Size and spacing of the wells or well points and pump sizes are key in design analysis.

Continuous pumping and maintaining water table much below the trench bed means more consumption of energy. Also the water level can be maintained by operating less number of high capacity wells or large number of wells with low capacity. There are effective location of well which lead to more drawdown. All these aspects lead to the fact that there is a pumping schedule and arrangement of well locations that will lead to a minimum cost of pumping

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C_I	Cost of installation (Rs)
C_E	Cost of energy (Rs)
C_3	Cost charge of energy per Kwh (Rs)
C_W	Cost of dewatering (Rs)
D (n)	Depth of excavation for given time step (m)
d	Thickness of the soil formation (m)
E (.)	Exponential integral
i	Observation point
G	Initial depth of water table (m)
g	Acceleration due to gravity (m^2/sec)
j	Pumping point
K (n)	Unit step response function
k	Permeability values of soil (cm/sec)
N_{WELL}	Number of well-points in the arrangement (nos)
Q_P	Pumping rate (m^3/day)
Q_C	Capacity of pump machine (Hp)
Q (n)	Discharge of pumping for different time steps of n integer value
r	Distance from the production well (pumping well) to the point of observation (m)
r_W	Diameter of pump (m)
S	The drawdown at time t since start of pumping (m/day)
T	Transmisivity of the aquifer (m^2/day)
W (u)	Well function
t	Time (days)
β	Hydraulic diffusity of the aquifer
δ (n)	Unit pulse response function or discrete kernel
γ	An integer index
η	Efficiency of pumps motor
ρ	Density of water (1000 kg/m^3)
Φ	Storativity of the aquifer

CHAPTER I

INTRODUCTION

1. 1. GENERAL

Construction of buildings, powerhouse, dams, locks, tunnel and graving dock frequently requires excavation below the water table into water bearing soils. Such excavation requires lowering water table below the slope and bottom of the excavation to prevent raveling or sloughing of the slope and to ensure dry, firm working conditions for construction operations. Dewatering is most often used to decrease water inflow into the excavation, thereby improving working condition in the excavation and increasing the stability of soils in sides and base of the excavation. The important input parameter for selecting and designing a dewatering system are the height of the ground water above the base of the excavation and the permeability of the surrounding soil of the excavation. To know the depth of groundwater lowering, one must know what the prevailing ground water levels are at site and the depth of excavation. The field permeability of the soil must be known to estimate the amount of pumping or flow rate that will be required to attain the required ground water level.

In many cases, especially during reconnaissance, type of ground water investigation and for water balance studies, it may not be practical or feasible to construct test wells and conduct the time consuming aquifer test for estimation of hydro-geological parameters. Also, some of the modern quantitative techniques such as those for which electric analog models or mathematical models are contemplated, a sufficiently large number of transmisivity and storativity are required. In all such cases, for the determination of hydro-geological parameters, quick and approximate methods may have to be resorted to. These properties can be estimated with reasonable accuracy by some of the indirect method based on analysis of water level fluctuation, specific capacity data of wells and well log etc.

A thorough knowledge of the characteristic of the soil adjacent to and beneath an excavation is of paramount importance in the design and installation of a dewatering system. The type and stratification of the foundation soils should be ascertained from proper borings. For deep or large excavation, several number of these boring should extent to the bottom of the excavation plus 1.5 times the depth of the excavation. The boring should be spaced sufficiently close to reveal any significant variation in soil conditions that would have a bearing on the need for dewatering or spacing of the wells. Samples should be taken at sufficiently frequent intervals to detect changes in soil type. For large excavation and excavation underlain by deep strata of sand, the depth of the sand and its permeability should be ascertained for its full depth. Formulae, which estimate flow and drawdown from sources to slots and radial flow to a single or circular array of wells, are used to solve design problem for dewatering excavations of different sizes and construction. The work of estimating pump capacity, bore hole depths and location should be considered with adequate allowance for in situ conditions which may differ from those presumed in the calculation.

There are several type of dewatering system such as :

1. Dewatering of trench using progressive well point system.
2. Dewatering of square or rectangular plan shape excavation by single or multi-level well points.

3. Dewatering of deep square or rectangular plan shape excavation with battered side slope with deep wells.
4. Dewatering of sheeted excavation where the sheeting does not achieve a seal within an impermeable stratum.

The pump is a basic unit to any dewatering system. Compared to the complexities of soils and ground water, the pump is a rather straightforward mechanical device, whose performance should be predictable and reliable. Yet many job difficulties can be traced to the pumps, usually because of misapplication, shoddy installation, or improper operation and maintenance. It behooves the dewatering engineer to be familiar with theory and specification of pumps, so that difficulties are not compounded with problems that should be avoidable.

Dewatering pumps are nearly always selected with capacity larger than they will be normally delivering. The extra capacity is necessary to handle storage depletion during the early stages of dewatering and rain falling in the excavation. Pumps that have been designed for less demanding service may be damaged when operated below rated capacity. For this reason, only pumps specifically designed for dewatering should be used in construction.

1.1.OBJECTIVES OF THE PRESENT STUDY

The purpose of this study is to carry out an analysis to decide about the number of wells to be installed for dewatering an area to be excavated having different soil characteristics. Duration of dewatering depends on the power of pump, installation cost, pump operation and maintenance cost, and the rate of excavation that depends upon the capacity of the excavator, etc. The present study has been carried out with the following two objectives

i) To identify the optimum number and location of well-points for dewatering an area with given soil characteristics when the duration of excavation is fixed.

ii) To identify the optimum number and location of well-points for dewatering an area with given soil characteristics when the rate of excavation is fixed.

To achieve these objectives, the basic concepts of well hydraulics have been discussed and then the computer program is written to estimate the draw down at an observation point in the area of excavation based on the rate of pumping at different well-points. To illustrate the whole methodology, hypothetical examples of dewatering an area with different radius, depths of dewatering, soil properties like transmisivity and storativity have been considered. In order to achieve the optimum number of well-points, the different cost parameters like the cost of pumps, energy cost, and the cost of installation have been considered.

CHAPTER II

REVIEW OF WELL HYDRAULICS

2.1. RADIAL UNSTEADY FLOW TO A WELL

When a well starts pumping at constant rate from an effectively infinite aquifer, the influence of pumping progresses radially outwards so that the water is drawn from wider and wider area. Figure 2.1 depicts a fully penetrating well in an unconfined aquifer.

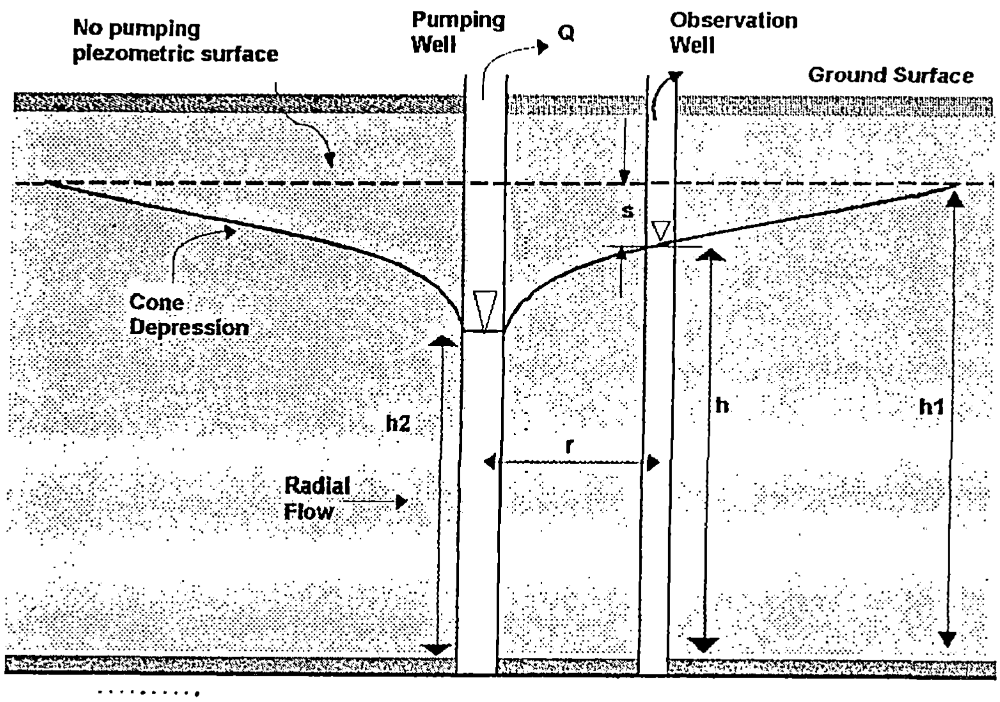


Fig. 2.1. Radial flow in an unconfined aquifer

The differential equation governing the unsteady state flow given by equation 1.1.

$$\frac{\partial^2 S}{\partial r^2}+\frac{1}{r}\frac{\partial S}{\partial r}=\frac{\Phi}{T}\frac{\partial S}{\partial t} \qquad \text{......(1.1)}$$

Theis (1935) presented a solution for a vertical well fully penetrating an confined horizontal isotropic aquifer of infinite extent. When this well is pumping at a constant rate, the influence of the hydraulic head difference extends outward with time. The problem is axis-symmetric around the well axis for the boundary conditions S = 0 before pumping begins and S approaches zero as r approaches infinity after pumping begins.

Using mathematical developments of heat conduction, Theis (1935) obtained a solution as :

$$S(r,t) = \frac{Q}{4\pi T} \int_{r^2\Phi/(4Tt)}^{\infty} \frac{e^{-U}}{u} du \qquad \text{......(2.2)}$$

where,

S (r, t) = The drawdown at time t since start of pumping

r = Distance from the production well (pumping well) to the point of observation where the drawdown S occurs.

Q = The constant pumping rate.

T = The transmisivity of the aquifer.

Φ = Storativity of the aquifer

The above integral is denoted by W (u) in the well hydraulic. This has been designated as the exponential integral function E_1 (u), defined as :

$$E_1(u) = -\gamma - \ln u + u/(1\text{x}1!) - u^2/(2\text{x}2!) + u^3/(3\text{x}3!) - \ldots \qquad \text{.....(2.3)}$$

where :

γ = 0.5772156649 … (the Euler constant)

$$u = \left(\frac{r^2\Phi}{4Tt}\right) \qquad \text{......(2.4)}$$

Equation (2.2) may be written as :

$$S(r,t) = \frac{Q}{4\pi T}\left[E_1\left(\frac{r^2\Phi}{4Tt}\right)\right] \qquad \text{........ (2.5)}$$

Drawdown at well face is found from equation (2.3) for r = rw

$$S(r_w,t) = \frac{Q}{4\pi T}\left[E_1\left(\frac{r_w^2\Phi}{4Tt}\right)\right] \qquad \text{........(2.6)}$$

Therefore,

$$S(r,t) = \frac{Q}{4\pi T}W(u) \qquad \text{...... (2.7)}$$

2.2. GENERAL ASSUMPTIONS USED IN WELL HYDRAULICS

The design methods to remove ground water by pumping make fundamental assumption regarding soil and ground water flow. The assumption includes :

- The aquifer extends horizontally with uniform thickness in all directions without encountering recharge or barrier boundaries.
- The initial piezometric surfaces in all the aquifer are same.
- The aquifer is isotropic, that is the permeability is the same in all directions.
- The aquifer releases water from storage instantly when the head is reduced.
- The coefficient of transmisibility is constant at all places and at all times.
- Flow is laminar and Darcy's law of flow is applicable.
- The flow is horizontal and uniform everywhere in a vertical section.
- The pumping well is frictionless and has small diameter.

However, these assumptions are only partially fulfilled at site. Therefore, a balance has to be struck between the result of such theoritical calculations and experience, preferably local experience, of the selected dewatering system.

The selection of a system that will perform economically for the parameters and constraints set forth is to be accomplished. Size and spacing of the wells or well points and pump sizes are key outputs in design analysis. Figure 2.2. shows the typical lay out of pumping arrangement for dewatering a site.

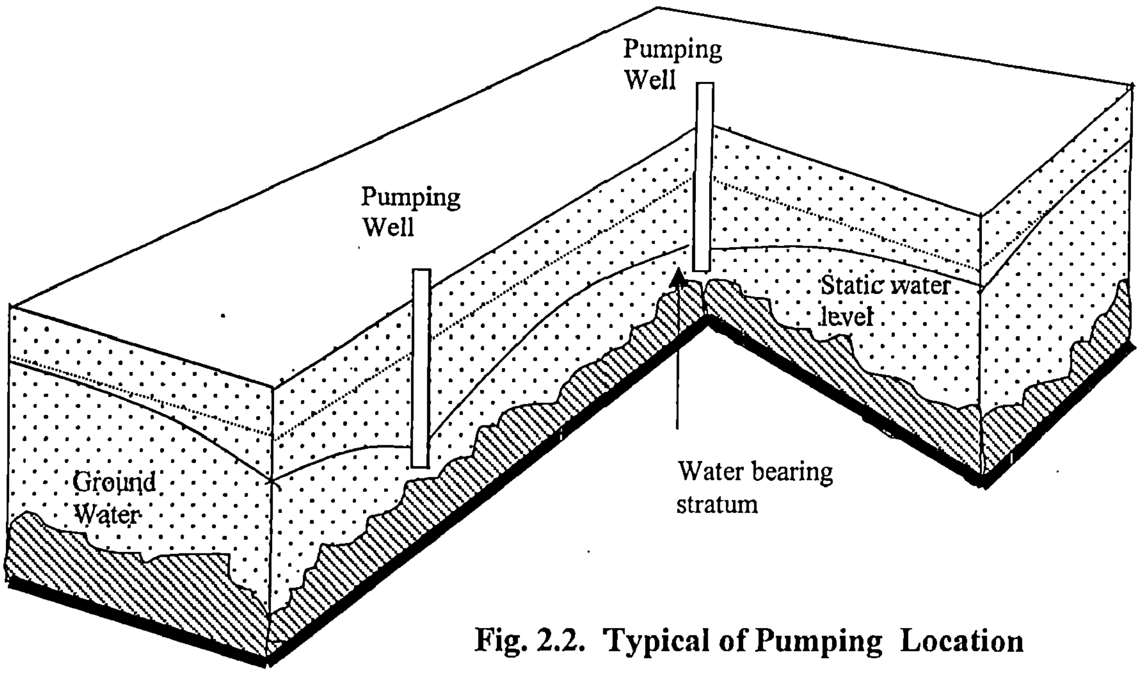


Fig. 2.2. Typical of Pumping Location

2.3. DESIGN INPUT PARAMETER

In designing a dewatering system for an area, a number of factors should be considered or investigated. These include the geological and soil conditions in the immediate vicinity of the site, size and depth of excavation, depth of water table to be lowered, permeability, stratification, and thickness of the pervious strata to be dewatered. However, the details of investigation of an individual item will depend upon the need of the project and the complexity of the dewatering problem. These are briefly described as follows :

2.3.1 Permeability (k)

The coefficient of permeability, also known as hydraulic conductivity reflects the combined effects of the porous medium and fluid properties. From an analogy of laminar flow through a conduit, the coefficient of permeability can be expressed as :

$$k = C d_m^{\,2} . \frac{\gamma}{\mu} \qquad \text{......(2.8)}$$

Where, d_m = mean particle size of the porous medium; γ = unit weight of the fluid; μ = dynamic viscosity of the fluid, and C = a shape factor that depends upon the porosity, packing, shape of grains and grain size distribution of the porous medium. Thus for a given porous material, the coefficient of permeability is inversly proportional to the kinetic viscosity (ν) which is function of temperature. Generally, the coefficient of permeability reflects the properties of medium ($C\ d_m^2$) incorporating the fluid properties (ν). The common values of intrinsic permeability that is a function of the medium only for a variety of soil and rock types are shown in table 2.1.

Tabel 2.1. Permeability Values for Common Soils (Groundwater and Well by Driscol)

Formation	Value of k (cm/sec)
A. Granular Material	
1. Clean Gravel	1 - 100
2. Clean coarse sand	0.01 – 1.0
3. Mixed sand	0.005 – 0.01
4. Fine sand	0.01 – 0.05
5. Silty sand	$1 \times 10^{-4} - 1 \times 10^{-3}$
6. Silt	$1 \times 10^{-5} - 1 \times 10^{-4}$
7. Clay	$< 10^{-6}$
B. Consolidated Material	
1. Sandstone	$10^{-6} - 10^{-3}$
2. Carbonate rock with secondary porosity	$10^{-5} - 10^{-3}$
3. Shale	10^{-10}
4. Fracture & weathered rock (aquifers)	$10^{-6} - 10^{-3}$

2.3.2. Transmisivity (T)

The coefficient of transmisivity indicates how much water will move through the soil formation. It is defined as the rate of the flow of water in m^3/days through a vertical strip of aquifer of unit width i.e. 1 m and extending through the full saturated thickness (d) under a unit hydraulic gradient. The relation between coefficient permeability of (k) and transmisivity (T) is given by :

$$T = k.d \qquad \text{......(2.9)}$$

2.3.3. Storage capacity / Storativity (Φ)

The storativity indicate how much water can be removed from the formation by pumping. It is defined as the volume of water released from storage per unit of surface area of the formation for a unit change in head.

2.3.4. Existing Groundwater Levels

A good starting point in assembling the information necessary to select and design a dewatering system is to determine where the prevailing groundwater level is at the site. This is usually accomplished with observation well or with piezometers. The most conservative approach would anticipate the highest water level possible during construction period. One might also want to weigh the effect of assuming a lower water level with potential economic effect of that lower level being exceeded during the construction period. That analysis usually result in the decision to be on the safer side by assuming the high water level.

2.3.5. Depth of Required Ground Water Lowering

The required depth of ground water lowering usually related to the bottom level of the excavation. The water level should be lowered to about 0.6 m to 1.5 m below the base level of the excavation. If the absolute bottom of the excavation is not known, a conservative (i.e. lowest possible) estimate should be made. This should include any over excavation required for footing, slabs, and shaft etc. The maximum. depth of ground water level lowering is the difference between the prevailing groundwater level and the required level during construction period.

2.3.6. Zone of Groundwater Lowering

The zone of groundwater lowering involves not only the depth but also the three-dimensional shape required. For instance, the requirement for a thin, linear, utility trench will be different from those for a large, square or circular parking structure. The limits of the excavation must be kown or estimated prior to design. For along linear excavation, the entire site may not need to be dewatered at the same time, it can be done zone wise along the length of excavation.

2.4. EXCAVATION WORK

The excavation work can be done either manually using labor, or by mechanical devices like excavator or any other excavating machine. The common type of mechanical devices used for excavation are :

1. Power shovels
2. Dragline excavators
3. Tower excavators
4. Backhoes
5. Trenching machine
6. Wheel mounted belt loader

Table 2.2. Gives the approximate capacities of power excavators such as shovel and dragline scrapers.

Table 2.2. Approximate Outputs of Power Excavators Used for Digging Soil

Bucket dipper, or scraper capacity (Cu. Yd.)	Machine with a short reach (Cu. yd. per hr.)	Machine with a longer reach (Cu. yd. per hr.)
0.5	30 – 100	25 – 75
0.75	45 – 130	40 – 100
1	60 – 160	55 – 125
1.25	75 – 190	70 – 150
1.5	90 – 120	80 – 175
1.75	105 – 245	90 – 200
2	120 – 270	100 – 220
2.5	145 – 320	120 – 260
3	170 – 370	140 – 300
3.5	190 – 420	160 – 330
4	210 – 460	175 – 350
5	250 – 550	
6	285 – 630	

2.5. TOTAL COST OF DEWATERING

The total cost for dewatering work is influenced by two types of cost, one is called fixed cost and other is called recurrent or variable cost. Fixed cost include the initial cost of exploration, data collection, analysis, drilling and installing a system, while recurrent cost include those of energy, labor, operation and maintenance.

2.4.1 Fixed Cost

The fixed cost depends on such factor as the depth of dewatering, distance of pumps from site, design discharge, ground water level, drawdown to the aquifer, diameter of the well, well screen length, and drilling cost which depend on the hydro-geological conditions of the site. Other factors considered are the location of the well, cost and availability of different types of energy. The latter is important for the selection of the type of pump to purchase, which has a significant effect on the total fixed cost.

2.4.2 Recurrent Cost

They are mainly the operation and maintenance costs. Recurring cost are considered one of the main components of total ground water production costs. These include cost that are function of the duration of operation, like energy cost, labor cost (for control and operation) and costs derived from repairing equipment and installation, etc.

CHAPTER – III

OPTIMAL DESIGN OF DEWATERING SYSTEM

3.1 PROBLEM DESCRIPTION

In a construction activity, excavation work is important which in turn depends upon the dewatering schedule if the water table is at shallow depth. Most dewatering systems consist of a number of well-points with pumping arrangement, to provide the required relief of substratum pressures or reduction of groundwater levels. The sites of dewatering have different sizes depending on the function and type of construction. There may be sites with different kind of soil formation and type of soils. Therefore, it is necessary to determine the relationship between drawdown caused by pumping rate as well as duration or schedule of excavation. As far as location of dewatering pumps is considered, the best location is the centre point of the site as the cone of depression at a well–point is circular. However, it will cause hindrance in the excavation work. Therefore, it is assumed that site must be clear of the pumps and pipelines, and, the well-points can only be constructed at the periphery of the site. Also, in order to illustrate the methodology, it is assumed in the present study that the site is circular in shape and the well-points are constructed at the periphery of a circle whose radius is 'R'. There can several number of pumps that can be put in circular arrangement. Each well-points will have a draw-down due to its own pumping and because of pumping at other well-points. If the well-points are symmetrical, their effects will be symmetrical, otherwise the effect will be asymmetrical. In the present study, minimum two number of well-points are considered for dewatering a given circular site so as to avoid asymmetrical dewatering. One can consider the asymmetrical placement of well-points as well, but will have to consider little bit more complex equations. Figure 3.1 shows the typical symmetrical placement of well-points which have been considered in the present study.

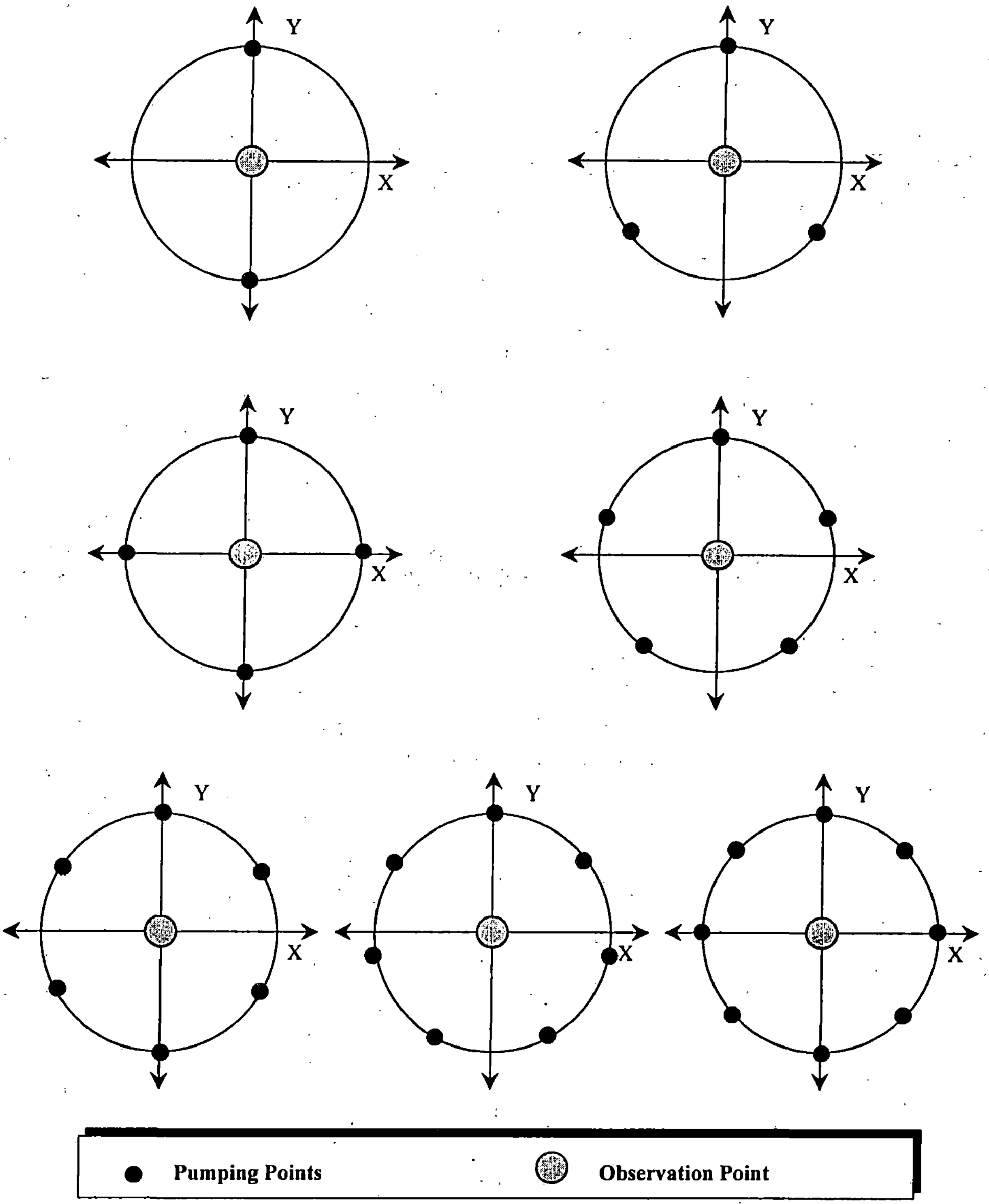


Fig. 3.1 Typical Location of Well-Points

It is necessary to determine the required drawdown at a site to satisfy the condition of excavation work. This drawdown will depend on the pumping well arrangement and their pumping schedule.

The required steps for solving the problem are:

- The first step is to identify the constraints due to the excavation work such as duration / schedule of excavation rate, and required depth of progress for each day by mechanical excavators.
- The second step is to fix the arrangement for pumping with the economical set-up, and with the minimum cost.
- Optimizing the relation between discharge for wells, cost of pumping set up and energy consumption.

In order to solve this problem, the following assumptions have been made :

1. The initial piezometric surfaces in all the aquifer are same.
2. The aquifer extends horizontally with uniform thickness in all directions without encountering recharge or barrier boundaries.
3. The aquifer is isotropic, that is, the permeability is the same in all directions.
4. The aquifer releases water from storage instantly when the head is reduced.
5. The coefficient of transmisivity is constant at all places and at all times.
6. Flow is laminar and Darcy's law of flow is applicable.
7. The flow is horizontal and uniform everywhere in a vertical section.

Based on these assumptions, the problem has been analysed mathematically and is explained in the subsequent sections.

3.2 ANALYSIS OF THE PROBLEM

When a well starts pumping at constant rate from an effectively infinite aquifer, the influence of pumping progresses radially outwards so that the water is drawn from wider and wider area. If there is no recharge through lateral boundaries to support the well discharge the water must come from the storage of the aquifer and cone of depression will continue to increase with time to make suitable additional water from storage. The water released from storage during an interval is equal to the storage coefficient of the aquifer multiplied by the decline in head integrated over the area affected by pumping.

The drawdown, S(n) in the aquifer at any distance r from the centre of the well can be found, using the relation

$$S(n) = \sum_{\gamma=1}^{n} Q_P(\gamma)\,\delta(n-\gamma+1)$$

where,

$$\delta(m) = \frac{1}{4\pi T}\left[E_1\left(\frac{r^2}{4\beta m}\right) - E_1\left(\frac{r^2}{4\beta(m-1)}\right)\right]$$

$$\beta = \frac{T}{\Phi}$$

= Hydraulic diffusivity of the aquifer

$E_1(*)$ = Exponential integral.

Drawdown for the well arrangement with any pumping well and observation well can be found by equation below:

$$S(i,k) = \sum_{\gamma=1}^{k} Q_p(i,\gamma)\delta(i,i,k-\gamma+1) + \sum_{\substack{j=1 \\ j\neq i}}^{N\,WELL} \sum_{\gamma=1}^{k} Qp(j,\gamma)\delta(i,j,k-\gamma+1)$$

For time k – 1 the drawdown is

$$S(i, k\text{-}1) = \sum_{\gamma=1}^{k-1} Q_p(i,\gamma)\delta(i,i,k-1-\gamma+1) + \sum_{\substack{j=1 \\ j \neq i}}^{N\,WELL} \sum_{\gamma=1}^{k-1} Q_p(j,\gamma)\delta(i,j,k-1-\gamma+1)$$

where, in δ (∗, ∗, ∗)

- The first index is observation point which may coincide with a pumping point

- The second index is a pumping points

Hence the average drawdown for time (k > 1) is:

$$\overline{S}(i,k) = \frac{S(i,k) + S(i,k-1)}{2}$$

$$= 0.5\sum_{\gamma=1}^{k} Q_p(i,\gamma)\,\delta(i,i,k-\gamma+1) + 0.5\sum_{j=1}^{NP\ WELL}\sum_{\gamma=1}^{k} Q_p(j,\gamma)\,\delta(i,j,k-\gamma+1)$$

$$+0.5\sum_{\gamma=1}^{k-1} Q_p(i,\gamma)\,\delta(i,i,k-1-\gamma+1) + 0.5\sum_{j=1}^{NP\ WELL}\sum_{\gamma=1}^{k-1} Q_p(j,\gamma)\,\delta(i,j,k-1-\gamma+1)$$

Discrete kernel coefficient have been used to obtain the drawdown during the time of excavation. Discrete kernel for drawdown is defined as the unit pulse response of the aquifer i.e. drawdown due to unit volume withdrawal in a unit time period. The response of the aquifer to continuous pumping at unit rate (per unit time) can be expressed as K(t). From Theis solution (Equation 2.2) :

$$K(t) = \frac{1}{4\pi T}\int_{r^2\Phi/(4Tt)}^{\infty} \frac{e^{-U}}{u}\,du$$

K(t) is the unit step response function for drawdown. The unit pulse response δ(n) is given by :

$$\delta(n) = K(n) - K(n-1)$$

δ(n) is the discrete kernel for drawdown.

3.4 COST ANALYSIS IN DEWATERING

The cost of dewatering depends upon the capacity of the pumps, its fixed and variable costs. The power of pump depends upon the height from which the water is to be lifted depend upon the capacity of the pump and energy required and is dependent upon the drawdown at any time 't'. The average drawdown for any interval is taken as

$$\overline{S}\,(i,k) = \frac{S\,(i,k) + S\,(i,k-1)}{2}$$

and the lift of water is taken as

$$\text{Lift}\,(i,k) = G + \frac{S\,(i,k) + S\,(i,k-1)}{2}$$

where,

G = Depth to initial water table position from the ground surface.

The energy used by the pump can be expressed as :

$$E = \sum_{i=1}^{NP\,WELL} \sum_{k=1}^{N\,TIME} Q_p(i,k)\ \rho.g \left[G + \frac{S(i,k-1) + S(i,k)}{2} \right]$$

where,

E = Energy consumed in joule per day

Q_P (i,k) = Pumping discharge from i^{th} well during k^{th} in m^3/day

ρ = Density of water (1000 kg/m^3)

g = Acceleration due to gravity (9.81 m^2/s)

S (i,k) = Drawdown at the end of time step k in m

S (i,k-1) = Drawdown at the end of time step (k-1) in m

Based on the maximum energy or power of the pump required, pumps are purchased and installed. The fixed cost of pumping unit consists of :

1. Cost of pumps

2. Cost of construction (drilling/boring) including cost of miscellaneous items like casing, pipes, valves, and labourer charges etc.

The variable or the recurring cost mainly consists of energy cost that is required for running a pump.

3.4.1 Cost of Pump

The cost of pump is based on the power rating of the pump. Price list of pump for power rating 1 Hp to 210 Hp has been obtained from Kirloskar pump industry (India) and is reported in Table 3.1.

Table 3.1 Cost of Pumps.

RATING OF PUMP	PRICE	RATING OF PUMP	PRICE	RATING OF PUMP	PRICE
HP	Rs	HP	Rs	HP	Rs
1	8000	21	31000	60	56000
2	8500	22	32000	65	61000
3	8900	23	32200	70	66000
4	9300	24	32700	75	69500
5	11000	25	33500	80	72500
6	14000	26	35000	85	78000
7	14200	27	35200	90	82300
8	14400	28	35700	95	84000
9	14600	29	36000	100	91000
10	15400	30	36300	110	99500
11	17000	31	36500	120	108900
12	18000	32	37000	130	120500
13	19000	33	37500	140	127300
14	20000	34	39000	150	139500
15	21000	35	39500	160	147800
16	22000	36	41000	200	169500
17	24000	40	43000	205	195000
18	26000	45	48000	210	215300
19	28000	50	49900		
20	30000	55	52000		

3.4.2 Cost of Construction/Installation

The cost of construction/installation of a well point is assumed to vary with the depth of well-point. It is assumed that there is a minimum cost of installation of Rs. 3000/- for each well point and there is a variable cost of Rs. 500/- per metre depth of well. Mathematically, it can be expressed as

$$C_I = (3000 + 500\ y)$$

Where, y = the required depth of drilling or boring in meter.

3.4.3 Cost of Energy

The cost of energy for pumping water depends on:

i) Position of water table below ground surface

ii) Drawdown in the well due to pumping.

The cost of energy spent for running the pumps can be obtained as:

$$C_E = C_3 \text{ x Energy consumed.}$$

Energy consumed during the entire operation will be

$$E = \frac{\rho 9.8}{\eta} \sum_{n=1}^{N} Q_p(n)(G + \bar{S}(n)) \text{ Joules}$$

$$= \frac{\rho(9.8) \sum_{n=1}^{N} Q_p(n)(G + \bar{S}(n))}{\eta 3.6x10^6} \text{ kwh}$$

where,

1kwh = 3.6×10^6 Joule

E = Energy consumed in kwh

C_E = Cost of energy in rupees

C_3 = Cost charges of energy per Kwh (unit cost) in rupees

$Q_P(n)$ = Pumping rate in m^3/day during n^{th} time period

η = Efficiency of pumps motor

ρ = Density of water (1000 kg/m^3)

G = Depth to water table or piezometric surface in meters

$\bar{S}(n)$ = Average drawdown in meters during n^{th} time period.

N = Duration of pumping period.

3.5 CASE I : OPTIMAL NUMBER OF PUMPS FOR DEWATERING AN EXACAVATION SITE BASED ON THE FIXED DURATION

3.5.1 Description and Formulation

In the present study, a site is considered which is to be dewatered in 10 days time. The initial ground water table is located at a depth of 2 m from the ground surface. The transmisivity of the soil is assumed to be 100 m^2/day, and the storativity as 0.01. It is desired that at any level of excavation, the water table should be at least 1m below the bed level of excavation as excavation progress. The objective is to identify the optimal number of pumps for different sites with a radius of (say) 100 m, 200 m, 300 m, and 400 m. The depth of excavation considered for each radius are (say) 2 m, 3 m, 4 m, 5 m, and 6 m.

A schematic arrangement of pumps is shown in Figure 3.1. The pumps are placed at equal distance along the periphery of the circular boundary. The observation point is at the centre, and it is assumed that the water table is highest (lowest drawdown) at the centre and should satisfy the criteria for the level of water table at any time of excavation. i.e., to reach at required depth of excavation the water has to be pumped out from the sub-soil of the site so that the drawdown at the centre of site goes as below as least 1 meter below the required depth of excavation.

The cost of pump and cost of installation should be minimum, and the minimization of problem can be stated as:

$$\text{Min } C = C_P + C_I + C_E$$

Subject to

$$G + S(n) - D(n) > 1 \text{ m}$$

$$Q_P < Q_C$$

$$Q_P > 0$$

where,

C	= Cost of dewatering in rupees
C_P	= Cost of pump in rupees
C_I	= Cost of instalation in rupees
C_E	= Cost of energy in rupees
$S(n)$	= Drawdown in the observation point at the end of time step n
$D(n)$	= Depth of excavation in meters measured from the ground surface
Q_P	= Pumping discharge of well in m^3/day
Q_C	= Capacity of the machine

The following steps have been followed in optimizing the dewatering in excavation work for above case.

- The pumping period is discretised to n units of equal time step.
- The discrete kernels $\delta(n)$ are generated making use equation (2.2) for different integer value of n.
- The drawdown is calculated using equation (2.1), the drawdown is computed considering the excavation schedule time and rate of excavation work.

- After the value of drawdown is obtained, the energy required for pumping is computed.
- From the above result, the capacity of pumping set up is found out.

The discrete kernel coefficient for T = 100 m^2/day, Φ = 0.01 and duration of excavation N = 10 days with radius of sites as 100 m, 200 m, 300 m, and 400 m are found and the results are tabulated in Table 3.2.

Tabel 3.2. The discrete kernel coefficient for T = 100 m^2/day, $\Phi = 0.01$, n = 10 days, and radius of site as 100, 200, 300, and 400 m

TIME	RADIUS OF SITE			
STEP (Days)	100 m	200 m	300 m	400 m
1	8.31E-04	1.74E-04	2.77E-05	3.01E-06
2	4.61E-04	2.71E-04	1.15E-04	3.59E-05
3	2.91E-04	2.14E-04	1.29E-04	6.35E-05
4	2.13E-04	1.71E-04	1.20E-04	7.22E-05
5	1.68E-04	1.42E-04	1.07E-04	7.26E-05
6	1.39E-04	1.21E-04	9.62E-05	6.99E-05
7	1.18E-04	1.05E-04	8.67E-05	6.62E-05
8	1.03E-04	9.30E-05	7.87E-05	6.73E-05
9	9.10E-05	8.33E-05	7.19E-05	5.85E-05
10	8.17E-05	7.55E-05	6.61E-05	5.50E-05
$\sum_{n=1}^{10}\delta(n)$	2.496×10^{-3}	1.451×10^{-3}	8.972×10^{-4}	5.639×10^{-4}

The required discharge for such pumping arrangement has been calculated using the equation given below:

$$S(10) = N_{WELL} \cdot Q_P \cdot \sum_{n=11}^{10}(n)$$

$$Q_P = \frac{S(10)}{N_{WELL} \cdot \sum_{n=1}^{10} \delta(n)}$$

where,

S(10) = Drawdown at the end of 10^{th} day

$\sum_{n=1}^{10} \delta(n)$ = Sum of discrete kernel values during time step 1 up to time step 10.

N_{WELL} = Number of wells in arrangement

Q_P = Pumping capacity (discharge) for each pump.

With known pumping rate, the drawdown at the observation point located at the centre of area for different depths varying from 2 m up to 6 m for different radius of site as 100 m to 400 m can be known.

3.5.2. Result and Discussion

Using the discrete kernel values as shown in Table 3.2, the cost of pumping was calculated for the site with radius 100 m, 200 m, 300 m, and 400 m with the coefficient of storativity as $\Phi = 0.01$, transmisivity as $T = 100$ m^2/day, and for depths of excavation as 2 m, 3 m, 4 m, 5 m, and 6 m. The results are tabulated in Table 3.3, 3.4, 3.5, and 3.6. One can identify from the Table 3.3 that for a radius of site 100 m, the optimal number of wells comes out to be 2. In Table 3.4, for 200 m radius, upto a depth of 5 m, the optimal number of wells are 2, whereas, for depth of 6 m, the number of optimal wells are 3. Similarly, from Tables 3.5 and 3.6, one can find that as the radius increases, even for smaller depths, the optimal number of wells required increases. For example, in Table 3.6, for a radius of 400 m and depth of excavation as 2 m, the optimal number of wells comes out to be 4, and it increases to 7 when the depth of excavation is 6 m. One can notice that for each day the rate of pumping is constant, and therefore, it is desired to have a constant discharge pump.

Graphically, these results are shown in Figure 3.2, 3.3, 3.4, and 3.5 for the radius of 100, 200, 300, and 400m.

Tabel 3.3. Cost Calculation of Dewatering for Different Depth of Excavation with Radius = 100 m and Constan Transmisivity = 100 m2/day, Storativity = 0.01

D = 2 m, R = 100 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	601	8.97	10.970	1.544	2	495.801	1487	17000	16970	33970	35457
10	3	401	6.73	8.730	0.820	1	389.306	1168	24000	22095	46095	47263
10	4	301	5.67	7.670	0.541	1	337.829	1013	32000	27340	59340	60353
10	5	241	5.10	7.100	0.401	1	309.318	928	40000	32750	72750	73678
10	6	200	4.65	6.650	0.311	1	289.900	870	48000	37950	85950	86820
10	7	172	4.39	6.390	0.257	1	275.573	827	56000	43365	99365	100192
10	8	150	4.17	6.170	0.217	1	267.037	801	64000	48680	112680	113481

D = 3 m, R = 100 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/day)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	801.29	11.956	13.956	2.619	3	836.548	2510	17800	19956	37756	40266
10	3	534.19	8.97	10.970	1.372	2	646.234	1939	25500	25455	50955	52894
10	4	400.65	7.552	9.552	0.896	1	555.751	1667	32000	31104	63104	64771
10	5	320.52	6.734	8.734	0.655	1	503.545	1511	40000	36835	76835	78346
10	6	267.097	6.206	8.206	0.513	1	469.836	1410	48000	42618	90618	92028
10	7	228.94	5.836	7.836	0.420	1	446.295	1339	56000	48426	104426	105765
10	8	200.323	5.57	7.570	0.355	1	429.280	1288	64000	54280	118280	119568

D = 4 m, R = 100 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/day)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1001.610	14.505	16.505	3.871	4	1284.089	3852	18600	22505	41105	44957
10	3	667.740	10.279	12.279	1.920	2	959.192	2878	25500	27419	52919	55796
10	4	500.810	8.259	10.259	1.203	2	776.192	2329	34000	32518	66518	68847
10	5	400.644	7.089	9.089	0.711	1	679.933	2040	40000	37723	77723	79762
10	6	333.870	6.332	8.332	0.558	1	617.572	1853	48000	42996	90996	92849
10	7	286.174	5.805	7.805	0.458	1	574.103	1722	56000	48318	104318	106040
10	8	250.400	5.417	7.417	0.435	1	542.216	1627	64000	53668	117668	119295

D = 5 m, R = 100 m, Transmisivity = 100 m2/day, Storativity = 0.01

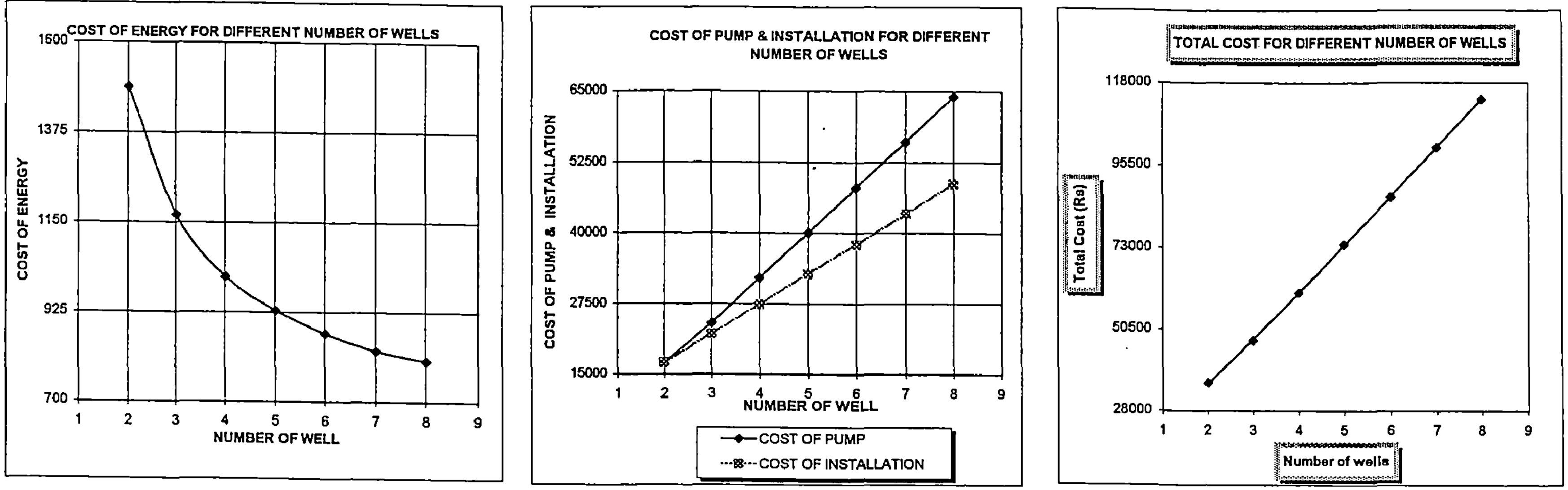
Time Step (day)	No. of wells (nos)	Discharge (m3/day)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1201.94	14.505	17.934	4.645	5	1781.469	5344	22000	23934	45934	51278
10	3	801.92	10.279	13.465	2.306	3	1355.235	4066	26700	29198	55898	59963
10	4	600.97	8.259	11.327	1.444	2	1149.643	3449	34000	34654	68654	72103
10	5	480.78	7.089	10.101	1.023	2	1032.198	3097	42500	40253	82753	85849
10	6	400.65	6.332	9.309	0.782	1	955.248	2866	48000	45927	93927	96793
10	7	343.41	5.805	8.755	0.628	1	903.415	2710	56000	51643	107643	110353
10	8	300.48	5.417	8.355	0.522	1	865.079	2595	64000	57420	121420	124015

D = 6 m, R = 100 m, Transmisivity = 100 m2/day, Storativity = 0.01

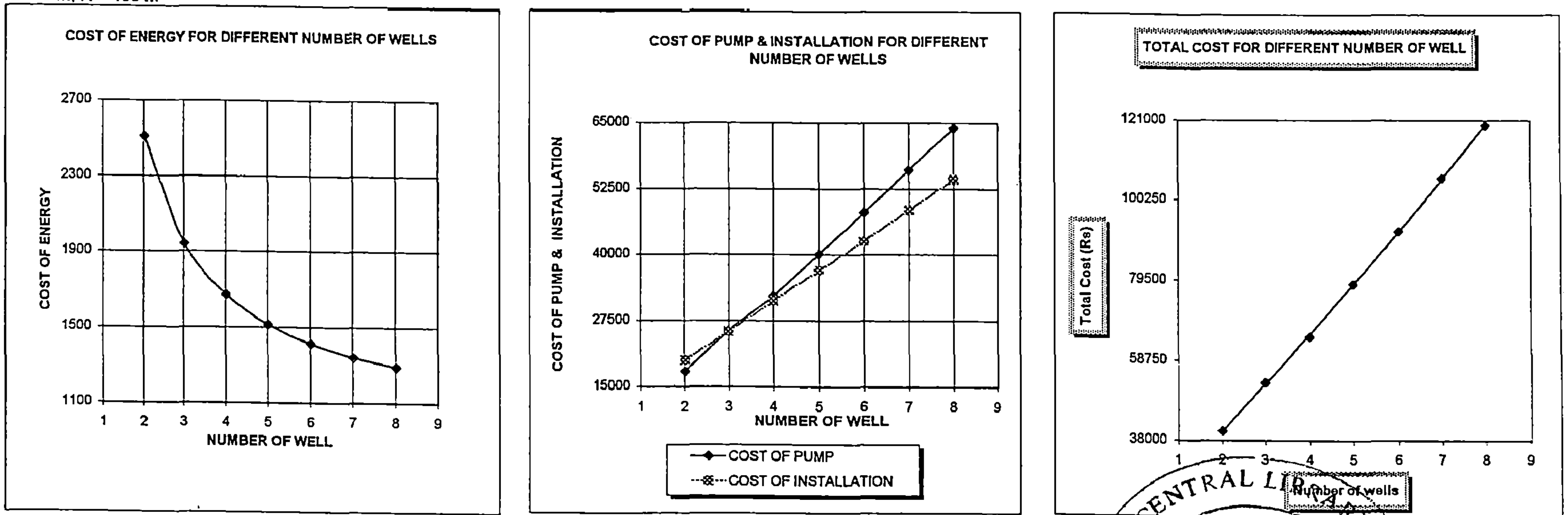
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1402.23	14.505	16.505	5.419	6	1284.089	3852	28000	22505	50505	54357
10	3	934.87	10.279	12.279	2.688	3	959.192	2878	26700	27419	54119	56996
10	4	701.15	8.259	10.259	1.684	2	776.192	2329	34000	32518	66518	68847
10	5	560.92	7.089	9.089	1.194	2	679.933	2040	42500	37723	80223	82262
10	6	467.43	6.332	8.332	0.912	1	617.572	1853	48000	42996	90996	92849
10	7	400.66	5.805	7.805	0.732	1	574.103	1722	56000	48318	104318	106040
10	8	350.57	5.417	7.417	0.609	1	542.216	1627	64000	53668	117668	119295

Fig. 3.2. Cost of Energy, Cost of Pump & Installation and Total Cost for Dewatering for Different Number of Well With Radius 100 m and Constant Transmisivity = 100 m2/day, storativity = 0.01

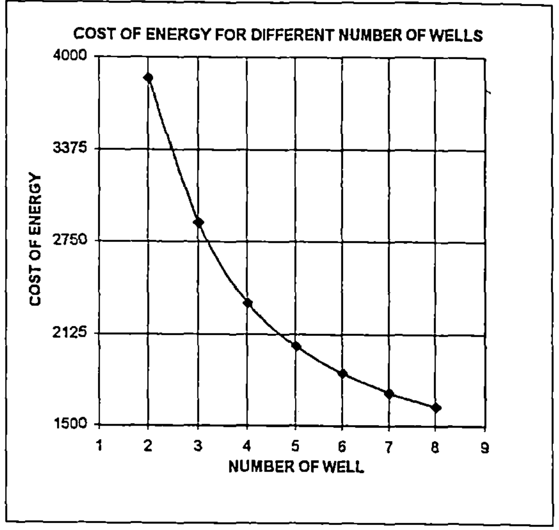
D = 2 m, R = 100 m

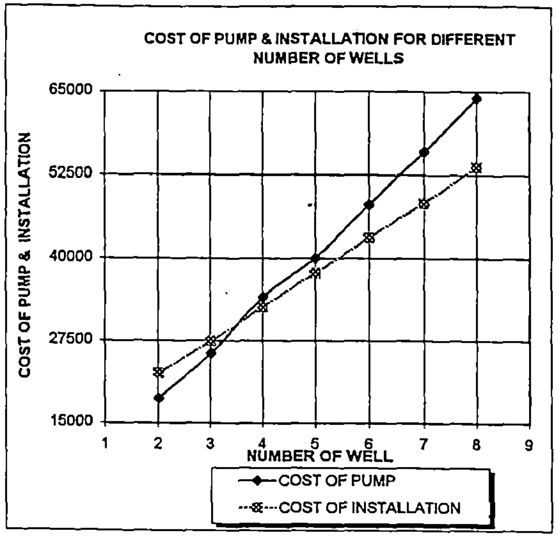


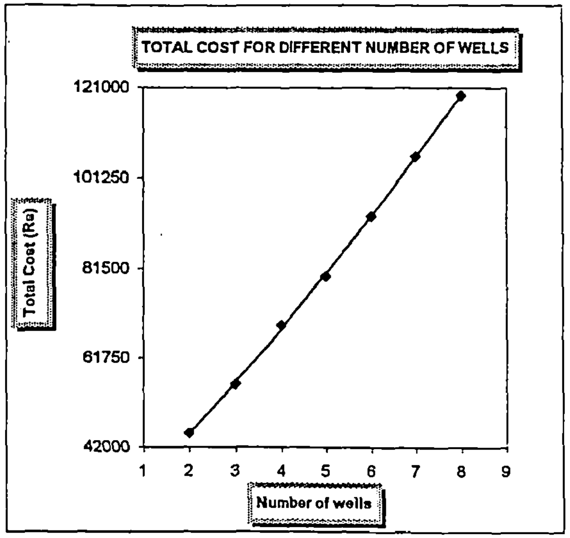
D = 3 m, R = 100 m



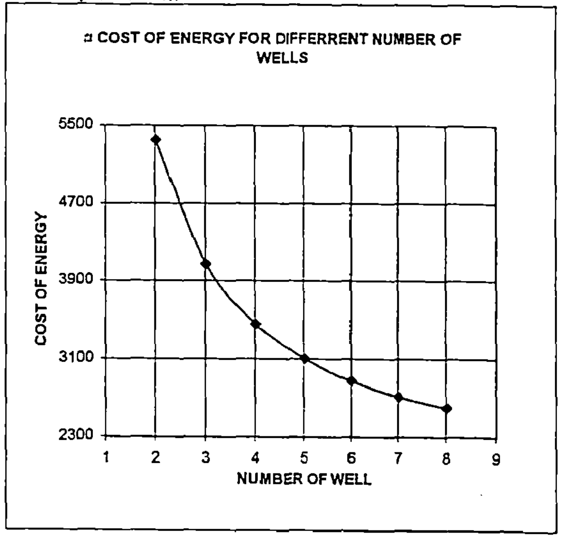
D = 4 m, R = 100 m

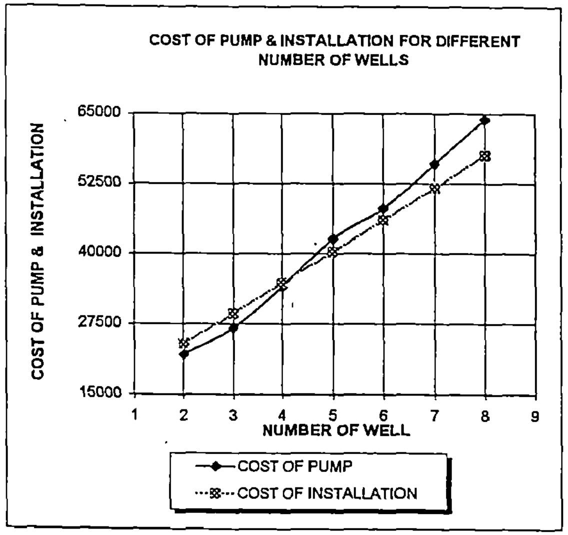


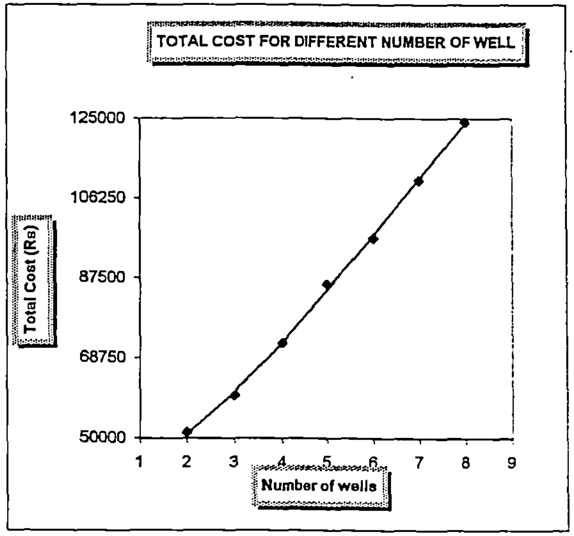




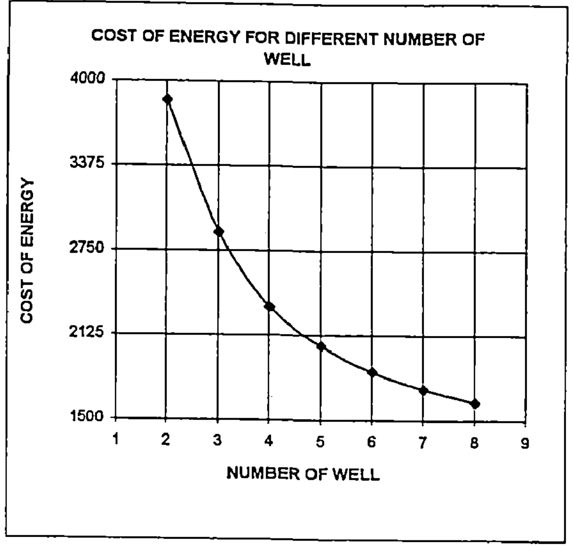
D = 5 m, R = 100 m

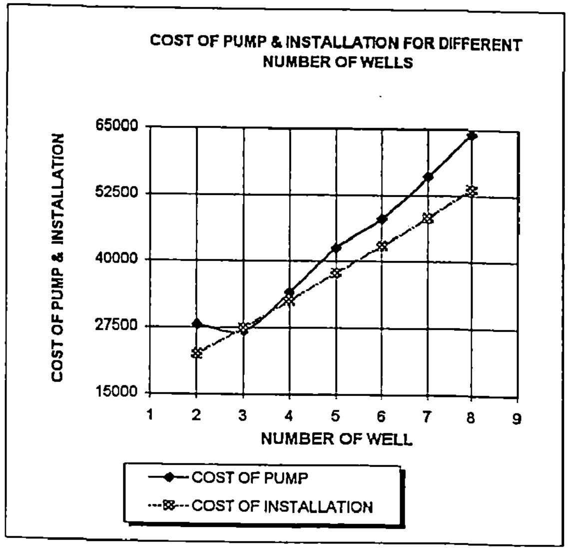


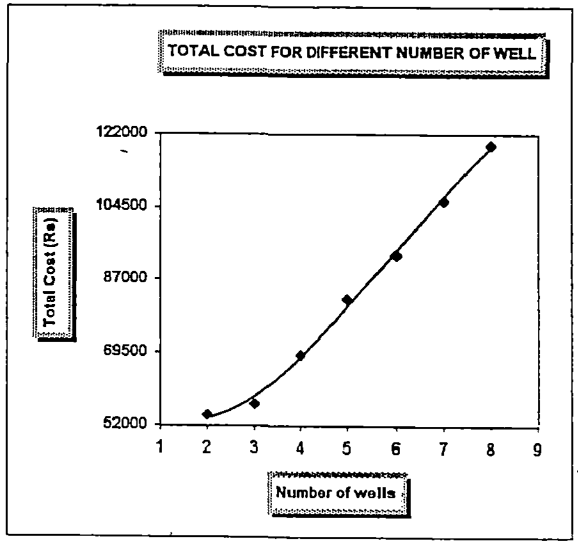




D = 6 m, R = 100 m


COST OF ENERGY FOR DIFFERENT NUMBER OF WELL
COST OF ENERGY
4000
3375
2750
2125
1500
1 2 3 4 5 6 7 8 9
NUMBER OF WELL


COST OF PUMP & INSTALLATION FOR DIFFERENT NUMBER OF WELLS
COST OF PUMP & INSTALLATION
65000
52500
40000
27500
15000
1 2 3 4 5 6 7 8 9
NUMBER OF WELL
COST OF PUMP
COST OF INSTALLATION


TOTAL COST FOR DIFFERENT NUMBER OF WELL
Total Cost (Rs)
122000
104500
87000
69500
52000
1 2 3 4 5 6 7 8 9
Number of wells

Tabel 3.4. Cost Calculation of Dewatering for Different Depth of Excavation with Radius = 200 m and Constan Transmisivity = 100 m2/day, Storativity = 0.01

D = 2 m, R = 200 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1033.98	14.505	16.505	3.996	4	1284.089	3852	18600	22505	41105	44957
10	3	689.32	10.279	12.279	1.982	2	959.192	2878	25500	27419	52919	55796
10	4	516.99	8.259	10.259	1.242	2	776.192	2329	34000	32518	66518	68847
10	5	413.59	7.089	9.089	0.880	1	679.933	2040	40000	37723	77723	79762
10	6	344.66	6.332	8.332	0.672	1	617.572	1853	48000	42996	90996	92849
10	7	295.42	5.805	7.805	0.540	1	574.103	1722	56000	48318	104318	106040
10	8	258.495	5.417	7.417	0.449	1	542.216	1627	64000	53668	117668	119295

D = 3 m, R = 200 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1378.63	19.342	21.342	6.889	7	2209.750	6629	28400	27342	55742	62371
10	3	919.09	13.71	15.710	3.381	4	1597.662	4793	27900	32565	60465	65258
10	4	689.32	11.012	13.012	2.100	3	1302.834	3909	35600	38024	73624	77533
10	5	551.45	9.818	11.818	1.526	2	1146.359	3439	42500	44545	87045	90484
10	6	459.55	8.44	10.440	1.123	2	1020.855	3063	51000	49320	100320	103383
10	7	393.89	7.74	9.740	0.898	1	943.577	2831	56000	55090	111090	113921
10	8	344.66	7.23	9.230	0.745	1	886.879	2661	64000	60920	124920	127581

D = 4 m, R = 200 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1723.29	24.18	26.180	10.564	11	2209.750	6629	34000	32180	66180	72809
10	3	1148.86	16.13	18.130	4.877	5	1597.662	4793	33000	36195	69195	73988
10	4	861.86	14.77	16.770	3.384	4	1302.834	3909	37200	45540	82740	86649
10	5	689.32	12.27	14.270	2.303	3	1146.359	3439	44500	50675	95175	98614
10	6	574.43	10.55	12.550	1.688	2	1020.855	3063	51000	55650	106650	109713
10	7	492.37	9.68	11.680	1.347	2	943.577	2831	59500	61880	121380	124211
10	8	430.82	9.03	11.030	1.113	2	886.879	2661	68000	68120	136120	138781

D = 5 m, R = 200 m, Transmisivity = 100 m2/day, Storativity = 0.01

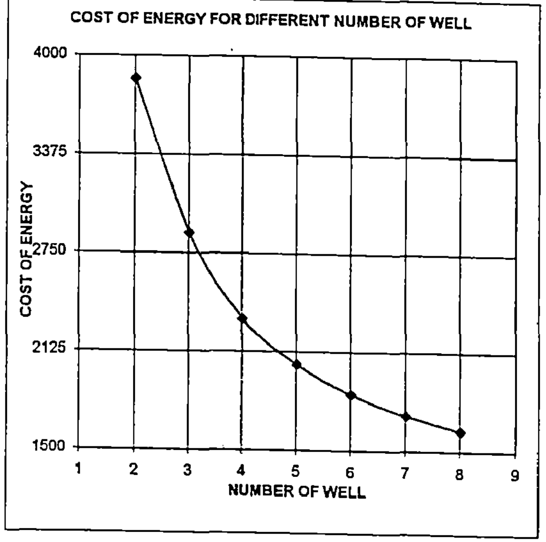
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost pump (Rs)	Cost install (Rs)	Tot. cost of pump (Rs)	Tot. cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	2067.95	29.01	31.010	15.016	16	4798.621	14396	44000	37010	81010	95406
10	3	1378.64	20.56	22.560	7.283	8	3421.374	10264	43200	42840	86040	96304
10	4	1033.98	16.52	18.520	4.484	5	2757.986	8274	44000	49040	93040	101314
10	5	827.12	14.73	16.730	3.240	4	2405.947	7218	46500	56825	103325	110543
10	6	689.32	12.66	14.660	2.366	3	2123.507	6371	53400	61980	115380	121751
10	7	590.84	11.61	13.610	1.883	2	1949.634	5849	59500	68635	128135	133984
10	8	516.99	10.83	12.830	1.553	2	1822.079	5466	68000	75320	143320	148786

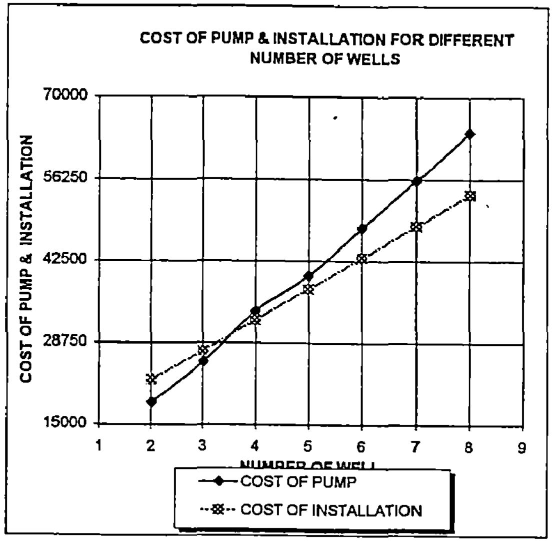
D = 6 m, R = 200 m, Transmisivity = 100 m2/day, Storativity = 0.01

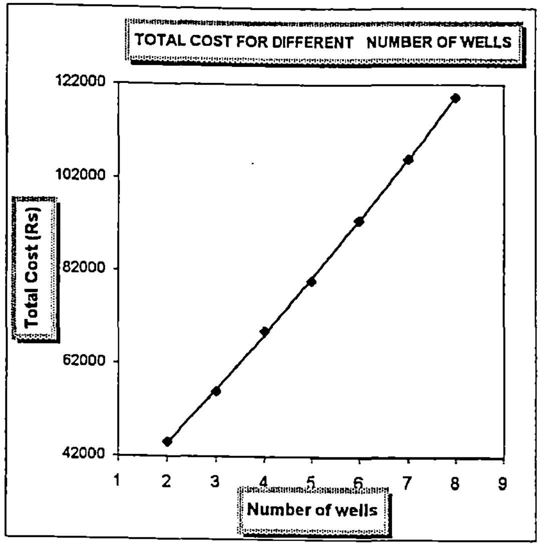
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	2412.6	30.85	32.850	18.558	19	6463.988	19392	62000	38850	100850	120242
10	3	1858.41	23.98	25.980	11.305	12	4589.421	13768	54000	47970	101970	115738
10	4	1106.31	19.27	21.270	5.510	6	3686.496	11059	56000	54540	110540	121599
10	5	965.04	17.18	19.180	4.334	5	3207.310	9622	55000	62950	117950	127572
10	6	804.2	14.78	16.780	3.160	4	2822.853	8469	55800	68340	124140	132609
10	7	689.32	13.55	15.550	2.510	3	2586.285	7759	62300	75425	137725	145484
10	8	603.15	12.64	14.640	2.068	3	2412.592	7238	71200	82560	153760	160998

Fig. 3.3. Cost of Energy, Cost of Pump & Installation and Total Cost for Dewatering for Different Number of Well With Radius 200 m and Constant Transmisivity = 100 m2/day, storativity = 0.01

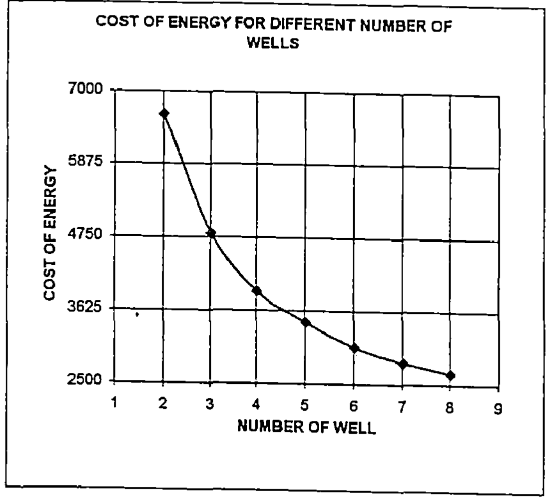
D = 2 m, R = 200 m

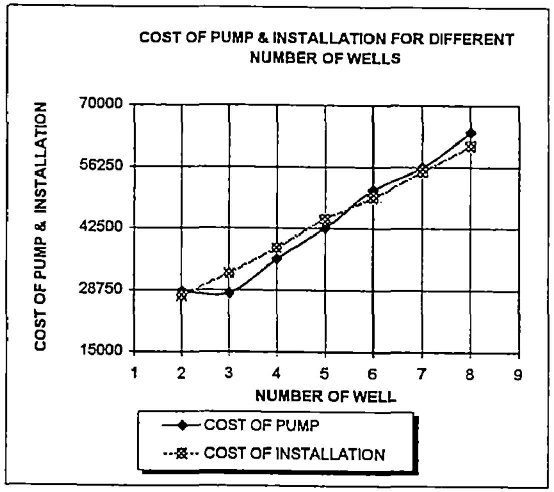


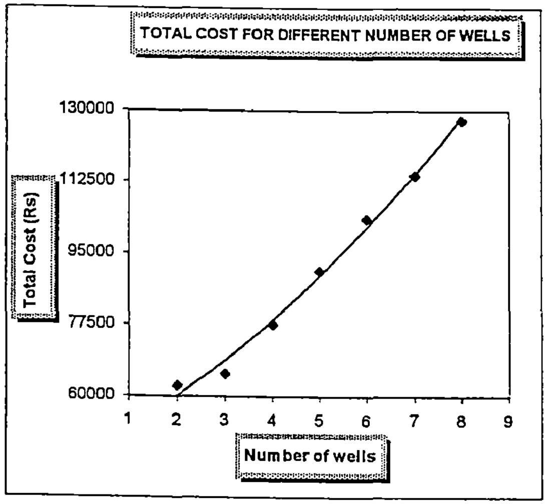




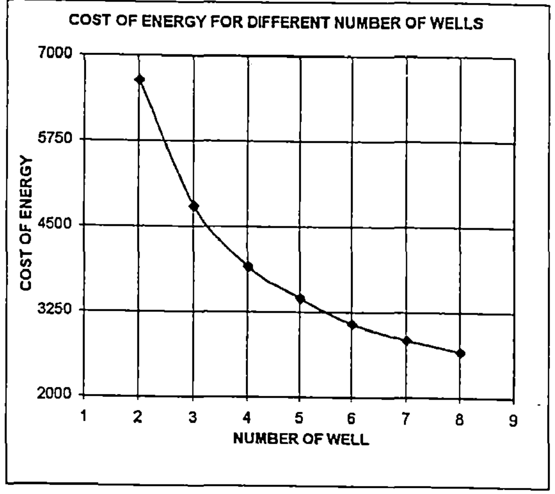
D = 3 m, R = 200 m

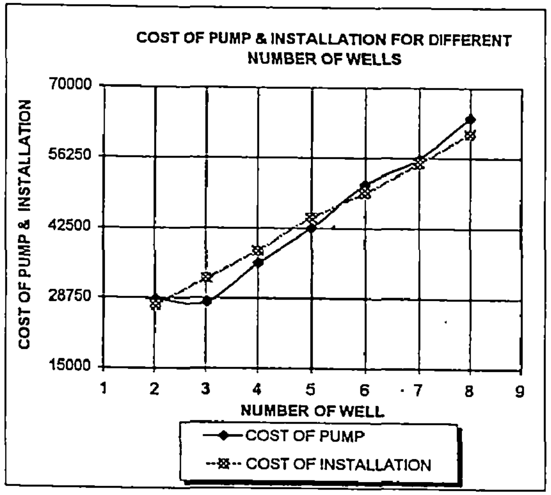


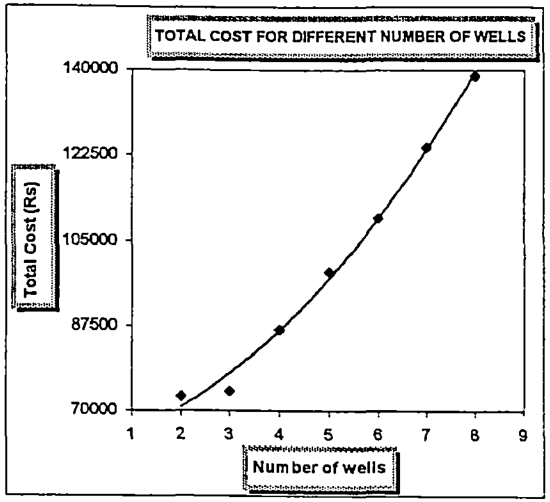




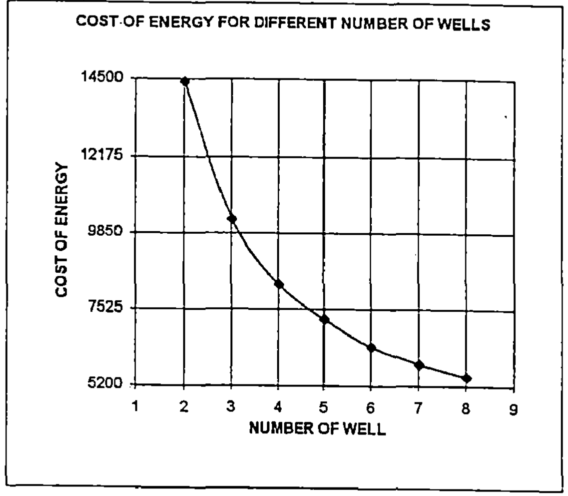
D = 4 m, R = 200 m

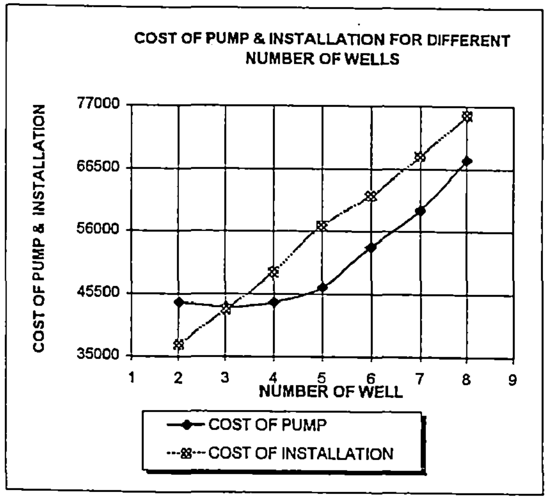


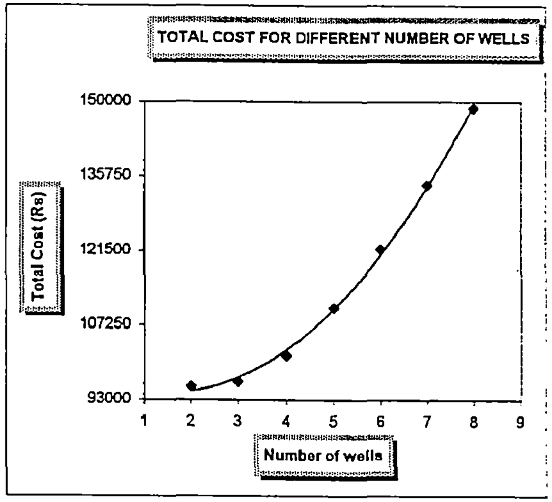




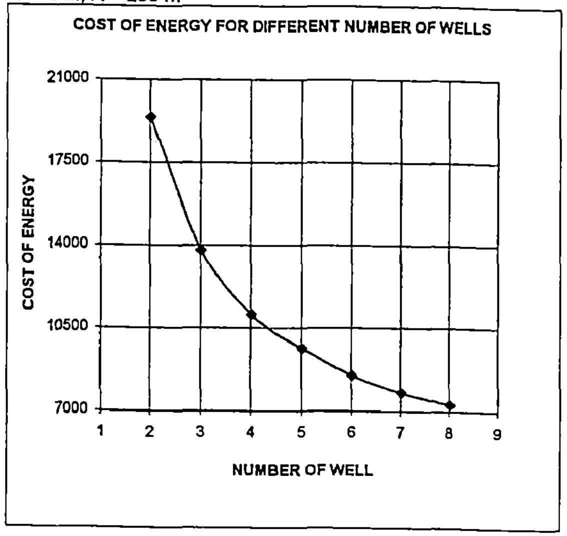
D = 5 m, R = 200 m



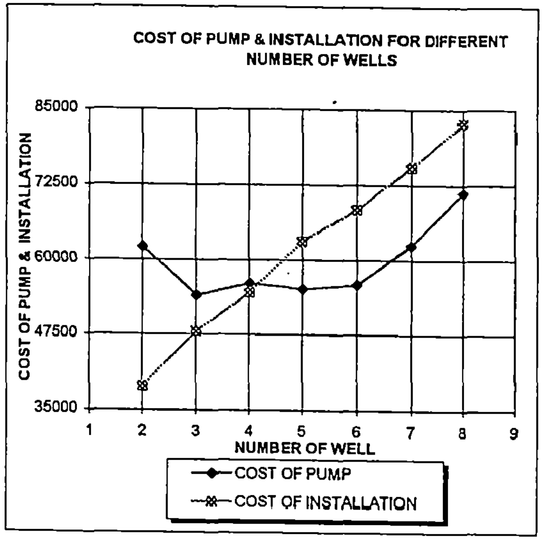




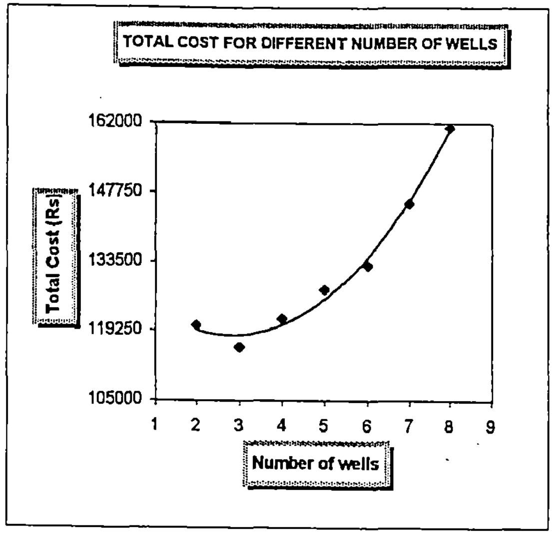
D = 6 m, R = 200 m



COST OF ENERGY FOR DIFFERENT NUMBER OF WELLS
21000
17500
14000
10500
7000
COST OF ENERGY
1 2 3 4 5 6 7 8 9
NUMBER OF WELL



COST OF PUMP & INSTALLATION FOR DIFFERENT NUMBER OF WELLS
85000
72500
60000
47500
35000
COST OF PUMP & INSTALLATION
1 2 3 4 5 6 7 8 9
NUMBER OF WELL
COST OF PUMP
COST OF INSTALLATION



TOTAL COST FOR DIFFERENT NUMBER OF WELLS
162000
147750
133500
119250
105000
Total Cost (Rs)
1 2 3 4 5 6 7 8 9
Number of wells

Tabel 3.5. Cost Calculation of Dewatering for Different Depth of Excavation with Radius = 300 m and Constan Transmisivity = 100 m2/day, Storativity = 0.01

D = 2 m, R = 300 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	1671.89	22.867	24.867	9.735	10	3148.200	9445	30800	30867	61667	71112
10	3	1114.59	15.709	17.709	4.622	5	2218.080	6654	33000	35564	68564	75218
10	4	835.94	12.265	14.265	2.792	3	1764.547	5294	35600	40530	76130	81424
10	5	668.75	10.266	12.266	1.921	2	1499.553	4499	42500	45665	88165	92664
10	6	557.29	8.97	10.970	1.431	2	1327.198	3982	51000	50910	101910	105892
10	7	477.68	8.066	10.066	1.126	2	1206.819	3620	59500	56231	115731	119351
10	8	417.97	7.401	9.401	0.920	1	1118.308	3355	64000	61604	125604	128959

D = 3 m, R = 300 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	2229.16	30.49	32.490	16.959	17	5472.067	16416	48000	38490	86490	102906
10	3	1486.11	20.95	22.950	7.986	8	3818.583	11456	43200	43425	86625	98081
10	4	1114.58	16.35	18.350	4.789	5	3074.605	9224	44000	48700	92700	101924
10	5	891.66	13.18	15.180	3.169	4	2595.668	7787	46500	52950	99450	107237
10	6	743.65	11.66	13.660	2.379	3	2234.841	6705	53400	58980	112380	119085
10	7	636.90	10.76	12.760	1.903	2	2020.812	6062	59500	65660	125160	131222
10	8	557.29	9.87	11.870	1.549	2	1863.479.	5590	68000	71480	139480	145070

D = 4 m, R = 300 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	2786.45	38.11	40.110	26.170	27	8433.288	25300	70400	46110	116510	141810
10	3	1857.63	26.18	28.180	12.258	13	5849.696	17549	57000	51270	108270	125819
10	4	1393.22	20.44	22.440	7.321	8	4589.925	13770	57600	56880	114480	128250
10	5	1114.58	16.48	18.480	4.823	5	3827.921	11484	55000	61200	116200	127684
10	6	928.82	14.95	16.950	3.686	4	3375.174	10126	55800	68850	124650	134776
10	7	796.13	13.44	15.440	2.878	3	3040.747	9122	62300	75040	137340	146462
10	8	696.61	12.33	14.330	2.337	3	2794.775	8384	68000	81320	149320	157704

D = 5 m, R = 300 m, Transmisivity = 100 m2/day, Storativity = 0.01

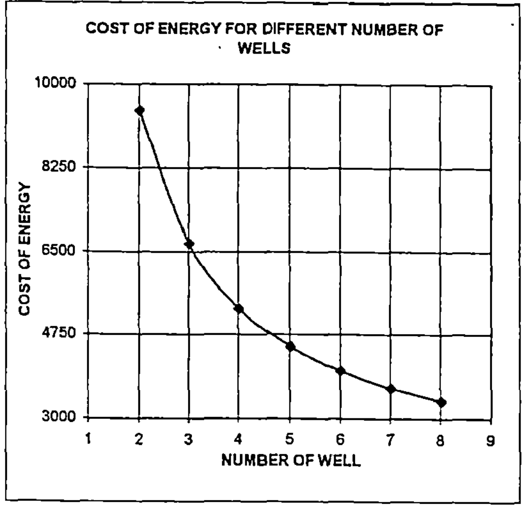
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = Rs 3 * 8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	3343.74	45.74	47.740	37.378	38	12031.792	36095	86000	53740	139740	175835
10	3	2129.16	31.42	33.420	16.662	17	8311.450	24934	72000	59130	131130	156064
10	4	1671.87	24.53	26.530	10.386	11	6497.375	19492	68000	65060	133060	152552
10	5	1337.49	19.78	21.780	6.821	7	5283.338	15850	71000	69450	140450	156300
10	6	1014.58	17.94	19.940	4.737	5	4748.075	14244	66000	77820	143820	158064
10	7	905.35	16.13	18.130	3.843	4	4266.458	12799	65100	84455	149555	162354
10	8	755.93	14.8	16.800	2.974	3	3912.421	11737	71200	91200	162400	174137

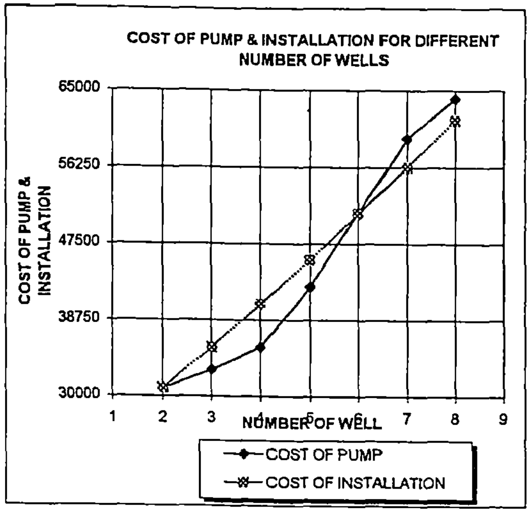
D = 6 m, R = 300 m, Transmisivity = 100 m2/day, Storativity = 0.01

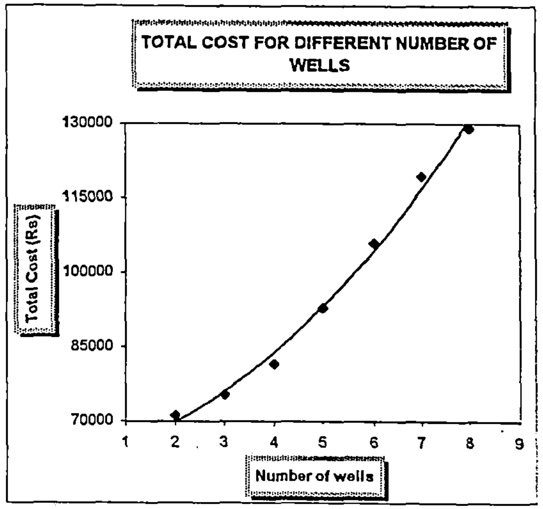
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	3901.02	53.36	55.360	50.568	51	16267.496	48802	104000	61360	165360	214162
10	3	2600.68	36.65	38.650	23.536	24	11203.721	33611	96600	66975	163575	197186
10	4	1950.52	28.92	30.920	14.122	15	8734.600	26204	80000	73840	153840	180044
10	5	1560.41	23.07	25.070	9.160	10	7191.038	21573	77000	77675	154675	176248
10	6	1300.34	20.93	22.930	6.982	7	6353.596	19061	85200	86790	171990	191051
10	7	1114.58	18.82	20.820	5.434	6	5698.158	17094	98000	93870	191870	208964
10	8	975.26	17.27	19.270	4.401	5	5216.333	15649	88000	101080	189080	204729

Fig. 3.4. Cost of Energy, Cost of Pump & Installation and Total Cost for Dewatering for Different Number of Well With Radius 300 m and Constant Transmisivity = 100 m2/day, storativity = 0.01

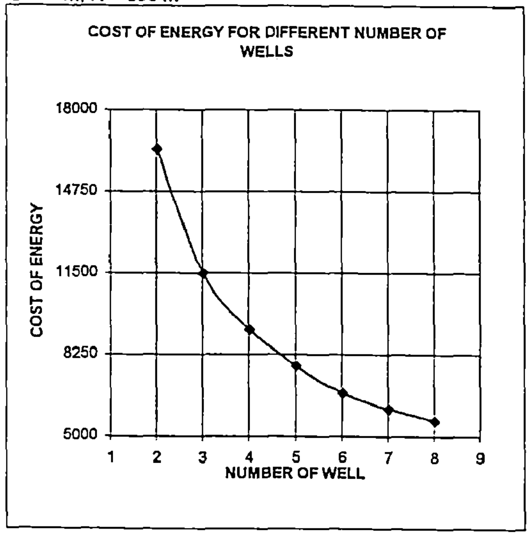
D = 2 m, R = 300 m

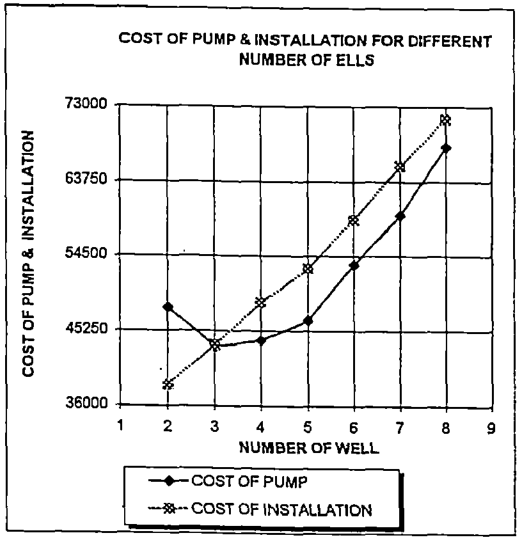


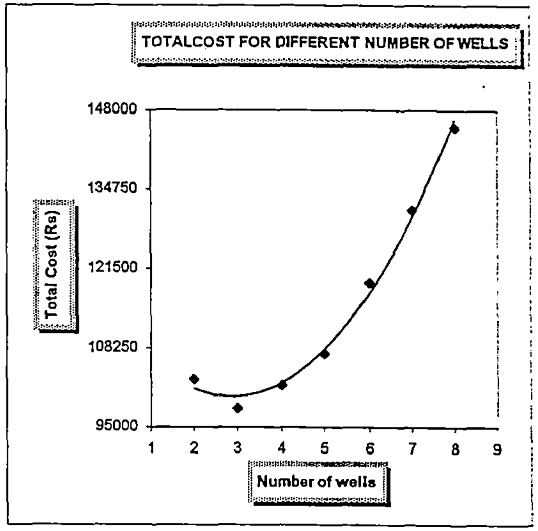




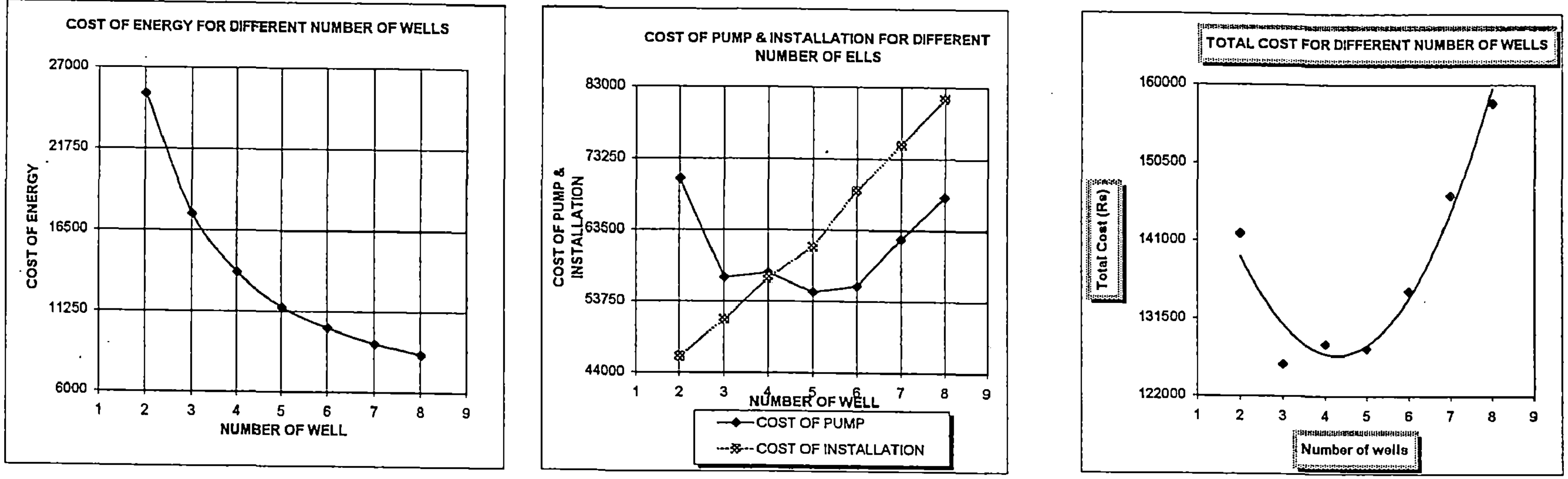
D = 3 m, R = 300 m



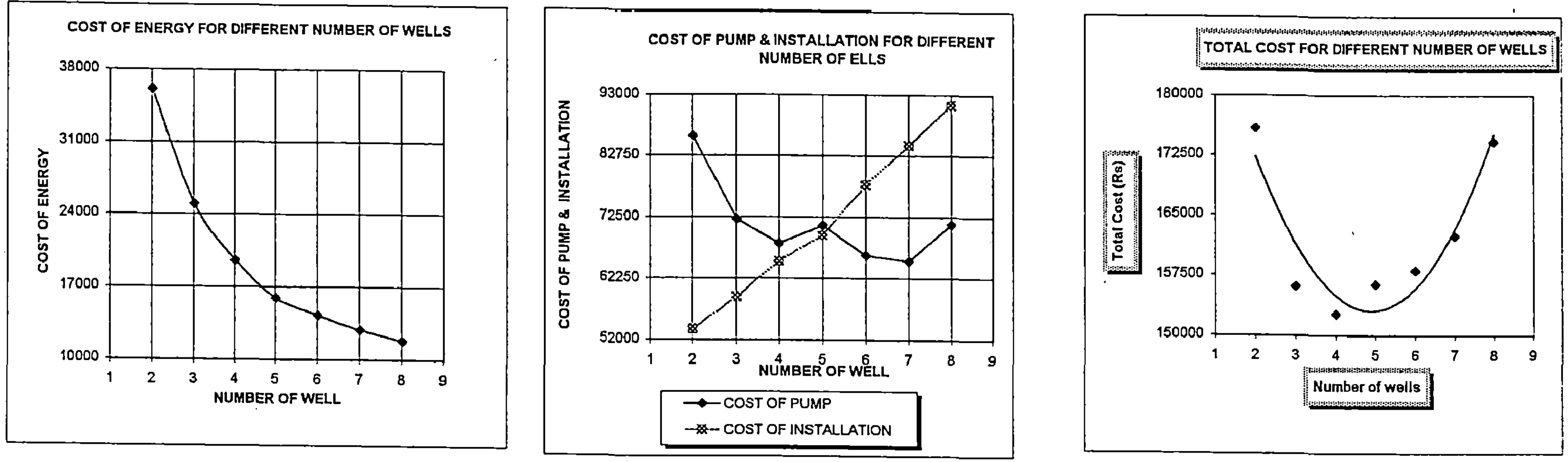




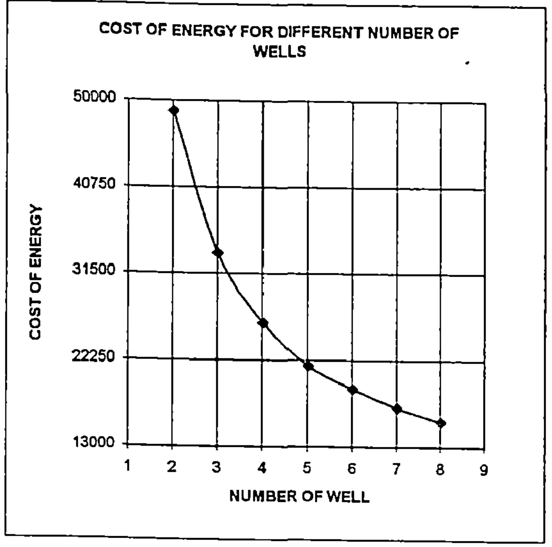
D = 4 m, R = 300 m



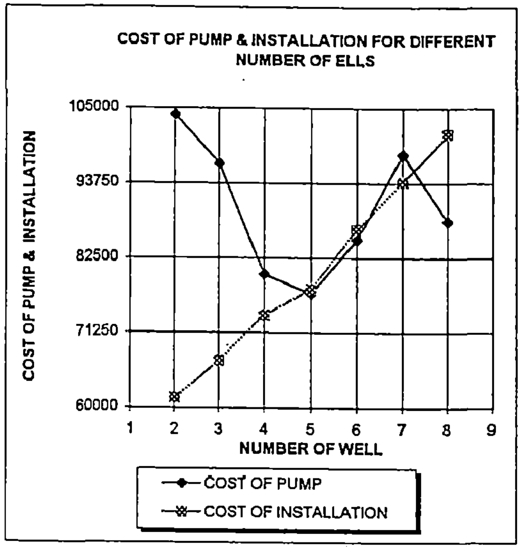
D = 5 m, R = 300 m



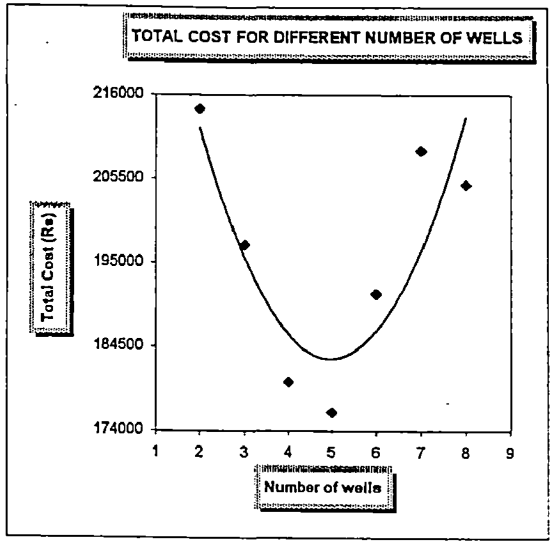
D = 6 m, R = 300 m



COST OF ENERGY FOR DIFFERENT NUMBER OF WELLS
COST OF ENERGY
50000
40750
31500
22250
13000
1 2 3 4 5 6 7 8 9
NUMBER OF WELL



COST OF PUMP & INSTALLATION FOR DIFFERENT NUMBER OF ELLS
COST OF PUMP & INSTALLATION
105000
93750
82500
71250
60000
1 2 3 4 5 6 7 8 9
NUMBER OF WELL
COST OF PUMP
COST OF INSTALLATION



TOTAL COST FOR DIFFERENT NUMBER OF WELLS
Total Cost (Rs)
216000
205500
195000
184500
174000
1 2 3 4 5 6 7 8 9
Number of wells

Tabel 3.6. Cost Calculation of Dewatering for Different Depth of Excavation with Radius = 400 m and Constan Transmisivity = 100 m2/day, Storativity = 0.01

D = 2 m, R = 400 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of Install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	2683.36	36.33	38.330	24.084	25	7806.025	23418	65400	44330	109730	133148
10	3	1788.91	24.548	26.548	11.120	12	5377.228	16132	54000	48822	102822	118954
10	4	1341.68	18.828	20.828	6.543	7	4180.908	12543	50000	53656	103656	116199
10	5	1073.34	14.498	16.498	4.146	5	3477.204	10432	55000	56245	111245	121677
10	6	894.45	13.335	15.335	3.212	4	3017.637	9053	55800	64005	119805	128858
10	7	766.67	11.826	13.826	2.482	3	2695.691	8087	62300	69391	131691	139778
10	8	670.84	10.714	12.714	1.997	2	2458.621	7376	68000	74856	142856	150232

D = 3 m, R = 400 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of Install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	3577.8	48.44	50.440	42.257	45	13677.292	41032	96000	56440	152440	193472
10	3	2385.21	32.73	34.730	19.397	20	9359.508	28079	90000	61095	151095	179174
10	4	1788.91	26.13	28.130	11.783	13	7232.758	21698	72000	68260	140260	165958
10	5	1431.14	21.49	23.490	7.872	24	6050.175	18151	72000	73725	145725	163876
10	6	1092.61	17.78	19.780	5.061	6	5164.779	15494	78000	77340	155340	170834
10	7	1022.23	15.77	17.770	4.253	5	4592.379	13777	77000	83195	160195	173972
10	8	894.45	14.29	16.290	3.412	4	4170.863	12513	74400	89160	163560	176073

D = 4 m, R = 400 m, Transmisivity = 100 m2/day, Storativity = 0.01

Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of Install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	4472.27	60.55	62.550	65.503	70	21183.463	63550	122000	68550	190550	254100
10	3	2981.51	41.93	43.930	30.669	34	14436.763	43310	108900	74895	183795	227105
10	4	2236.12	33.36	35.360	18.514	18	11113.621	33341	104000	82720	186720	220061
10	5	1788.91	27.86	29.860	12.508	13	9265.875	27798	95000	89650	184650	212448
10	6	1490.76	25.23	27.230	9.505	10	7882.450	23647	90000	99690	189690	213337
10	7	1277.79	22.43	24.430	7.309	7	6988.129	20964	99400	106505	205905	226869
10	8	1118.07	20.56	22.560	5.906	6	6329.883	18990	112000	114240	226240	245230

D = 5 m, R = 400 m, Transmisivity = 100 m2/day, Storativity = 0.01

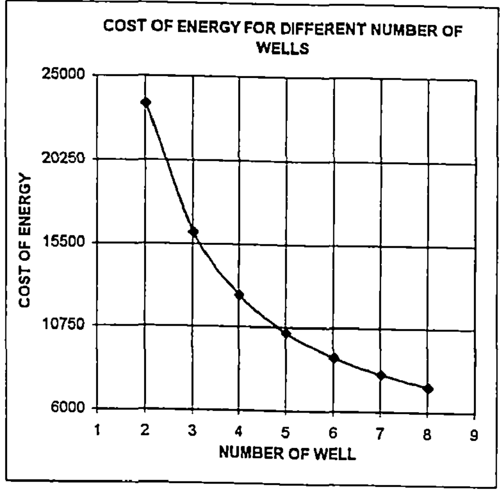
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of Install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	5366.73	72.66	74.660	93.821	95	30324.254	90973	168000	80660	248660	339633
10	3	3577.82	49.1	51.100	42.810	45	20608.971	61827	144000	85650	229650	291477
10	4	2683.36	37.66	39.660	24.919	25	15823.675	47471	128800	91320	220120	267591
10	5	2146.69	33.23	35.230	17.709	18	13162.854	39489	120000	103075	223075	262564
10	6	1788.91	31.87	33.870	14.188	15	11204.463	33613	108000	119610	227610	261223
10	7	1533.35	27.65	29.650	10.646	11	9882.938	29649	107800	124775	232575	262224
10	8	1341.68	24.32	26.320	8.269	8	8934.525	26804	115200	129280	244480	271284

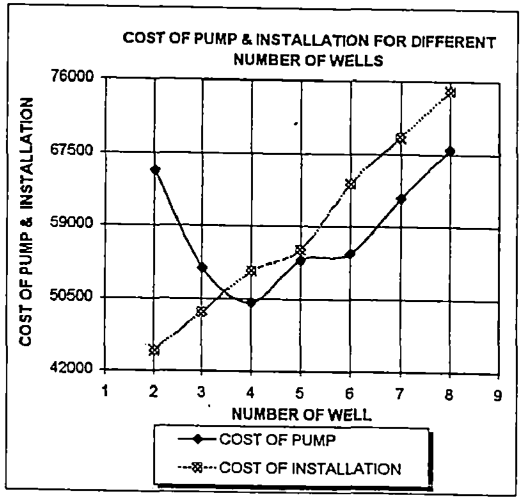
D = 6 m, R = 400 m, Transmisivity = 100 m2/day, Storativity = 0.01

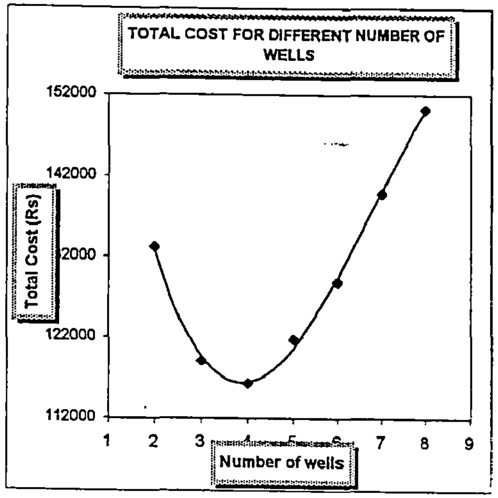
Time Step (day)	No. of wells (nos)	Discharge (m3/hr)	Depth (m)	Cor.depth (m)	Power (Hp)	Available Pump	Energy (Kwh)	Cost of energy (Rs)	Cost of pump (Rs)	Cost of Install (Rs)	Tot. cost of pump (Rs)	Total Cost (Rs)
1	2	3	4	5	6	7	8	9 = 3*8	10	11	12 = 10 + 11	13 = 9 + 11
10	2	6261.18	80.77	82.770	121.348		41099.629	123299				
10	3	4174.12	51.28	53.280	52.075	60	27876.067	83628	168000	88920	256920	340548
10	4	3130.59	39.93	41.930	30.736	34	21362.829	64088	156000	95860	251860	315948
10	5	2504.47	33.6	35.600	20.877	21	17741.108	53223	160000	104000	264000	317223
10	6	2287.06	30.12	32.120	17.201	18	15029.567	45089	156000	114360	270360	315449
10	7	1988.91	28.59	30.590	14.246	15	13276.808	39830	147000	128065	275065	314895
10	8	1765.29	25.9	27.900	11.532	12	11985.842	35958	144000	135600	279600	315558

Fig. 3.5. Cost of Energy, Cost of Pump & Installation and Total Cost for Dewatering for Different Number of Well With Radius 400 m and Constant Transmisivity = 100 m2/day, storativity = 0.01

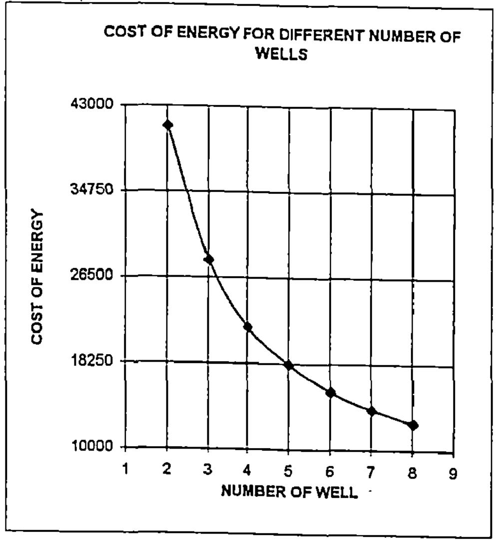
D = 2 m, R = 400 m

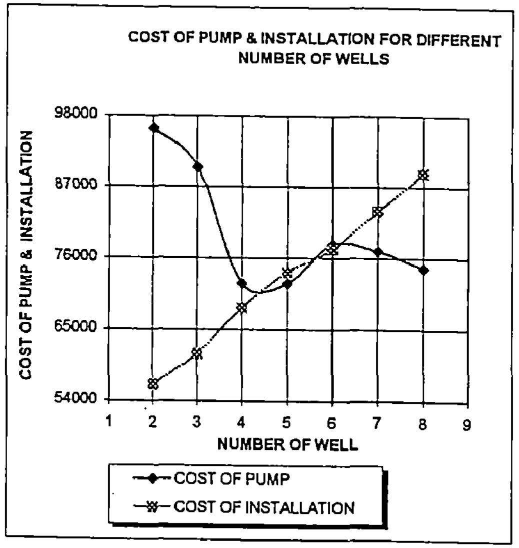


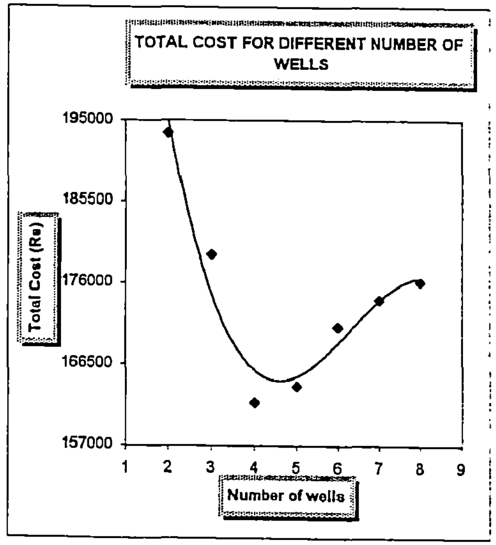




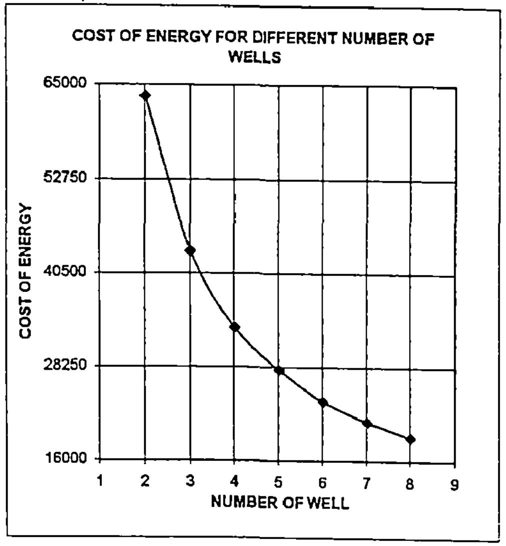
D = 3 m, R = 400 m

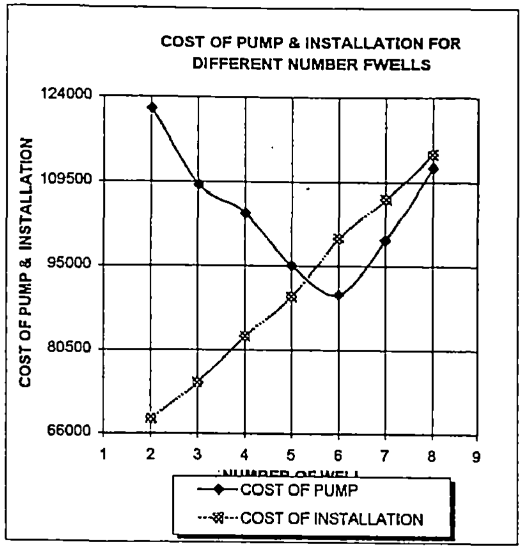


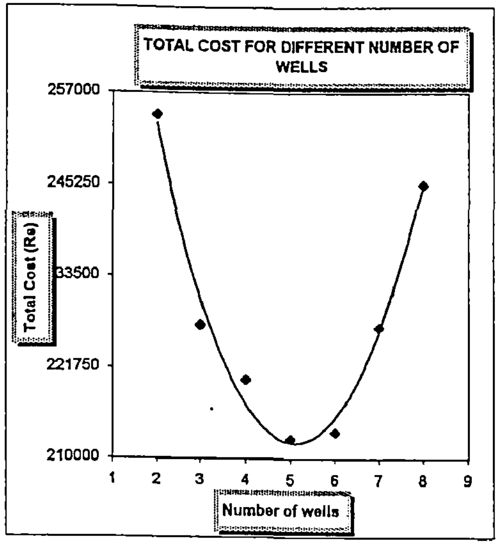




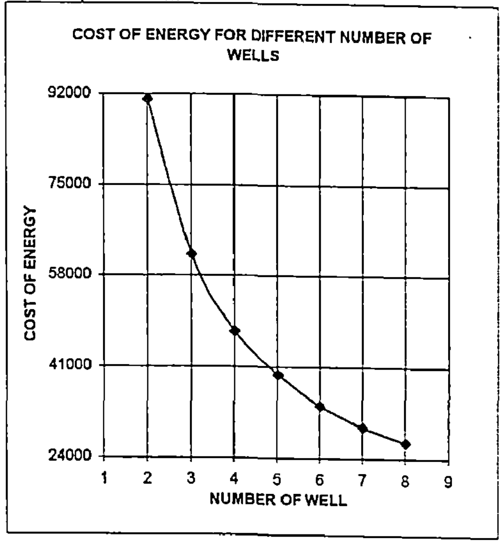
D = 4 m, R = 400 m

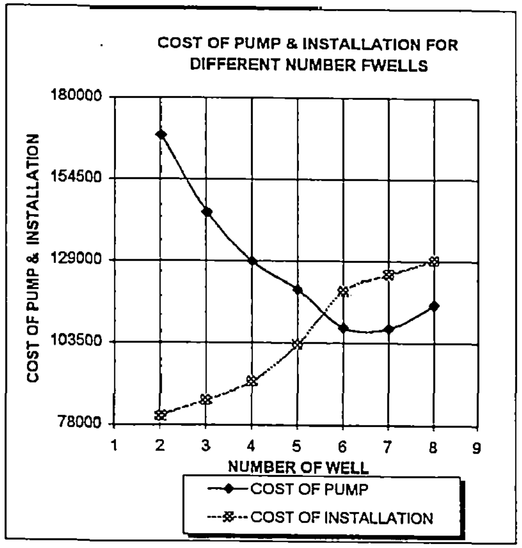


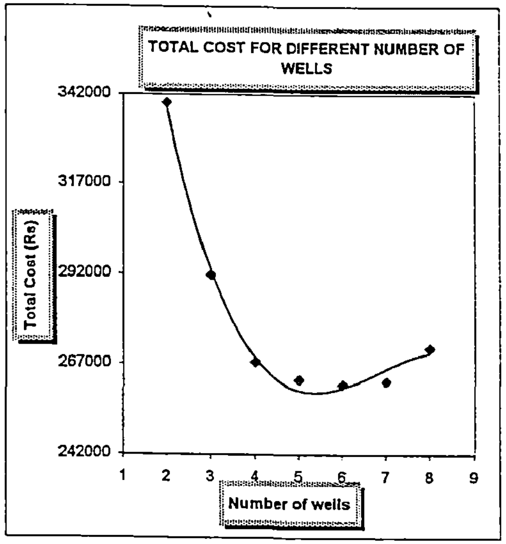




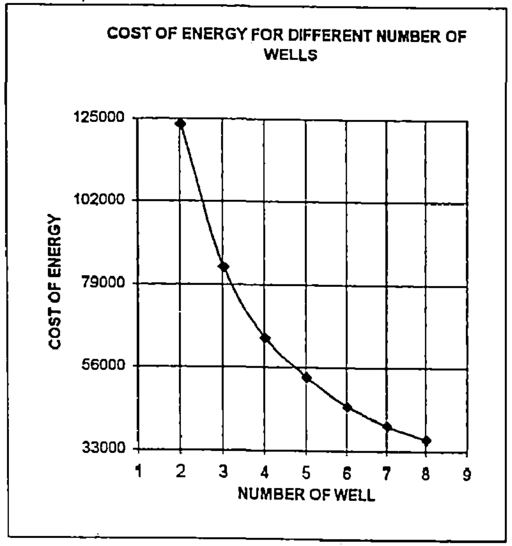
D = 5 m, R = 400 m



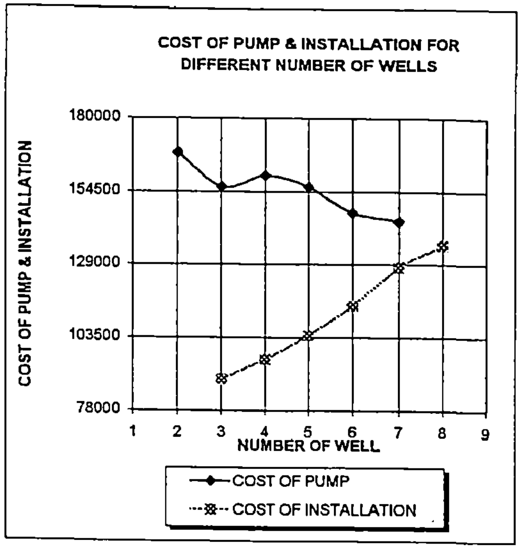




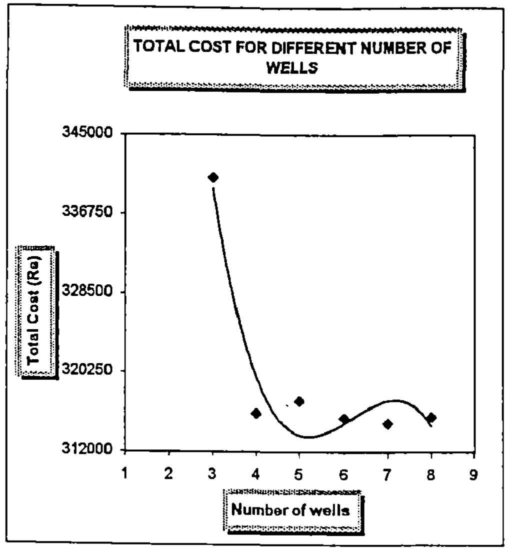
D = 6 m, R = 400 m



COST OF ENERGY FOR DIFFERENT NUMBER OF WELLS
COST OF ENERGY
125000
102000
79000
56000
33000
1 2 3 4 5 6 7 8 9
NUMBER OF WELL



COST OF PUMP & INSTALLATION FOR DIFFERENT NUMBER OF WELLS
COST OF PUMP & INSTALLATION
180000
154500
129000
103500
78000
1 2 3 4 5 6 7 8 9
NUMBER OF WELL
COST OF PUMP
COST OF INSTALLATION



TOTAL COST FOR DIFFERENT NUMBER OF WELLS
Total Cost (Rs)
345000
336750
328500
320250
312000
1 2 3 4 5 6 7 8 9
Number of wells

Table 3.7 Optimal cost for different depth of excavation & different radius of site with constant T = 100 m2/day,Storativity = 0.01

D = 3 M	COST OF DIFFERENT RADIUS OF SITE			
NO. OF WELL	100 M	200 M	300 M	400 M
2	**35457.40**	**44957.27**	**71111.60**	133148.08
3	47262.92	55796.08	75217.74	118953.68
4	60353.49	68846.58	81423.64	**116198.73**
5	73677.95	79762.30	92663.66	124176.61
6	86819.70	92848.72	105891.60	128857.91
7	100191.72	106039.81	119351.46	139778.07
8	113481.11	119294.65	128958.92	150231.86

D = 4 M	COST OF DIFFERENT RADIUS OF SITE			
NO. OF WELL	100 M	200 M	300 M	400 M
2	**40265.64**	**62371.25**	102906.20	193471.88
3	52893.70	65257.99	**98080.75**	179173.53
4	64771.25	77532.50	101923.82	165958.28
5	78345.64	90484.08	107237.00	**163875.53**
6	92027.51	103382.57	119084.52	170834.34
7	105764.89	113920.73	131222.44	173972.14
8	119567.84	127580.64	145070.44	176072.59

D = 5 M	COST OF DIFFERENT RADIUS OF SITE			
NO. OF WELL	100 M	200 M	300 M	400 M
2	**44957.27**	**72809.25**	141809.86	254100.39
3	55796.08	73987.99	**125819.09**	233105.29
4	68846.58	86648.50	128249.78	216100.86
5	79762.30	98614.08	127683.76	**212447.63**
6	92848.72	109712.57	134775.52	213337.35
7	106039.81	124210.73	146462.24	220849.39
8	119294.65	138780.64	157704.33	234429.65

D = 6 M	COST OF DIFFERENT RADIUS OF SITE			
NO. OF WELL	100 M	200 M	300 M	400 M
2	**51278.41**	**95405.86**	175835.38	339632.76
3	59963.20	96304.12	156064.35	291476.91
4	72102.93	101313.96	**152552.13**	267591.03
5	83062.22	110542.84	156300.01	262563.56
6	96792.74	121750.52	158064.23	**261223.39**
7	110352.75	133983.90	162354.38	262223.81
8	124015.24	148786.24	174137.26	265323.58

D = 7 M	COST OF DIFFERENT RADIUS OF SITE			
NO. OF WELL	100 M	200 M	300 M	400 M
2	**54357.27**	120241.96	214162.49	0
3	56996.08	**115738.26**	197186.16	349548.20
4	68846.58	121599.49	180043.80	323948.49
5	82262.30	127571.93	**176248.11**	317223.33
6	92848.72	132608.56	191050.79	315448.70
7	106039.81	145483.86	208964.48	**314895.43**
8	119294.65	160997.78	204729.00	315557.53

The results of all these cases are summarised in Table 3.7 and graphically, it is shown in Fig. 3.6. Using this table or figure, one can identify the optimal number of wells required for the prescribed site conditions and soil property.

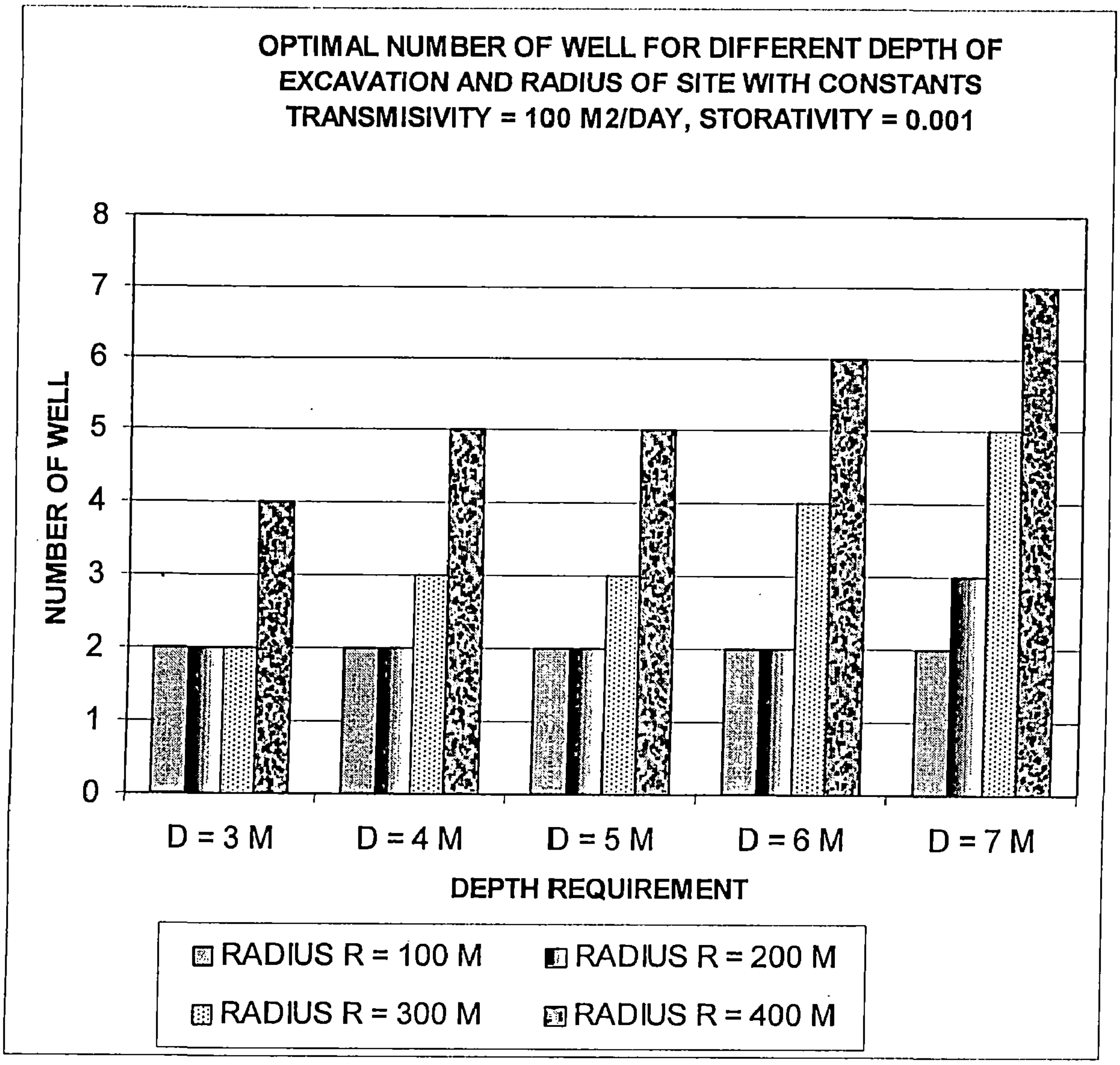


Fig 3.6. Optimal Number of Well for Different Depth of Excavation and Radius of Site with Constant Transmisivity = 100 m²/day and Storativity = 0.01

3.6. CASE II : OPTIMAL NUMBER OF DEWATERING PUMPS FOR A GIVEN RATE OF EXCAVATION

3.6.1 Description and formulation

The problem in first case deals with the optimal number of pumps required for dewatering a site in 10 days with fixed rate of pumping which is independent of the excavation schedule. However, the schedule of excavation depends on the type of equipment used, their capacity and also the depth and volume of excavation. From practical point of view, it is desired that the pumping schedule should match with that of excavation schedule. In other words, it is the excavation schedule that should govern the pumping schedule.

Case II deals with the identification of optimal pumps if the rate of excavation is fixed. For illustration purpose, the rate of excavation is assumed to be fixed as 0.5 m per day. The initial ground water table is assumed to be located at a depth of 2 m from the ground surface. The site is to be excavated up to 5 m in 10 days. The radius of site is 100m. It is required that the water table must be at least below 1 m from the level of excavation. i.e., at the end of 10 days, the water table should be at least 6 m in the site of excavation. The objective is to identify the optimal number of pumps for different soil conditions like storativity (Φ) as 0.01, 0.02 and 0.03, and the transmisivity (T) as 100 m^2/day, 200 m^2/day, 300 m^2/day and 400 m^2/day.

The above minimization problem can be stated as:

Min $C_w = C_P + C_I + C_E$

subject to

$G + S(k) - D(k) > 1m$ for all k

$Q_P(j, k) < Q_C$

$Q_P(j, k) > 0$

where,

C_W = Cost of dewatering in rupees.

C_P = Cost of pump in rupees

C_I = Cost of installation in rupees.

C_E = Cost of energy in rupees.

S (k) = Drawdown at the end of k^{th} time step

D (k) = Depth of excavation at the end of k^{th} time step

$Q_P(j,k)$ = Pumping discharge for j^{th} well at time step k time in m^3/day.

Q_P = Capacity of the machine.

The following steps have been followed to find out the optimum condition of dewatering in excavation work for this case :

- The pumping period is discretised to n units of equal time step.
- The discrete kernel δ(m) are generated making use equation (2.2) for different integer value of m.
- The number of pumps to be installed for dewatering is decided based on the analysis carried out in case I.

- The discharge is calculated which is based on the rate of excavation depth per day.
- After the value of discharge per day is obtained, the power of the machine and the energy consumed is computed.
- Based on the pumping arrangement decided, the power machine of the and the energy consumed, cost of each condition is calculated.
- From the above result, the optimum condition of pumping arrangement is found.

To find the discharge for each time step, first of all one has to determine the discrete kernel values of each condition based on equation 2.1.

With the initial water table at 2 m below the ground surface, and the rate of excavation as 0.5 m /day, the excavation can be carried out for first two days without any pumping. The dewatering will start from third day onwards. Therefore, the discrete kernel values are desired for 8 days time step only.

From these discrete kernel values, one can estimate the desired rate of pumping during the different time steps using the following mathematical expressions :

During 1st day of pumping (i.e. 3rd day of excavation)

$S(1) = N_{WELL} \times Q(1) \times \delta(1)$

$0.5\ m = N_{WELL} \times Q(1) \times \delta(1)$

$$Q(1) = \frac{0.5}{N_{well} x \delta(1)}$$

During 2nd day of pumping (i.e. 4th day of excavation)

$S(2) = N_{WELL} \times Q(1) \times \delta(2) + N_{WELL} \times Q(2) \times \delta(1)$

$1\ m = N_{WELL} \times Q(1) \times \delta(2) + N_{WELL} \times Q(2) \times \delta(1)$

$$Q(2) = \frac{1 - (N_{WELL} \times Q(1) \times \delta(2))}{N_{WELL} x \delta(1)}$$

During 3rd day of pumping (i.e. 5th day of excavation)

$S(3) = N_{WELL} \times Q(1) \times \delta(3) + N_{WELL} \times Q(2) \times \delta(2) + N_{WELL} \times Q(3)\ \delta(1)$

$1.5\ m = N_{WELL} \times Q(1) \times \delta(3) + N_{WELL} \times Q(2) \times \delta(2) + N_{WELL} \times Q(3)\ \delta(1)$

$$Q(3) = \frac{1.5 - (N_{WELL} \times Q(1) \times \delta(3) + N_{well} x Q(2) x \delta(2))}{N_{WELL} x \delta(1)}$$

-
-
-

During 8th day of pumping (i.e. 10th day of excavation)

$S(8) = N_{WELL} \times Q(1) \times \delta(8) + N_{WELL} \times Q(2) \times \delta(7) + \ldots + N_{WELL} \times Q(8)\ x\delta(1)$

$4\ m = N_{WELL} \times Q(1) \times \delta(8) + N_{WELL} \times Q(2) \times \delta(7) + \ldots + N_{WELL} \times Q(8)\ x\delta(1)$

$$Q(8) = \frac{4 - (N_{WELL} \times Q(1) \times \delta(8) + \ldots + N_{well} x Q(7) x \delta(2))}{N_{WELL} x \delta(1)}$$

where,

S(n) = Required drawdown, in this case drawdown obtained from time step 1st day to 8th day, in meter.

δ(n) = Discrete kernel value, which have been obtained from 1st day to 10th day.

Q(n) = Pumping discharge for each well from 1st day to 8th day, in m^3/day.

For all the different values of storativity (Φ = 0.01 – 0.03) and Transmisivity (T = 100 m^2/day – 400 m^2/day), the discharge values for each time step has been computed. The calculation applied for the number of pumping arrangement from 2 nos up to 6 nos.

3.6.2. Result and Discussion

The discrete kernel values for the data used in second case were calculated. Thereafter, the discharge through each pump, power of the pump, and the energy consumed are calculated for the different values of transmisivity T = 100, 200, 300, and 400 m^2/day and storativity Φ = 0.01, 0.02, and 0.03 for a radius of site as 100m. The results are shown in Table 3.8 to 3.10. The cost calculations are shown in Tables 3.11 to 3.13. Graphically, these results are shown as bar charts in Fig. 3.7 to 3.9. One can conclude that with the increase in storativity, the cost of dewatering increases, remaining the other parameters same. Also, same is the case with transmisivity. Based on these calculations, for a fixed rate of excavation, one can decide about the number of pumps to be installed so as meet the requirements of groundwater tables. One can go for lesser number of pumps of higher capacity, or the larger number of pumps with lower capacity. However, before deciding about the numbers and capacity, one has to take into consideration about the cost of installation and the cost of running the pumps etc. Final decision should be based on the total cost of dewatering. The calculations shown in the tables help in the process of decision making about the dewatering system to be finally decided.

Table 3.8. Calculation of discharge, power of machine, and energy consumed based on discrete kernel value for different transmisivity with constant storativity = 0.01, radius = 100 m

Transmisivity = 100 m2/day R = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
8.31E-04	4.61E-04	2.91E-04	2.13E-04	1.68E-04
6	**7**	**8**	**9**	**10**
1.39E-04	1.16E-04	1.03E-04	9.10E-05	8.17E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	300.84	2.5	0.1761	6.3061
	Q (2)	518.26	3.0	0.3641	13.0361
	Q (3)	706.10	3.5	0.5787	20.7212
2 WELLS	Q (4)	878.22	4.0	0.8226	29.4540
	Q (5)	1040.17	4.5	1.0960	39.2465
	Q (6)	1194.83	5.0	1.3989	50.0910
	Q (7)	1343.89	5.5	1.7307	61.9741
	Q (8)	1488.46	6.0	2.0912	74.8808
				Tot. Energy	295.7099
	Q (1)	200.56	2.5	0.1174	4.2041
	Q (2)	364.04	3.0	0.2557	9.1571
	Q (3)	510.95	3.5	0.4187	14.9945
3 WELLS	Q (4)	648.13	4.0	0.6071	21.7373
	Q (5)	778.70	4.5	0.8205	29.3811
	Q (6)	904.40	5.0	1.0588	37.9150
	Q (7)	1026.28	5.5	1.3217	47.3271
	Q (8)	1145.06	6.0	1.6087	57.6052
				Tot. Energy	222.3215
	Q (1)	150.42	2.5	0.0881	3.1531
	Q (2)	279.99	3.0	0.1967	7.0427
	Q (3)	399.26	3.5	0.3272	11.7169
4 WELLS	Q (4)	512.16	4.0	0.4797	17.1771
	Q (5)	620.58	4.5	0.6539	23.4150
	Q (6)	725.62	5.0	0.8495	30.4204
	Q (7)	827.98	5.5	1.0663	38.1828
	Q (8)	928.14	6.0	1.3040	46.6924
				Tot. Energy	177.8003
	Q (1)	120.34	2.5	0.0704	2.5224
	Q (2)	227.33	3.0	0.1597	5.7181
	Q (3)	327.36	3.5	0.2683	9.6068
5 WELLS	Q (4)	422.94	4.0	0.3961	14.1847
	Q (5)	515.32	4.5	0.5430	19.4433
	Q (6)	605.24	5.0	0.7086	25.3737
	Q (7)	693.21	5.5	0.8927	31.9674
	Q (8)	779.53	6.0	1.0952	39.2166
				Tot. Energy	148.0330
	Q (1)	100.28	2.5	0.0587	2.1020
	Q (2)	191.29	3.0	0.1344	4.8117
	Q (3)	277.30	3.5	0.2273	8.1378
6 WELLS	Q (4)	360.04	4.0	0.3372	12.0750
	Q (5)	440.38	4.5	0.4640	16.6160
	Q (6)	518.88	5.0	0.6075	21.7530
	Q (7)	595.88	5.5	0.7674	27.4792
	Q (8)	671.63	6.0	0.9436	33.7881
				Tot. Energy	126.7628

Transmisivity = 200 m2/day R = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
6.46E-04	2.52E-04	1.53E-04	1.10E-04	8.63E-05
6	**7**	**8**	**9**	**10**
7.09E-05	6.02E-05	5.23E-05	4.62E-05	4.14E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	387.06	2.5	0.2266	8.1133
	Q (2)	698.58	3.0	0.4907	17.5719
	Q (3)	978.91	3.5	0.8023	28.7272
2 WELLS	Q (4)	1241.21	4.0	1.1625	41.6283
	Q (5)	1491.32	4.5	1.5714	56.2686
	Q (6)	1732.42	5.0	2.0283	72.6283
	Q (7)	1966.47	5.5	2.5325	90.6845
	Q (8)	2194.79	6.0	3.0835	110.4146
				Tot. Energy	426.0367
	Q (1)	258.04	2.5	0.1511	5.4089
	Q (2)	482.50	3.0	0.3389	12.1368
	Q (3)	690.92	3.5	0.5662	20.2760
3 WELLS	Q (4)	889.39	4.0	0.8330	29.8286
	Q (5)	1080.83	4.5	1.1389	40.7805
	Q (6)	1266.94	5.0	1.4833	53.1141
	Q (7)	1448.80	5.5	1.8658	66.8121
	Q (8)	1627.15	6.0	2.2860	81.8583
				Tot. Energy	310.2153
	Q (1)	193.53	2.5	0.1133	4.0567
	Q (2)	368.17	3.0	0.2586	9.2610
	Q (3)	533.18	3.5	0.4370	15.6467
4 WELLS	Q (4)	691.97	4.0	0.6481	23.2077
	Q (5)	846.29	4.5	0.8917	31.9310
	Q (6)	997.14	5.0	1.1674	41.8031
	Q (7)	1145.19	5.5	1.4748	52.8110
	Q (8)	1290.91	6.0	1.8136	64.9429
				Tot. Energy	243.6599
	Q (1)	154.82	2.5	0.0906	3.2453
	Q (2)	297.56	3.0	0.2090	7.4848
	Q (3)	433.89	3.5	0.3556	12.7330
5 WELLS	Q (4)	566.00	4.0	0.5301	18.9829
	Q (5)	695.02	4.5	0.7323	26.2238
	Q (6)	821.63	5.0	0.9619	34.4452
	Q (7)	946.27	5.5	1.2186	43.6374
	Q (8)	1069.25	6.0	1.5022	53.7915
				Tot. Energy	200.5439
	Q (1)	129.02	2.5	0.0755	2.7044
	Q (2)	249.65	3.0	0.1754	6.2795
	Q (3)	365.71	3.5	0.2997	10.7323
6 WELLS	Q (4)	478.73	4.0	0.4484	16.0560
	Q (5)	589.50	4.5	0.6212	22.2423
	Q (6)	698.49	5.0	0.8178	29.2828
	Q (7)	806.02	5.5	1.0380	37.1700
	Q (8)	912.33	6.0	1.2818	45.8970
				Tot. Energy	170.3643

Transmisivity = 300 m2/day R = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
5.28E-04	1.73E-04	1.04E-04	7.45E-05	5.81E-05
6	**7**	**8**	**9**	**10**
4.76E-05	4.04E-05	3.50E-05	3.09E-05	2.77E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	473.75	2.5	0.277329	9.930613
	Q (2)	869.81	3.0	0.611008	21.87896
	Q (3)	1231.96	3.5	1.009645	36.15337
2 WELLS	Q (4)	1573.89	4.0	1.474136	52.78588
	Q (5)	1901.88	4.5	2.004002	71.7593
	Q (6)	2219.43	5.0	2.598453	93.0454
	Q (7)	2528.75	5.5	3.256652	116.6142
	Q (8)	2831.32	6.0	3.9778	142.4371
				Tot. Energy	**544.6048**
	Q (1)	315.84	2.5	0.184886	6.620409
	Q (2)	597.14	3.0	0.419468	15.02031
	Q (3)	861.49	3.5	0.706025	25.28133
3 WELLS	Q (4)	1115.10	4.0	1.04442	37.39858
	Q (5)	1361.02	4.5	1.434107	51.3525
	Q (6)	1601.06	5.0	1.87448	67.12139
	Q (7)	1836.36	5.5	2.364956	84.68435
	Q (8)	2067.72	6.0	2.904996	104.0221
				Tot. Energy	**391.501**
	Q (1)	236.88	2.5	0.138665	4.965307
	Q (2)	454.33	3.0	0.31915	11.42811
	Q (3)	661.71	3.5	0.542302	19.41874
4 WELLS	Q (4)	862.52	4.0	0.807853	28.9276
	Q (5)	1058.53	4.5	1.115367	39.93906
	Q (6)	1250.80	5.0	1.464401	52.43727
	Q (7)	1440.03	5.5	1.854541	66.4074
	Q (8)	1626.71	6.0	2.285409	81.83592
				Tot. Energy	**305.3594**
	Q (1)	189.50	2.5	0.110932	3.972245
	Q (2)	366.57	3.0	0.257503	9.220668
	Q (3)	536.99	3.5	0.440089	15.75869
5 WELLS	Q (4)	702.99	4.0	0.658436	23.57726
	Q (5)	865.72	4.5	0.912206	32.66429
	Q (6)	1025.88	5.0	1.201071	43.00795
	Q (7)	1183.93	5.5	1.524725	54.59735
	Q (8)	1340.20	6.0	1.882891	67.42257
				Tot. Energy	**250.221**
	Q (1)	157.92	2.5	0.092443	3.310204
	Q (2)	307.20	3.0	0.215799	7.727323
	Q (3)	451.78	3.5	0.37025	13.25791
6 WELLS	Q (4)	593.18	4.0	0.555581	19.89423
	Q (5)	732.21	4.5	0.771527	27.62684
	Q (6)	869.37	5.0	1.017836	36.44668
	Q (7)	1004.99	5.5	1.294276	46.34543
	Q (8)	1139.30	6.0	1.600635	57.31555
				Tot. Energy	**211.9242**

Transmisivity = 400 m2/day R = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
4.49E-04	1.32E-04	7.86E-05	5.62E-05	4.38E-05
6	**7**	**8**	**9**	**10**
3.59E-05	3.04E-05	2.63E-05	2.33E-05	2.08E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	556.79	2.5	0.3259	11.6712
	Q (2)	1031.86	3.0	0.7248	25.9554
	Q (3)	1470.18	3.5	1.2049	43.1442
2 WELLS	Q (4)	1886.20	4.0	1.7667	63.2602
	Q (5)	2286.68	4.5	2.4095	86.2781
	Q (6)	2675.44	5.0	3.1323	112.1625
	Q (7)	3054.90	5.5	3.9343	140.8778
	Q (8)	3426.71	6.0	4.8143	172.3899
				Tot. Energy	**655.7393**
	Q (1)	371.20	2.5	0.2173	7.7808
	Q (2)	706.07	3.0	0.4960	17.7604
	Q (3)	1022.83	3.5	0.8383	30.0162
3 WELLS	Q (4)	1328.00	4.0	1.2438	44.5390
	Q (5)	1624.81	4.5	1.7121	61.3052
	Q (6)	1915.16	5.0	2.2422	80.2896
	Q (7)	2200.31	5.5	2.8337	101.4682
	Q (8)	2481.11	6.0	3.4858	124.8191
				Tot. Energy	**467.9786**
	Q (1)	278.40	2.5	0.1630	5.8356
	Q (2)	536.36	3.0	0.3768	13.4916
	Q (3)	783.64	3.5	0.6422	22.9969
4 WELLS	Q (4)	1023.89	4.0	0.9590	34.3395
	Q (5)	1258.97	4.5	1.3266	47.5018
	Q (6)	1490.01	5.0	1.7445	62.4658
	Q (7)	1717.75	5.5	2.2122	79.2149
	Q (8)	1942.73	6.0	2.7294	97.7342
				Tot. Energy	**363.5803**
	Q (1)	222.72	2.5	0.1304	4.6685
	Q (2)	432.36	3.0	0.3037	10.8755
	Q (3)	634.97	3.5	0.5204	18.6339
5 WELLS	Q (4)	832.87	4.0	0.7801	27.9333
	Q (5)	1027.28	4.5	1.0824	38.7602
	Q (6)	1218.94	5.0	1.4271	51.1016
	Q (7)	1408.33	5.5	1.8137	64.9456
	Q (8)	1595.80	6.0	2.2420	80.2811
				Tot. Energy	**297.1997**
	Q (1)	185.60	2.5	0.1086	3.8904
	Q (2)	362.12	3.0	0.2544	9.1086
	Q (3)	533.66	3.5	0.4374	15.6609
6 WELLS	Q (4)	701.84	4.0	0.6574	23.5387
	Q (5)	867.51	4.5	0.9141	32.7317
	Q (6)	1031.17	5.0	1.2073	43.2299
	Q (7)	1193.19	5.5	1.5367	55.0244
	Q (8)	1353.81	6.0	1.9020	68.1069
				Tot. Energy	**251.2914**

Table 3.9. Calculation of discharge, power of machine, and energy consumed based on discrete kernel value for different transmisivity with constant storativity = 0.02, radius = 100 m

Transmisivity = 100 m2/day Radius = 100 m
Storativity = 0.02
Discrete kernel value from time step 1 - 10

1	2	3	4	5
4.46E-04	3.86E-04	2.63E-04	1.98E-04	1.59E-04
6	7	8	9	10
1.32E-04	1.14E-04	9.94E-05	8.84E-05	7.95E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
2 WELLS	Q (1)	561.17	2.5	0.3285	11.7629
	Q (2)	879.48	3.0	0.6178	22.1222
	Q (3)	1137.37	3.5	0.9321	33.3775
	Q (4)	1368.28	4.0	1.2816	45.8899
	Q (5)	1582.66	4.5	1.6676	59.7151
	Q (6)	1785.49	5.0	2.0904	74.8531
	Q (7)	1979.50	5.5	2.5493	91.2852
	Q (8)	2166.56	6.0	3.0439	108.9944
				Tot. Energy	448.0004
3 WELLS	Q (1)	374.11	2.5	0.2190	7.8420
	Q (2)	640.29	3.0	0.4498	16.1057
	Q (3)	864.04	3.5	0.7081	25.3562
	Q (4)	1065.80	4.0	0.9983	35.7454
	Q (5)	1253.80	4.5	1.3211	47.3069
	Q (6)	1432.15	5.0	1.6767	60.0400
	Q (7)	1603.18	5.5	2.0647	73.9311
	Q (8)	1768.43	6.0	2.4845	88.9654
				Tot. Energy	355.2928
4 WELLS	Q (1)	280.58	2.5	0.1643	5.8815
	Q (2)	500.45	3.0	0.3516	12.5883
	Q (3)	692.08	3.5	0.5672	20.3099
	Q (4)	867.58	4.0	0.8126	29.0974
	Q (5)	1032.48	4.5	1.0879	38.9564
	Q (6)	1189.76	5.0	1.3929	49.8784
	Q (7)	1341.18	5.5	1.7272	61.8492
	Q (8)	1487.93	6.0	2.0904	74.8544
				Tot. Energy	293.4154
5 WELLS	Q (1)	224.47	2.5	0.1314	4.7052
	Q (2)	410.08	3.0	0.2881	10.3150
	Q (3)	575.93	3.5	0.4720	16.9013
	Q (4)	729.83	4.0	0.6836	24.4772
	Q (5)	875.58	4.5	0.9226	33.0361
	Q (6)	1015.33	5.0	1.1887	42.5658
	Q (7)	1150.42	5.5	1.4816	53.0520
	Q (8)	1281.74	6.0	1.8008	64.4813
				Tot. Energy	249.5340
6 WELLS	Q (1)	187.06	2.5	0.1095	3.9210
	Q (2)	347.13	3.0	0.2438	8.7316
	Q (3)	492.70	3.5	0.4038	14.4589
	Q (4)	629.16	4.0	0.5893	21.1009
	Q (5)	759.24	4.5	0.8000	28.6467
	Q (6)	884.55	5.0	1.0356	37.0830
	Q (7)	1006.10	5.5	1.2957	46.3967
	Q (8)	1124.58	6.0	1.5800	56.5753
				Tot. Energy	216.9140

Transmisivity = 200 m2/day Radius = 100 m
Storativity = 0.02
Discrete kernel value from time step 1 - 10

1	2	3	4	5
4.16E-04	2.30E-04	1.46E-04	1.07E-04	8.40E-05
6	7	8	9	10
6.93E-05	5.90E-05	5.14E-05	4.55E-05	4.08E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
2 WELLS	Q (1)	601.68	2.5	0.3522	12.6122
	Q (2)	1036.55	3.0	0.7281	26.0732
	Q (3)	1412.24	3.5	1.1574	41.4439
	Q (4)	1756.46	4.0	1.6451	58.9090
	Q (5)	2080.37	4.5	2.1921	78.4939
	Q (6)	2389.68	5.0	2.7978	100.1827
	Q (7)	2687.79	5.5	3.4615	123.9487
	Q (8)	2976.93	6.0	4.1824	149.7626
				Tot. Energy	591.4262
3 WELLS	Q (1)	401.12	2.5	0.2348	8.4082
	Q (2)	728.10	3.0	0.5115	18.3146
	Q (3)	1021.93	3.5	0.8375	29.9898
	Q (4)	1296.28	4.0	1.2141	43.4753
	Q (5)	1557.42	4.5	1.6410	58.7627
	Q (6)	1808.80	5.0	2.1177	75.8306
	Q (7)	2052.56	5.5	2.6434	94.6547
	Q (8)	2290.13	6.0	3.2175	115.2111
				Tot. Energy	444.6469
4 WELLS	Q (1)	300.84	2.5	0.1761	6.3061
	Q (2)	559.98	3.0	0.3934	14.0856
	Q (3)	798.54	3.5	0.6544	23.4342
	Q (4)	1024.33	4.0	0.9594	34.3546
	Q (5)	1241.17	4.5	1.3078	46.8305
	Q (6)	1451.26	5.0	1.6991	60.8411
	Q (7)	1655.97	5.5	2.1326	76.3658
	Q (8)	1856.28	6.0	2.6079	93.3853
				Tot. Energy	355.6032
5 WELLS	Q (1)	240.67	2.5	0.1409	5.0449
	Q (2)	454.66	3.0	0.3194	11.4364
	Q (3)	654.73	3.5	0.5366	19.2139
	Q (4)	845.88	4.0	0.7923	28.3696
	Q (5)	1030.64	4.5	1.0860	38.8868
	Q (6)	1210.50	5.0	1.4172	50.7477
	Q (7)	1386.42	5.5	1.7855	63.9351
	Q (8)	1559.08	6.0	2.1904	78.4335
				Tot. Energy	296.0678
6 WELLS	Q (1)	200.56	2.5	0.1174	4.2041
	Q (2)	382.59	3.0	0.2688	9.6235
	Q (3)	554.61	3.5	0.4545	16.2758
	Q (4)	720.08	4.0	0.6744	24.1503
	Q (5)	880.77	4.5	0.9281	33.2321
	Q (6)	1037.76	5.0	1.2150	43.5062
	Q (7)	1191.76	5.5	1.5348	54.9586
	Q (8)	1343.26	6.0	1.8872	67.5764
				Tot. Energy	253.5270

Transmisivity = 300 m2/day Radius = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
3.65E-04	1.63E-04	1.00E-04	7.27E-05	5.70E-05
6	7	8	9	10
4.69E-05	3.99E-05	3.46E-05	3.06E-05	2.75E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	685.68	2.5	0.4014	14.3730
	Q (2)	1218.00	3.0	0.8556	30.6374
	Q (3)	1690.21	3.5	1.3852	49.6012
2 WELLS	Q (4)	2128.61	4.0	1.9937	71.3904
	Q (5)	2544.53	4.5	2.6812	96.0069
	Q (6)	2944.00	5.0	3.4468	123.4215
	Q (7)	3330.71	5.5	4.2895	153.5971
	Q (8)	3707.10	6.0	5.2082	186.4959
				Tot. Energy	725.5232
	Q (1)	457.12	2.5	0.2676	9.5820
	Q (2)	846.08	3.0	0.5943	21.2822
	Q (3)	1203.24	3.5	0.9861	35.3106
3 WELLS	Q (4)	1541.02	4.0	1.4433	51.6834
	Q (5)	1865.30	4.5	1.9655	70.3794
	Q (6)	2179.44	5.0	2.5516	91.3690
	Q (7)	2485.55	5.5	3.2010	114.6221
	Q (8)	2785.06	6.0	3.9128	140.1100
				Tot. Energy	534.3386
	Q (1)	342.84	2.5	0.2007	7.1865
	Q (2)	647.34	3.0	0.4547	16.2831
	Q (3)	932.53	3.5	0.7642	27.3661
4 WELLS	Q (4)	1205.42	4.0	1.1290	40.4279
	Q (5)	1469.52	4.5	1.5484	55.4463
	Q (6)	1726.89	5.0	2.0218	72.3966
	Q (7)	1978.85	5.5	2.5485	91.2555
	Q (8)	2226.32	6.0	3.1278	112.0012
				Tot. Energy	422.3631
	Q (1)	274.27	2.5	0.1606	5.7492
	Q (2)	524.01	3.0	0.3681	13.1808
	Q (3)	760.83	3.5	0.6235	22.3275
5 WELLS	Q (4)	989.22	4.0	0.9265	33.1771
	Q (5)	1211.48	4.5	1.2765	45.7101
	Q (6)	1428.98	5.0	1.6730	59.9071
	Q (7)	1642.61	5.5	2.1154	75.7497
	Q (8)	1853.02	6.0	2.6034	93.2212
				Tot. Energy	349.0226
	Q (1)	228.56	2.5	0.1338	4.7910
	Q (2)	440.08	3.0	0.3091	11.0697
	Q (3)	642.38	3.5	0.5265	18.8514
6 WELLS	Q (4)	838.56	4.0	0.7854	28.1239
	Q (5)	1030.22	4.5	1.0855	38.8709
	Q (6)	1218.35	5.0	1.4264	51.0769
	Q (7)	1403.59	5.5	1.8076	64.7273
	Q (8)	1586.41	6.0	2.2288	79.8089
				Tot. Energy	297.3200

Transmisivity = 400 m2/day Radius = 100 m
Storativity = 0.01
Discrete kernel value from time step 1 - 10

1	2	3	4	5
3.23E-04	1.26E-04	7.66E-05	5.52E-05	4.32E-05
6	7	8	9	10
3.55E-05	3.01E-05	2.61E-05	2.31E-05	2.07E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	773.99	2.5	0.4531	16.2241
	Q (2)	1397.02	3.0	0.9814	35.1405
	Q (3)	1957.68	3.5	1.6044	57.4505
2 WELLS	Q (4)	2482.28	4.0	2.3250	83.2519
	Q (5)	2982.49	4.5	3.1426	112.5315
	Q (6)	3464.67	5.0	4.0563	145.2497
	Q (7)	3932.76	5.5	5.0648	181.3607
	Q (8)	4389.38	6.0	6.1668	220.8198
				Tot. Energy	852.0287
	Q (1)	516.00	2.5	0.3021	10.8161
	Q (2)	964.90	3.0	0.6778	24.2709
	Q (3)	1381.72	3.5	1.1324	40.5480
3 WELLS	Q (4)	1778.62	4.0	1.6659	59.6521
	Q (5)	2161.48	4.5	2.2775	81.5544
	Q (6)	2533.68	5.0	2.9664	106.2199
	Q (7)	2897.39	5.5	3.7314	133.6140
	Q (8)	3254.07	6.0	4.5717	163.7047
				Tot. Energy	620.3800
	Q (1)	387.00	2.5	0.2265	8.1121
	Q (2)	736.25	3.0	0.5172	18.5196
	Q (3)	1066.24	3.5	0.8738	31.2899
4 WELLS	Q (4)	1383.80	4.0	1.2961	46.4106
	Q (5)	1692.41	4.5	1.7833	63.8557
	Q (6)	1994.08	5.0	2.3346	83.5981
	Q (7)	2290.17	5.5	2.9494	105.6121
	Q (8)	2581.59	6.0	3.6270	129.8740
				Tot. Energy	487.2722
	Q (1)	309.60	2.5	0.1812	6.4896
	Q (2)	595.04	3.0	0.4180	14.9676
	Q (3)	867.68	3.5	0.7111	25.4630
5 WELLS	Q (4)	1131.88	4.0	1.0601	37.9615
	Q (5)	1389.90	4.5	1.4645	52.4418
	Q (6)	1643.08	5.0	1.9237	68.8831
	Q (7)	1892.33	5.5	2.4370	87.2657
	Q (8)	2138.28	6.0	3.0041	107.5721
				Tot. Energy	401.0444
	Q (1)	258.00	2.5	0.1510	5.4080
	Q (2)	499.22	3.0	0.3507	12.5574
	Q (3)	731.34	3.5	0.5994	21.4619
6 WELLS	Q (4)	957.36	4.0	0.8967	32.1082
	Q (5)	1178.86	4.5	1.2422	44.4794
	Q (6)	1396.82	5.0	1.6354	58.5589
	Q (7)	1611.86	5.5	2.0758	74.3316
	Q (8)	1824.45	6.0	2.5632	91.7839
				Tot. Energy	340.6893

Table 3.10. Calculation of discharge, power of machine, and energy consumed based on discrete kernel value for different transmisivity with constant storativity = 0.03, radius = 100 m

Transmisivity = 100 m2/day R = 100 m
Storativity = 0.03
Discrete kernel value from time step 1 - 10

1	2	3	4	5
2.71E-04	3.23E-04	2.37E-04	1.84E-04	1.50E-04
6	**7**	**8**	**9**	**10**
1.27E-04	1.09E-04	9.61E-05	8.58E-05	7.75E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	923.19	2.5	0.5404238	19.351494
	Q (2)	1295.81	3.0	0.9102588	32.594548
	Q (3)	1592.45	3.5	1.305083	46.732412
2 WELLS	Q (4)	1861.39	4.0	1.7434116	62.428082
	Q (5)	2111.62	4.5	2.2250067	79.673041
	Q (6)	2347.95	5.0	2.7489237	98.433459
	Q (7)	2573.54	5.5	3.3143367	118.67977
	Q (8)	2790.68	6.0	3.9207057	140.39263
				Tot. Energy	598.28543
	Q (1)	615.46	2.5	0.3602825	12.900996
	Q (2)	986.22	3.0	0.6927855	24.807263
	Q (3)	1274.57	3.5	1.0445661	37.403821
3 WELLS	Q (4)	1527.51	4.0	1.4306983	51.230445
	Q (5)	1760.39	4.5	1.8549201	66.42098
	Q (6)	1979.66	5.0	2.3177341	82.993424
	Q (7)	2188.75	5.5	2.81879	100.93523
	Q (8)	2389.90	6.0	3.3576337	120.23015
				Tot. Energy	496.92231
	Q (1)	461.60	2.5	0.2702119	9.6757471
	Q (2)	785.55	3.0	0.551819	19.759533
	Q (3)	1049.46	3.5	0.8600785	30.79769
4 WELLS	Q (4)	1282.88	4.0	1.2015737	43.025951
	Q (5)	1498.00	4.5	1.5784381	56.520713
	Q (6)	1700.63	5.0	1.9910588	71.295835
	Q (7)	1894.00	5.5	2.4391961	87.342734
	Q (8)	2080.15	6.0	2.922462	104.64752
				Tot. Energy	423.06572
	Q (1)	369.28	2.5	0.2161695	7.7405977
	Q (2)	650.46	3.0	0.4569255	16.361588
	Q (3)	887.97	3.5	0.727727	26.05845
5 WELLS	Q (4)	1101.06	4.0	1.0312769	36.927962
	Q (5)	1298.69	4.5	1.3684222	49.000463
	Q (6)	1485.49	5.0	1.7391717	62.27626
	Q (7)	1664.17	5.5	2.1432011	76.743746
	Q (8)	1836.47	6.0	2.5801094	92.388556
				Tot. Energy	367.49762
	Q (1)	307.73	2.5	0.1801413	6.450498
	Q (2)	554.29	3.0	0.3893659	13.942413
	Q (3)	768.08	3.5	0.6294716	22.540118
6 WELLS	Q (4)	962.41	4.0	0.9014094	32.277669
	Q (5)	1143.90	4.5	1.2053239	43.16024
	Q (6)	1316.20	5.0	1.5409674	55.178962
	Q (7)	1481.49	5.5	1.9079379	68.319442
	Q (8)	1641.23	6.0	2.3058153	82.566634
				Tot. Energy	324.43597

Transmisivity = 200 m2/day R = 100 m
Storativity = 0.03
Discrete kernel value from time step 1 - 10

1	2	3	4	5
2.97E-04	2.11E-04	1.38E-04	1.03E-04	8.16E-05
6	**7**	**8**	**9**	**10**
6.77E-05	5.79E-05	5.05E-05	4.48E-05	4.03E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	842.03	2.5	0.4929	17.6503
	Q (2)	1385.29	3.0	0.9731	34.8453
	Q (3)	1838.44	3.5	1.5067	53.9512
2 WELLS	Q (4)	2247.52	4.0	2.1051	75.3784
	Q (5)	2629.15	4.5	2.7703	99.1997
	Q (6)	2991.38	5.0	3.5022	125.4076
	Q (7)	3338.90	5.5	4.3000	153.9746
	Q (8)	3674.71	6.0	5.1627	184.8663
				Tot. Energy	745.2734
	Q (1)	561.36	2.5	0.3286	11.7669
	Q (2)	989.92	3.0	0.6954	24.9003
	Q (3)	1362.74	3.5	1.1168	39.9910
3 WELLS	Q (4)	1704.63	4.0	1.5966	57.1707
	Q (5)	2026.36	4.5	2.1352	76.4562
	Q (6)	2333.57	5.0	2.7321	97.8303
	Q (7)	2629.64	5.5	3.3866	121.2667
	Q (8)	2916.78	6.0	4.0979	146.7363
				Tot. Energy	576.1184
	Q (1)	421.02	2.5	0.2465	8.8252
	Q (2)	767.34	3.0	0.5390	19.3015
	Q (3)	1077.88	3.5	0.8834	31.6317
4 WELLS	Q (4)	1367.07	4.0	1.2804	45.8493
	Q (5)	1641.73	4.5	1.7299	61.9436
	Q (6)	1905.66	5.0	2.2311	79.8913
	Q (7)	2161.24	5.5	2.7834	99.6666
	Q (8)	2410.05	6.0	3.3859	121.2438
				Tot. Energy	468.3531
	Q (1)	336.81	2.5	0.1972	7.0601
	Q (2)	625.82	3.0	0.4396	15.7418
	Q (3)	890.24	3.5	0.7296	26.1251
5 WELLS	Q (4)	1139.30	4.0	1.0671	38.2102
	Q (5)	1377.61	4.5	1.4516	51.9783
	Q (6)	1607.84	5.0	1.8824	67.4057
	Q (7)	1831.69	5.5	2.3589	84.4690
	Q (8)	2050.30	6.0	2.8805	103.1459
				Tot. Energy	394.1362
	Q (1)	280.68	2.5	0.1643	5.8834
	Q (2)	528.16	3.0	0.3710	13.2852
	Q (3)	757.77	3.5	0.6210	22.2378
6 WELLS	Q (4)	975.90	4.0	0.9140	32.7302
	Q (5)	1185.82	4.5	1.2495	44.7420
	Q (6)	1389.49	5.0	1.6268	58.2515
	Q (7)	1588.15	5.5	2.0453	73.2382
	Q (8)	1782.69	6.0	2.5045	89.6829
				Tot. Energy	340.0512

Transmisivity = 300 m2/day R = 100 m
Storativity = 0.03
Discrete kernel value from time step 1 - 10

1	2	3	4	5
2.77E-04	1.54E-04	9.71E-05	7.10E-05	5.60E-05
6	7	8	9	10
4.62E-05	3.93E-05	3.43E-05	3.03E-05	2.72E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	902.53	2.5	0.52833	18.9184
	Q (2)	1554.82	3.0	1.09221	39.1098
	Q (3)	2118.38	3.5	1.7361	62.1662
2 WELLS	Q (4)	2634.74	4.0	2.46775	88.3651
	Q (5)	3120.61	4.5	3.28818	117.743
	Q (6)	3584.59	5.0	4.19675	150.277
	Q (7)	4031.77	5.5	5.19233	185.927
	Q (8)	4465.48	6.0	6.27368	224.648
				Tot. Energy	**887.154**
	Q (1)	601.68	2.5	0.35222	12.6122
	Q (2)	1092.16	3.0	0.7672	27.4719
	Q (3)	1532.91	3.5	1.25628	44.9849
3 WELLS	Q (4)	1944.44	4.0	1.8212	65.2137
	Q (5)	2336.16	4.5	2.46161	88.1452
	Q (6)	2713.24	5.0	3.1766	113.748
	Q (7)	3078.89	5.5	3.96515	141.984
	Q (8)	3435.24	6.0	4.82627	172.819
				Tot. Energy	**666.979**
	Q (1)	451.26	2.5	0.26416	9.45918
	Q (2)	839.97	3.0	0.59005	21.1285
	Q (3)	1197.82	3.5	0.98166	35.1513
4 WELLS	Q (4)	1536.51	4.0	1.43913	51.5323
	Q (5)	1861.78	4.5	1.96175	70.2464
	Q (6)	2176.91	5.0	2.54867	91.2627
	Q (7)	2483.99	5.5	3.19901	114.55
	Q (8)	2784.46	6.0	3.91196	140.08
				Tot. Energy	**533.41**
	Q (1)	361.01	2.5	0.21133	7.56734
	Q (2)	681.98	3.0	0.47907	17.1545
	Q (3)	982.10	3.5	0.80487	28.8208
5 WELLS	Q (4)	1268.83	4.0	1.18841	42.5547
	Q (5)	1545.97	4.5	1.62899	58.3307
	Q (6)	1815.76	5.0	2.12584	76.1222
	Q (7)	2079.64	5.5	2.67827	95.9036
	Q (8)	2338.63	6.0	3.28562	117.651
				Tot. Energy	**444.105**
	Q (1)	300.84	2.5	0.17611	6.30612
	Q (2)	573.88	3.0	0.40313	14.4353
	Q (3)	831.92	3.5	0.68179	24.4137
6 WELLS	Q (4)	1080.12	4.0	1.01166	36.2256
	Q (5)	1321.16	4.5	1.39211	49.8485
	Q (6)	1556.66	5.0	1.82249	65.2598
	Q (7)	1787.66	5.5	2.30224	82.4385
	Q (8)	2014.91	6.0	2.8308	101.365
				Tot. Energy	**380.293**

Transmisivity = 400 m2/day R = 100 m
Storativity = 0.03
Discrete kernel value from time step 1 - 10

1	2	3	4	5
2.54E-04	1.21E-04	7.47E-05	5.42E-05	4.26E-05
6	7	8	9	10
3.51E-05	2.98E-05	2.59E-05	2.29E-05	2.06E-05

NO. OF WELL	STEP DISCHARGE	DISCARGHE M3/DAY	HEAD M	POWER HP	ENERGY KWH
	Q (1)	985.03	2.5	0.5766	20.6477
	Q (2)	1736.22	3.0	1.2196	43.6726
	Q (3)	2398.00	3.5	1.9653	70.3720
2 WELLS	Q (4)	3010.21	4.0	2.8194	100.9578
	Q (5)	3589.71	4.5	3.7825	135.4423
	Q (6)	4145.40	5.0	4.8533	173.7881
	Q (7)	4682.69	5.5	6.0306	215.9442
	Q (8)	5205.12	6.0	7.3128	261.8577
				Tot. Energy	**1022.6824**
	Q (1)	656.69	2.5	0.3844	13.7651
	Q (2)	1209.44	3.0	0.8496	30.4221
	Q (3)	1714.24	3.5	1.4049	50.3063
3 WELLS	Q (4)	2190.06	4.0	2.0513	73.4514
	Q (5)	2645.86	4.5	2.7879	99.8304
	Q (6)	3086.67	5.0	3.6138	129.4026
	Q (7)	3515.64	5.5	4.5276	162.1253
	Q (8)	3934.94	6.0	5.5283	197.9576
				Tot. Energy	**757.2608**
	Q (1)	492.51	2.5	0.2883	10.3238
	Q (2)	926.57	3.0	0.6509	23.3068
	Q (3)	1331.33	3.5	1.0911	39.0695
4 WELLS	Q (4)	1717.57	4.0	1.6087	57.6047
	Q (5)	2090.64	4.5	2.2029	78.8813
	Q (6)	2453.64	5.0	2.8727	102.8640
	Q (7)	2808.59	5.5	3.6170	129.5190
	Q (8)	3156.87	6.0	4.4352	158.8147
				Tot. Energy	**600.3837**
	Q (1)	394.01	2.5	0.2306	8.2591
	Q (2)	750.61	3.0	0.5273	18.8807
	Q (3)	1087.57	3.5	0.8913	31.9160
5 WELLS	Q (4)	1411.77	4.0	1.3223	47.3485
	Q (5)	1726.71	4.5	1.8194	65.1502
	Q (6)	2034.50	5.0	2.3819	85.2925
	Q (7)	2336.50	5.5	3.0091	107.7485
	Q (8)	2633.67	6.0	3.7001	132.4937
				Tot. Energy	**497.0891**
	Q (1)	328.34	2.5	0.1922	6.8826
	Q (2)	630.70	3.0	0.4430	15.8646
	Q (3)	919.02	3.5	0.7532	26.9696
6 WELLS	Q (4)	1198.03	4.0	1.1221	40.1800
	Q (5)	1470.21	4.5	1.5492	55.4722
	Q (6)	1737.06	5.0	2.0337	72.8229
	Q (7)	1999.56	5.5	2.5751	92.2106
	Q (8)	2258.42	6.0	3.1729	113.6159
				Tot. Energy	**424.0184**

Tab. 3.11. Cost calculation of dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.01, radius = 100 m

NO. OF WELL	COST OF DEWATERING FOR DIFFERENT TRANSMISIVITY AND CONSTANT STORATIVITY = 0.01, RADIUS OF SITE = 100 M													
	T = 100 M2/DAY							T = 200 M2/DAY						
	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)
2	2.091	3	17800	295.710	1774	12000	31574	3.084	4	18600	426.037	2556	12000	33156
3	1.609	2	25500	222.321	2001	18000	45501	2.286	3	26700	310.215	2792	18000	47492
4	1.304	2	34000	177.800	2134	24000	60134	1.814	2	34000	243.660	2924	24000	60924
5	1.095	2	42500	148.033	2220	30000	74720	1.502	2	42500	200.544	3008	30000	75508
6	0.944	1	51000	126.763	2282	36000	89282	1.282	2	51000	170.364	3067	36000	90067
	T = 300 M2/DAY							T = 400 M2/DAY						
2	3.978	4	18600	544.605	3268	12000	33868	4.814	5	22000	655.739	3934	12000	37934
3	2.905	3	26700	391.501	3524	18000	48224	3.486	4	33000	467.979	4212	18000	55212
4	2.285	3	35600	305.359	3664	24000	63264	2.729	3	44000	363.580	4363	24000	72363
5	1.883	2	42500	250.221	3753	18000	64253	2.242	3	55000	297.200	4458	30000	89458
6	1.601	2	51000	211.924	3815	24000	78815	1.902	2	66000	251.291	4523	36000	106523

Tab. 3.12. Cost calculation of dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.02, radius = 100 m

NO. OF WELL	COST OF DEWATERING FOR DIFFERENT TRANSMISIVITY AND CONSTANT STORATIVITY (0.02), RADIUS OF SITE (100 M)													
	T = 100 M2/DAY							T = 200 M2/DAY						
	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)
2	3.0439	4	18600	448.0004	2688	12000	33288	4.182	5	22000	591.426	3549	12000	37549
3	2.4845	3	26700	355.2928	3198	18000	47898	3.217	4	27900	444.647	4002	18000	49902
4	2.0904	3	35600	293.4154	3521	24000	63121	2.608	3	35600	355.603	4267	24000	63867
5	1.8008	2	42500	249.5340	3743	30000	76243	2.190	3	44500	296.068	4441	30000	78941
6	1.5800	2	51000	216.9140	3904	36000	90904	1.887	2	51000	253.527	4563	36000	91563
	T = 300 M2/DAY							T = 400 M2/DAY						
2	5.208	6	28000	725.523	4353	12000	44353	6.167	7	28400	852.029	5112	12000	45512
3	3.913	4	27900	534.339	4809	18000	50709	4.572	5	33000	620.380	5583	18000	56583
4	3.128	4	37200	422.363	5068	24000	66268	3.627	4	37200	487.272	5847	24000	67047
5	2.603	3	44500	349.023	5235	18000	67735	3.004	3	44500	401.044	6016	30000	80516
6	2.229	3	53400	297.320	5352	24000	82752	2.563	3	53400	340.689	6132	36000	95532

Tab. 3.13. Cost calculation of dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.03, radius = 100 m

NO. OF WELL	COST OF DEWATERING FOR DIFFERENT TRANSMISIVITY AND CONSTANT STORATIVITY (0.01), RADIUS OF SITE (100 M)													
	T = 100 M2/DAY							T = 200 M2/DAY						
	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)	HIGHEST POWER HP	POWER AVAILABLE HP	COST OF PUMP	TOTAL ENERGY KWH	COST OF ENERGY (RS)	COST OF INSTALL (RS)	TOTAL COST (RS)
2	3.921	4	18600	598.285	3590	12000	34190	5.163	6	28000	745.273	4472	12000	44472
3	3.358	4	27900	496.922	4472	18000	50372	4.098	5	33000	576.118	5185	18000	56185
4	2.922	3	35600	423.066	5077	24000	64677	3.386	4	37200	468.353	5620	24000	66820
5	2.580	3	44500	367.498	5512	30000	80012	2.881	3	44500	394.136	5912	30000	80412
6	2.306	3	53400	324.436	5840	36000	95240	2.505	3	53400	340.051	6121	36000	95521
	T = 300 M2/DAY							T = 400 M2/DAY						
2	6.274	7	28400	887.154	5323	12000	45723	7.313	8	28800	1022.682	6136	12000	46936
3	4.826	5	33000	666.979	6003	18000	57003	5.528	6	42000	757.261	6815	18000	66815
4	3.912	4	37200	533.410	6401	24000	67601	4.435	5	44000	600.384	7205	24000	75205
5	3.286	4	46500	444.105	6662	18000	71162	3.700	4	46500	497.089	7456	30000	83956
6	2.831	3	53400	380.293	6845	24000	84245	3.173	4	55800	424.018	7632	36000	99432

Fig.3.7 Cost analysis for dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.01, radius = 100 m

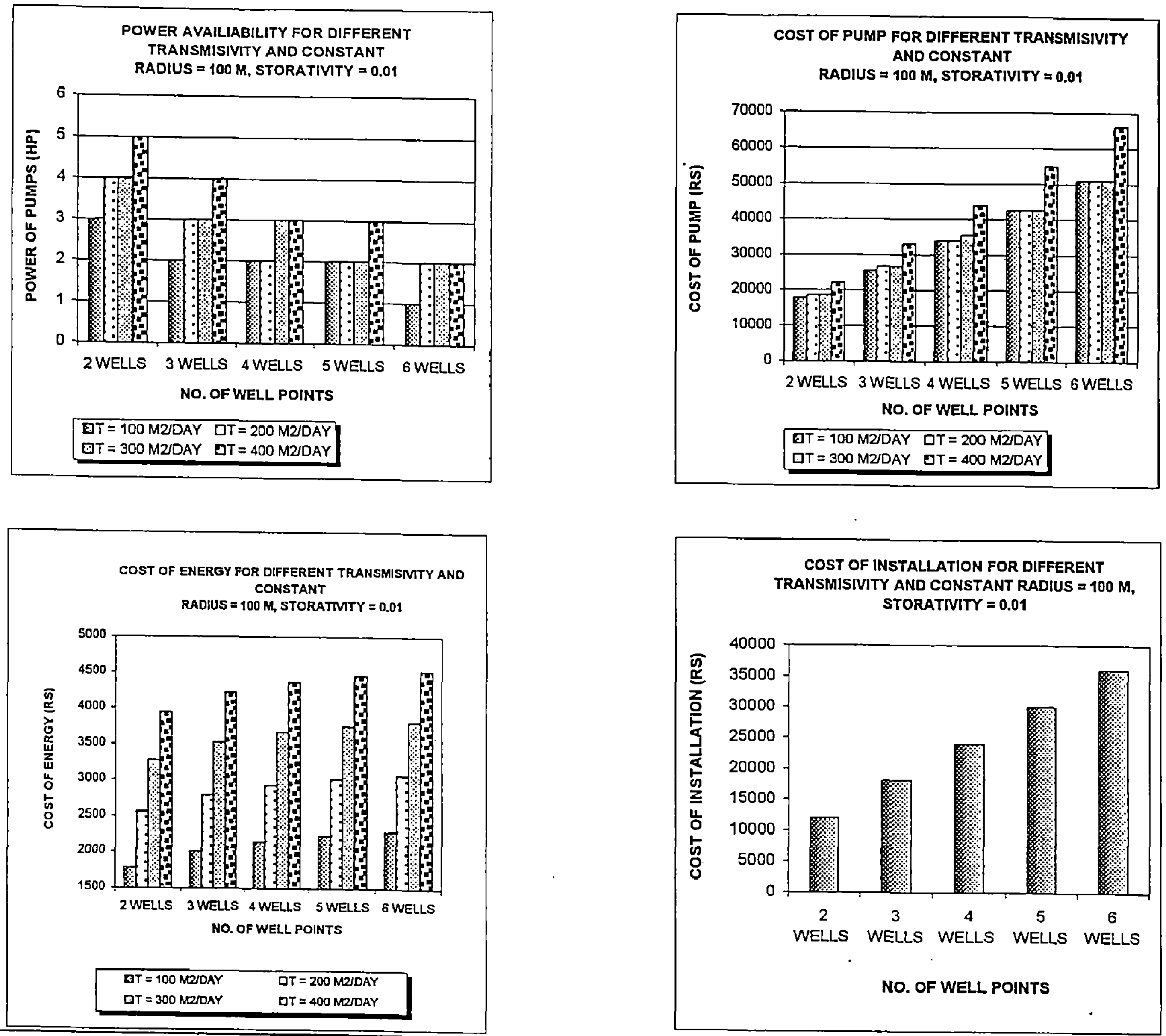


Fig.3.8 Cost analysis for dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.02, radius = 100 m

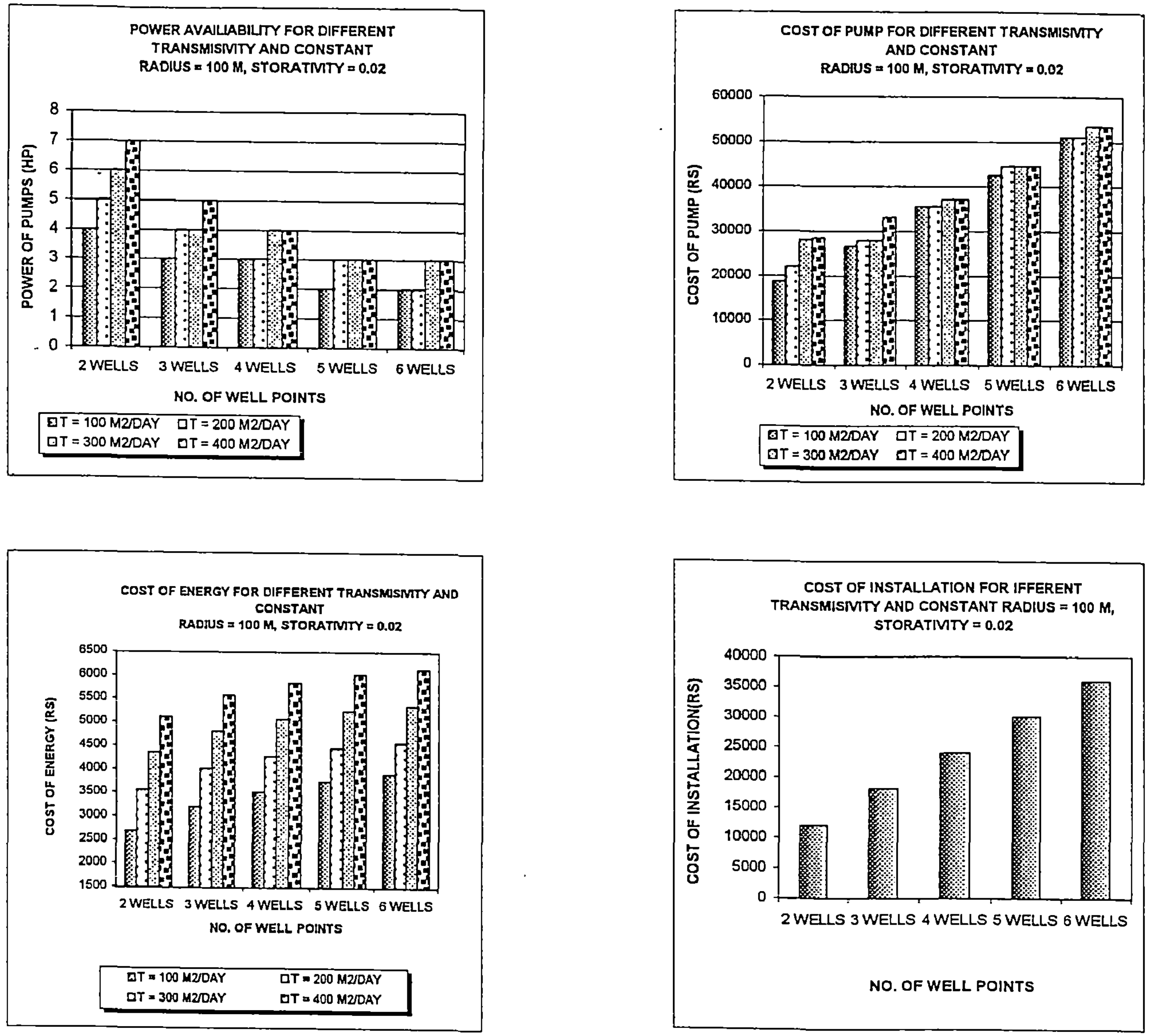
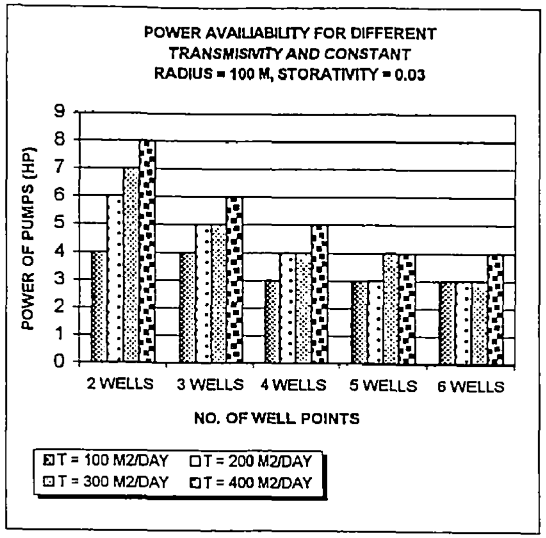
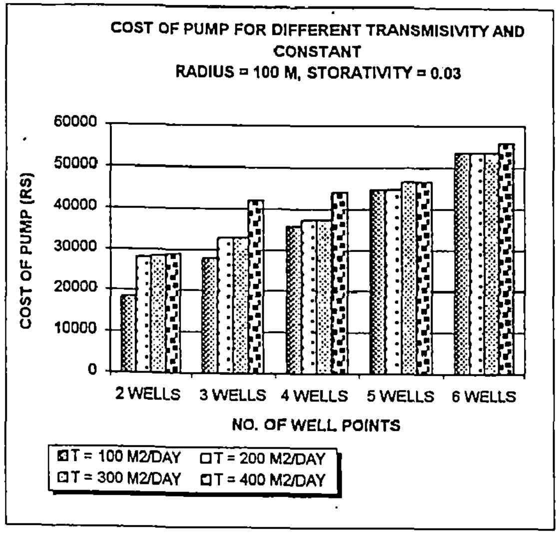
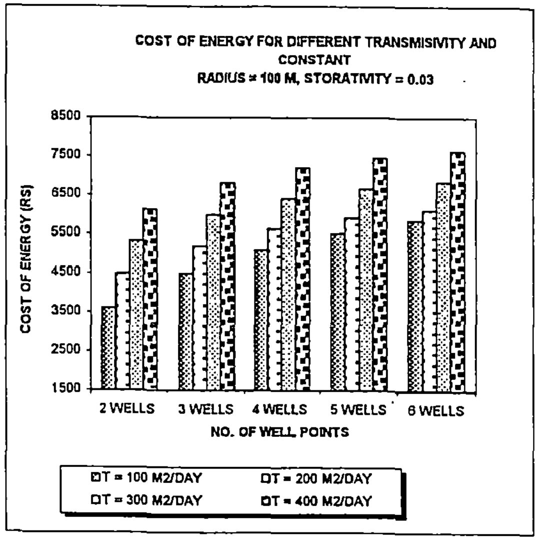


Fig.3.9 Cost analysis for dewatering with fixed rate of excavation for different transmisivity and constant storativity = 0.03, radius = 100 m







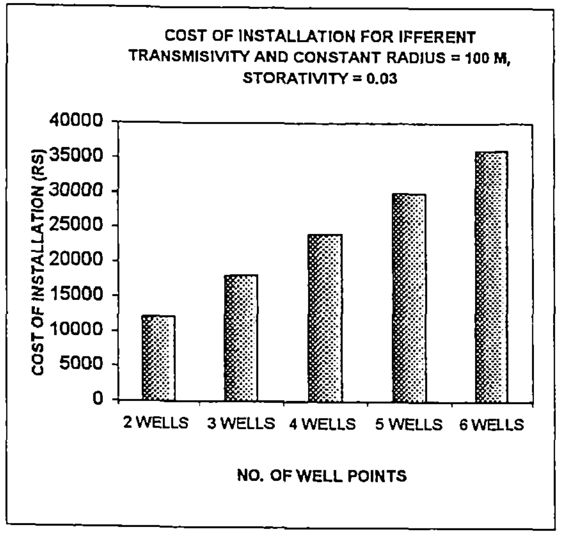
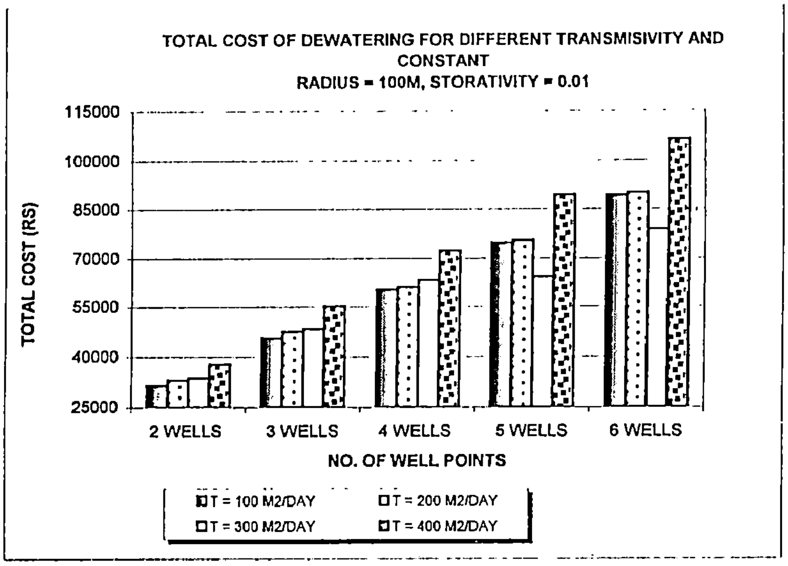
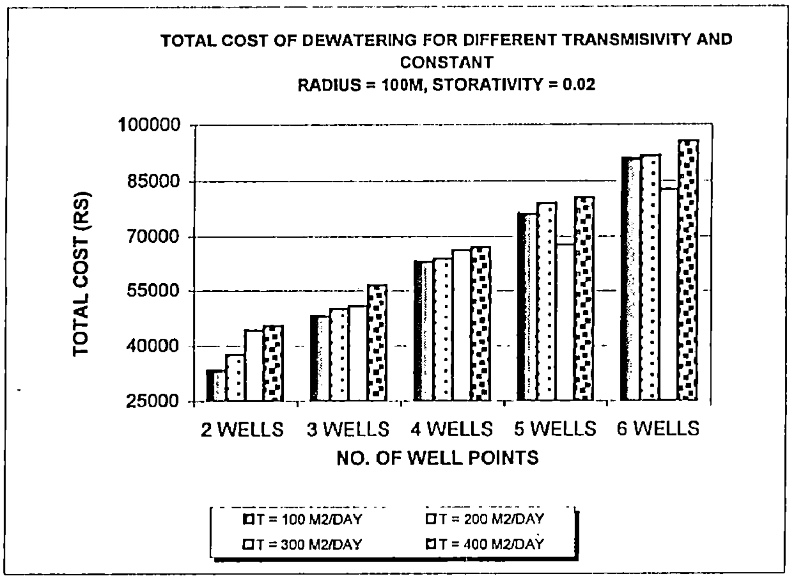
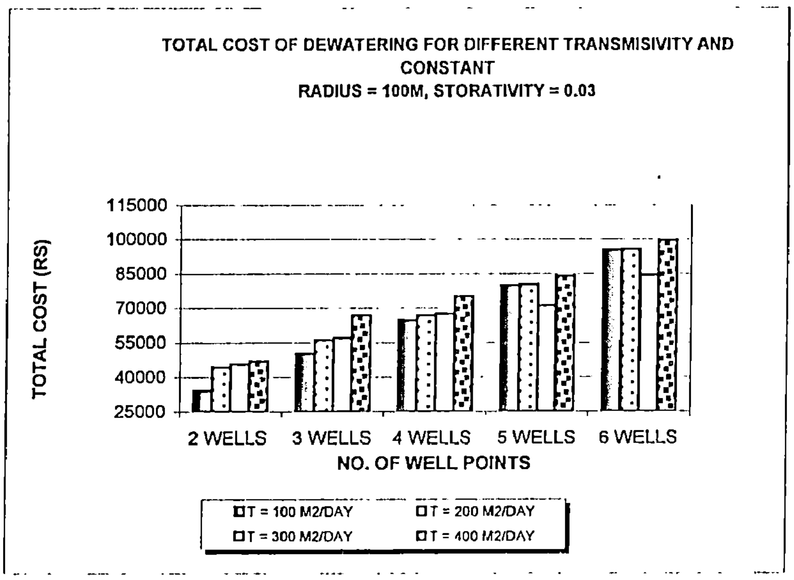


Fig. 3.10. Total cost of dewatering with fixed rate of excavation for different transmisivity and storativity with constan radius







CHAPTER IV

CONCLUSION

Excavation of site is an important construction activity. The excavation becomes more difficult if the water table in the construction activity zone is high. Under such circumstances, the engineers have to go for dewatering the area to such an extent so that the excavation work can be carried out with out any difficulty. The aim of present study is to decide about the dewatering system for a given site. Naturally, the dewatering will depends upon the size of the site, and the soil characteristics such as transmissivity and storativity. Also, the problem can be in two forms, i.e., i) to decide about the optimal number of pumps required to be installed for carrying out the excavation in fixed duration of time, and, ii) to decide about the optimal number of dewatering units if the rate of excavation is fixed which may be because of capacity of equipments, etc. The present study has attempted to find the solution for both these problems. The whole methodology has been explained with the help of illustrative examples dealing with different sizes of the site, and soil and ground water conditions.

As far as location of dewatering pumps is considered, the best location is the centre point of the site as the cone of depression at a well–point is circular. However, it will cause hindrance in the excavation work. Therefore, it is assumed that site must be clear of the pumps and pipelines, and, the well points can only be constructed at the periphery of the site.

The methodology based on discrete kernel approach is very useful to account for variable pumping rate and analyzing the drawdown for dewatering purpose. The discrete kernel approach is also very useful to obtain cost for dewatering work.

Based on these calculations, one can decide about the optimal number of pumps for given depth of dewatering and the radius of site as shown in case i). For a fixed rate of excavation as shown in case ii), one can decide about the number of pumps to be installed so as to meet the requirements of groundwater tables. One can go for lesser number of pumps of higher capacity, or larger number of pumps with lower capacity. However, before deciding about the numbers and capacity, one has to take into consideration about the cost of installation and the cost of running the pumps etc. Final decision should be based on the total cost of dewatering.

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APPENDIXES

- **APPENDIX – A**

Program of Drawdown Calculation

- **APPENDIX – B**

Input and Output of Program

```
      DIMENSION THEISK(20,20,100),QP(20,100),DRAW(20,20,100),ENC(100),
     1 PX(20),PY(20),OX(20),OY(20),TDRAW(20,0:100),ENERGY(10,100)
      OPEN (UNIT=1,FILE='DIN21.DAT',STATUS='OLD')
      OPEN (UNIT=2,FILE='DIN21.OUT',STATUS='UNKNOWN')
C      IN THEISK(I,J,K),I=OBSERVATION POINT,J=PUMPING POINT,K=TIME

      PAI=3.14159265

      READ(1,*)TRANS
      READ(1,*)STOR
      READ(1,*)PRATE
      READ(1,*)NTIME
C      NUMBER OF OBSERVATIN WELLS INCLUDE PUMPING WELLS
      READ(1,*)NPWELL,NOWELL
       READ(1,*)RW
      WRITE(2,701)
701   FORMAT(6X,'TRANS')
      WRITE(2,702)TRANS
702   FORMAT(F10.0)
      WRITE(2,703)
703   FORMAT(6X,'STOR')
      WRITE(2,704)STOR
704   FORMAT(F10.3)
      WRITE(2,705)
705   FORMAT(6X,'PUMPING RATE')
      WRITE(2,702)PRATE
      WRITE(2,706)
706   FORMAT(6X,'WELL RADIUS')
      WRITE(2,704)RW

C     POSITION OF PUMPING WELLS ARE LOCATED FROM J=1 TO J=NPWELL
      DO  J=1,NPWELL
       DO  K=1,NTIME
       QP(J,K)=PRATE
      END DO
      END DO
```

```
      ISTART=NPWELL+1
      DO  J=ISTART,NOWELL
      DO  K=1,NTIME
      QP(J,K)=0.
      END DO
      END DO

      DO J=1,NOWELL
      READ(1,*)PX(J),PY(J)
      OX(J)=PX(J)
      OY(J)=PY(J)
      END DO
      WRITE(2,707)
707   FORMAT(8X,'X', 8X, 'Y')
708   FORMAT(2F10.1)
      DO J=1,NOWELL
      WRITE(2,708)PX(J),PY(J)
      END DO


C     DRAWDOWN IS TO BE COMPUTED AT EXCAVATION SITE TO SATISFY
C     THE CONSTRAINT
C     DRAWDOWN AT PUMPING WELL IS TO BE COMPUTEDTOCALCULATE C
      ENERGY CONSUMPTION

      RWSQ=RW**2
      DO 100 I=1,NOWELL
      DO 200 J=1,NOWELL
      DISTSQ=(OX(I)-PX(J))**2+(OY(I)-PY(J))**2
      IF(DISTSQ.LE.0.001)DISTSQ=RWSQ
      X1=DISTSQ/(4.*TRANS/STOR)
      EXFNP=0.
      DO 300 K=1,NTIME
      TIME=K
      X=X1/TIME
      CALL EXI(X,EXFN)
      THEISK(I,J,K)=(EXFN-EXFNP)/(4.*PAI*TRANS)
      EXFNP=EXFN
```

```
300     CONTINUE
200     CONTINUE
100     CONTINUE

        DO I=1,NOWELL
        DO J=1,NOWELL
        WRITE(2,*)'I=',I, 'J=',J
        WRITE(2,20)(THEISK(I,J,K),K=1,NTIME)
20      FORMAT(5E13.4)
        END DO
        END DO

        DO 10 I=1,NOWELL
        DO 9  J=1,NOWELL
        DO 8 K=1,NTIME
        SUM1=0.
        DO 7 NGAMA=1,K
        SUM1=SUM1+QP(J,NGAMA)*THEISK(I,J,K-NGAMA+1)
7       CONTINUE
        DRAW(I,J,K)=SUM1
8       CONTINUE
9       CONTINUE
10      CONTINUE

        DO I=1,NOWELL
        DO K=1,NTIME
        SUM2=0.
        DO J=1,NOWELL
        SUM2=SUM2+DRAW(I,J,K)
        END DO
        TDRAW(I,K)=SUM2
        END DO
        END DO

C       WRITE(2,*) 'DRAWDOWN DUE TO INDIVIDUAL PUMPING '
C       DO I=1,NOWELL
C       DO J=1,NOWELL
C       WRITE(2,*)'OBSERVATION WELL=',I,'PUMPING WELL',J
```

```
C        DO K=1,NTIME
C        WRITE(2,*)I,J,K,DRAW(I,J,K)
C        END DO
C        END DO
C        END DO

         WRITE(2,*)'TIME', 'RESULTANT DRAWDOWN'
         DO I=1,NOWELL
         WRITE(2,*)'OBSERVATION WELL=', I
         DO K=1,NTIME
       WRITE(2,30)K,TDRAW(I,K)
30       FORMAT(I5,F10.3)
         END DO
         END DO

C        COMPUTATION OF ENERGY
         G=2.0
         ACCDG=9.81
         DENSITY=1000.
         DO I=1,NPWELL
         TDRAW(I,0)=0.
         END DO
         DO K=1,NTIME

         DO I=1,NPWELL
         AVDRAW=(TDRAW(I,K-1)+TDRAW(I,K))*0.5
         ALIFT=G+AVDRAW
         WDONE=DENSITY*ACCDG*QP(I,K)*ALIFT
C        WRITE(2,*)AVDRAW,ALIFT
         ENERGY(I,K)=WDONE
         END DO
         END DO
         SUM2=0.
         DO K=1,NTIME
         SUM1=0.
         DO I=1,NPWELL
         SUM1=SUM1+ENERGY(I,K)
         END DO
```

```
      ENC(K)=SUM1
      END DO
      DO K=1,NTIME
      SUM2=SUM2+ENC(K)
      END DO
      WRITE(2,710)
710   FORMAT(2X,'DAILY ENERGY CONSUMPTION')
      WRITE(2,711)( ENC(K),K=1,NTIME)
711   FORMAT(5E13.4)
      WRITE(2,712)
712   FORMAT(2X,'TOTAL ENERGY CONSUMPTION ')
      WRITE(2,*)SUM2
      STOP
      END

      SUBROUTINE EXI(X,EXFN)
C     DOUBLE PRECISION X,EXFN
            IF(X-1.0)10,10,20
10    EXFN=-ALOG(X)-0.57721566+0.99999193*X-0.24991055*X**2
  1         +0.05519968*X**3-0.00976004*X**4+0.00107857*X**5
      RETURN
20    CONTINUE
            IF(X- 80.)50,40,40
50    CONTINUE
      EXFN=((X**4+8.5733287*X**3+18.059017*X**2+8.6347608*X
  1         +0.26777373)/(X**4+9.5733223*X**3+25.632956*X**2+21.099653*X
  2         +3.9584969))/(X*EXP(X))
      RETURN
40    EXFN=0.
      RETURN
      END
```

DATA INPUT :

- TRANSMISIVITY :
  100 M^2/DAY

- STORATIVITY :
  0.01

- PUMPING RATE :
  300 M^3/DAY

- WELL RADIUS
  0.10 M

- COORDINATE OF PUMPING POINTS (in meters) :

- Pumping Point

X	Y
0	100
-100.0	0
0	-100
100.0	0

- Observation Point

0	0

OUT PUT

DISCRETE KERNEL FOR OBSERVATION POINTS "I" DUE TO PUMPING POINT "J"

I= 1 J= 1

.1164E-01	.5516E-03	.3227E-03	.2289E-03	.1776E-03
.1451E-03	.1227E-03	.1063E-03	.9373E-04	.8384E-04

I= 1 J= 2

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 1 J= 3

.1746E-03	.2709E-03	.2142E-03	.1714E-03	.1419E-03
.1209E-03	.1051E-03	.9296E-04	.8330E-04	.7545E-04

I= 1 J= 4

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 1 J= 5

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 2 J= 1

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 2 J= 2

.1164E-01	.5516E-03	.3227E-03	.2289E-03	.1776E-03
.1451E-03	.1227E-03	.1063E-03	.9373E-04	.8384E-04

I= 2 J= 3

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 2 J= 4

.1746E-03	.2709E-03	.2142E-03	.1714E-03	.1419E-03
.1209E-03	.1051E-03	.9296E-04	.8330E-04	.7545E-04

I= 2 J= 5

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 3 J= 1

.1746E-03	.2709E-03	.2142E-03	.1714E-03	.1419E-03
.1209E-03	.1051E-03	.9296E-04	.8330E-04	.7545E-04

I= 3 J= 2

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 3 J= 3

.1164E-01	.5516E-03	.3227E-03	.2289E-03	.1776E-03
.1451E-03	.1227E-03	.1063E-03	.9373E-04	.8384E-04

I= 3 J= 4

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 3 J= 5

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 4 J= 1

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 4 J= 2

.1746E-03	.2709E-03	.2142E-03	.1714E-03	.1419E-03
.1209E-03	.1051E-03	.9296E-04	.8330E-04	.7545E-04

I= 4 J= 3

.4455E-03	.3856E-03	.2628E-03	.1981E-03	.1588E-03
.1324E-03	.1136E-03	.9939E-04	.8836E-04	.7954E-04

I= 4 J= 4

.1164E-01	.5516E-03	.3227E-03	.2289E-03	.1776E-03
.1451E-03	.1227E-03	.1063E-03	.9373E-04	.8384E-04

I= 4 J= 5

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 5 J= 1

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 5 J= 2

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 5 J= 3

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 5 J= 4

.8310E-03	.4609E-03	.2912E-03	.2129E-03	.1679E-03
.1386E-03	.1180E-03	.1028E-03	.9101E-04	.8166E-04

I= 5 J= 5

.000E-0	.000E-0	.000E-0	.000E-0	.000E-0
.000E-0	.000E-0	.000E-0	.000E-0	.000E-0

TIMERESULTANT DRAWDOWN

OBSERVATION WELL= 1

1	3.817
2	4.296
3	4.615
4	4.855
5	5.046
6	5.206
7	5.342
8	5.462
9	5.568
10	5.664

OBSERVATION WELL= 2

1	3.817
2	4.296
3	4.615
4	4.855
5	5.046
6	5.206
7	5.342
8	5.462
9	5.568
10	5.664

OBSERVATION WELL= 3

1	3.817
2	4.296
3	4.615
4	4.855
5	5.046
6	5.206
7	5.342
8	5.462
9	5.568
10	5.664

OBSERVATION WELL= 4

1	3.817
2	4.296
3	4.615
4	4.855
5	5.046
6	5.206
7	5.342
8	5.462
9	5.568
10	5.664

OBSERVATION WELL= 5

1	.999
2	1.553
3	1.903
4	2.159
5	2.361
6	2.527
7	2.669
8	2.793
9	2.902
10	3.000

DAILY ENERGY CONSUMPTION

.1970E+02	.3052E+02	.3253E+02	.3394E+02	.3502E+02
.3591E+02	.3665E+02	.3730E+02	.3787E+02	.3838E+02

TOTAL ENERGY CONSUMPTION

337.8134 Kwh