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OPTIMAL OPERATION OF FARM TURBINE PUMPS

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التشغيل الأمثل للمضخات التوربينية فى المزرعة

خلاصـــــــــــة

إمداد مياه الرى هو أكثر العناصر تكلفة فى الزراعة ، يهدف هذا البحث إلى تشغيل المضخات التوربينية بصورة تتمشى مع متطلبات الرى من حيث كمية المياه وضغط التشغيل وذلك بإختيار سرعة المضخة المناسبة ، ومن المرغوب فيه أيضا الحصول على تصرف ثابت مع تغير منسوب الماء الأرضى الاستاتيكى ويتم ذلك عن طريق ضبط سرعة المضخة للمحافظة على هذا التصرف ،

أجريت الدراسة على مضختين توربينيتين كل منهما أربع عشرة مرحلة بمحطة التجارب والبحوث الزراعية والتى تخدم مزرعة الكلية شاملة محورين للرى بالرش ، انشئت منحنيات ضاغط النظام للرى وتقاطع هذه المنحنيات مع منحنيات الأداء للمضخة عند سرعات مختلفة تعطى نقط التشغيل ، يمكن إختيار السرعة المناسبة التى تتناسب مع متطلبات الرى من حيث كمية المياه والضغط حسب جدولة الإحتياجات المائية المقترحة ،

شملت الدراسة إيجاد المعادلات الخاصة بمنحنيات ضاغط النظام وكذلك منحنيات الأداء لكل مضخة والتى يمكن منها إيجاد نقط التشغيل المناسبة ،

ABSTRACT

One of the costiest items in agriculture is the cost of providing water. The purpose of this investigation is to operate the turbine pumps to cope with the irrigation water and pressure requirements for the existing system of irrigation. It is also desired to maintain a constant pump discharge for different static water levels by varying the pump speed to adjust an increase or decrease in water discharge.

The study was carried out on two turbine pumps at the College Research Station, each of which has fourteen stages; these pumps are supposed to irrigate the College Farm including two centre pivots. The system head curves were constructed, points of intersection with the pump characteristic curves at different pump speeds, are the operating points, which could be used to give the required discharge and pressure at a specified pump speed according to the given tables for the gross irrigation water requirements.

Equations of system head curves and pump characteristic curves are presented, from which the operating points could be obtained.

INTRODUCTION

There has not been much attention given to optimal operation of farm turbine pumps. A number of studies concerning optimal pump operation exists. Among these studies are optimal operation of large centrifugal pumps for municipal water distribution by Tarqui and Dowdy (1989). Methodology for optimal operation of pumping stations in water distribution system, based on solving large scale of nonlinear programming problem was also given by Brion and Larry (1991) and Duan and Larry (1990). The main objective of these studies was to minimize the pumping cost by reducing the power consumption.

However, attempts to improve pump operation efficiency are a function of three different elements, inefficient pump combination; inefficient pump scheduling; and inefficient pumps. Mathematically, an optimum operation of turbine pump is a complicated problem, because of the size of the number and non linearity of decision variables and constraints.

Physical, economic and legal constraints result in a maximum desirable pump discharge as well as a minimum specially when applied to irrigation. The maximum discharge of a well is limited by both the aquifer properties and the construction and development of the well itself. The well should be operated at the most economical discharge. Too high discharge can result in high velocity entering the well screen and causes sand packing around the screen and decreasing the hydraulic conductivity (6) or the proposed optimum flow rate may require well drawdown that is larger than the aquifer can provide. Too large pumping rate may result in pump surging or pumping sand both of which will damage the pump installation (8).

High value of pump discharge also requires larger capital cost for the pump and unit power. Erosion and runoff may occur, particularly under sprinkler irrigation systems. However, selection of optimal pump discharge is a function of both crop water requirements and soil physical properties for a given well design.

FIELD WORK

A survey was carried out to find lengths of the main pipe network, levels at the centre pivots and pump foundations, and heights of end spray nozzles with respect to the pump foundations.

Water samples were collected and analyzed using the electrical conductivity method. It was found that the water (EC) ranged from

1500 mmhos/cm to 1600 mmhos/cm i.e. salinity varied between 960 p.p.m and 1024 p.p.m. This value of salinity required an increase in irrigation water requirement necessary for leaching, by 4 % in Wheat and 5 % in Alfalfa for sprinkler irrigation and 10 % in case of drip irrigation. Table (1) gives the irrigation water requirement for both pivots. Table (2) exhibits the irrigation water requirements for the drip irrigation areas. The values of water requirement are based on monthly net water requirement and irrigation efficiency 70 % for pivots and 85 % for drip irrigation (2).

Each pump, 14 stages, has been driven by an internal combustion engine (670 HP) through a drive shaft and gear head to transmit the power to the pump line shaft Fig. (2a). The speed ratio between the pump and the drive shaft is 1:1. The speed can be changed using throttle setting in the engine.

Flow was measured using the revolution dial of the existing propeller type meter and a stop watch; pressure was measured using a dial gauge mounted on the inlet of the discharge pipe of the pump.

SYSTEM HEAD CURVE

A system head curve is determined by computing the head required by irrigation system to deliver different values of discharges. When a pump is being purchased, it should be specified that the pump head discharge curve intersect the system head curve at the required discharge. This intersection should be at the pump's best efficiency or very close to it (9). Point of intersection of a system head curve with pump head-discharge characteristic curve is known as the operating point. Brake horse power, efficiency, and net positive head for the pump can be obtained once the operating point is known.
The system head is computed using the equation :

$$H_S = S_L + D_L + H_O + D_D + H_F + M_L + V_H \qquad (1)$$

in which;
H_S = system head;
S_L = suction side lift;
H_O = operating head;
D_L = discharge side lift;
D_D = well water drawdown;
H_F = friction head loss;
M_L = minor losses through fittings; and
V_H = velocity head.

The friction head loss includes column pipe of pump friction loss, pipe network friction loss and lateral of pivot friction loss.

Static Lift

Ground water level was measured by using electrical logging, Gamma ray and Neutron, during the construction of Well (1) in 1986. It was found the water level at 85 m from the ground surface Fig. (2b). The estimated rate of ground water depletion at the pumps location is 3.5 m per year. Based on this value the expected water level (static lift) is 359 ft for well (1) and 336 ft for well(2).

The static lift can also be estimated by knowing the pump speed and the corresponding water discharge and pressure at the inlet of delivery pipe. The pump total head can be calculated from the discharge head curve at the specified speed. The static lift can be estimated by subtracting the pressure head at the inlet of delivery pipe, the friction loss in the pump head, the friction loss in the column pipe and the well drawdown from the total head of the pump.

Static Discharge Head

The static discharge head is the measure of the elevation between the centreline of the discharge pipe and the eventual point of use. The elevation of the end spray nozzle on the lateral of the pivot with respect to the pivot foundation is 1.81 m for the north centre pivot and 3.7 m for the middle centre pivot. Referring to levels in Fig. (1), the static discharge head of the north pivot is -2.79 ft for well (1) and is -4.56 ft for well (2). The static discharge head of the middle pivot is 0.51 ft for well (1) and -1.59 ft for well (2).

Operating Head

Most irrigation systems using pumps require some operating head, proper selection of pumps for a specific system depends on how the operating head changes.

Recommended value of normal minimum pressure of the existing sprinkle type, spray nozzle on drop tube is between 15 psi and 30 psi (7). However, it depends on the number of towers of the centre pivot. For six towers pivot, pressure ranges from 31 psi to 42 psi and five towers pivot, the pressure ranges from 31 psi to 37 psi (5).

Friction Losses

Two equations were used for the calculations of the pipe friction. The Hazen-Williams formula for PVC pipes and the laterals of the center pivots after modification, and Scobey equation for the steel pipes in the pipe network. Minor losses were considered to be 10 % from the main losses.

1 - Hazen-Williams Formula

$$h_f = \frac{(0.285C)^{-1.852}\ L\ Q^{1.85}}{D^{4.87}} \qquad (2)$$

in which;
h_f = pipe friction loss;
C = Hazen-Williams coefficient = 150;
L = length of pipe (ft.);
Q = flow rate (gpm); and
D = diameter of pipe (in).

Hazen-Williams formula for uniformly distributed discharge along the pipe line,(lateral of the centre pivot) is given by (13):

$$h_f = \frac{5.7\ C^{-1.852}\ L\ Q^{1.852}}{D^{4.87}} \qquad (3)$$

in which;
D = diameter of lateral = 6.5 inch,
L = length of lateral (ft.) ; and
C = 130 for galvanized steel.

2 - Scobey Equation:

$$h_f = \frac{K\ L\ Q^{1.9}}{D^{4.9}} \qquad (4)$$

in which;
K = friction factor that depends on pipe material;
L = length of pipe (ft.);
Q = flow rate (gpm); and
D = diameter of pipe (in.).

K is determined by the following equation:

$$K = \frac{K_s}{348} \qquad (5)$$

Values of K_s depend on pipe material and diameter, for welded steel 10 inch outside diameter, K_s = 0.3, K = 8.62 $(10)^{-4}$.

Column pipe friction loss

The friction losses in the discharge head and column pipe for vertical turbine pumps were calculated using curves. These losses depend on the column pipe diameter, discharge and diameter of the pump shaft, condition and age of pipe. However the losses should be less than 5 ft/100 ft, otherwise consideration should be given to select the next column pipe size. Each pump has a column pipe of 600 ft length, 10 inches diameter, and shaft diameter 1 15/16 inch.

Well Drawdown

The value of drawdown depends on the pumping rate, aquifer characteristics, well radius and the time of pumping. The drawdown (D_D) in a confined aquired can be calculated using the equation (10):

$$D_D = \frac{Q\ W(u)}{4\ \pi\ T} \quad \ldots\ldots (6)$$

in which;

Q = pumping rate (m^3 /day);

W(u) = well function;

T = aquifer transmissivity (m^2 /day); and

$u = R^2 .\ Sc/4\ T\ t$ .... (7)

where, R = well radius; S_c = storage coefficient, dimensionless; and t is the time in days since pump started

Transmissivity in El-Saq aquifer ranges between 0.0 and 2450 m^2 /day. The estimated value in the region is 1987 m^2 /day, estimated storage coefficient is 1.3 x 10^{-3} , well radius is 12.25 inch and the pumping time is 12 hours.

Based on these informations, the drawdown was calculated for different values of discharge covering the pump characteristic curve.

AFFINITY LAWS

Changing the speed of an impeller changes the characteristic curves, the resulting discharge and head can be estimated using the following two equations (7,8):

$$Q_2 = Q_1 \left(\frac{N_2}{N_1}\right) \qquad (8)$$

$$H_2 = H_1 \left(\frac{N_2}{N_1}\right)^2 \qquad (9)$$

in which; subscripts (1) and (2) refer to the original and new performance points respectively.

Different values of pump speed were chosen, and the corresponding discharges and heads were calculated. Affinity laws are valid for wide range in pump speed because all physical components have the same dimensions. These laws say nothing about the pump efficiency with speed. Generally speaking, pump that are efficient at one speed will be probably be efficient at slightly different speed (7).

RESULTS AND ANALYSES

The system head curves for both the north pivot and middle pivot were constructed using two approximate methods. $S.H.C_1$ is the system head curve based on estimated static water level since the construction of the well, and $S.H.C_2$ which is the system head curve based on actual measurements of discharge and pressure in the inlet of discharge pipe at different values of pump speeds, from which the mean static water level could be estimated. However water levels in the well field are not static because of the original and local changes induced by the pumping wells within the field. The system head curves could be shifted upward or downward according to the static water level.

Changes in the valve opening in the pump discharge line or bypass line, changes in static water level or discharge lift, changes in the operating head, aging of pipe and well drawdown. These factors influence the system head curve and determine the pump discharge.

Fig. (3) and Fig. (4) give the operating points at different pump speeds of pump (1) for the middle pivot and the north pivot respectively. Also Fig. (5) and Fig. (6) exhibit the operating points at different pump speeds of pump (2) for the middle pivot and north pivot respectively.

Pump speeds having values less than or equal to 1100 r.p.m are not suitable to give both the water and pressure requirements for both pivots. Minimum recommended value for six towers pivot (middle pivot) and five towers pivot (north pivot) is 400 gpm (5).

Due to practical reason, maximum pump speed of 1770 r.p.m or even 1700 r.p.m could not be used, it generates pressure, the existing pipe network can not sustain.

Statistical Analysis

Statistical Analysis, using SAS program (12), provided the best fit for pump characteristic curves and the system head curves. The head-discharge curve of pump (1) could be represented by polynomial from the third degree in the form :

$$H_1 = 71.24 - 27.1\,(10)^{-3}\,Q + 17.3\,(10)^{-6}\,Q^2 - 5.27\,(10)^{-9}\,Q^3$$
$R^2 = 0.9974$ .... (10)

and also pump (2) the characteristic curve could be fitted by third degree polynomial :

$$H_2 = 98.28 - 40.4\,(10)^{-3}\,Q + 21.7\,(10)^{-6}\,Q^2 - 4.96\,(10)^{-9}\,Q^3$$
$R^2 = 0.9627$ .... (11)

The above two equations at pump speed of 1770 r.p.m. The equation could be simply related to any value of pump speed by multiplying the right side by $(N/1770)^2$ where N is the speed at which the equation is required.

It was also found that the system head curves could be fitted by polynomial from the second degree.

Well (1)

Middle pivot

$H = 422.05 + 0.0250\,Q + 0.000030\,Q^2$ $R^2 = 0.998$ .... (12)

North pivot

$H = 416.44 + 0.0293\,Q + 0.000042\,Q^2$ $R^2 = 0.9999$........... (13)

Well (2)

North pivot

$H = 417.65 + 0.0282\,Q + 0.000041\,Q^2$ $R^2 = 0.9999$ .... (14)

Middle pivot

$H = 421.88 + 0.0335\ Q + 0.000055\ Q^2$ $R^2 = 0.9999$ ....(15)

Equations (12), (13), (14), and (15) could be written as:

$H = x - 2.950 + 0.0250\ Q + 0.000030\ Q^2$ ....(12a)

$H = x - 3.556 + 0.0293\ Q + 0.000042\ Q^2$ ....(13a)

$H = x - 2.348 + 0.0282\ Q + 0.000041\ Q^2$ .... (14a)

$H = x - 3.120 + 0.0335\ Q + 0.000055\ Q^2$ .... (15a)
in which ; x represents the sum of the operating head, static water level and the discharge lift.

Solution of the system head equation with the characteristic curve of the pump at any speed providing the operating point at that speed.

Application Example

Suppose the middle pivot is cultivated by Alfalfa and it is required to be irrigated from Well(2) in the month of March. The daily irrigation water requirement for this pivot is 368 gpm, Table (1), fruits and vegetables is 57.1 gpm, Table (2), then the total, daily irrigation water requirements is 425.1 gpm. Increasing this value say by 5% for domestic and other purposes in the farm, the required water discharge is 446.4 gpm. The pivot at its maximum velocity makes one turn in about 12 hours. If the pivot makes one turn at its maximum velocity in a day, the water discharge during the 12 hours is 2 (446.4) = 892.8 gpm which requires pump speed of 1245 r.p.m with respect to $S.H.C_1$ and 1325 r.p.m with respect to $S.H.C_2$. The water discharge for the pivot only is 2 (368) = 736 gpm. This value of discharge needs a pump speed of 1200 r.p.m according to $S.H.C_1$ and 1280 r.p.m according $S.H.C_2$, Fig. (6a).

If the pivot makes one turn at 50 % from its maximum speed i.e in 24 hours, the water discharge will be 446.4 gpm which needs a pump speed of 1110 r.p.m with respect to $S.H.C_1$ and 1190 r.p.m with respect to $S.H.C._2$ Fig. (6a).

Points of intersections of the system curves with the pumps characteristic curves at maximum speed of 1770 r.p.m have provided an efficiency ranged from 81% to 82% for both pumps Fig. (7) and Fig. (8). Theoretically speaking, this means a good choice of both pumps. However, it is common for a turbine pump to remain in service for 15 years or more through normal wear. In some cases poor maintenance techniques could decrease the pump efficiency. Values of calculated efficiency of the pump in well (2) at 1200 r.p.m. and at 1400 r.p.m. are 25% and 44% respectively .

CONCLUSIONS

The gross irrigation water requirements for every pivot and for the drip irrigation areas are given in the form of tables. These requirements include net irrigation requirement, leaching requirement water losses based on measured water salinity and operational waste. The tables present the monthly water requirements for various crops as daily water demand in gpm.

A system of characteristic curves at different pump speeds for both pumps are given. The system head curves are constructed; points of intersections between characteristic curves and the corresponding system curves are points of operation. The optimal speed can be selected to cope with the gross water requirements from tables.

Statistical analysis showed the characteristic curves of both two pumps are polynomial equations from the third degree at the maximum value of pump speed. These equations could be simply modified to any value of pump speed. Also the system head curves can be fitted by polynomial equations from the second degree. The solution of system head equation with a pump characteristic equation at a specified speed gives water discharge and total head at this speed.

Points of operation depend on the position of the system head curve, mainly on the static lift. It will be more beneficial to install water level gauge beside the pump to measure the static water level and water drawdown at different periods.

As the turbine pumps are mechanical devices, they are liable to wear, and because one pump was installed in 1986 and the other was installed in 1989, the pump characteristic curves may not be representative of the existing head-flow relationship. The current performance curve of each pump at a maximum pump speed is recommended to be determined, from which the characteristic curve at any value of pump speed will be more accurate.

Water drawdowns during pumping were based on estimated values of both the storage coefficient and transmissivity of the Saq aquifer it will be more useful to do a pump test at or nearby the farm to determine the local actual values of these two parameters.

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NOTATION

The following symbols are used in this paper :

C	= Hazen - Williams coefficient;
C_f	= column friction loss;
D	= diameter of pipe;
D_D	= well drawdown;
D_L	= discharge side lift;
EC	= electrical conductivity;
H	= head of one stage pump;
H_f	= friction head loss;
H_O	= operating head;
H_s	= system head;
H_t	= total head of pump;
h_f	= pipe friction loss;
K	= friction factor;
K_s	= height of pipe roughness;
L	= length of pipe;
L_f	= lateral friction loss;
M_L	= minor losses through fittings;
P_f	= pipe friction loss;
Pf_t	= total head loss;
Q	= pumping rate;
R	= well radius;
R^2	= multiple correlation coefficient of determination;
S_C	= storage coefficient;
S_H	= system head;
S_L	= suction side lift;
S.H.C.	= system head curve;
T	= aquifer transmissivity;
t	= time of pumping;
u	= parameter;
V_H	= velocity head;
$W(u)$	= well function; and
x	= parameter.

Subscripts

m	= middle pivot ; and
n	= north pivot.

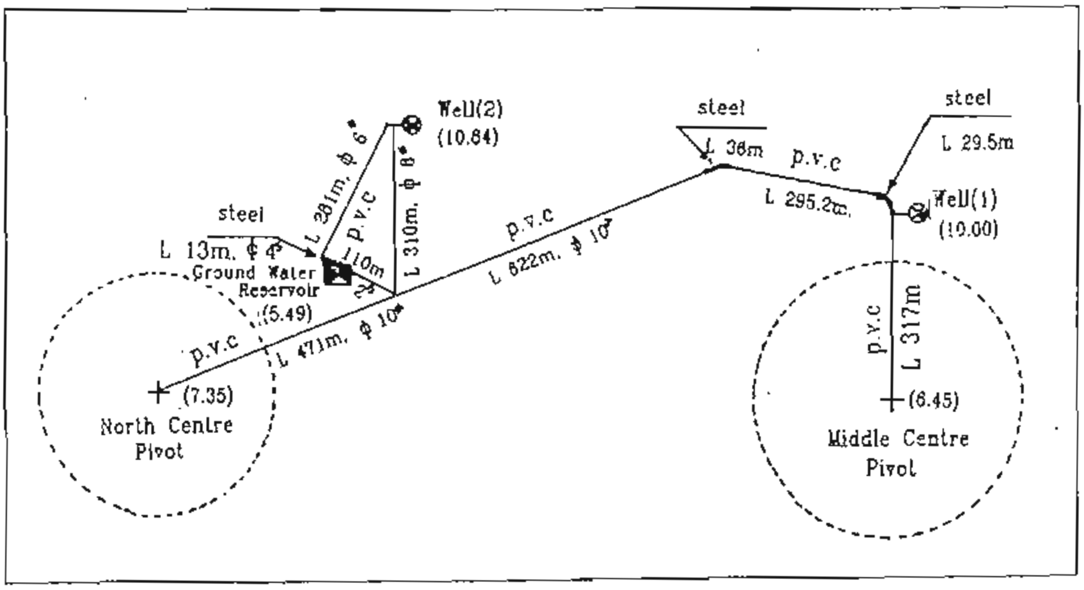


Fig (1) Layout of Farm Main Pipes.

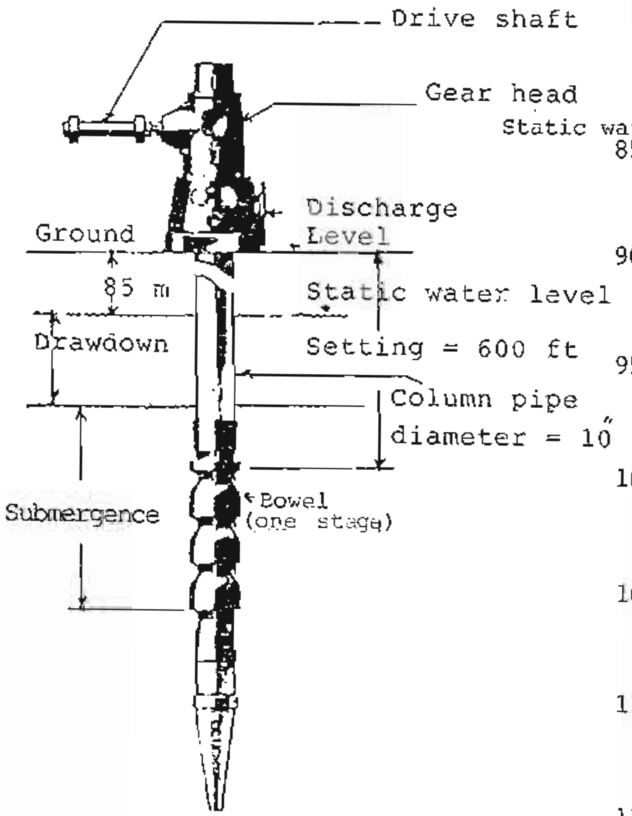


Fig. (2a) Vertical Turbine Pump

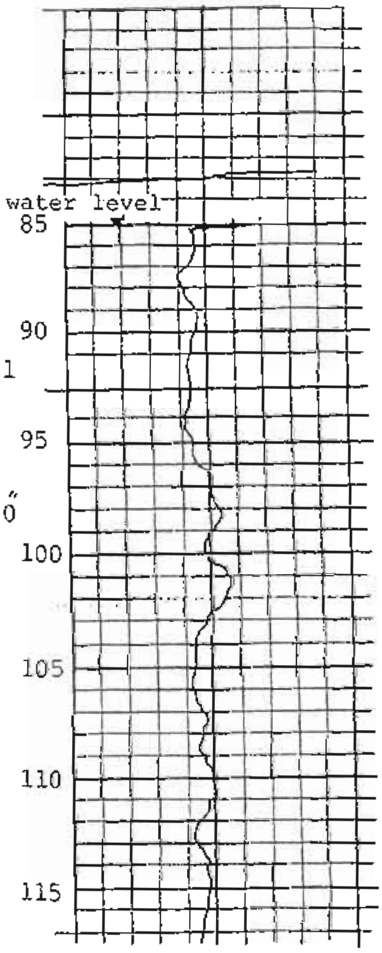
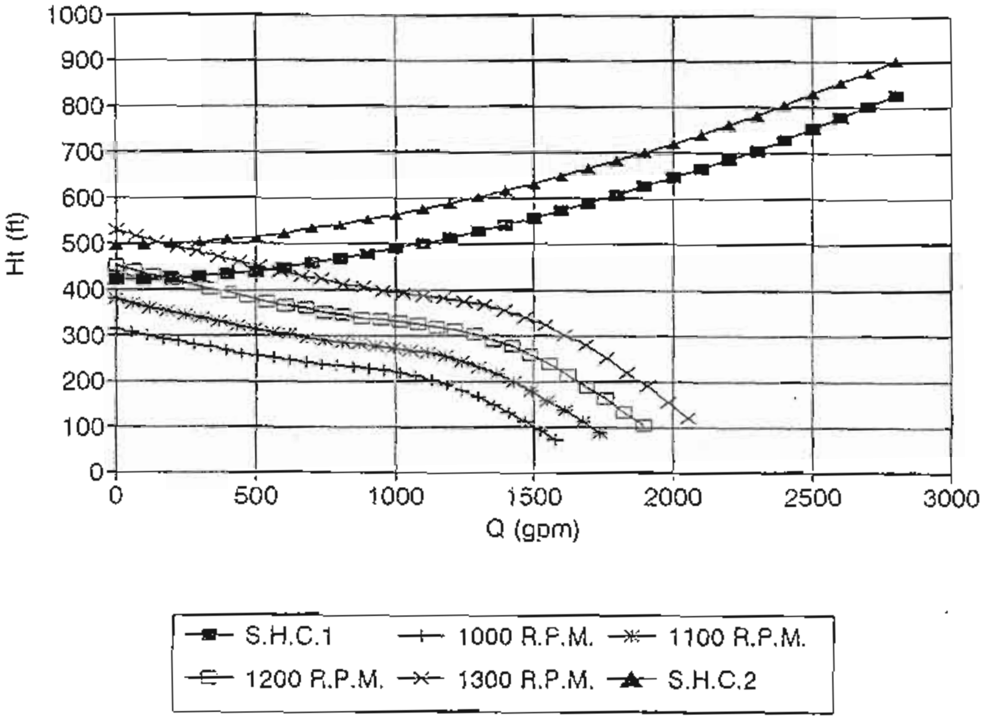
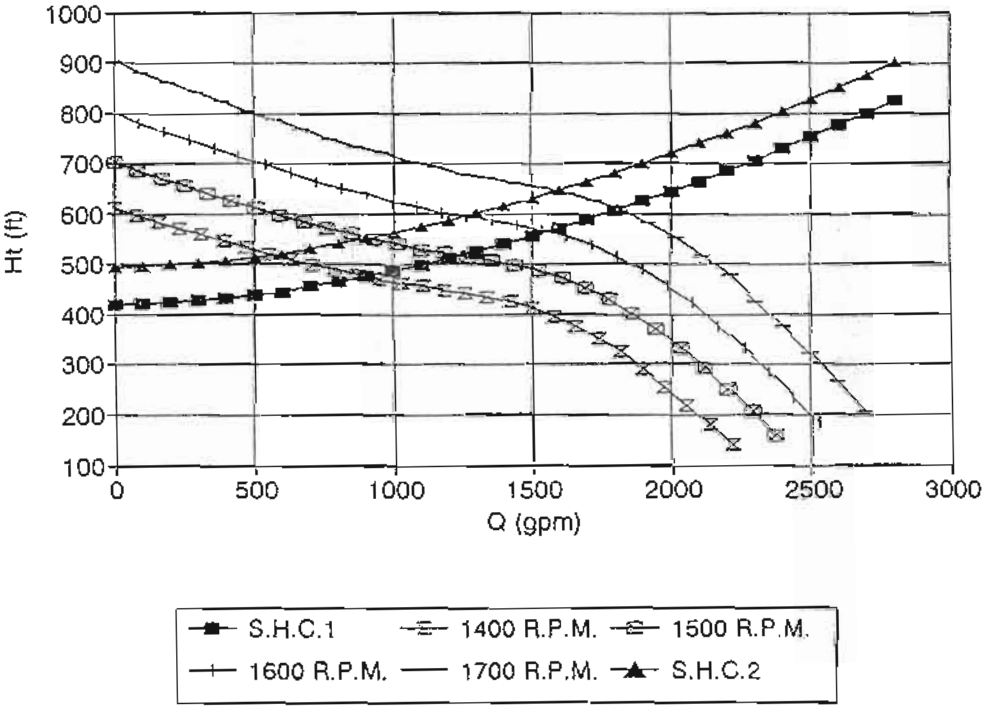


Fig. (2b) Electrical Logging
(Neutron)

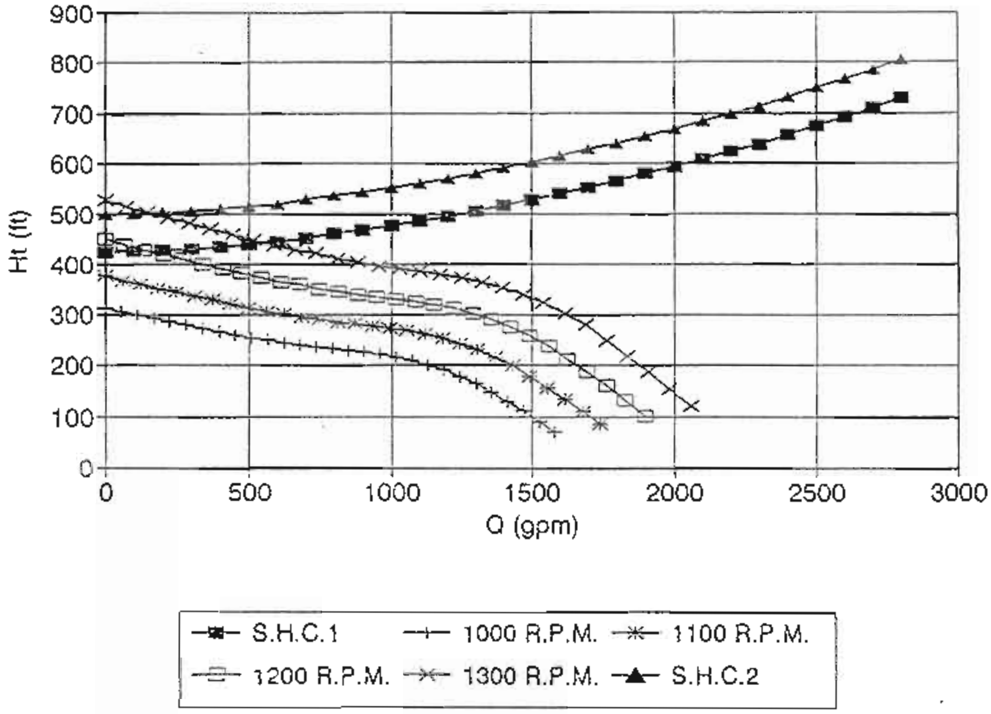
Fig(3a) Operating Points,for Different Pump Speeds,Well(1),North Centre Pivot



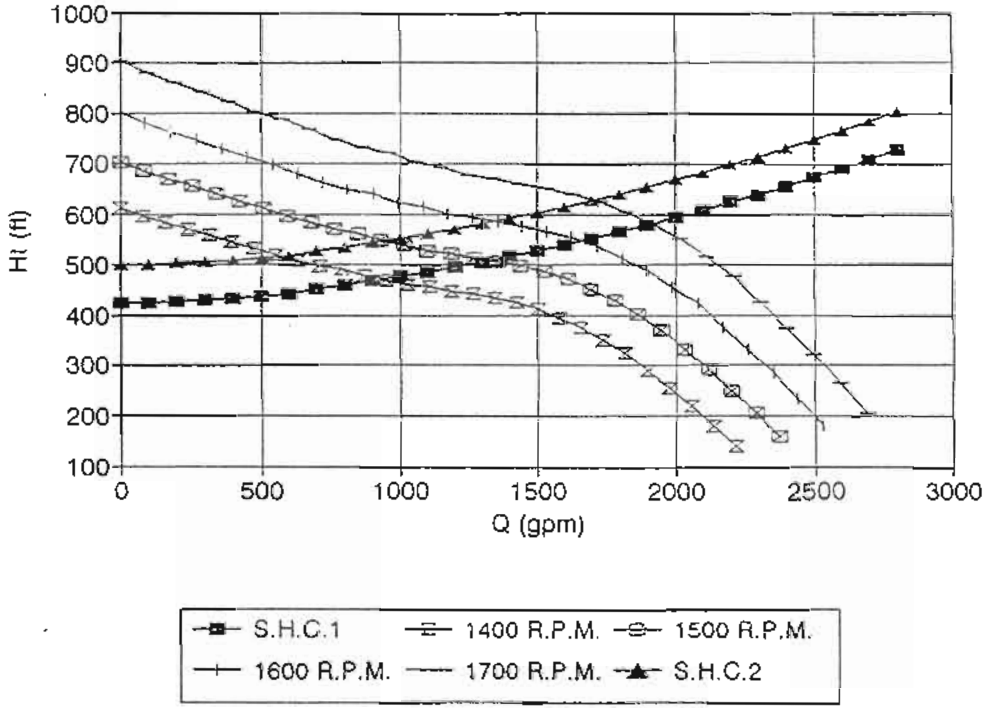
Fig(3b) Operating Points for Different Pump Speeds,Well(1),North Centre Pivot



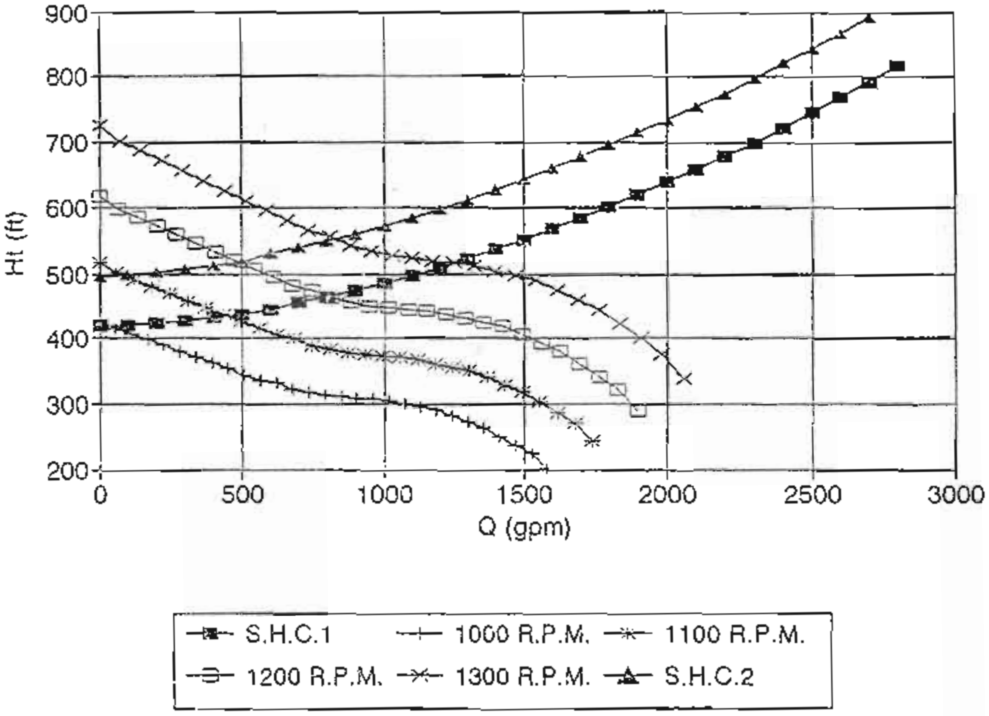
Fig(4a) Operating Points for Different Pump Speeds,Well(1),Middle Centre Pivot



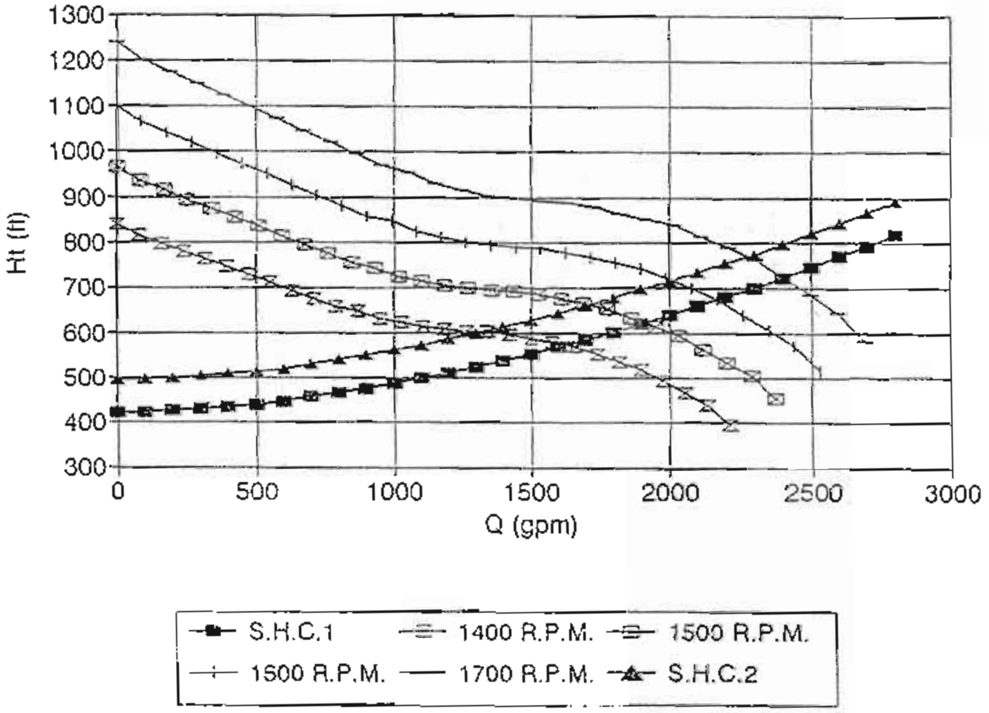
Fig(4b) Operating Points for Different Pump Speeds,Well(1),Middle Centre Pivot



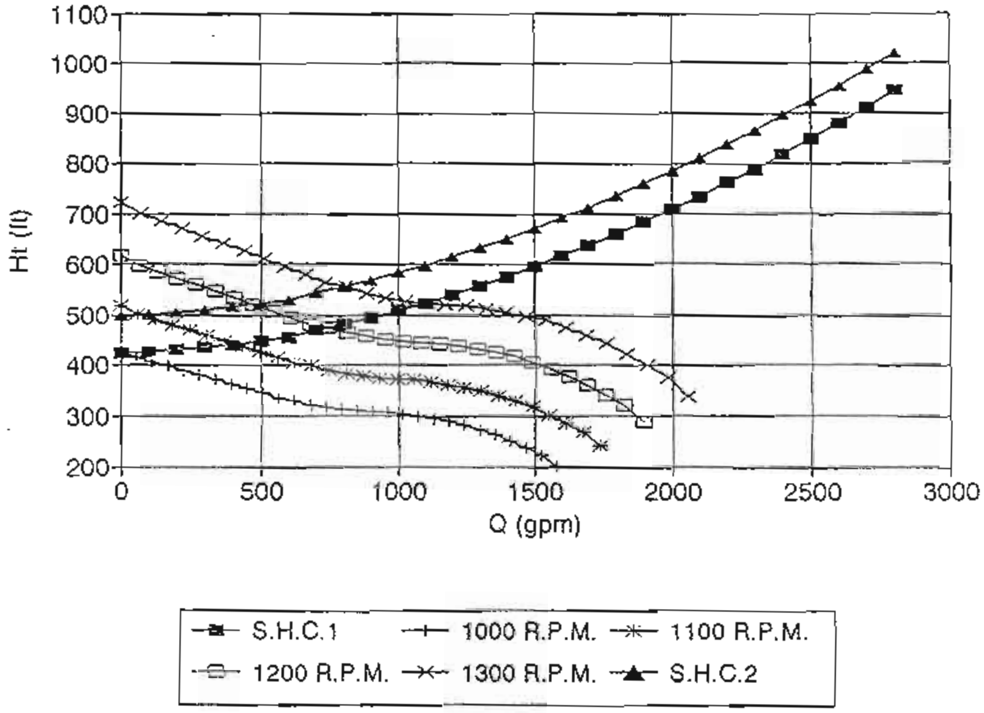
Fig(5a)Operating Points for Different Pump Speeds,Well(2),North Centre Pivot



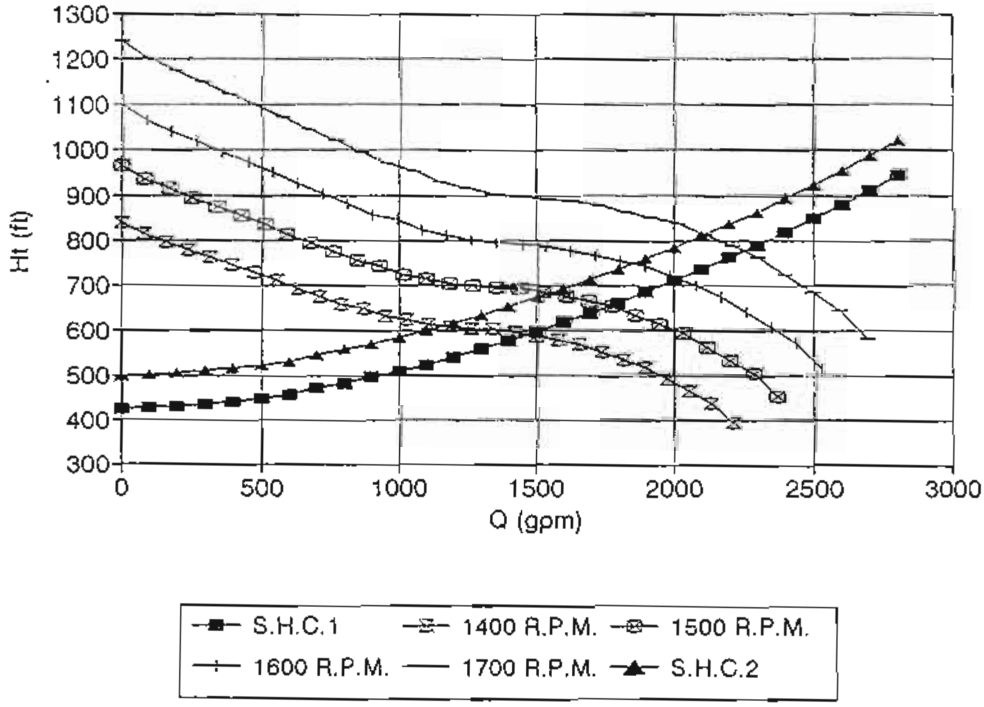
Fig(5b) Operating Points for Different Pump Speeds,Well(2),North Centre Pivot



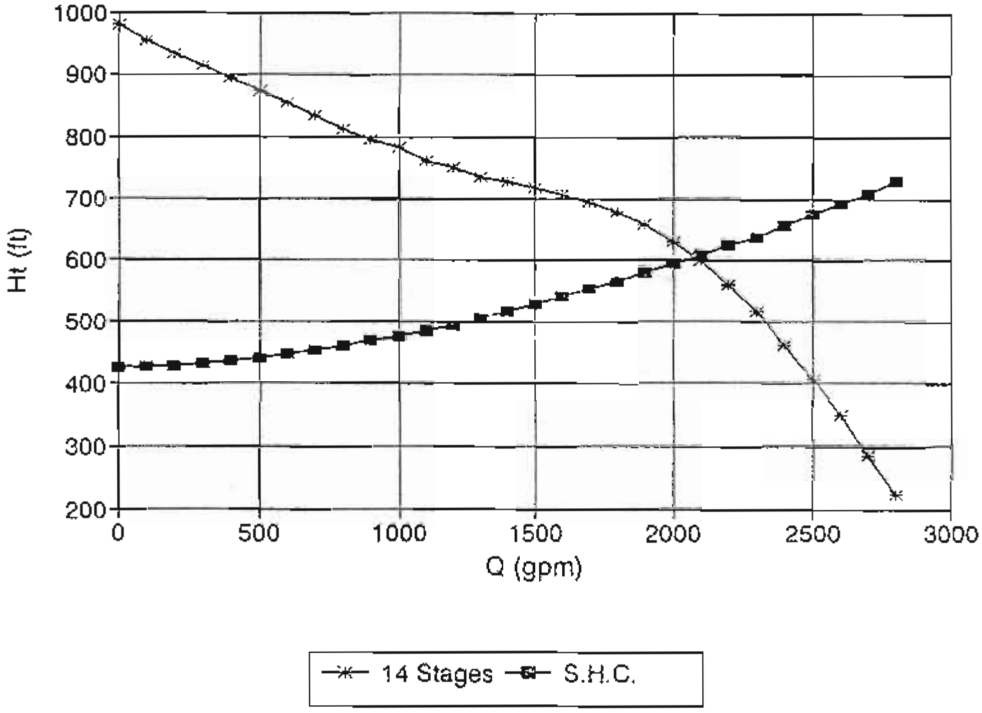
Fig(6a) Operating Points for Different Pump Speeds,Well(2),Middle Centre pivot



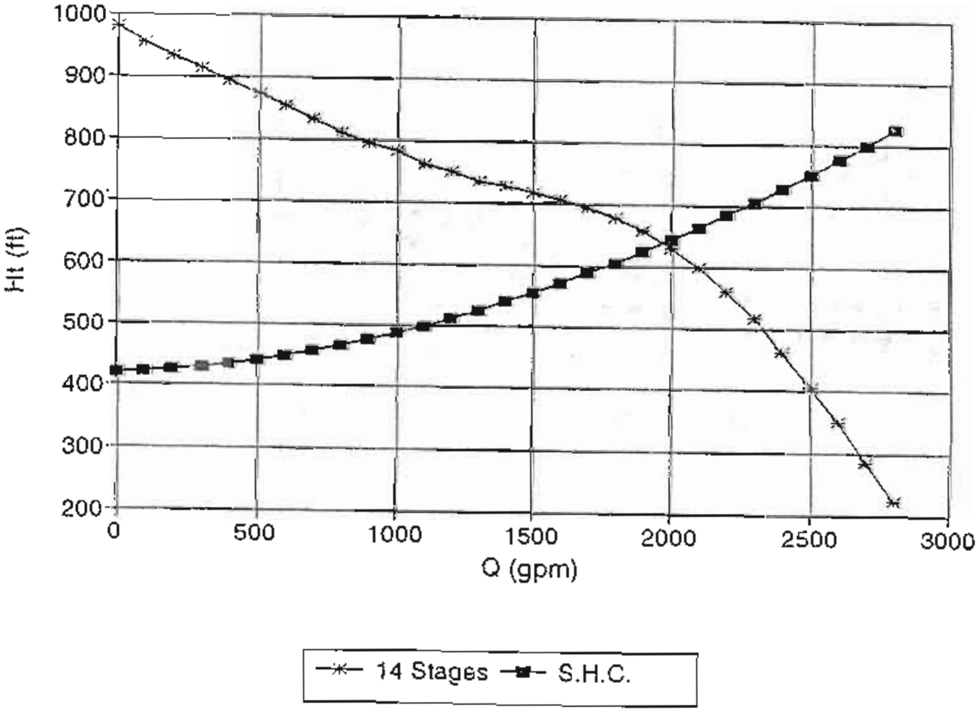
Fig(6b) Operating Points for Different Pump Speeds,Well(2),Middle Centre pivot



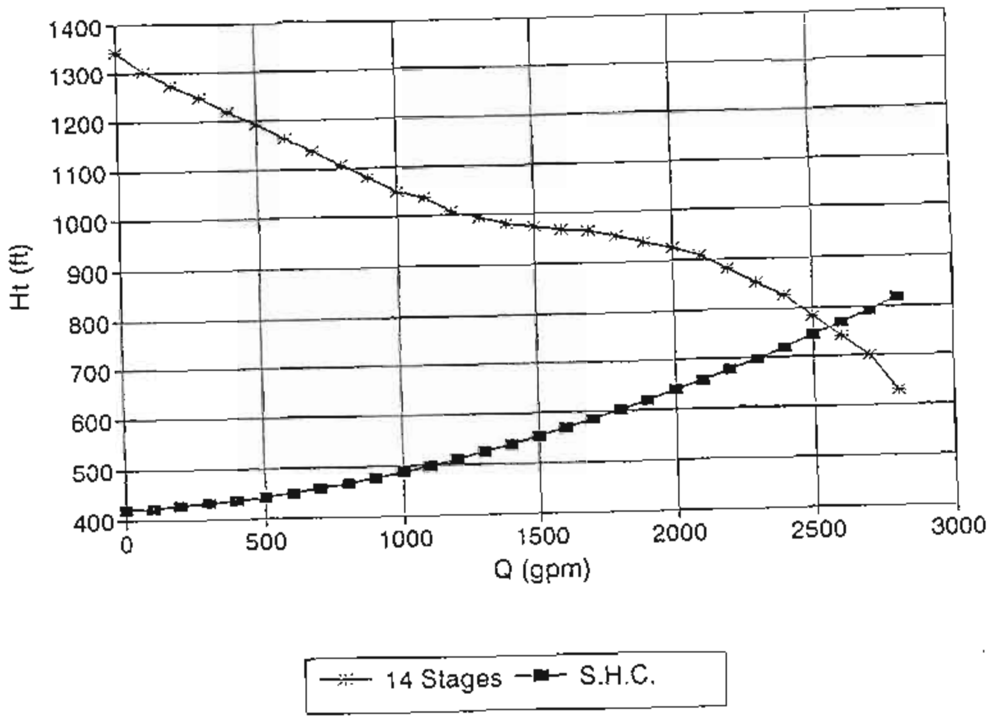
Fig(7a)Operating Point Well (1)
Middle Centre Pivot,Speed 1770 R.P.M.



Fig(7b)Operating Point Well (1)
North Centre Pivot,Speed 1770 R.P.M.



Fig(8a)Operating Point Well(2)
North Centre Pivot,Speed 1770 R.P.M



Fig(8b)Operating Point Well(2)
Middle Centre pivot,Speed 1770 R.P.M

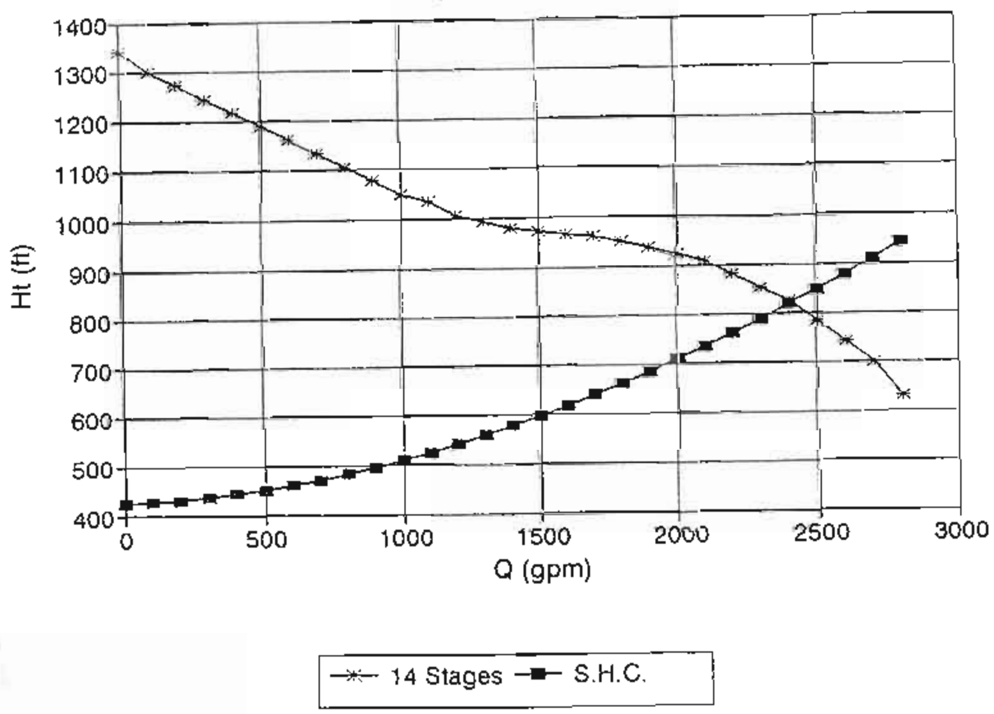


Table (1) : Gross Irrigation Water Requirements (gpm)
Based on Water Salinity 1000 p.p.m. and Irrigation Efficiency 70%

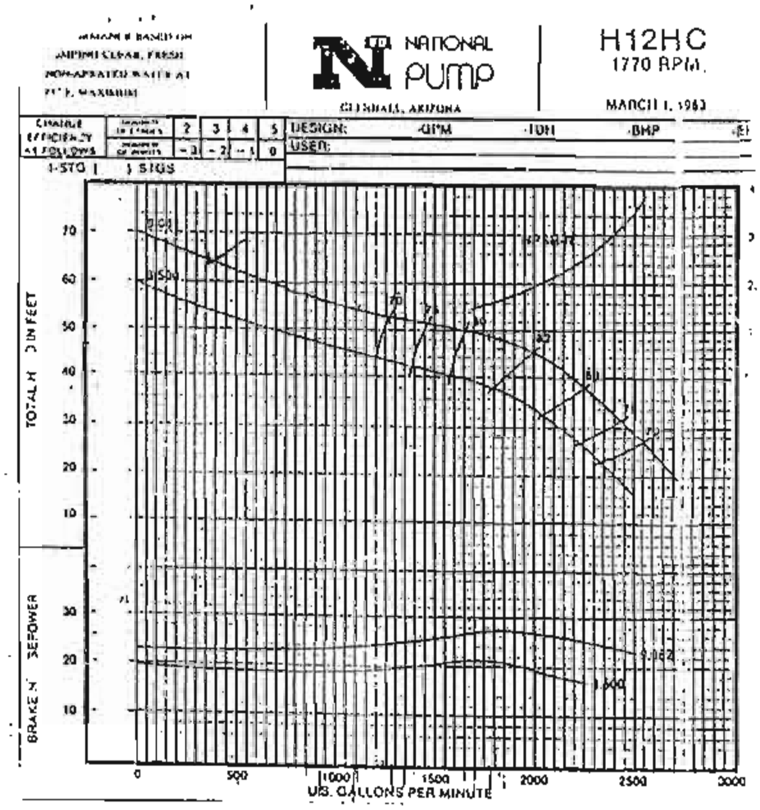
		Date of planting	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Middle centre pivot	Wheat	15 Nov.	235	262	204	-	-	-	-	-	-	-	74	169
		01 Dec.	214	263	257	65	-	-	-	-	-	-	-	132
		15 Dec.	169	262	404	122	-	-	-	-	-	-	-	60
		01 Jan.	132	238	431	361	-	-	-	-	-	-	-	-
	Alfalfa		200	222	368	456	546	656	672	656	557	405	251	198
North centre pivot	Wheat	15 Nov.	164	181	141	-	-	-	-	-	-	-	52	117
		01 Dec.	149	183	247	45	-	-	-	-	-	-	-	92
		15 Dec.	117	181	281	85	-	-	-	-	-	-	-	-
		01 Jan.	92	165	299	251	-	-	-	-	-	-	-	-
	Alfalfa		138	155	255	317	380	456	467	456	387	282	174	138

Table (2): Irrigation Water Requirements for Fruits and Vegetables (gpm)
Based on Water Salinity 1000 p.p.m and Drip Irrigation Efficiency 85%

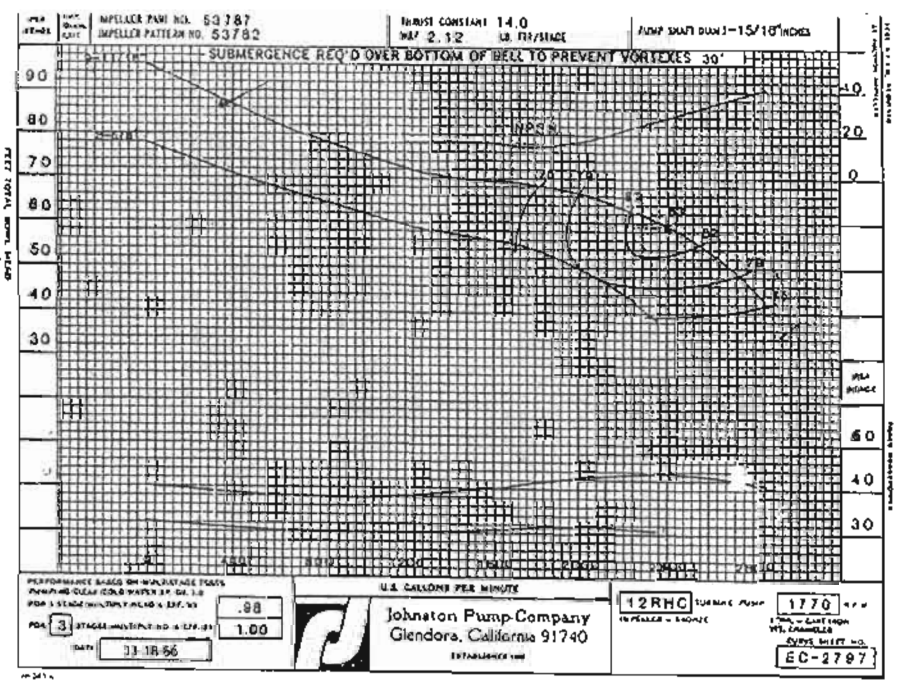
	Area	Fruits	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	3.0 ha	Dates	10.0	11.1	18.2	27.1	33.4	42.9	44.0	42.9	36.5	25.3	14.8	10
	1.0 ha	Citrus	4.8	5.4	8.3	10.0	11.9	13.4	13.7	13.4	11.3	9.0	5.6	4.3
	1.5 ha	Grapes	-	1.3	5.8	9.0	15.5	21.5	23.5	21.5	14.6	8.1	4.0	-
Net water requirements		Total	14.8	17.8	32.3	46.1	60.8	77.8	81.2	77.8	62.4	42.4	24.4	14.8
Irrigation water requirements			19.4	23.3	42.2	60.3	79.5	101.7	106.1	101.7	81.6	55.4	31.9	19.4
Tomatoes,15 Feb.	1.0 ha													
Net water requirements			-	2.56	11.34	15.8	13.91	-	-	-	-	-	-	-
Irrigation water requirements			-	3.30	14.9	20.7	18.2	-	-	-	-	-	-	-

APPENDIX (1) Pump Characteristic Curves

Well (1)



Well (2)



APPENDIX (2) Calculations of System Head Curve
Well (1) Middle Centre Pivot

Q (gpm)	H	Cf	Pf m	Lf m	DD	Pf t	S.H.
	ft.	ft.	ft.	ft.	ft.	ft.	ft.
0	70.00	0.00	0.00	0.00	0.00	0.00	425.00
100	68.20	0.11	0.07	0.34	1.23	0.08	426.75
200	66.70	0.44	0.24	1.23	2.46	0.26	429.39
300	65.20	1.00	0.52	2.61	3.67	0.57	432.86
400	63.80	1.78	0.88	4.45	4.92	0.97	437.12
500	62.30	2.78	1.33	6.73	6.14	1.46	442.11
600	61.00	4.00	1.87	9.43	7.38	2.06	447.87
700	59.50	5.44	2.49	12.55	8.60	2.74	454.33
800	58.00	6.96	3.19	16.06	9.84	3.51	461.37
900	56.80	8.70	3.96	19.98	11.06	4.36	469.09
1000	56.00	10.86	4.81	24.29	12.27	5.29	477.71
1100	54.50	12.42	5.74	28.98	13.52	6.31	486.23
1200	53.70	14.52	6.75	34.04	14.73	7.43	495.72
1300	52.50	16.86	7.83	39.48	15.98	8.61	505.93
1400	52.00	19.92	8.98	45.29	17.19	9.88	517.28
1500	51.20	22.20	10.20	51.46	18.44	11.22	528.32
1600	50.50	25.38	11.50	58.00	19.65	12.65	540.68
1700	49.60	28.08	12.86	64.89	20.87	14.15	552.98
1800	48.50	30.78	14.30	72.13	22.11	15.73	565.75
1900	47.00	34.44	15.81	79.73	23.33	17.39	579.89
2000	45.00	38.04	17.38	87.68	24.57	19.12	594.41
2100	42.80	41.22	19.02	95.97	25.79	20.92	608.90
2200	40.00	45.30	20.74	104.60	27.04	22.81	624.75
2300	37.00	46.68	22.50	113.58	28.25	24.75	638.26
2400	33.00	52.56	24.36	122.89	29.50	26.80	656.74
2500	29.00	57.06	26.27	132.54	30.71	28.90	674.21
2600	25.00	61.62	28.25	142.53	31.92	31.08	692.15
2700	20.50	65.22	30.30	152.85	33.17	33.33	709.57
2800	16.00	70.68	32.41	163.50	34.38	35.65	729.22

Well (1) North centre Pivot

Q (gpm)	H	Cf	Pf n	Lf n	DD	Pf t	S.H.
	ft.	ft.	ft.	ft.	ft.	ft.	ft.
0	70.00	0.00	0.00	0.00	0.00	0.00	420.00
100	68.20	0.11	0.32	0.28	1.23	0.35	421.97
200	66.70	0.44	1.13	1.03	2.46	1.24	425.17
300	65.20	1.00	2.39	2.18	3.67	2.63	429.48
400	63.80	1.78	4.07	3.71	4.92	4.48	434.89
500	62.30	2.78	6.15	5.60	6.14	6.77	441.28
600	61.00	4.00	8.50	7.86	7.38	9.35	448.59
700	59.50	5.44	11.48	10.45	8.60	12.63	457.11
800	58.00	6.96	14.72	13.38	9.84	16.19	466.38
900	56.80	8.70	18.31	16.65	11.06	20.14	476.55
1000	56.00	10.86	22.25	20.23	12.27	24.48	487.84
1100	54.50	12.42	26.56	24.14	13.52	29.22	499.29
1200	53.70	14.52	31.20	28.60	14.73	34.32	512.17
1300	52.50	16.86	36.20	32.89	15.98	39.82	525.55
1400	52.00	19.92	41.54	37.73	17.19	45.69	540.54
1500	51.20	22.20	47.21	42.87	18.44	51.93	555.44
1600	50.50	25.38	53.21	48.31	19.65	58.53	571.87
1700	49.60	28.08	59.53	54.05	20.87	65.48	588.48
1800	48.50	30.78	66.19	60.09	22.11	72.81	605.79
1900	47.00	34.44	73.18	66.42	23.33	80.50	624.69
2000	45.00	38.04	80.47	73.03	24.57	88.52	644.16
2100	42.80	41.22	88.10	79.94	25.79	96.91	663.86
2200	40.00	45.30	96.04	87.13	27.04	105.64	685.11
2300	37.00	46.68	104.29	94.61	28.25	114.72	704.26
2400	33.00	52.56	112.86	102.37	29.50	124.15	728.57
2500	29.00	57.06	121.74	110.41	30.71	133.91	752.09
2600	25.00	61.62	130.91	118.73	31.92	144.00	776.28
2700	20.50	65.22	140.41	127.32	33.17	154.45	800.16
2800	16.00	70.68	150.21	136.19	34.38	165.23	826.49

APPENDIX (2) Cont.

Well (2) North Centre Pivot

Q (gpm)	H ft.	Cf ft.	Pf n ft.	Lf n ft.	DD ft.	Pf t ft.	S.H. ft.
0	96.00	0.00	0.00	0.00	0.00	0.00	420.00
100	93.00	0.11	0.30	0.28	1.23	0.33	421.95
200	91.00	0.44	1.07	1.03	2.46	1.18	425.11
300	89.00	1.00	2.27	2.18	3.67	2.50	429.35
400	87.00	1.78	3.87	3.71	4.92	4.26	434.67
500	85.00	2.78	5.85	5.60	6.14	6.44	440.95
600	83.00	4.00	8.20	7.86	7.38	9.02	448.26
700	81.00	5.44	10.91	10.45	8.60	12.00	456.49
800	79.00	6.96	13.96	13.38	9.84	15.36	465.54
900	77.00	8.70	17.37	16.65	11.06	19.11	475.51
1000	75.00	10.86	21.11	20.23	12.27	23.22	486.58
1100	74.00	12.42	25.18	24.14	13.52	27.70	497.78
1200	72.00	14.52	29.59	28.60	14.73	32.55	510.40
1300	71.00	16.86	34.32	32.89	15.98	37.75	523.48
1400	70.00	19.92	39.37	37.73	17.19	43.31	538.15
1500	69.50	22.20	44.74	42.87	18.44	49.21	552.72
1600	69.00	25.38	50.41	48.31	19.65	55.45	568.79
1700	68.75	28.08	56.40	54.05	20.87	62.04	585.04
1800	68.00	30.78	62.70	60.09	22.11	68.97	601.95
1900	67.00	34.44	69.30	66.42	23.33	76.23	620.42
2000	66.00	38.04	76.22	73.03	24.57	83.84	639.49
2100	65.00	41.22	83.42	79.94	25.79	91.76	658.71
2200	63.00	45.30	90.92	87.13	27.04	100.01	679.48
2300	61.00	46.68	98.72	94.61	28.25	108.59	698.13
2400	59.00	52.56	106.82	102.37	29.50	117.50	721.93
2500	56.00	57.06	115.21	110.41	30.71	126.73	744.91
2600	53.00	61.62	123.89	118.73	31.92	136.28	768.55
2700	50.00	65.22	132.86	127.32	33.17	146.15	791.86
2800	45.00	70.68	142.12	136.19	34.38	156.33	817.59

Well (2) Middle Centre Pivot

Q (gpm)	H ft.	Cf ft.	Pf m ft.	Lf m ft.	DD ft.	Pf t ft.	S.H. ft.
0	96.00	0.00	0.00	0.00	0.00	0.00	425.00
100	93.00	0.11	0.49	0.34	1.23	0.54	427.22
200	91.00	0.44	1.70	1.23	2.46	1.87	431.00
300	89.00	1.00	3.64	2.61	3.67	4.00	436.29
400	87.00	1.78	6.20	4.45	4.92	6.82	442.97
500	85.00	2.78	9.36	6.73	6.14	10.30	450.94
600	83.00	4.00	13.14	9.43	7.38	14.45	460.27
700	81.00	5.44	17.49	12.55	8.60	19.24	470.83
800	79.00	6.96	22.42	16.06	9.84	24.66	482.53
900	77.00	8.70	27.86	19.98	11.06	30.65	495.38
1000	75.00	10.86	33.86	24.29	12.27	37.25	509.67
1100	74.00	12.42	40.40	28.98	13.52	44.44	524.36
1200	72.00	14.52	47.49	34.04	14.73	52.24	540.53
1300	71.00	16.86	55.90	39.48	15.98	61.49	558.81
1400	70.00	19.92	63.21	45.29	17.19	69.53	576.93
1500	69.50	22.20	71.82	51.46	18.44	79.00	596.10
1600	69.00	25.38	80.96	58.00	19.65	89.06	617.09
1700	68.75	28.08	90.55	64.89	20.87	99.61	638.44
1800	68.00	30.78	100.69	72.13	22.11	110.76	660.78
1900	67.00	34.44	111.33	79.73	23.33	122.46	684.96
2000	66.00	38.04	122.41	87.68	24.57	134.65	709.95
2100	65.00	41.22	133.98	95.97	25.79	147.38	735.36
2200	63.00	45.30	146.08	104.60	27.04	160.69	762.62
2300	61.00	46.68	158.59	113.58	28.25	174.45	787.96
2400	59.00	52.56	171.62	122.89	29.50	188.78	818.73
2500	56.00	57.06	185.11	132.54	30.71	203.62	848.93
2600	53.00	61.62	199.06	142.53	31.92	218.97	880.04
2700	50.00	65.22	213.51	152.85	33.17	234.86	911.10
2800	45.00	70.68	228.40	163.50	34.38	251.24	944.80