H. McEnroy

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

3RD ANNUAL SEMINAR ON GROUNDWATER DEVELOPMENT

"COST FACTORS IN GROUNDWATER DEVELOPMENT"

KILLESHIN HOTEL, PORTLAOISE - TUESDAY & WEDNESDAY, 19TH & 20TH APRIL, 1983

PROGRAMME

Tuesday, 19th April

10.30 - 11.00 a.m.	Registration & Coffee	
11.00 a.m.	Welcome & Introduction	Dr. David Burdon
11.15 a.m.	Well Design Options	Mr. Jeremy Randal, UOP Johnson Wellscreens Ltd.
12.00 Noon	Pumping Costs	E. Creed, Nicholas O'Dwyer & Partners
12.45 p.m.	Discussion	
1.00 p.m.	Lunch	
2.30 p.m.	Pumping tests & their uses	Dr. Lewis Clark, Water Research Centre.
3.15 p.m.	Film	
3.45 p.m.	Tea	
4.15 p.m.	Optimising groundwater development	Dr. Lewis Clark
5.00 p.m.	Case histories & discussion	
6.00 p.m.	Close	

Wednesday 20th April

09.30 a.m.	Sanitary Protection for wells	Mr. Bill Jungmann, UOP Johnson Wellscreens Ltd.
10.30 a.m.	Coffee	
11.00 a.m.	Pump selection, installation & maintenance	Tom Ruddy, Electrical & Pump Services Ltd.
11.45 a.m.	Groundwater-source heat pumps - their potential in Ireland	John Walls, Energy Management Contractors Ltd.
12.30 p.m.	General Discussion & Close	
1.00 p.m.	Lunch	

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Ladies and Gentlemen,

On behalf of the Irish Group of the International Association of Hydrogeologists, I welcome you to this Third Annual Seminar on Groundwater Development. The subject this year is "Cost Factors in Groundwater Development", a subject which the acute economic recession renders most urgent and important.

A fine series of lectures have been arranged for today and tomorrow. I welcome all the lecturers and thank them for coming. They cover all aspects of the cost of developing and extracting groundwater, such as well design, pumping costs, pumping tests and the optimising of groundwater development for today; for tomorrow, we have sanitary protection of wells, selection of pumps, and the potential of heat pumps in Ireland.

I am particularily pleased with the inclusion of this last subject - the heat pump. I think that by obtaining energy from groundwater we can substantially increase its development and use in Ireland, which is low in sources of indigenous energy. In France, the National Authority are undertaking the installation of heat from normal "cold" groundwater in some 400,000 flats and appartments by 1990, involving the pumping of some 56 m^3/sec. from 10,000 boreholes, and with an energy production equivalent of 800,000 tonnes of oil. Let us hope that Ireland will follow, if somewhat slowly.

However, all these methods for the economic development of groundwater assume that suitable aquifers are available for development, and that the quantity and quality of the groundwater is suitable for the uses to which it is to be put. There is no harm in taking a brief look at the cost of locating the aquifers, since such is a legitimate cost in groundwater development.

In Ireland, the Groundwater Division of the Geological Survey is carrying out much groundwater investigation, as on the map which I am showing. It will be seen that only for very limited areas, as Castlecomber and part of the Barrow Valley, can the work be considered as complete; in most places, the surveys are reconnaissance or well surveys, and at least half of the country is unsurveyed. An Foras Forbatha has combined with the Geological Survey to carry out a reconnaissance survey of the North-East Regional Development Area; it is a start. While the cost of such surveys are not usually included in the cost of groundwater developed in such areas, it is a true cost and one which should be acknowledged if not detailed.

In Ireland, such regional or large-scale groundwater surveys are rarely or never undertaken. Ireland mainly follows the old "Hunting and Shooting" approach, which implies the taking of groundwater where it may chance to occur, without regard to its origin and composition, the amount available on a long-term basis, or the effects on others of its abstraction. In the old jingle :

"I drilled a borehole in the ground
And there, by chance, I water found."

D. J. BURDON D.Sc. D. J. BURNS Ph.D.
Registered in Ireland No. 34949
VAT Reg. No. 8D 81360B

WELL DESIGN
OPTIONS.

DESIRED DESIGN RESULTS.

Allow water to enter freely.

Do not allow earth materials to enter.

Provide structural strength prevent collapse.

DESIGN PARAMETERS.

ascending vel < 5ft/sec

Diameter

Pump clearance.

Hydraulic efficiency.

Diameter with respect to yield. not a factor 6" 100 gpm 48" 137 gpm

Well depth. 0.1 ft/sec not vel thro a screen ∴ design

Screen (Intake) length.

Artesian aquifers.

Water table aquifers.

Materials.

WELL EFFICIENCY.

Definitions.

Practical measurements.

Relative cost.

WELL MAINTENANCE, DESIGN FACTORS.

Durability.

Access.

Monitoring.

Relative costs.

Do nothing.

Regular repair.

Jeremy Randall
Johnson Screens Europe.
April 19, 1983.

PUMPING OPTIONS AND COST FACTORS

BY

E. J. CREED, B.E., C. Eng., M.I.E.I., M.I.W.E.S.

SENIOR ENGINEER

NICHOLAS O'DWYER & PARTNERS

1. INTRODUCTION

1.1 This paper deals with Pumping Options and Cost factors for Borehole sources, but before proceeding to discuss that subject it is opportune to consider the question of borehole vis a vis surface sources. While it is generally true that development of groundwater sources will be cheaper than that of surface sources of similar output, provided that a suitable aquifer has been identified, the actual cost of groundwater exploration and testing may far exceed the cost of drilling and developing the production wells, and these costs must be taken into account in assessing the likely total cost of groundwater development.

1.2 In the provision of public water supplies it is important that the total water resources of an area should be identified and the best solution may often be found to be a combination of surface and groundwater sources. Such a combination can be extremely useful from an operational point and costs can be minimised by making the best use of both types of sources.

1.3 Where a surface source provides a reliable supply in all but drought periods the availability of complimentary groundwater sources can make up the deficiency if the aquifer has sufficient storage to allow of increased pumping during such periods. Groundwater sources are also an invaluable asset in the event of temporary pollution of rivers or malfunctions or breakdowns in treatment plant.

1.4 Where reliable groundwater sources are available they provide great flexibility in periods of growing demand while extensions are planned and constructed to large river abstraction plants, or while finance for new trunk distribution mains is awaited.

1.5 In the event of suitable groundwater sources being identified in or adjacent to the service area the most economic course will clearly be their utilisation in supplying the area. It is important that the scheme be designed on sound Engineering principles and that the cheapest solution should not necessarily be accepted.

£68000
10 km

2. SIZE & TYPE OF SCHEME

2.1 In this paper I will confine the consideration of costs to schemes with a demand in the range of 250 to 5,000 m3/day, i.e. with population equivalents in the range of 1,000 to 20,000 persons. Demands under the lower limit will usually be supplied from one borehole and the operational costs will generally not be high enough to justify detailed aquifer investigations or refined economic anlaysis.

2.2 Schemes with a demand in excess of 5,000 m3/day will usually require detailed individual analysis and design, very often with several service reservoirs and more than one aquifer being used to provide the supply. Nevertheless, the general guidelines used will apply to many schemes, particularly regional schemes, with population equivalents in excess of 20,000 persons.

3. PRODUCTION WELLS & STANDBY

3.1 The size and yield of individual production wells will depend to a large extent on the aquifer characteristics. The design and cost of production wells is being dealt with by other speakers and I will only refer to them with regard to their impact on pumping costs.

3.2 From the standpoint of pump selection and operating costs the most important well parameters are drawdown and specific capacity. These parameters must be established accurately if the correct pumpset is to be installed in the well and any serious deviation from the calculated values in operation will lead to increased pumping costs and the possibility of inadequate pump output.

3.3 The provision of standby capacity will usually be a choice between having a spare pumpset or sets or providing additional wells which can be used during repair or maintenance work. The choice will depend on the operating conditions of the individual scheme and many factors, including cost, will influence the final decision.

3.4 No scheme of any importance should depend on a single production well and at least two wells should be provided and equipped with pumps. Where well capacities and pump duties are reasonably similar and where access to wellheads is good, the provision of one or more standby pumps will generally provide adequate cover. At a cost in the order of IR£ 2,500 to IR£ 5,000 per pumpset this choice will provide economical cover in the event of breakdown.

3.5 On larger schemes, or where the aquifer characteristics are such that well deterioration may be a problem, it is desireable to provide additional wells complete with pumpsets and the proportion of standby may vary from 25% to 100% depending on the individual circumstances. The provision of such standby will cost from IR£ 15,000 to IR£ 25,000 per well, depending on the size of the boreholes and their proximity to other wells. This expenditure will constitute only a small part of the total cost of a major scheme and may well be justified by the gain of flexibility in operation.

3.6 Where additional wells are provided they should not lie idle until standby is required as this will lead to deterioration of the pumps and electrical equipment. All production wells should be pumped in rotation with the number of wells in use at any one time being sufficient to provide the required total hourly supply. On larger schemes the selection of pumping wells can be carried out by microprocessor in accordance with a preset programme, whilst on smaller schemes changeover can be carried out manually at weekly or shorter intervals.

3.7 An important advantage of standby wells lies in that an aquifer may be over-pumped for short periods and water supplies can be transferred to adjacent supply areas or unusual short-term demands can be met. A further advantage is that non-pumping wells can be used for observation purposes and much useful information can be gained on aquifer characteristics and performance.

4. RESERVOIR STORAGE & PUMP CAPACITY

4.1 On all substantial schemes reservoir capacity equal to not less than 2 days demand should be provided. This storage should be located at a level sufficient to provide a residual head of 12 to 15m at maximum demand over the highest level in the distribution area. In the case of distribution systems serving a wide area, such as regional schemes, several reservoirs may be provided, each serving a local distribution system and, in turn, served from a single head reservoir through trunk supply mains. The main reservoir storage should preferably be located as close as possible to the point of demand and where a multi-reservoir system is provided the head reservoir will provide only sufficient storage to cover short-term variations in pump output.

4.2 The principal advantages of surface reservoir storage are:-

4.2.1 Contingency storage is available to cover pump breakdown, power failure or rising main faults.

4.2.2 Longer pumping hours can be utilised with consequent reduction in size of production wells, pumps, and rising mains, and advantage can be taken of off-peak electricity rates.

4.2.3 The distribution system can be designed to provide for daily demand variation and the hydraulic regime for each section of the system can be readily and simply designed and checked under operational conditions.

4.2.4 Provision for fire flows can be incorporated in the distribution system and with the available storage reserve no increase in pump capacity will be required.

4.2.5 Waste-water meters can be installed on the outflow from each reservoir allowing close control of waste in the distribution system.

4.2.6 Chemical dosing can be carried out at the reservoir site allowing central control and adequate contact time before water enters the distribution system.

4.3 Pumping directly from the production well to the distribution system may be undertaken in certain circumstances such as:-

4.3.1 In small schemes where it may not be economical to provide reservoir storage with a separate distribution system.

4.3.2 In larger schemes where sites at suitable elevation are not available for surface reservoirs and the cost of water towers is found to be uneconomic.

4.3.3 In existing schemes where groundwater sources are available and it is necessary to provide augmentation of supplies prior to the construction of additional reservoir storage.

4.4 When pumping directly to distribution the pumping plant will require to have capacity to meet the maximum demand of the system and this will normally require an output 2 or 3 times greater than that needed when pumping to a reservoir, which means that the total daily output of a particular well will be from 50% to 66% less than when pumping to storage. The effect of this on pumping costs is considered in Section 8.

5. TYPES OF PUMPING STATIONS

5.1 For groundwater schemes with borehole production wells submersible pumps are by far the most common installation. The borehole pump can deliver to a service reservoir or direct to the distribution system, or, less commonly, several wells can deliver to an adjacent surface treatment plant, with the treated water flowing to a clear water tank and being subsequently pumped to the service reservoir. The latter type of installation is similar to a surface water abstraction scheme and is not considered further in this paper.

5.2 A distinction is often made between low-lift and high-lift pumps and attempts are made to define the range of heads involved. I consider that the term low-lift pump is best confined to the last type of installation mentioned in section 5.1 and the raw-water pumps for river abstraction schemes. Since the general characteristics of submersible pumps do not alter with increase of head, except for the addition of further stages, it seems to me that all submersibles delivering to reservoirs or pressure systems should be treated as high-lift pumps.

5.3 The cheapest form of well-head installation is the provision of a pit containing the control valves with removable covers for access to the borehole and pump. The pump starter and instruments can be housed in a kiosk and a typical layout is shown in Fig. 1.

5.4 Where ground conditions are unsuitable for the pit type installation, due, for example, to a high water table, a small permanent structure can be erected over the well, as shown in Fig. 2. This can be particularly useful if there is an adjacent observation well as all of the instruments can be housed in one location. A station of this type is less likely to be vandalised and, in itself, provides protection to the well from local surface pollution.

5.5 Booster stations are required where a portion of the service area is too high to be supplied by gravity from the reservoir, or where water is transferred to a high-level reservoir from the principal storage reservoir. The use of submersible pumps for in-line boosting, as shown in Fig. 3, is becoming increasingly popular and among its advantages are the flexibility in location of the booster station and the small site area required so that the station can usually be located on public property.

5.6 Submersible pumps are also very suitable for use as boosters from low-level to high-level reservoirs when they can be mounted horizontally on the reservoir floor with considerable savings in both structure and pipework.

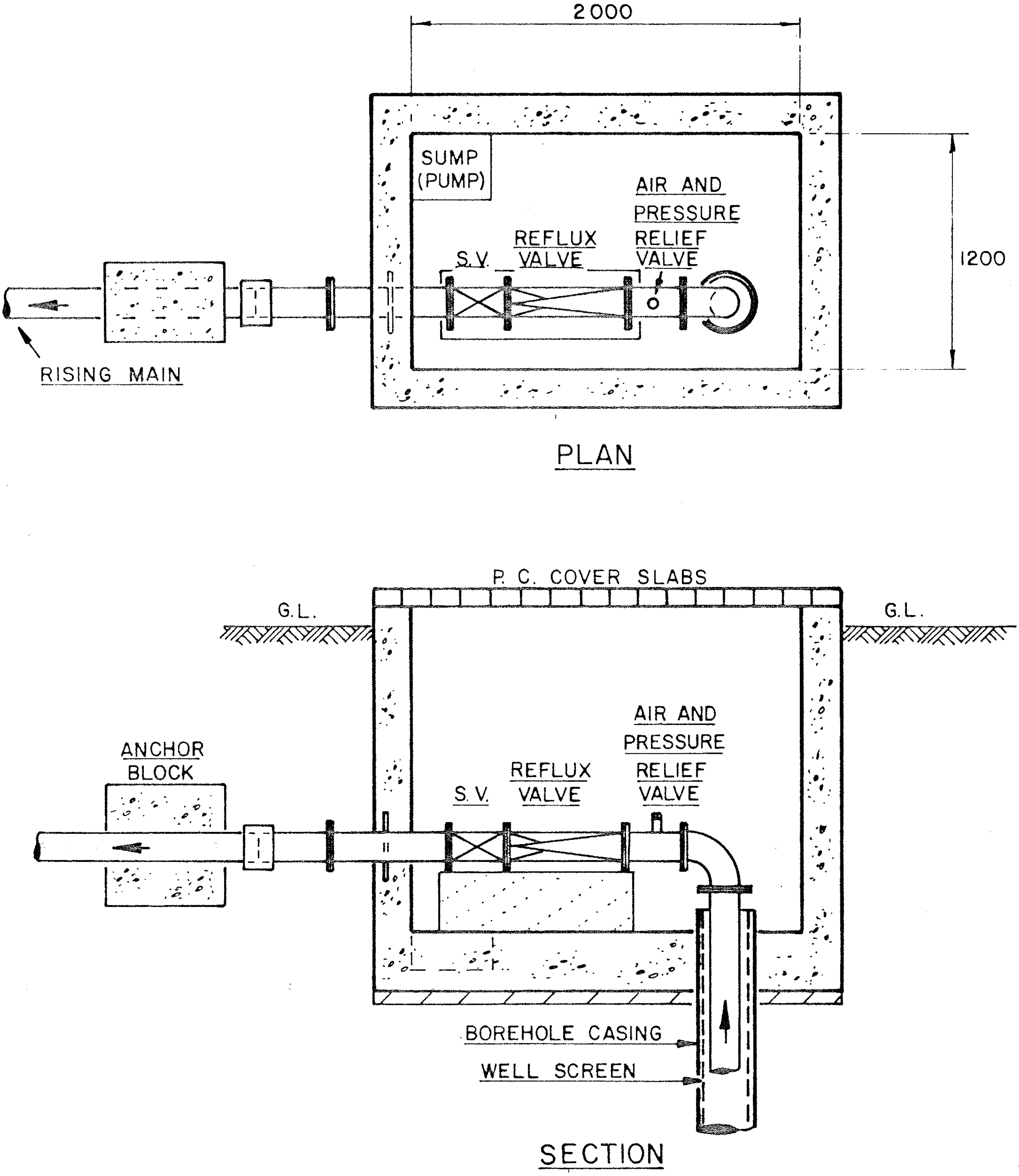


FIG. I WELL-HEAD LAYOUT - PIT TYPE

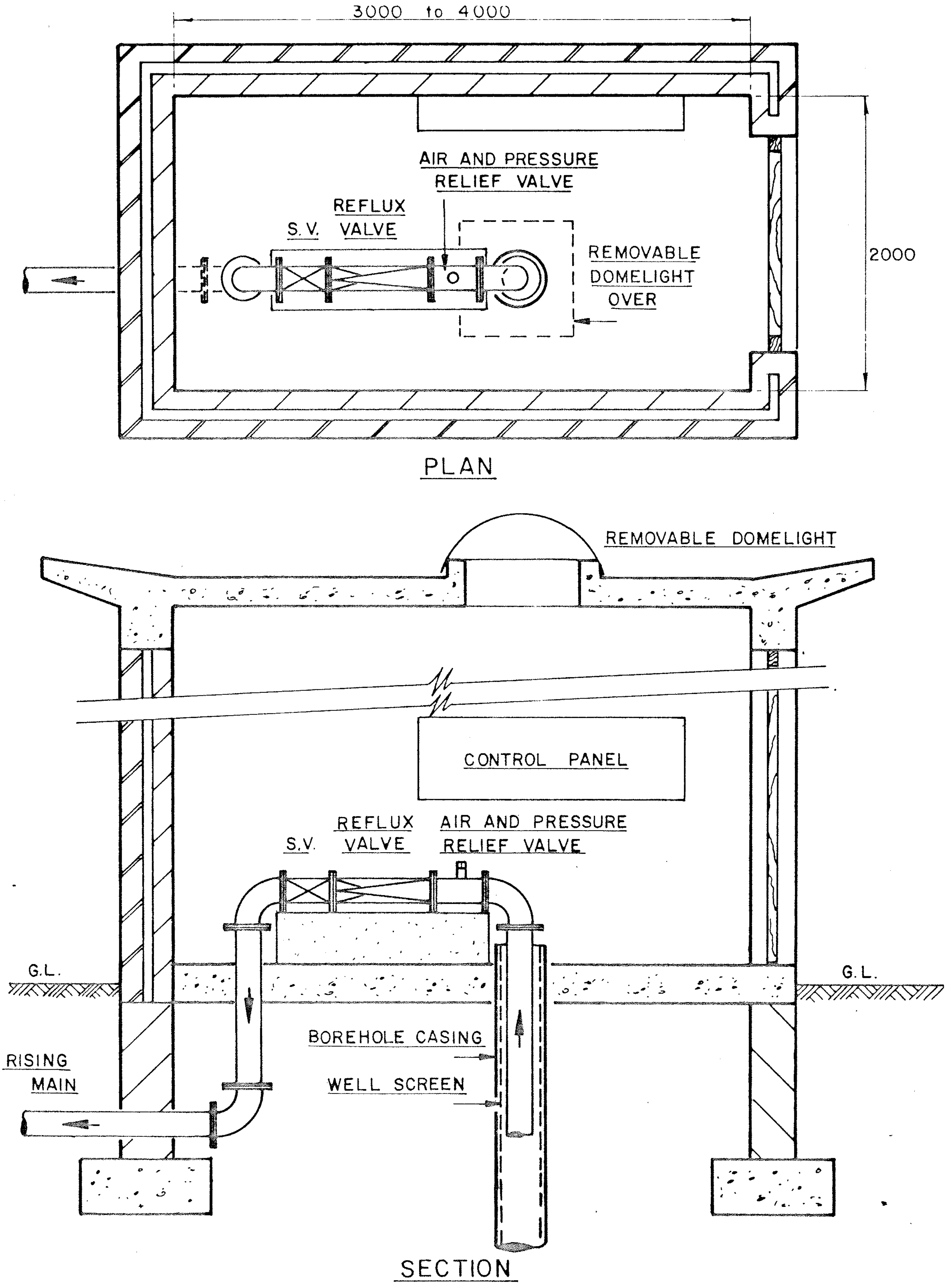
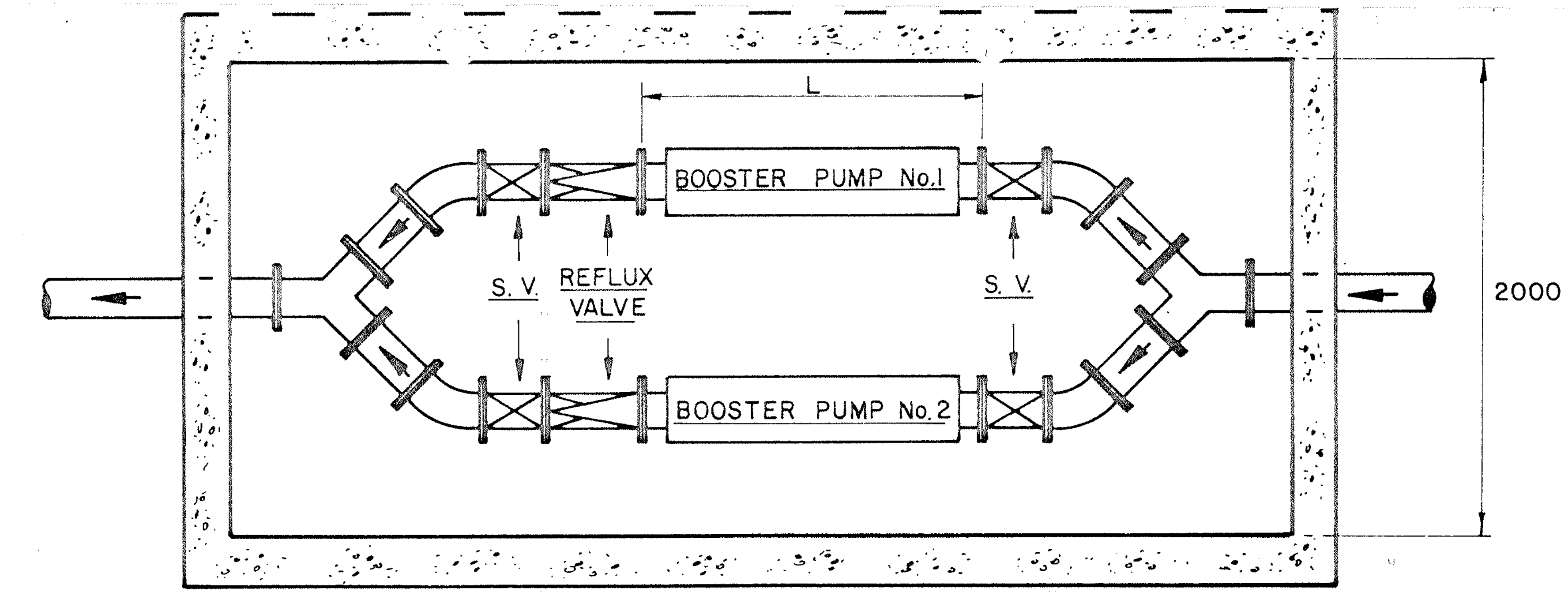
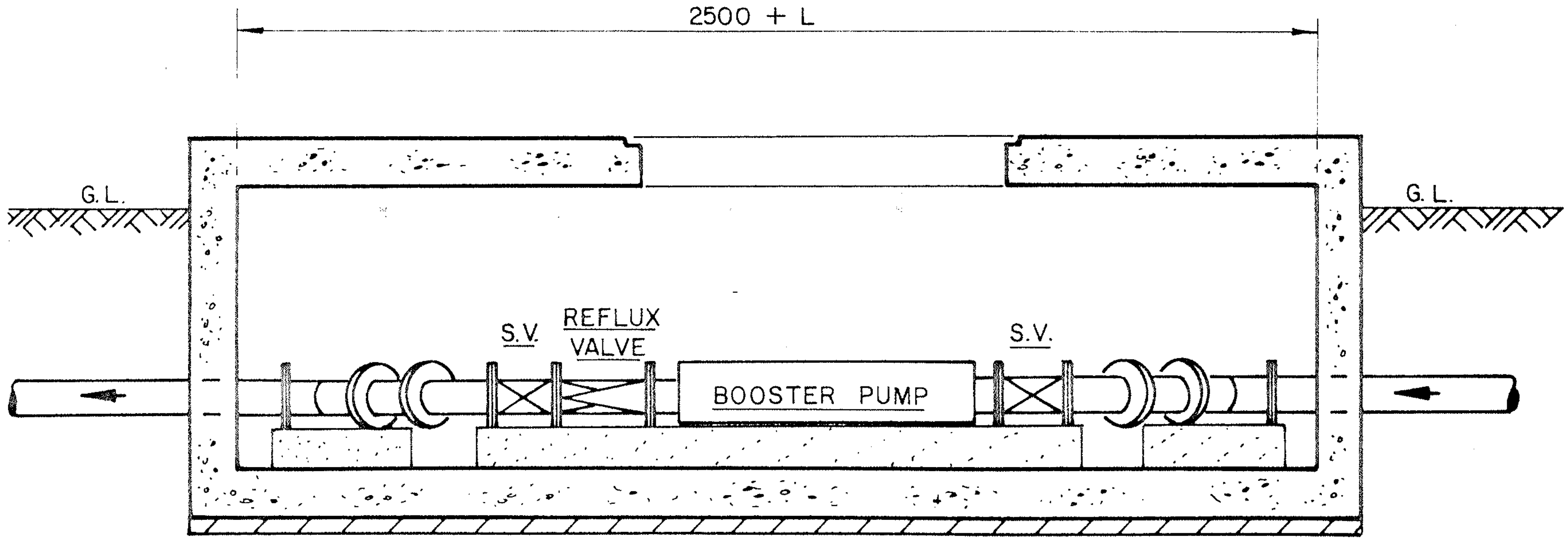


FIG. 2 WELL-HEAD LAYOUT - HOUSE TYPE



PLAN



SECTION

FIG. 3 IN-LINE BOOSTER STATION

6. INSTRUMENTATION & CONTROLS

6.1 The type and amount of instrumentation provided will vary with the size and importance of the scheme. The purposes of instrumentation are:-

(i) Control and Monitoring of Pumps.

(ii) Monitoring of Aquifer/Well performance and parameters.

6.2 Since submersible pumps cannot be visually examined whilst in operation monitoring can only be carried out by instrumentation and this must not be stinted. For all but the smallest installations there should essentially be for each unit:-

(i) Stop/start controls and low water level cut-out.

(ii) Ammeter and voltmeter.

(iii) Delivery pressure gauge (and suction pressure gauge for a booster).

(iv) Overload and phase failure protection.

(v) Hours run meter.

(vi) Flow meter

(vii) "Burst Main" pressure switch.

The ammeter is the most immediate indicator of something going wrong and should never be omitted.

6.3 Where it is proposed to monitor and record the performance of the well and/or aquifer it is desireable to provide an observation well adjacent to the production well and the additional instruments required will be:-

(i) Automatic level indicators in the production well and observation well.

(ii) PH indicator in the observation well.

(iii) Temperature indicator in the observation well.

6.4 A decision to use recording instruments for several of the above measurements will depend on the degree of importance of the scheme and the use to be made of the information. There is no purpose in keeping records for the sake of keeping them and unless they are regularly analysed and the extracted information stored in readily accessible manner the provision of recording instruments is a wasted expenditure. The exceptions are the hours-run meter, which should have a minimum of 5 digits, and the flow meter which should have an indicator and integrator.

6.5 On a major scheme with several wells in one aquifer delivering to a common rising main it may be feasible to have a central control point with a cable connection, or Post Office line, to each wellhead. A telemetry system can then be employed to send signals between the control point and the wells and the information from the monitoring equipment can be displayed and recorded on the central control panel. With this system a microprocessor or mini-computer can be installed at the control point to start and stop pumps in a pre-determined sequence.

6.6 A mimic diagram for a scheme recently designed on the principles outlined in Section 6.5 is shown on Fig. 4. This scheme provides for the control of one surface well and two production boreholes. The surface well has duplicate duty/standby pumps and each borehole has 100% standby and an observation well. Water levels in the service reservoir and outflow from the reservoir will be recorded on the control panel and the reservoir levels will be used to activate the pump control system in the microprocessor. Provision is included for the addition of three further boreholes wells with 100% standby at future stages of the scheme. Advantage is being taken of the accessible location of the control point to provide chlorine and fluorine dosing before the water reaches the service reservoir. A further advantage of this layout is that it can be incorporated with other neighbouring schemes at a future date and automatic control and monitoring can be added.

6.7 The cost of instrumentation will obviously vary with the type of installation but it can be estimated to add from 10% to 80% of the total cost of wells and pumping plant. It is clear that a detailed analysis of the economics of instrumentation should be made at the design stage of the project and the range of information required and controls provided should be tailored to the particular scheme.

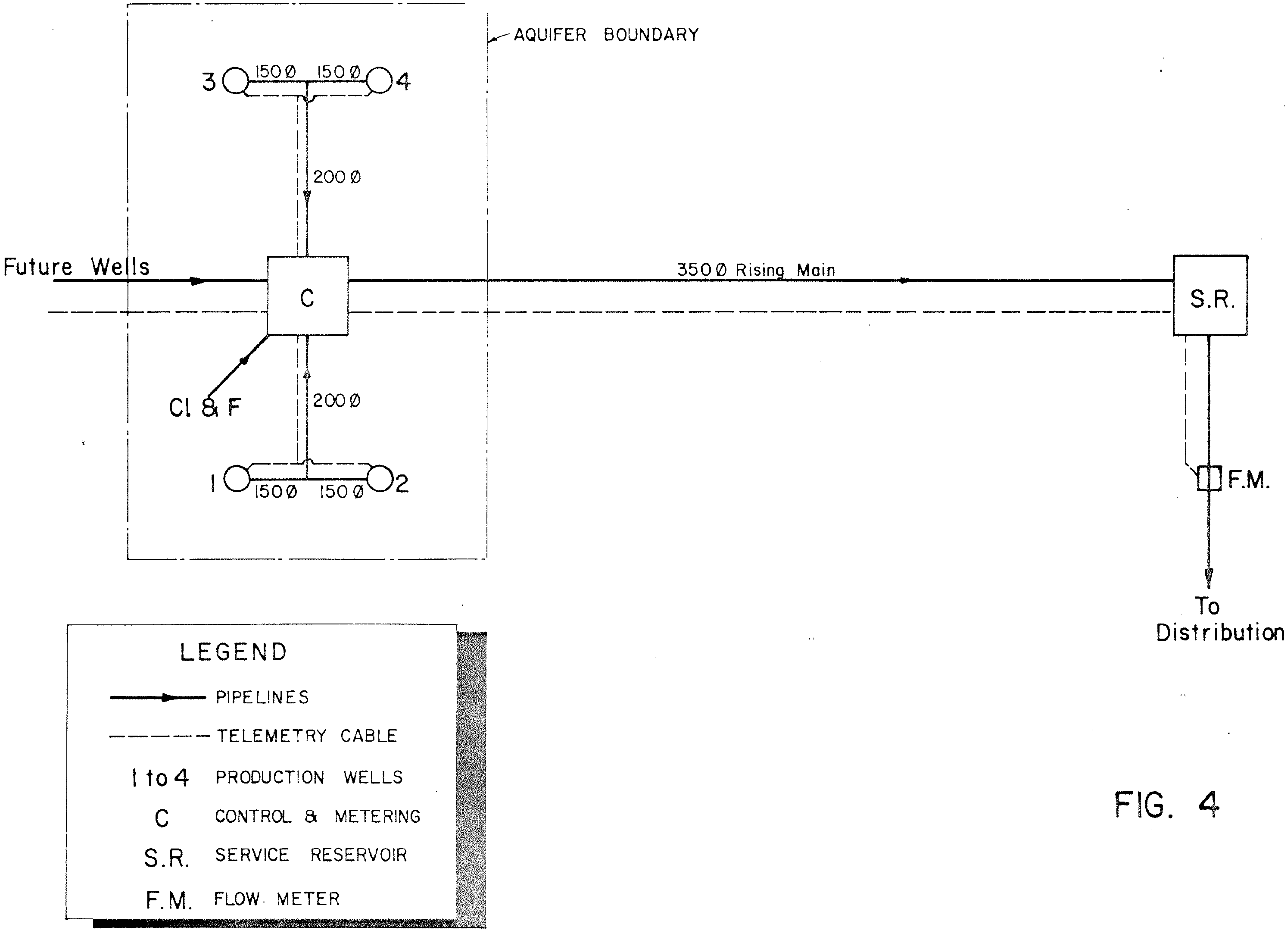

AQUIFER BOUNDARY
3
150 Ø
150 Ø
4
200 Ø
Future Wells
C
350 Ø Rising Main
S.R.
Cl & F
200 Ø
1
150 Ø
150 Ø
2
F.M.
To
Distribution
LEGEND
PIPELINES
TELEMETRY CABLE
1 to 4 PRODUCTION WELLS
C CONTROL & METERING
S.R. SERVICE RESERVOIR
F.M. FLOW METER

FIG. 4

7. ELECTRICITY CHARGES AND SUPPLIES

7.1 E.S.B. rates of charge for non-domestic installations are given in Leaflet ND (latest issue June 1982, but shortly subject to revision). The types of charge which relate to pumping plant are:-

7.1.1 Flat Rate of charge for all units used plus a small fixed standing charge per two-month period.

7.1.2 Night & Day Rate of charge with units used between 23.00 hours and 08.00 hours being charged at approx. 35% of the day rate. There is also a small fixed standing charge per two-month period.

7.1.3 Max Demand Rate of charge in two parts:-

A. Demand Charges - A fixed charge per kW of recorded maximum demand in each two-month period but subject to a minimum chargeable demand of 30 kW. During the period November - February inclusive the chargeable maximum demand is that recorded during specified peak hours only, again subject to a minimum of 30 kW. The practical effect of these charges is that a rebate of all demand charges over 30 kW can be obtained during the four winter months by shutting down during the specified period, usually two hours in the afternoon, Monday to Friday.

B. Unit Charges

(i) Day Charges per 2 month period

(a) 350 kWh per 2 month period at top rate

(b) Balance of day kWh at lower rate {96% of (a)}

(ii) Night Charges

All kWh at lowest rate {63.5% of (i)(a)}.

The above rates are for supplies at low tension (220/380V three phase) and all are subject to surcharge for low power factor (generally less than 0.95). A lower Max. Demand Rate is available for supplies at high tension (10,000V) but this is of interest only for very large installations and is outside the scope of this paper.

7.2 A comparison of the annual cost of the three rates of charge is given in Fig. 5, where curves A, B and C are the flat rate, night/day rate, and max. demand rate respectively. A 20 hour pumping day is assumed and, for B and C, the proportion of day to night running is assumed to be 2:1. The graph shows that, in this instance, for demands above 7 kW, the max. demand rate is most advantageous to the consumer and this will still be valid even with shorter pumping hours, so that, except for small installations, the max. demand tariff is usually accepted by the consumer. It should be noted that special individual flat rates (e.g. for night storage heating) will not be applied to part of a supply where the remainder is charged at max. demand rates.

7.3 As each metering point is treated as a separate supply by the E.S.B. for the purpose of calculating max. demand charges it is an advantage to have a single metering point for a group of wells where this can be economically arranged. The fixed minimum max. demand charge of 30 kW per 2 month period can amount to as much as 40% of the total cost of electricity in a 10 kW installation. Where the operating capacity is greater than 30 kW the winter rebate, although small, is still a useful cost reduction and can amount to as much as 5% of the total annual electricity cost in a 90 kW installation.

7.4 The E.S.B. will require a capital contribution from the consumer to the cost of providing an electricity supply at each pumping station. Depending on the size of the installation and its distance from existing services with adequate spare capacity this contribution will vary from nil up to IR£ 10,000 or more. It is essential that the E.S.B. be informed of the project at an early date and given a map showing the proposed supply points and the approximate load to be serviced at each point, so that they can decide what new services may be required and obtain any necessary wayleaves. An estimate of the capital contribution should be obtained at this stage for inclusion in the capital budget for the scheme.

7.5 The E.S.B. will require full payment of the capital contribution and submission of a standard application for supply signed by the consumer who is to be responsible for payment of accounts, before work on the provision of the required services is commenced. It is, therefore, essential that these formalities be put in train as soon as work on the project commences so that delays in commissioning can be avoided. Adequate provision must be made to provide space for E.S.B. meters and consultation with the local E.S.B. District Office is essential.

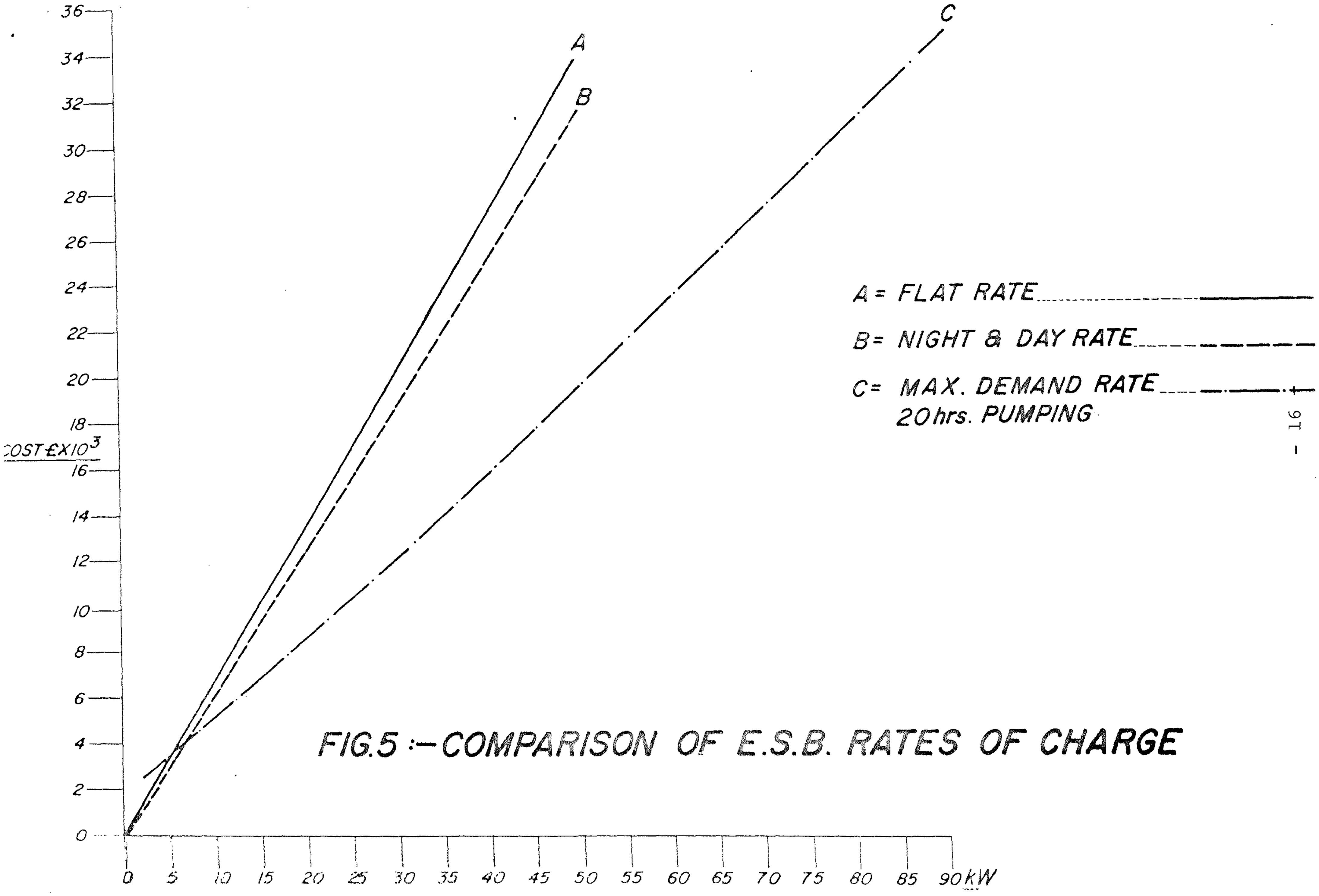


FIG.5 :— COMPARISON OF E.S.B. RATES OF CHARGE

8. PUMPING COSTS

8.1 A typical head/discharge curve for a pumping system is shown on Fig. 6. The total pumping head H is the sum of

h1 static head from top water level in well to discharge level

h2 friction losses in pump and well pipework which are proportional to the discharge Q

h3 drawdown in well which is calculated from the discharge and specific capacity.
drawdown s = Q ÷ specific capacity

h4 friction losses in rising main which are proportional to the discharge Q and can be read directly from the discharge tables for the particular size and pipe material. An allowance, usually 10%, should be made for valves and specials in the line.

8.2 The energy required for the pump can be calculated simply from the formula

kW = QH ÷ (eff. x constant). The value of the constant will depend on the units used for Q and H. Thus if Q is in m3/hr. and H is in metres

kW = QH ÷ (eff. x 362)

Pumping costs are capitalised using standard D.C.F. tables in accordance with the formula

$$\text{Present Worth} = [\{A - (A + r)\}^{-n} / r]$$

Where A = annual cost
Where n = number of years
and r = rate of interest

If the pumping cost increases annually due to increasing demand the method can still be used and tables are available to assist in the calculations.

8.3 The pumping rate will usually be decided in the light of the available well discharge and the total demand of the scheme. The electricity cost for any particular pump will be minimised when the longest possible daily pumping hours are employed. Fig. 7 shows the average unit cost of electricity for pumping periods of 10, 16, and 22 hours per day, when pumping against a total head of 60m. At an output of 3,000 m3/day the 22 hour pumping period has a cost advantage of 11% over the 16 hour period and 21% over the 10 hour period. There would, of course, be an additional capital advantage gained by using the longest pumping period as a smaller diameter rising main would be required for the same pumping head.

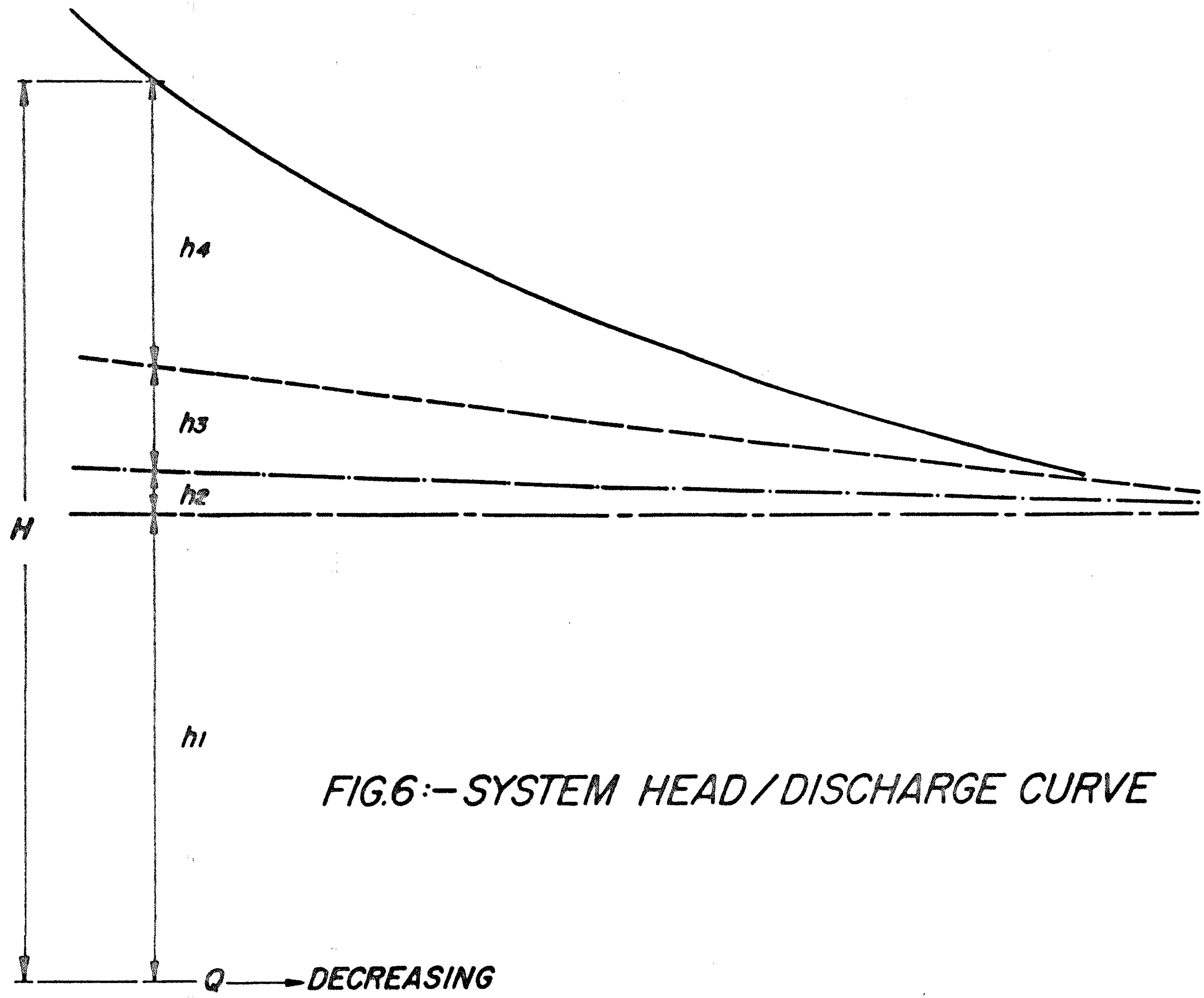


FIG.6:—SYSTEM HEAD/DISCHARGE CURVE

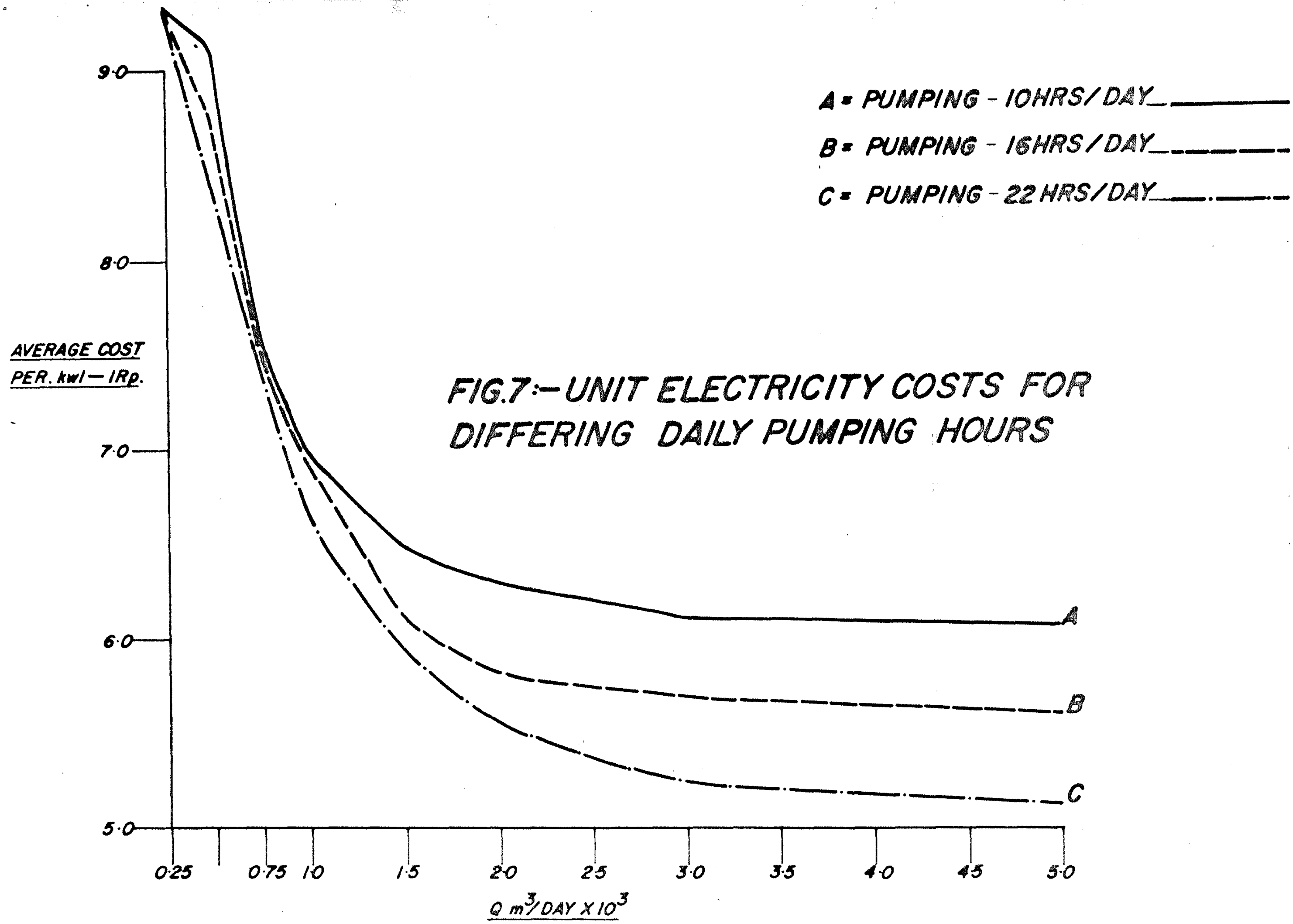


FIG.7:— UNIT ELECTRICITY COSTS FOR DIFFERING DAILY PUMPING HOURS

8.4 Three components of the total pumping head h1, h2 and h3 are virtually fixed for any particular well and pump output but the friction loss in the rising main can be reduced to a very low level by increasing the diameter of the rising main. The economic size of rising main for any particular pumping rate can be obtained by constructing a graph as shown in Fig. 8. Curve A shows the capital cost of the rising main for a range of pipe diameters. Curve B shows the capitalised cost of annual pumping charges for the same range of pipe diameters and curve C shows the combined cost of A and B. The most economic size of rising main is indicated by the lowest point on curve C.

8.5 Decisions on the daily pumping hours and economic size of rising mains can be complicated if several wells are delivering to a common rising main and the demand is expected to increase annually. While the calculations can be carried out using a relatively simple computer programme it is not unusual to size the rising main for the long-term flow as the anticipated life of the pipeline will far exceed that of the pumps. The expected annual increase in demand can be provided by lengthening the daily pumping period e.g. from 16 hrs/day in the first year to 20 hrs/day at full demand.

8.6 While detailed discussion on pump selection will be the subject of a later paper there are certain selection points which I propose to refer to at this time. Fig. 9 shows typical pump characteristics of head/discharge and efficiency. It is important to select a pump where the theoretical duty point is close to the middle of its range and where the efficiency curve is reasonably flat. The reason for this requirement is that a borehole pump seldom operates at an exact duty point as the water level in the aquifer is subject to variations in level with the season of year and amount of pumping. The specific yield can also vary with the quantity of recharge reaching the aquifer. The total head and discharge are therefore constantly varying and the average efficiency will be less than the theoretical efficiency at duty point.

8.7 During its working life the pump efficiency will fall due to wear and as a result output will be reduced and longer daily pumping hours will be required to deliver the design demand. An economic analysis can be carried out to determine when the increased cost due to the loss of efficiency will justify the repair or replacement of the pump. For example take a 50 kW pump with electricity cost of £19,500 p.a. as shown on Fig. 5. A 5% drop in efficiency from 70% to 65% will result in an increase of £1,500 p.a. in electricity cost. Assuming an interest rate of 15% and a loan repayment period of 5 years a capital expenditure of £5,000 to bring the efficiency back to 70% would be economically justifiable at this time.

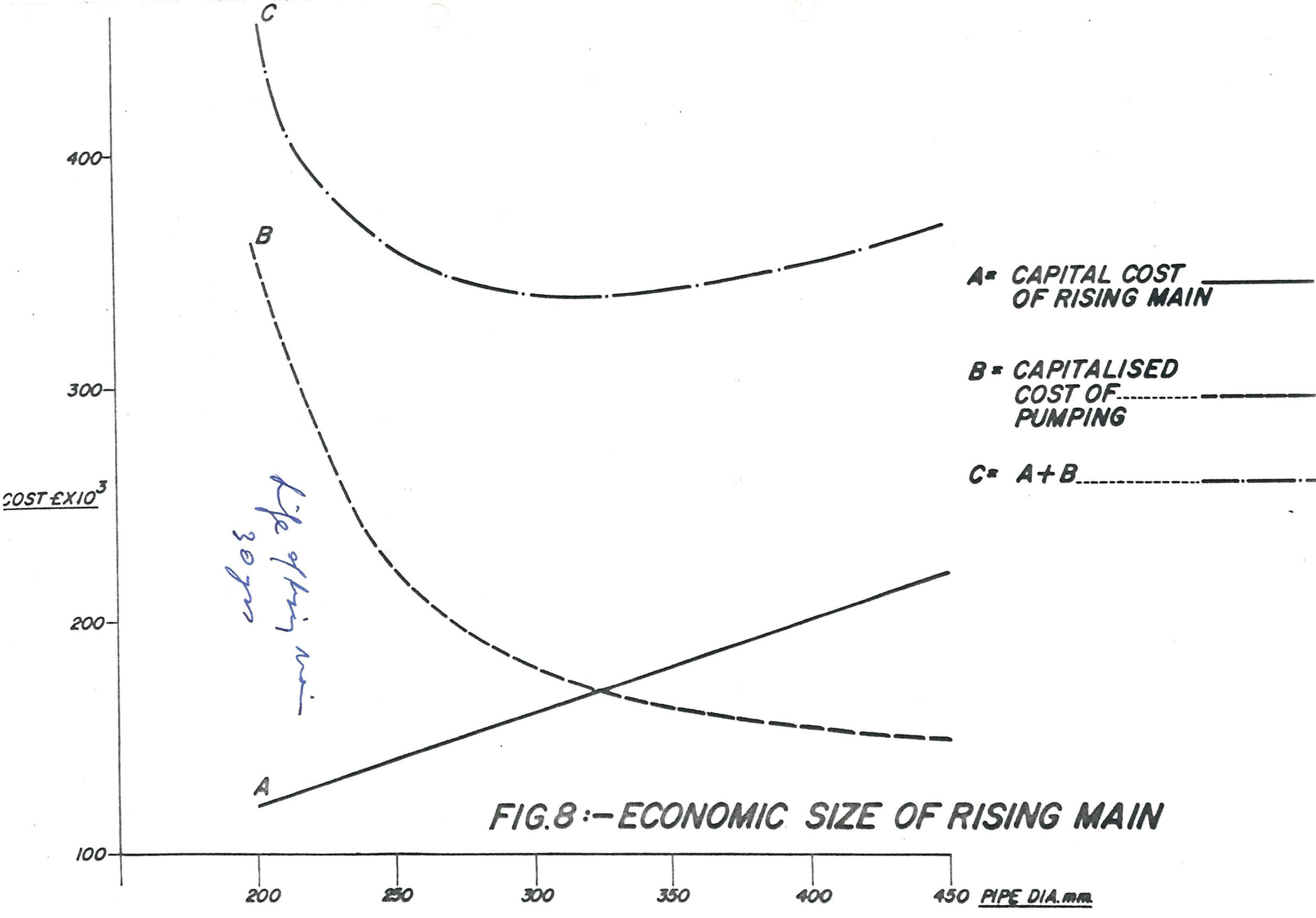


FIG.8:- ECONOMIC SIZE OF RISING MAIN

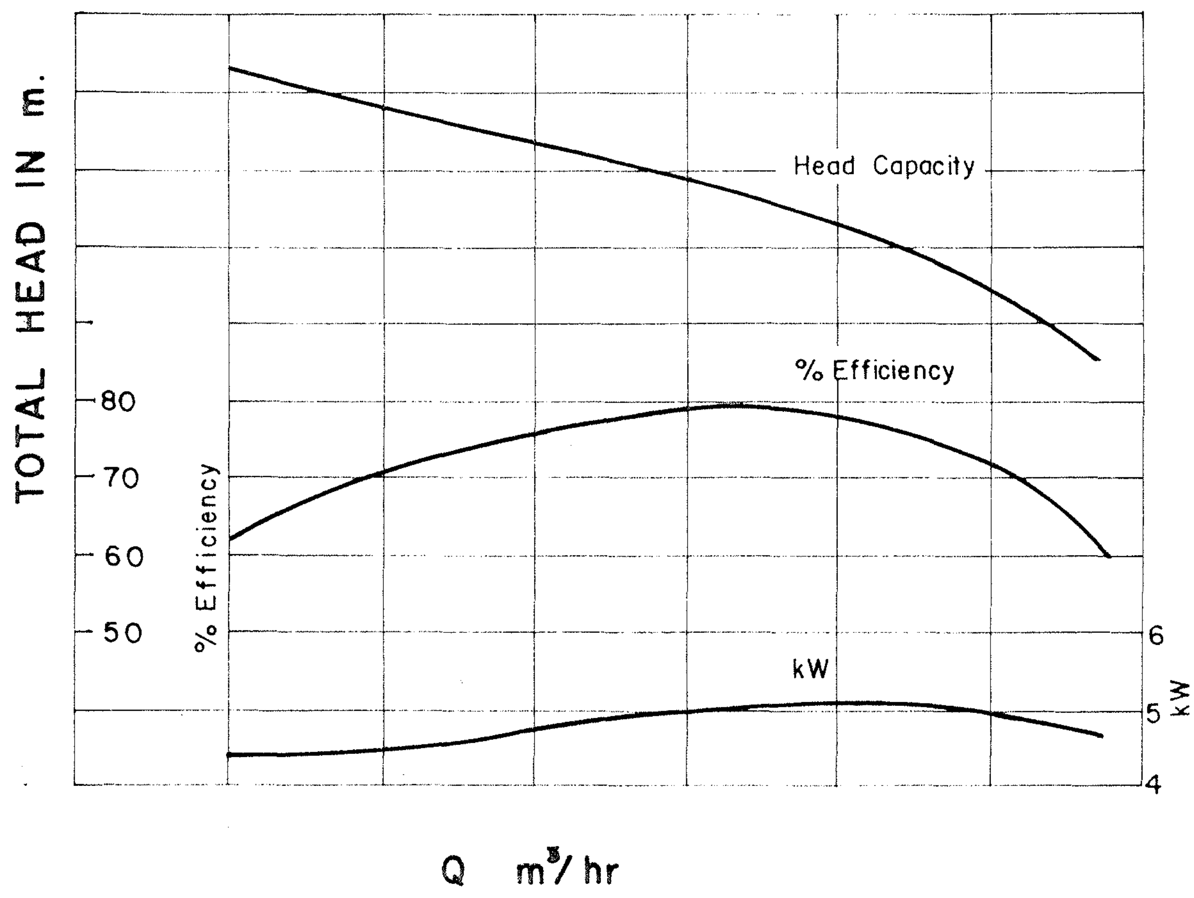


FIG. 9 TYPICAL PUMP CHARACTERISTICS

8.8 Where a fall-off in pump output is observed it is important to ascertain whether this is due to pump wear or well deterioration. If the specific yield of the well drops due to encrustation or aquifer silting then the drawdown will increase.

8.9 Where the service area has wide variations in level the question may arise whether a single high level reservoir should be used or the entire supply be pumped to an intermediate reservoir and part of it boosted to a high level reservoir. An economic analysis can be carried out where the approporate capital costs and capitalised pumping costs are combined to find the most cost-effective solution. However, it will generally be found that the single reservoir system is the least costly but operational considerations may form the basis for a different decision, or the fact that certain facilities already exist may alter the cost equation.

8.10 The problem of selecting the optimum daily pumping period would obviously become much simpler if a submersible pump with variable output were available. This desireable situation can, in fact, be achieved by altering the speed of the pump motor. Varying the speed of the motor will produce a different Q/H curve for each speed and there will be some loss of efficiency and this becomes significant at less than 80% of full speed. There are several methods of producing variable speed electrical drives and one of the most suitable for pumping applications is the A.C. inverter, since it is fitted above ground and retains the simple squirrel cage motor with no alterations. This system can also be by-passed and can be fitted to an existing pumping system. For further discussion on the A.C. inverter reference should be made to the paper delivered by H. Pitt Esq., on 17/1/1983 to a joint meeting of the I.E.I. and I.W.E.S. in Dublin.

9. ANNUAL OPERATING COSTS OF A BOREHOLE SCHEME

9.1 The estimated annual operating costs of the borehole scheme shown in Fig. 4 are given hereunder. The design output is 4,500 m3/day with provision for doubling the output at a future date if continuing aquifer investigations are successful.

9.2 Estimated operating costs

1. Electricity

4 No. borehole pumps each 30 kW.
2 duty/2 standby 20hrs/day pumping.
Heating, Lighting & Instruments 5 kW.
Chemical Dosing Plant 5kW.
Total daily operating load 70kW.

2 monthly cost	£		
(a) Demand 70 x 10.40	728		
(b) Units 70 x 20 x 61 = 85,400			
assume 13 hours at day rate			
7 hours at night rate			
First 350 x 0.0537	19		
Day 55160 x 0.0517	2,852		
Night 29890 x 0.0341	1,019		
Total per 2 months	£ 4,618	x 6 =	£27,708
Less winter rebate 40 x 10.40 x 2			832
	Annual Cost		£26,876

2. CHEMICALS for 4,500 m3/day output

	£
Fluorine (1.0mg/l) $\frac{4.5 \times 365}{1000}$ = 1.65 tonnes x£1500	2,475
Chlorine (2.0 mg/l) $\frac{9.0 \times 365}{1000}$ = 3.3 tonnes x £1260	4,158
Annual Cost	£ 6,633

3. LABOUR

		£
1 operative full time		12,000
1 technician part time		3,500
Skilled labour part time		5,000
	Annual Cost	£20,500

4. MAINTENANCE & SPARES

		£
Capital cost of mechanical plant (excluding cables & installation) £150,000		
allow 5% p.a. for maintenance & spares		7,500
Consumable stores		1,500
Instrument Servicing		3,000
	Annual Cost	£12,000

SUMMARY

1. Electricity		£26,900
2. Chemicals		6,633
3. Labour		20,500
4. Maintenance		12,000
5. Miscellaneous		6,667
	TOTAL ANNUAL COST	£72,700

Cost per 100 m3	£4.43
Cost per 1,ooo gall	£0.20

IRISH MEETING

SUMMARY OF TALK: PUMPING TESTS AND THEIR USES

1. DEFINITION

A pumping test is a method of testing the performance of a well or an aquifer by pumping water from the well and measuring the effects.

A recharge test is similar to a pumping test except water is recharged to the well instead of being removed from it.

2. REASONS FOR DOING A PUMPING TEST

Pumping tests are normally carried out to obtain data with which to do three things:

i) Assess the hydraulic behaviour of a well and so determine its usefulness as a source of water, predict its performance under different pumping regimes, select the most suitable pumping plant for long-term use and give some estimate of probable pumping costs.

ii) Determine the hydraulic properties of the aquifer, or aquifers which yield water to the well. These properties include the transmissivity and related hydraulic conductivity, storage coefficient and the presence, type and distance of any hydraulic boundaries.

iii) Determine the effects of pumping upon neighbouring wells or streams.

3. HOW TO RUN A PUMPING TEST

A pumping test must be planned to give the information required within the budget available. A simple yield test is worthless but a useful test can be either a step drawdown test to give information on the well (2i) or a constant discharge test to give information on the aquifer (2ii). The optimum test programme is one combining the two types of tests - a step test followed by a constant discharge test.

The value of the tests depends on the measurements taken so these should be taken as carefully as possible to ensure accuracy. Discharges should be measured by weir tanks or orifice weirs. Flow meters should not be used for step tests. Water levels can be measured by electric tapes or automatic recorders.

4. INTERPRETATION OF TESTS

The interpretation of pumping tests is a full subject in its own right and should be undertaken by experienced people. There are numerous analytical methods but they are generally either graphical or mathematical solutions to flow problems. Their value is that they enable one to predict the behaviour of aquifers in the future and allow planning of groundwater use.

In shallow aquifers the groundwater levels can respond to rainfall quite rapidly so that pump test results in winter (high water levels) can be rather different to those in summer (low water levels). It is important for long-term monitoring of water levels to be undertaken to ensure test conditions are not extreme - and to trace the long-term effects of pumping to be followed.

Lewis Clark
April 1983

Ref. BS Code of Practice for Test Pumping Water Wells
BS 6316: 1983. British Standards Institution

MEETING IN IRELAND

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PUMPING TESTS AND THEIR USES

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iii) Determine the effects of pumping upon neighbouring wells or streams.

A pumping test also provides a good opportunity to obtain information on water quality and its variation with time and perhaps with discharge rate, although this information can be collected at other times without resort to the expense of a pumping test.

3. THE USES OF PUMPING TESTS

This section is an amplification of Section 2 - the reasons for doing a test.

A pumping test, from the point of view of usefulness, can be considered as two independent tests - a well-test and an aquifer test. A well-test tests the well for the reasons listed in paragraph (1) of Section 2, while the aquifer test determines the aquifer characteristics listed in paragraph (2) of Section 2.

3.1. Well Tests

The commonest test of a borehole, if a test is done at all, is a so-called yield test where the borehole is pumped at the discharge rate of the pump for a few hours. The discharge is measured and the borehole certified for that discharge. This is the least useful of all tests and, as a measure of well-performance, is totally useless.

A more useful test is a yield test in which the water level in the well is also measured. The data for discharge and drawdown from such a test will give information on the well performance. I will discuss the analysis of test data later.

The best well-test is a step drawdown test in which the discharge from the well is started at a low rate and then increased suddenly in a series of steps. The effect on the water level in the well is to draw it down in steps - hence the name of the test.

S L I D E 1

The analysis of the data from such a test will provide information of enormous value to the owner of the well:

i) The variation of drawdown with discharge rate leading to the ability to choose the best pump for the borehole in order to optimise the yield. (Pump the cheapest water)

ii) Determine the efficiency of the well in order to see if it has been constructed correctly.

iii) Provide a base-line against which future well performance can be measured. Very commonly we meet a well owner who complains about deteriorating performance. When asked how he knows his well is deteriorating the answer is akin to "Because I say so". Peoples' memories are extremely suspect for figures more than 10 minutes old. However, the data from a step drawdown test can be compared with data from a new test and the two well efficiencies compared. Once deterioration has been proved or not remedial work can be vindicated.

The step drawdown test is obviously a bit more complicated to run than the other two but it takes no more time and costs no more than the two simpler tests. The information it provides is worth the trouble it takes to do the test properly every time.

3.2. <u>Aquifer Tests</u>

The aquifer tests are designed to get information about the aquifer from which the water is being pumped. The most common type of test, and the only one I shall be considering, is the constant discharge test. In such a test the well is pumped at as high a rate as possible without any danger of pumping the well dry. This rate can be obtained from a step drawdown test of the well. Through the period of the test the water level in the well and the discharge rate from the well, are measured systematically.

Also to be measured are the water levels in all neighbouring wells.

In the case of major abstraction sources - say above $\frac{1}{4}$ mgd one should think about measuring flow in nearby streams.

In the case of major abstraction sources and those sources where continuity of supply is vital then an observation well several meters (about 50 m) from the pumped well should be installed. This is expensive but it does improve the reliability of the test data and is the only way to get any accurate measure of the storage in the aquifer.

S L I D E 2

The analysis of the aquifer test data from a short test - say 8 hours pumping with no observation well will give a close estimation of transmissivity and will allow an estimation of the effects of pumping for an extended period of about 3 days continuously. The effects of only the closest boundaries will have been noticed and only the closest neighbouring wells will have been affected by the test pumping.

The analysis of a longer test using at least one observation well will produce much more data and information on the aquifer:

The aquifer transmissivity
The aquifer storage coefficient
The occurrence of recharge/barrier boundaries
The interference with surface supplies or existing boreholes

It is safe to say that the longer the test and the greater the number of observation wells then the more accurate will be any conclusions drawn from the test results.

The pumping tests are not just scientific fads - they are hard-nosed economic necessities if you want to run your water supply most efficiently. I am at present working on a job in Saudi Arabia - I have just come back from there - where the resurrection of a goldmine depends on having a 10 year supply of water for treatment. A source of water has been found but the amount of water - the resource - available is not known. We are in the middle of a 3 month pumping test which will be used to measure the water resource in the aquifer - no water - no goldmine.

The Saudi example also illustrates the use of long pumping tests in predicting the performance of aquifers over a long period. The goldmine needs a supply for 10 years - if it runs out in 5 years it would be disastrous - and a long pump test is the only way to start to predict over such a long time period.

In a large development several wells may be pumped together - a group pumping test - in order to spread the effect over a wide area and so determine transmissivity and storage over a wide area. In Saudi we have 3 wells and about 20 observation wells. The Shropshire scheme had seven test wells and about 30 observation wells.

The data from the interpretation of such a group test or, indeed, a number of separate tests can be fed into a computerised mathematical model to simulate what happens when different combinations of boreholes are pumped at different rates.

S L I D E 3

Two uses that come from a shorter test of a single borehole, or one with only one observation well, are the study of water quality and the effect on other wells. The water can be sampled and analysed through the test to see if it is potable (bacteria free) and to indicate what treatment is needed before being put into supply. An acidic water may need to be neutralised to prevent corrosion or a ferriginous water may need an oxidation phase to remove iron.

The effects on other wells are very important. In UK a condition of licence for groundwater abstraction is commonly that there will be no significant derogation of existing supplies. I believe this is not legally so in Eire but I would bet that an Irish farmer's reaction if he thought you were stealing his water would be similar to an Englishman's reaction - he would sue! The pumping test, when carefully, carried out is an effective way of finding the amount of drawdown at various radii from the pumped well after various time periods.

4. HOW TO RUN A PUMPING TEST

4.1. Planning

The kind of pumping test you will run will depend on the size of the project involved and the amount of money involved. I will discuss only the smaller tests because this will apply to most cases of private development.

I have already said that a simple yield test is worthless so don't waste money. For the same price you should be able to run a simple four step - step drawdown test. Each step lasts 100 minutes so the whole test, with recovery will take 8-9 hours. This well-test should be considered the minimum testing required for any site.

The step test can be combined with a constant-discharge 24 hour aquifer test to give a comprehensive package.

The optimum test package in my view is a step-drawdown test followed by an overnight recovery followed by a 3 day (72 hour) constant discharge test. These tests, particularly if two observation wells are available will tell you most of the things there are to tell about a site. More extensive testing would have to be for special uses to be justified in most cases.

4.2. Measurements during the Tests

The two main measurements to be made during a test are of the well discharge and the water levels in all available boreholes or wells. Other measurements may be of a streamflow, should any cross the site - rainfall (from the Met Office?) and barometric pressure (from the Met Office).

Well discharge

The analysis of a pump test depends on good quality data so all measurements, discharge and water level, should be made carefully and accurately. Getting bad data from a test is akin to lighting cigarettes with Punt notes.

Two common methods are used in UK and Eire. Timing the filling of a vessel of known volume - a 45 gallon drum and, for greater discharges, a weir tank.

S L I D E S 4 AND 5

Another convenient method used more abroad is the orifice weir.

S L I D E 6

All these methods depend upon the apparatus being made to tight specifications.

The discharge rate should be measured at least twice during each step of a step test and at hourly intervals during a constant discharge test.

A water meter can be used for discharge measurements in a constant discharge test provided the discharge rate is in the calibrated range of the meter. A meter is not recommended for a step test.

Water levels

S L I D E S 7 AND 8

By far the most common method of measuring water levels is by electric tape but other methods include air line and

S L I D E 9

pressure transducers. The latter are useful in that they can feed readings back into a data-logger ready for computer analysis. Readings can be made of water levels in observation wells by autographic recorders.

S L I D E 10

Irrespective of methods it is important to take the measurements carefully using the same well-marked fixed datum all the time. The time of each reading should be recorded accurately and because most analytical methods depend on a long relationship between time and drawdown the times of measurement should be on a log scale. I use:

1, 2, 3, 5, 7, 10, 15, 30, 35, 40, 50, 60, 70, 80, 90
120, 150, 180, 240, 300, 420, 600, 720, 840, 960, 1080, 1200
1320, 1440, 1680, 1920, 2160, 2400 etc

The time can be measured with a stop watch but modern digital watches are sufficient.

5. THEORY OF PUMP TEST ANALYSIS

The analysis of pump tests is a full subject in its own right so I refer you to various groundwater manuals. I will merely touch on aspects which may illustrate the usefulness of the pumping tests.

Well Tests (Step-Drawdown Tests)

S L I D E S 11 AND 12

This analysis is by two Australians, Eden and Hazel, and without going into detail it is a plot of drawdown versus a function H which is a summation of the discharge rate and log time. The slope of the various graphs is proportional to the aquifer transmissivity. From this graph we take the values of drawdown at one minute and use them to plot a graph of drawdown versus specific drawdown. The slope of this graph is dependent on the well efficiency - the steeper the slope, the less efficient the well and in a perfect well the graph would be horizontal. This graph is perfect for showing deterioration of a well with time using the results of step tests run several years apart.

S L I D E 13

Aquifer Tests (Constant Discharge Tests)

S L I D E 14

This is the plot of data from a straight forward test lasting seven days (10,000 minutes). The data has enabled us to get values for transmissivity and storativity but it also has a direct value. One can project such a smooth data curve forward with confidence for at least one log cycle of time (100,000 minutes, 70 days) or possibly two log cycles (1,000,000 minutes, 700 days). The test therefore gives us powers of prediction which again allows us to optimise the production pump with increased confidence.

The data on the slide show no effect of boundaries. If a barrier boundary - say the edge of the aquifer is reached - then the gradient of the curve will increase and there will be greater drawdown. With a recharge boundary - say a major river then the opposite will occur.

Models

Through the tests we have mentioned storage and transmissivity without really saying why it is of use measuring them. These two parameters govern the way water moves in an aquifer - T governs the ease water passes through the aquifer and S governs how much water is in storage and how fast pumping effects are felt over the area of an aquifer. When we know T and S, and their distribution over an aquifer we can predict how the water in the aquifer will respond to various effects - natural drought, recharge or pumping from different areas with different amounts.

S L I D E S 15 AND 16

That is we can manage our resource intelligently rather than sucking it and seeing.

END

IRISH MEETING

SUMMARY OF TALK: OPTIMISATION OF WELL DESIGN

The field of well design optimisation can be divided into two parts - well field design and the design of individual wells.

Well field design

The optimisation of a well field will depend on the needs of the consumer whether or not the design will be optimised on reliability of supply, quality of supply or on quantity of supply. Most people equate optimum with cheapest but this is not necessarily so. Many pumping stations have three boreholes on a site - not because the extra discharge is needed but because the continuity of supply is needed.

In the optimisation designed to maximise a well field discharge three options have to be considered:

To increase yield by increasing well diameters or by increasing the number of wells.

To increase yield by increasing well depths or by increasing the number of wells.

To space the wells far apart or close together.

The optimisation in a small well field can be done either graphically or mathematically controlled by a great dose of commonsense, but with a large well field a computer may be necessary.

Individual well design

The factors concerned in the physical design of a well are:

Depth
Diameter
Screen/casing length and materials

These factors can be optimised to give a minimum cost construction within the constraints of the demand figures and site limitations. The capital costs and running costs of a well are inversely related to each factor, therefore the present value can be expressed in an equation containing all factors. This present value is then partially differentiated with respect to any of the factors involved and equated to zero for minimum cost.

This mathematical optimisation however, must be tempered by commonsense, and commonly site factors severely limit optimisation options. In a thin aquifer the aquifer thickness defines the screen length, not a mathematical expression. At all times, however, one's mind must be open to well design features which will reduce the capital cost or the running cost of a well - this is optimisation in practice.

Lewis Clark
April 1983

IRELAND MEETING

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OPTIMISATION OF WELL DESIGN

The field of well design optimisation can be divided into two parts - well-field design and the design of individual wells. To my mind these two parts should be treated as phases of the same process; I consider that it would be dangerous to separate them.

1. WELL-FIELD DESIGN

The broad factors affecting well design, particularly well-field design, are the demand for water and the geology of the area. These two factors will govern the number and size of wells necessary for any scheme. The geology will dictate the amount of water available and the possible yield of the proposed wells, while the demand will then dictate the number of wells. This would appear to be self-evident but sometimes one meets engineers and planners who believe the demand dictates the amount of water available. Recently in Nigeria I was on a water supply project and on many sites with no surface water I was asked to provide, from groundwater, 70 litres per head per day to populations of 50,000 or more. This was in granite and metamorphic terrain with a 40% failure rate for boreholes and an average yield from a successful borehole of around 1 ℓ/sec (800 gph). A theoretical 60 bores would be needed to supply 50,000 people and the planners were quite upset when told it was not possible - they would have to take what the earth would give, not what they felt like demanding.

In a prolific aquifer with a small demand one borehole may supply the whole demand and this situation raises the question of reliability of supply. In an extreme case a disruption of supply of only a few minutes may not be acceptable. At WRC, for example, we have just finished a borehole for a special laboratory supply of raw water. This cannot be interrupted so we designed the well to accept two pumps with an automatic cross-over switch should one fail.

In most situations a down time of several hours can be tolerated and in this time the broken pump can be removed and a spare one, held on site could be installed. I would recommend, however, that in all cases where water is supplied from the ground on a regular basis, at least two boreholes be installed; one for supply and one for stand-by. This allows maintenance of pumps and work-over of boreholes to be undertaken on a routine rather than an emergency basis.

In the design of well-fields aimed at maximising the discharge three options are commonly discussed:

(1) To increase yield by increasing well diameters or by increasing numbers of wells.

(2) To increase yield by increasing well depths or by increasing numbers of wells.

(3) To space the wells far apart or close together.

With respect to point one - one thing has to be made clear - doubling the diameter of a well does not double the possible discharge. It is most likely to follow the increases tabled by Johnsons:

S L I D E 1

Well Diameters

6"	12"	18"	24"	30"	36"	48"	
100	110	117	122	127	131	137	
	100	106	111	116	119	125	
		100	104	108	112	117	Efficiency
			100	104	107	112	increases
				100	103	108	% from 100
					100	105	

Drilling two wells on the other hand will come close to doubling the discharge. In the case of increasing the yield from a single well then a second well is quite definitely the best option - it doubles the yield and increases the reliability of supply.

With the second point - the depth of a well; theoretically, in a uniform aquifer, the deeper the well the more water it will yield. However, in practice, most aquifers are limited in thickness and the depths of the wells are limited by aquifer thickness. In fissured aquifers like the Old Red Sandstone or Chalk the effective aquifer, that part capable of transmitting water - is of limited thickness and effectively defines the depths of wells. Drilling to greater depths into blind zones will not increase the well yield.

When siting wells in a well-field the wells should never be drilled so close together that their mutual interference threatens to pull the water level to below pump level. The drawdown to be expected from a well at a given radius (The interferences!) can be predicted with fair accuracy from pumping test results. Within the constraint of not pumping wells dry the well spacing can be optimised in terms of energy costs incurred by increased drawdowns at close spacings versus increased costs incurred by increased mains at wide separations. In a big well-field this optimisation is best

S L I D E 2

done on a computer.

2. INDIVIDUAL WELL DESIGN

The siting of boreholes will not be discussed here but one supposes that an optimum position will have been chosen by reference to other wells, to existing records and possibly by geophysical site investigation.

Two decisions have to be made prior to drilling a well -

1) the drilling technique to be used, and
2) the physical design of the well.

I shall not discuss drilling techniques other than to list the main kinds:

Percussion
Direct circulation mud flush rotary
Reverse circulation rotary
Air flush rotary
Down-the-hole Hammer Percussion

Each technique has its strong points and its weak points but for all wells the technique should be chosen which can do the job with the minimum damage to the aquifer. It is no good using a technique which lets the hole be drilled in a day if it also pushes mud into the aquifer so far that the aquifer is sealed off.

All techniques will damage the aquifer to some extent. This cannot be avoided irrespective of well design so measures to remedy the damage must always be taken. These measures are called well-development and all design features which help in development should be emphasized. I personally consider thorough development the most important part of drilling a well.

The factors concerned in the physical design of a well are:

depth
diameter
screen/casing
gravel-pack

The first three factors can all be optimised as the capital costs and running costs of a well are inversely related to each factor. I shall give the screen optimisation as an example only, because, in most situations the approach has to be much more pragmatic.

S L I D E 3

The present value of a borehole, PV, of capital costs plus running costs is given by:

$$PV = C_1 + C_2L + C_3Q + C_4 \frac{PQ}{L} + C_5 \frac{PQ^2}{L}$$

S L I D E 4

where C_1 - 5 are constants depending on the costs of drilling, screen, fuel etc

Q is the discharge rate

L is the screen length

P is derived from the relationship, Drawdown = 1.32 Q/KL = PQ/L which has been obtained from a large number of tests

K is the aquifer permeability

The present value can be partially differentiated with respect to any of the parameters involved and equated to zero for minimum cost. For example,

S L I D E 5

$$\frac{d\ PV}{d\ L} = C_2 - \frac{C_4PQ}{L^2} - \frac{C_5\ PQ^2}{L^2} = 0$$

$$\therefore L^2 = \frac{PQ}{C_2}(C_4 + C_5\ Q)$$

Thus the optimum length of screen can be calculated for any discharge rate. Here is a plot for Optimum screen length with

S L I D E 6

running and capital costs separated out.

In the real world the depth of a borehole is governed by the depth and thickness of an aquifer and there is little room for modification. This does not apply strictly to fissured rocks like the English Chalk or the Old Red Sandstone and Granites.

S L I D E 7

Joint systems tend to close with depth because of rock loading and lack of weathering so in these cases there is a <u>maximum</u> depth beyond which it is not worth going and an <u>optimum</u> depth which, on average, is the depth showing the largest yield per unit depth. These two depths are statistical numbers really and vary from place to place but most commonly the maximum depth will be around 100 m and the optimum depth about 50 m.

The diameter of boreholes can be optimised mathematically but most rules are merely commonsense. The overriding law is that if you are going to put something down a hole the hole must be big enough to receive it. Don't laugh! - less than two months ago in Saudi I saw a contract specifying 4 inch pipe to be installed in a 3 inch bore.

The factors that have to be balanced in selecting a finished well diameter are:

i) Gravel pack or not

ii) Yield expected from the aquifer

iii) Size of pump needed to discharge that yield

iv) Relative drilling costs for various diameters

Should a gravel pack be incorporated into the well-design then the drilled diameter should be at least 8 inches (200 mm) greater than the finished internal diameter. In places where demand is low (less than 1000 gph) and where the aquifer is reasonable then a 4 inch ID well could supply demand at the theoretical optimum cost per unit discharge. However, my personal view is that installing a 4 inch well imposes unnecessary constraints on the user compared with a 6 inch well. With 4 inch ID there are few allowances for lack of verticality and little allowance for any increase in demand. A 6 inch diameter well would cost very little more than a 4 inch well, possibly an extra 10%, and give one much more freedom. I would recommend, therefore, a minimum ID of 6 inches for any production well.

The maximum diameter of a well will be a pay-off between extra drilling costs for larger diameters versus the increased yield to be expected. It is unlikely to be

S L I D E 1

much greater than 12 inches ID in relation to the yield but could be greater to accommodate high yield pumps. At these large diameters costs tend to escalate rapidly and, as I have said before, one should consider drilling extra wells to achieve greater yields from an aquifer.

In high yield wells or very deep wells the cost of installation can be reduced by using a multiple screen string

S L I D E 3

The pump chamber is drilled at a large diameter to accommodate the pumps to a depth below the expected production pumping water level. The hole is then continued to total depth at a slimmer diameter governed by the discharge required from the hole. The cost in steel casing and in drilling can be reduced significantly by this design. WRC are using it in the Midlands at present on a contract for CEGB where large diameter pump chamber casing 450 mm ID is set to about 150 m, intermediate casing of 375 mm ID is set to the base of the Keuper Marls at about 210 m and the hole completed through the Bunter Aquifer at 300 mm.

I have shown how a screen length can be optimised in a very thick aquifer where the discharge rate can be met by partial penetration. In practice in this country this case rarely applies and one would screen the whole aquifer. The whole purpose of drilling is to screen the aquifers therefore it is important to accurately identify the aquifers so you can set the screen to a precise depth. The only technique which can do this adequately is geophysical logging and I recommend logging every hole drilled.

A factor in well design which is open to dispute is the choice of screen design and material. I haven't time to argue the pros and cons of the use of screens but I would give the following comments:

1) Don't use screens at all if they are unnecessary. If the borehole walls will stand then leave them.

2) In coarse gravel aquifers there is considerable evidence that very high open areas in screens are not necessary to produce maximum yield. This means that ordinary plastic casing with machined slots to give a fair open area (8 - 15%) will give as good a yield as any others.

3) Mild steel cut-slot casing is subject to corrosion, encrusting and bacterial growth so should be avoided.

4) Stainless steel screen is corrosion resistant, has high open area, is strong and can withstand development techniques but is expensive. The slot size in SS screen can be manufactured to a fine tolerance.

5) The cost of screen is usually small compared with the overall cost of a borehole and yet this is where the water comes from. I would recommend using the kind of screen, within your financial constraints, that would give you most safety factors on well performance and deterioration.

The final feature of well design I want to talk about is the use of gravel packs in wells. The use of a pack adds considerably to the cost of a well, and yet I feel many people use them in most unnecessary places.

1) Packs are not needed in boreholes where the aquifer will stand without a screen.

2) Packs are not needed in fine to medium ill-sorted aquifers - you can use fine-slotted wire-wound screen and develop a natural pack.

3) Packs are not needed in coarse sands and gravels - any screen with a fair (8-15%) open area will develop a natural pack.

Packs are needed when an unstable fine-grained very well-sorted sand aquifer is being screened. A well-sorted sand can pass through a screen in large quantities if the screen slot size is slightly wrong. I would also use a pack in a mixed aquifer where fine and coarse bands intercalate and a multiple screen string would be very complex and probably wrong.

When one chooses to use a pack then I would advise you to use the correct pack - not the standard English gravel pack of a truckload of 4-6 mm road chippings. Match the pack grain size to the aquifer and then the screen slot size to the pack according to well publicised rules.

To end the talk I would advise everyone to avoid complex laws on well design. To optimise well design follow the KISS Law - Keep It Simple and Stupid. Very basic commonsense cannot be beaten.

E N D

SANITARY PROTECTION OF WATER WELLS.

Dergo Tape

THE SERMON.

THE CAUSE.

Protection from what?

Nature.

- Natural drains, ditches, bogs.

Man.

- Septic tanks, barn yards, soak pits, silos, outdoor toilets, rubbish tips, industrial wastes, oil spillages, unplugged oilwells, travellers, horse boxes, abbatoirs, nitrate fertilizers, salt depots, water softener discharges, pump installers and other well-drillers.

Why?

Baterial Infections.

- Mammalian digestive tract, Escherichia coli. harmless, normal until out of place; presumption of contamination.
- Strong pathogens: typhoid, typhus, cholera, hepatitis.

Man-made compounds.

- Washing-up liquids) Septic tanks.
- Drain cleaners)
- Petroleum products.

Chemical overload.

- Nitrates, nitrites, sodium chloride, sulfates.

Iron Bacteria.

- Thrive in water of low average temperature.
- Iron content necessary for life cycle, $>0.1mg/l$.
- Pathogenically harmless.
- Incredible nuisance.
- Probably preventable in majority of infections.

THE PREVENTION AND CURE (?).

Location.

Rules of thumb.

- 100 feet from source of pollution.
- Uphill from source of pollution.
- Upgradient from source of pollution.
- Don't drill under power lines.
- Be diplomatic, don't loose the job, but don't drill wells in barnyards even if they are covered with concrete.

Design.

DO.	DON'T.
Use T + C steel, welded joints or plastic, HD.	Use concrete or clay tile for casing.
Seat surface pipe into rock, heavy clay.	Back fill around top of casing from mud pit, slush pond.
Cement surface pipe into place.	See above.
Provide gradient, at least 1:4, away from exposed casing top.	Don't run power cable trench to casing or interrupt gradient.
Use pitless adaptor, sanitary well seals.	If you don't use P.A., bring pump discharge above ground and protect.

Execution.

- Oversized hole, dump bailer, air pressure.
- Float shoes.
- Annulus cemented, dump bailer.
- Cost.

Miscellaneous.

William L. Jungmann
UOP Johnson Well Screens (Ireland)

April 19, 1983.

DESIGN

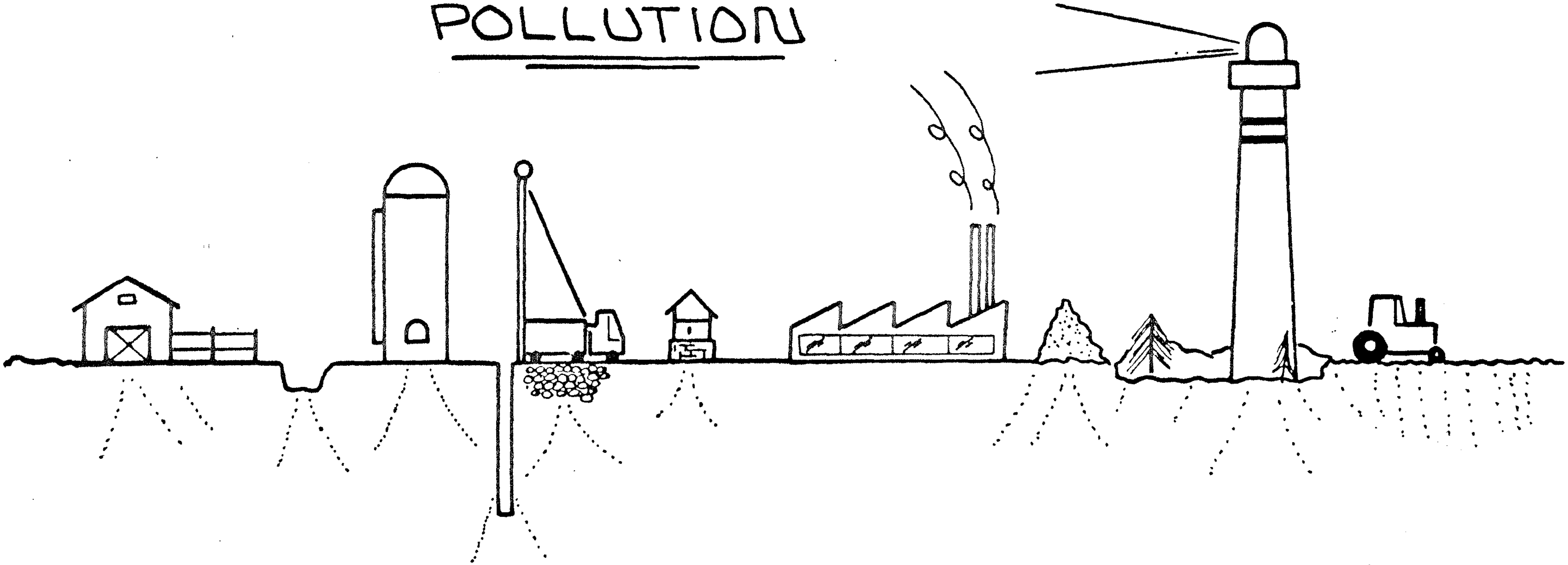
DO

- STEEL, T AND C, WELDED, PLASTIC
- SEAT SURFACE PIPE
- CEMENT SURFACE PIPE INTO PLACE
- LEAVE SITE GRADED AWAY FROM WELL. 1:4; EXPOSED CASING AT LEAST ONE FOOT
- USE SANITARY WELL CAPS, ADAPTORS

DON'T

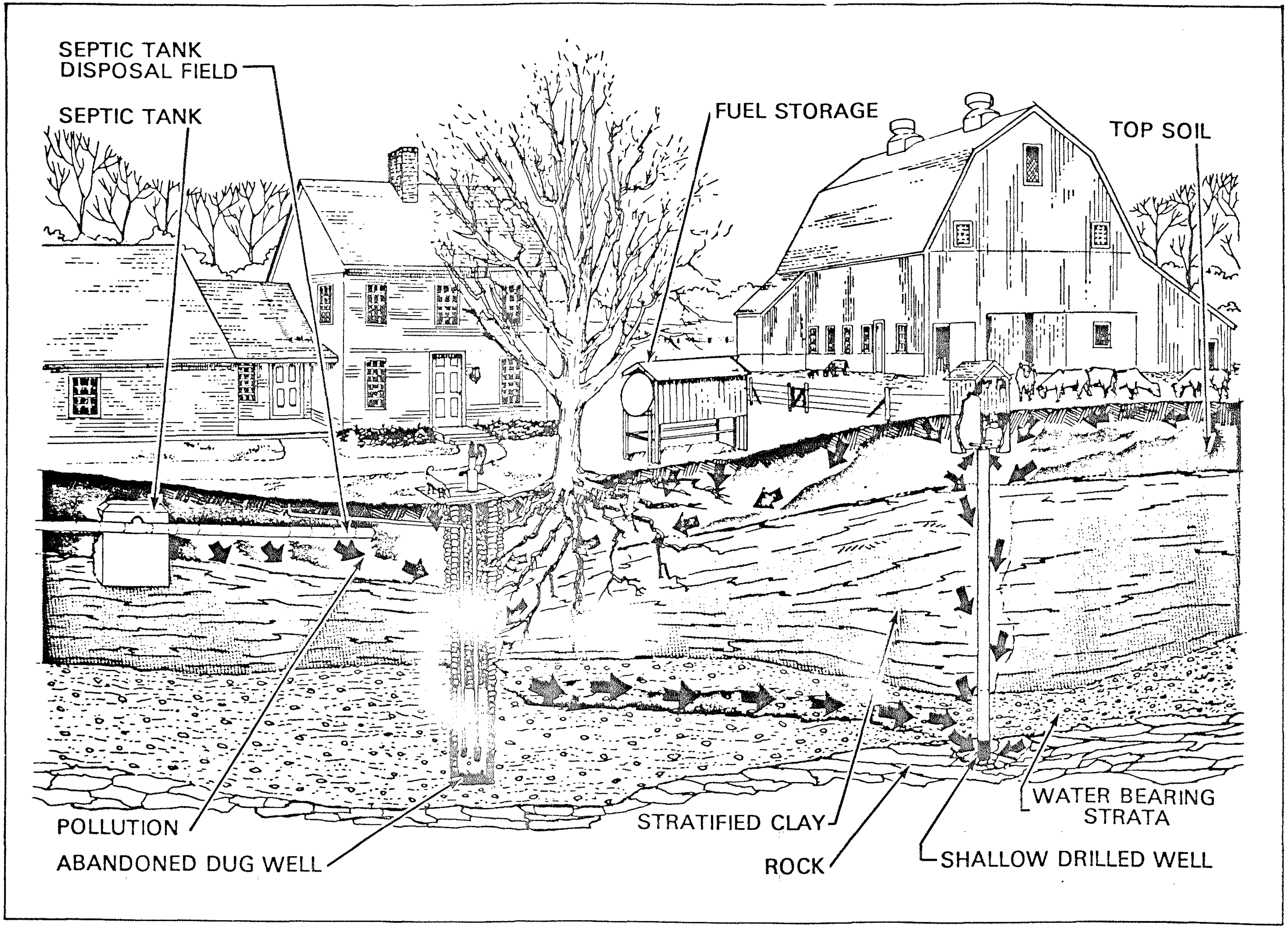
- CONCRETE OR CLAY TILE USED OIL FIELD CASING (UNLESS FIRED)
- BACKFILL AROUND CASING FROM MUDPIT SLUSH POND
- SEE ABOVE
- RUN POWER CABLE TRENCH TO CASING
- FORGET TO BRING PUMP DISCHARGE ABOVE GROUND IF YOU DON'T USE PITLESS ADAPTOR

SOME SCOURCES OF POLLUTION

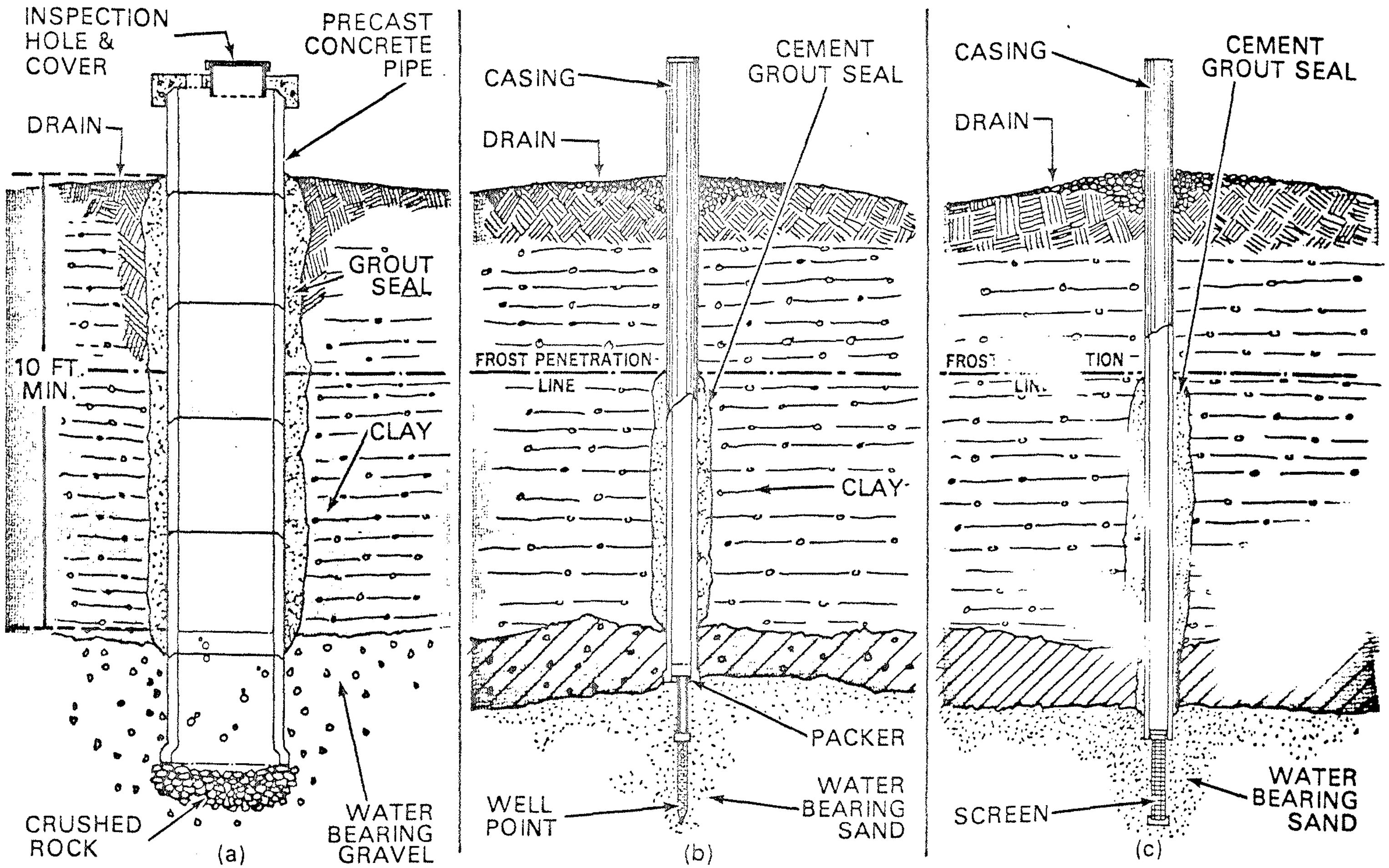


BARNYARDS ; SILOS ; SOAK PITS ; INDUSTRIAL WASTE ; RUBBISH TIPS ; TILLAGE

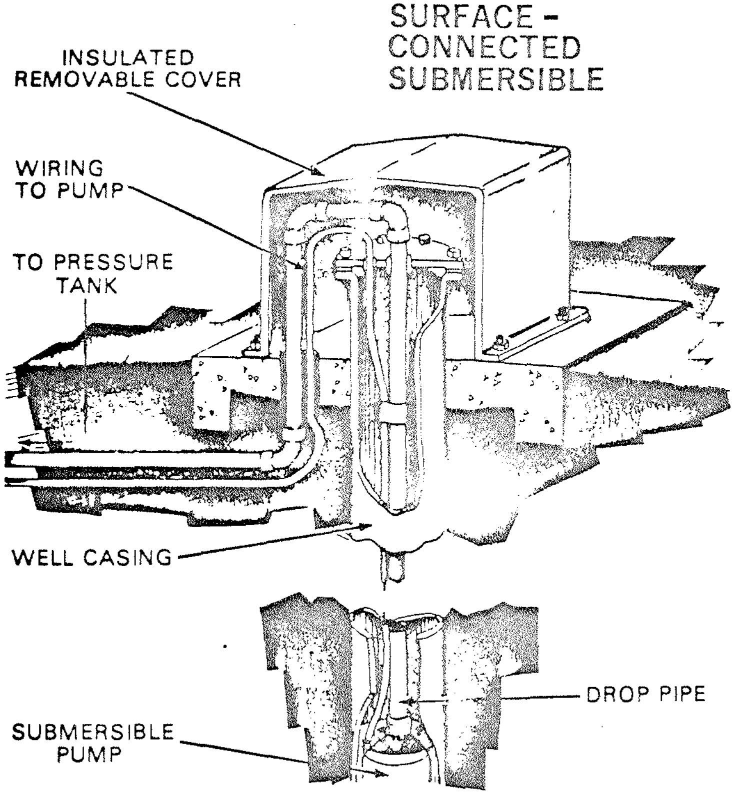
DUG WELLS ; DRAINAGE CANALS ; DRILLED WELLS ; BOGS .

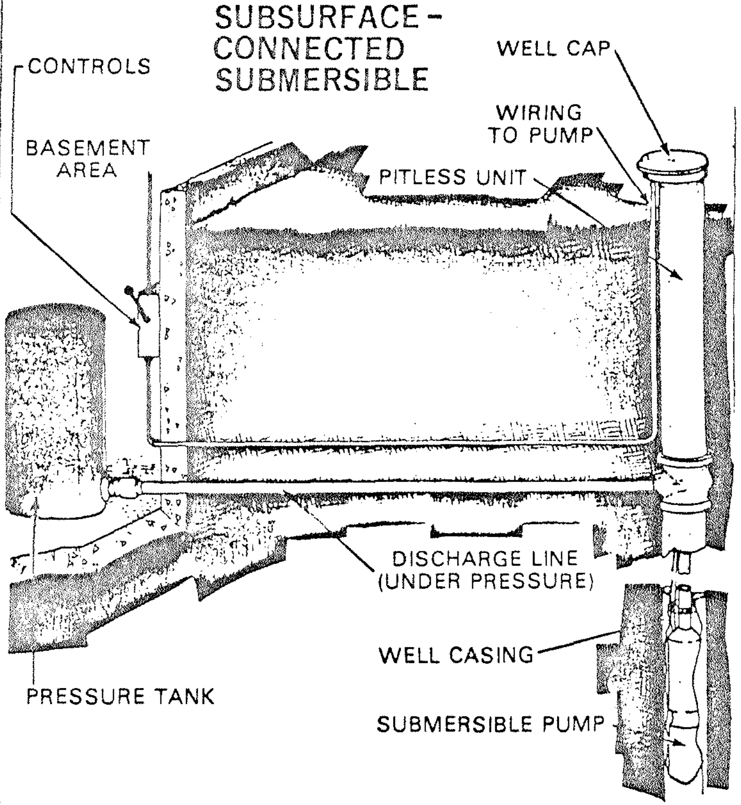


Shallow wells can become polluted more readily than deep wells. Note that pollution can come from underground sources as well as from surface sources.



Methods of protecting wells from surface pollution, (a) Dug well. (b) Bored well with driven well point. (c) Drilled well.[21]


SURFACE-
CONNECTED
SUBMERSIBLE
INSULATED
REMOVABLE COVER
WIRING
TO PUMP
TO PRESSURE
TANK
WELL CASING
DROP PIPE
SUBMERSIBLE
PUMP


SUBSURFACE-
CONNECTED
SUBMERSIBLE
CONTROLS
WELL CAP
WIRING
TO PUMP
BASEMENT
AREA
PITLESS UNIT
DISCHARGE LINE
(UNDER PRESSURE)
WELL CASING
PRESSURE TANK
SUBMERSIBLE PUMP

INTERNATIONAL ASSOCIATION OF HYDROGEOLISTS (IRISH GROUP).

THIRD ANNUAL SEMINAR ON GROUND WATER DEVELOPMENT

COSTS FACTORS IN GROUND WATER DEVELOPMENT.

PUMP SELECTION, INSTALLATION and MAINTENANCE.

Speaker: T. A. Ruddy, M.E. TCH.,
Director,
Electrical and Pump Services, Ltd.

I N T R O D U C T I O N

Other speakers have dealt with the well development, its protection and efficient utilisation. This paper (which will take approx. 30 minutes to read) will set out to assist in the proper selection, installation and maintenance of the pump unit to be installed in the properly developed well, and will be sub-divided into the following topics:-

1. Types of borehole pumps, electro submersible pumps, and types of submersible motors.

2. Pump selection - Information required, well water and site conditions.

3. Installation and maintenance of submersible pumps, motors, and ancillary equipment.

4. Conclusions.

/2.

TYPE OF BOREHOLE PUMPS.

1. Recriprocating Pumps.

This is one of the oldest forms of borehole pumping plant using a crank and a driveshaft to the piston. The drive unit is installed above ground and the piston and cylinder submerged at water level. Problems with shaft deflection, wear on bearings and high capital cost make this unit no longer viable for larger diameter wells. However, manual low lift units are utilised particularly in third world countries.

2. Air Lift Pumps.

This is an inefficient way of pumping. However, it is used when the borehole contains sand or gritty matter in suspension. Its main advantage is the absence of working parts below the surface and it is normally used simply for cleaning or developing bores prior to the installation of the production pump.

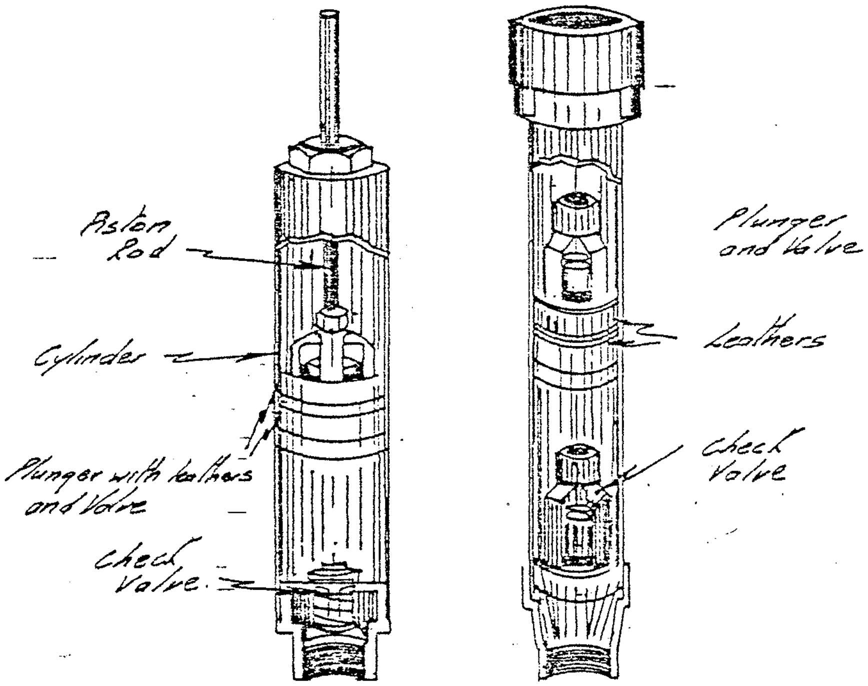
3. Ejector or Jet Pump.

This system utilised a centrifugal pump which is installed above ground level and has a pressure tapping taken off the pump discharge side and led down the borehole to a special ejector at the bottom of the suction pipe. A venturi jet body is used at the pumping level and with sufficient pressure of force, the discharge side of the pump assists the water up the suction pipe into the pump inlet. Ejector or jet pumps are mainly used on smaller quantities and powers up to, approximately, 3 h.p. for domestic use. This unit is obviously inefficient in comparison to submersible pumps.

4. Vertical Spindle Pumps. (Centrifugal and Positive Displacement).

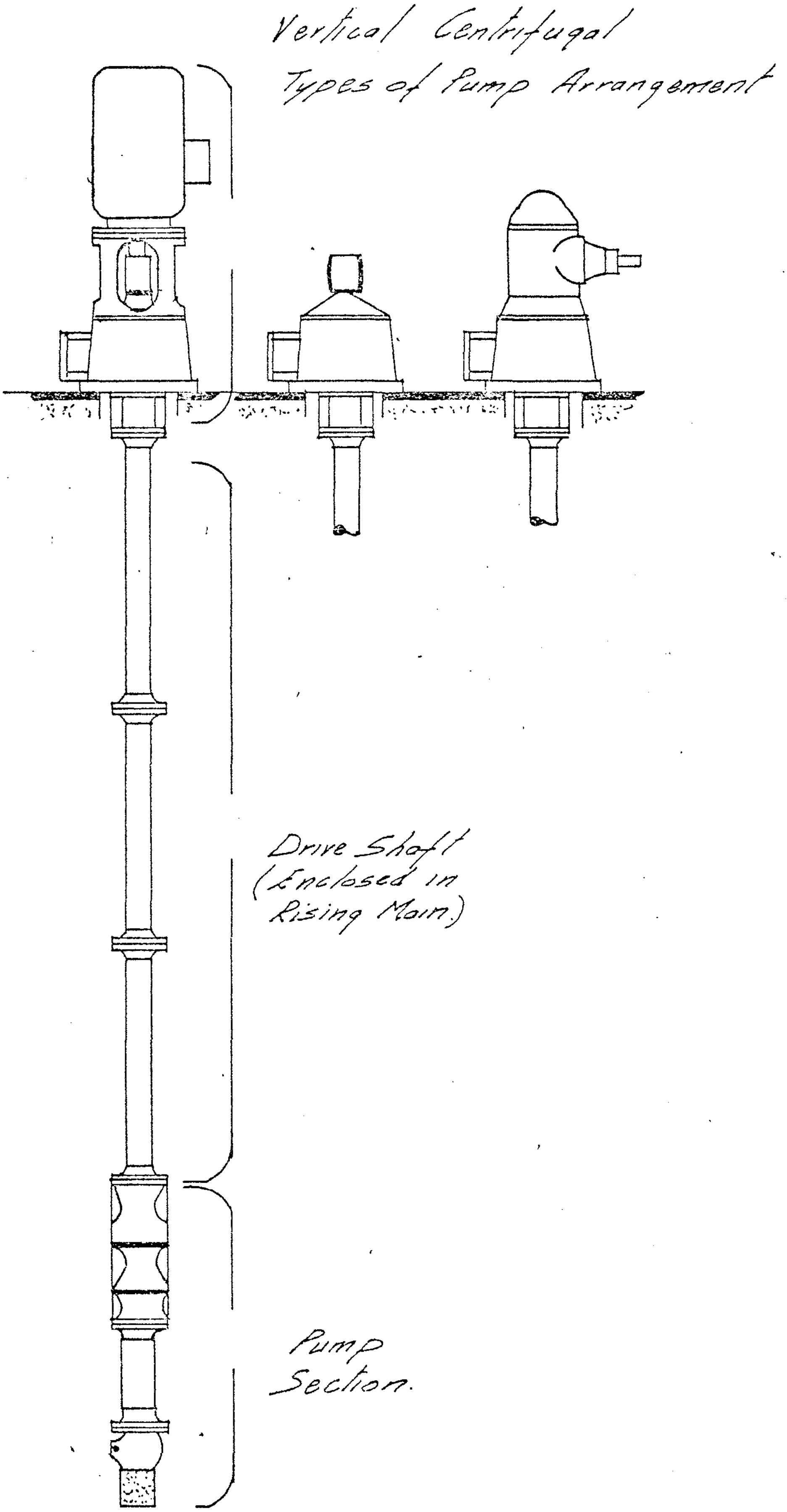
The vertical spindle pump has its driver unit mounted above ground level with the shaft drive enclosed in the rising main column passing down and connecting o n to the pump which will be submerged at the pumping level. These units are being superseded by the borehole submersible pump and motor unit because of the constraints on shaft design, their length and installation cost. It may prove competitive, however, on low lift, high quantity applications or on silty or sandy wells (helical rotor positive displacement pumps). Also, can be driven by petrol, diesel, tractor units.

FIG 1



PISTON PUMPS

SHAFT DRIVEN SUSPENDED BOREHOLE PUMPS



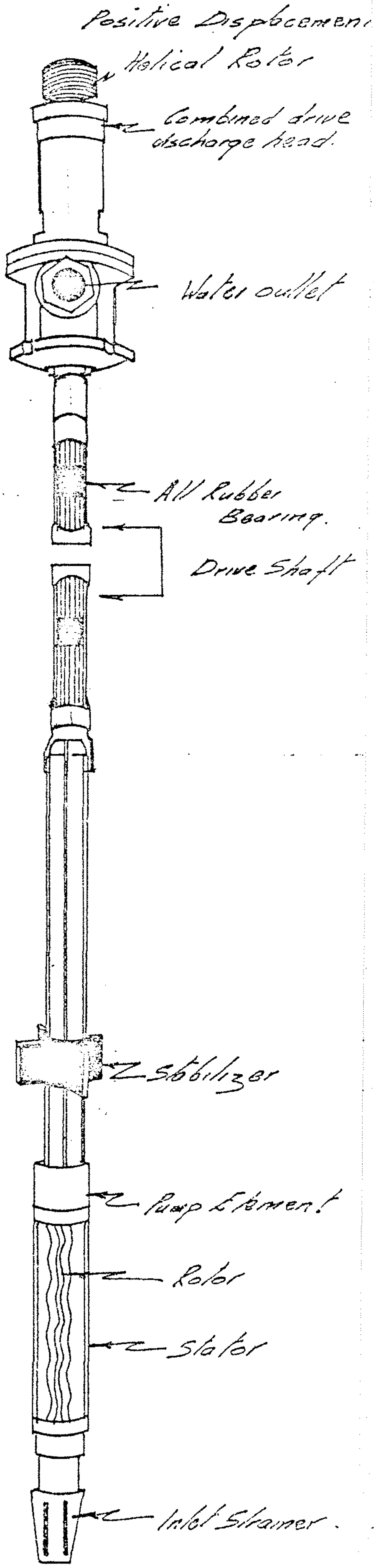


FIG 3

EJECTOR OR JET PUMP

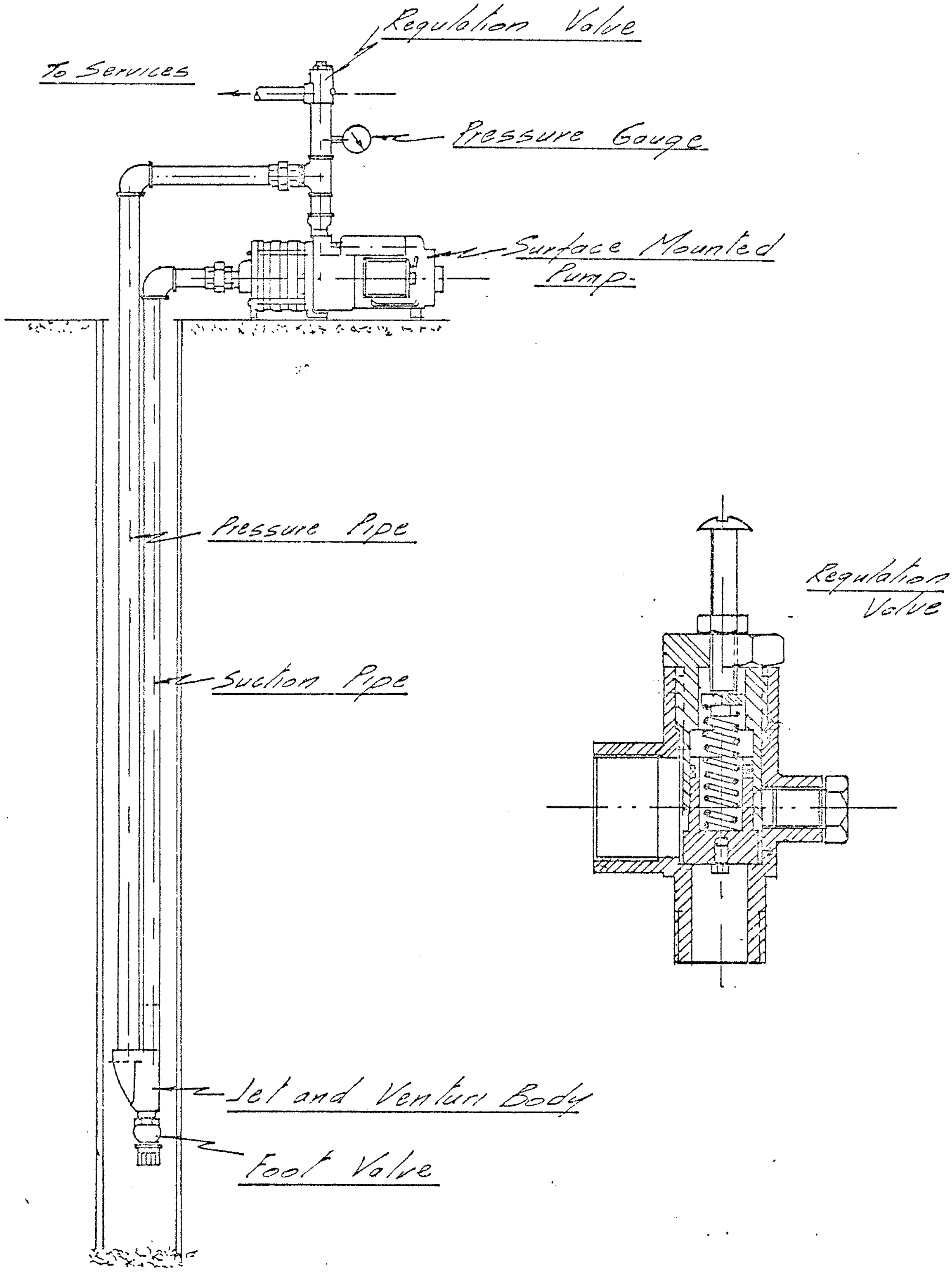
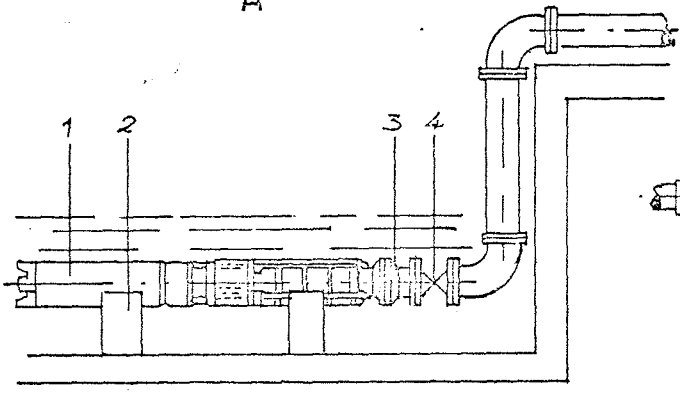


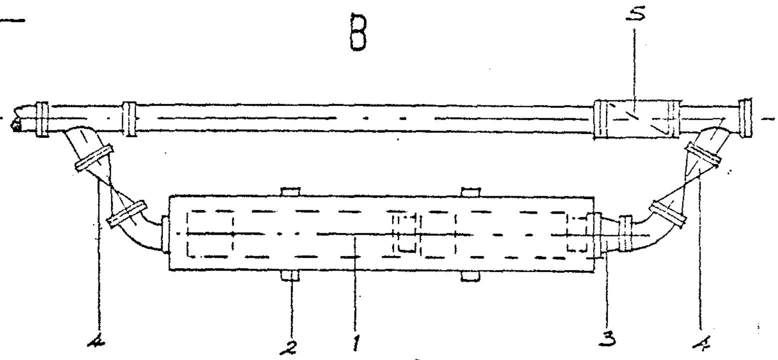
FIG 4

A



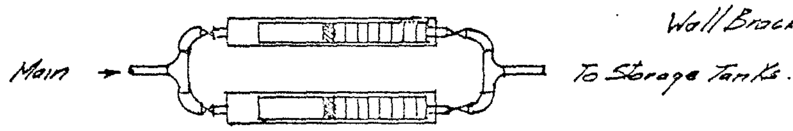
1 Submersible Electropump
2 Pump Saddle
3 Non Return Valve
4 Gate Valve.

B



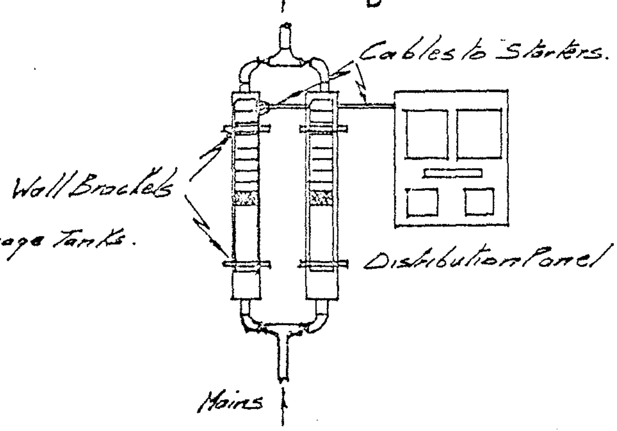
1 Submersible Electropump with outer Mantle
2 Pimp Saddle
3 Non Return Valve.
4 Gate Valve.
5 Non Return Valve in Main.

C



Duplicate Booster Units fitted horizontally against a Wall or on the floor.

D



TYPICAL PUMP ARRANGEMENTS

5. Electro Submersible pump and motor units.

Submersible electric pump and motor units have become the most common type of pump unit employed in the lifting and distribution of water from boreholes, due to significant developments in submersible motor construction which enables the motors to work in a submerged condition at ever increasing depths and pressures. The first submersible motors were produced in the early 1900's and were produced in commercially viable form around the 1930's.

The advantages of the electro submersible pump are:-

(a) No overground pumphouse is required.
(b) There are no priming problems as the pump is always submerged.
(c) Pumpset is simpler and, hence, cheaper to install and remove when compared to shaft driven borehole pump units.
(d) Minimal maintenance costs.
(e) Good hydraulic efficiency characteristics, minimal shaft losses.
(f) The overall installation is less costly than other forms of shaft driven or positive displacement submersible pump units.

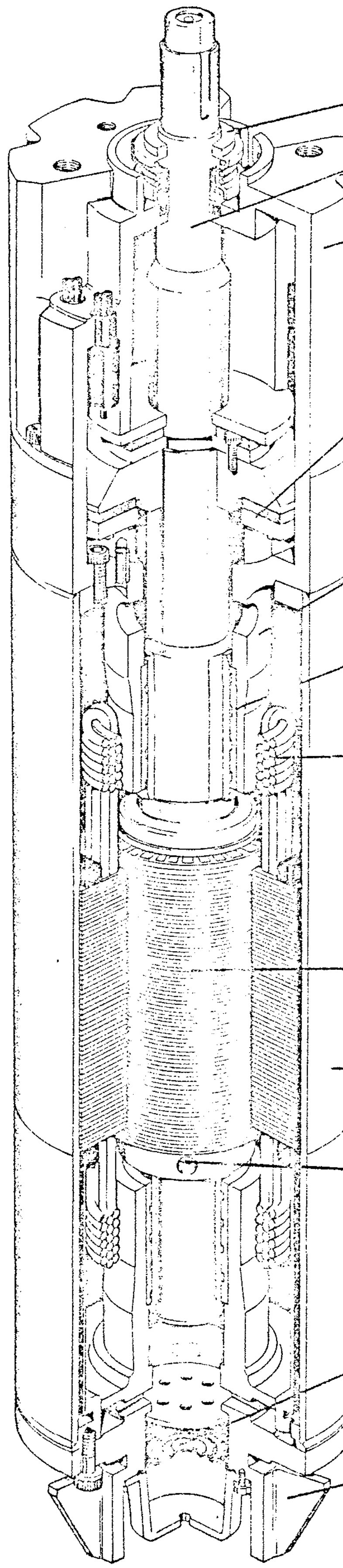
Submersible Motors.

The submersible motor has been developed in the following basic types of construction.

1. The Canned Submersible Motor.

This unit uses enamelled wire for the stator winding which is encapsulated in a thin stainless steel cylinder and is placed in the air gap to seal the stator. The rotor space is filled with water to lubricate the bearing and assist the cooling of the motor. Canned Submersible Motors are wound up to 75 kws. The advantage is low price but has the disadvantage of extra can losses and the difficulty in rewinding the stator if a fault should develop in service.

submersible motor



Mechanical seal

Motor shaft
Stainless steel.

Top cover and thrust housing
Bronze; aluminium bronze; stainless steel or cast iron.

Thrust bearing
Kingsbury type. Top mounted for stability.
Self-aligning and water lubricated, with phenolic disc and stainless steel pads.

Bearing housings
Bronze; aluminium bronze; stainless steel or cast iron.

Journal bearings
Replaceable phenolic bushings and hardened stainless steel sleeves.

Stator windings
XLP (cross linked polythene) insulation.
Wet stator design with circulation passages for cooling water flow around windings.

High torque rotor
Minimizes starting current inrush.

Outer casing
Stainless steel or carbon steel.

Forced circulation
through hollow shaft auxilliary impeller provides efficient cooling of the windings and bearings.

Caged diaphragm
Moulded neoprene.
Balances internal and external pressures.

Skid ring
Bronze; aluminium bronze; stainless steel or cast iron.
Finned and strengthened to resist damage during installation.

2. The Wet or Water Filled Submersible Motor.

This is wound with PVC, or polypropolyene insulated copper wire. The motor is completely filled with water or antifreeze mixture. This acts as a heat transfer medium and lubricates the bearing of carbon or reinforced resin. Motors of this type are manufactured from 10-3000 kws. The advantage of a wet submersible is a good cooling system due to the water filling and high efficiencies. The disadvantages are the low capabilities of the insulation and bearing materials, resulting in larger and more expensive motor construction than the canned counterpart.

3. The Oil Filled Submersible Motor.

This is similar to the canned motor with oil as a cooling media. Oil filled motors have the advantages of high temperature in operation. However, the disadvantages are fluid loss with subsequent contamination of well.

Conclusion.

In general, water cooled submersible motors have a short thermal time constant compared to air cooled motors, and also the insulation of the wet submersible motor is to Class Y, and only suitable for continuous use up to temperatures of 90^{o} C. Consequently, the overload protection required should be of the quick trip variety.

/5.

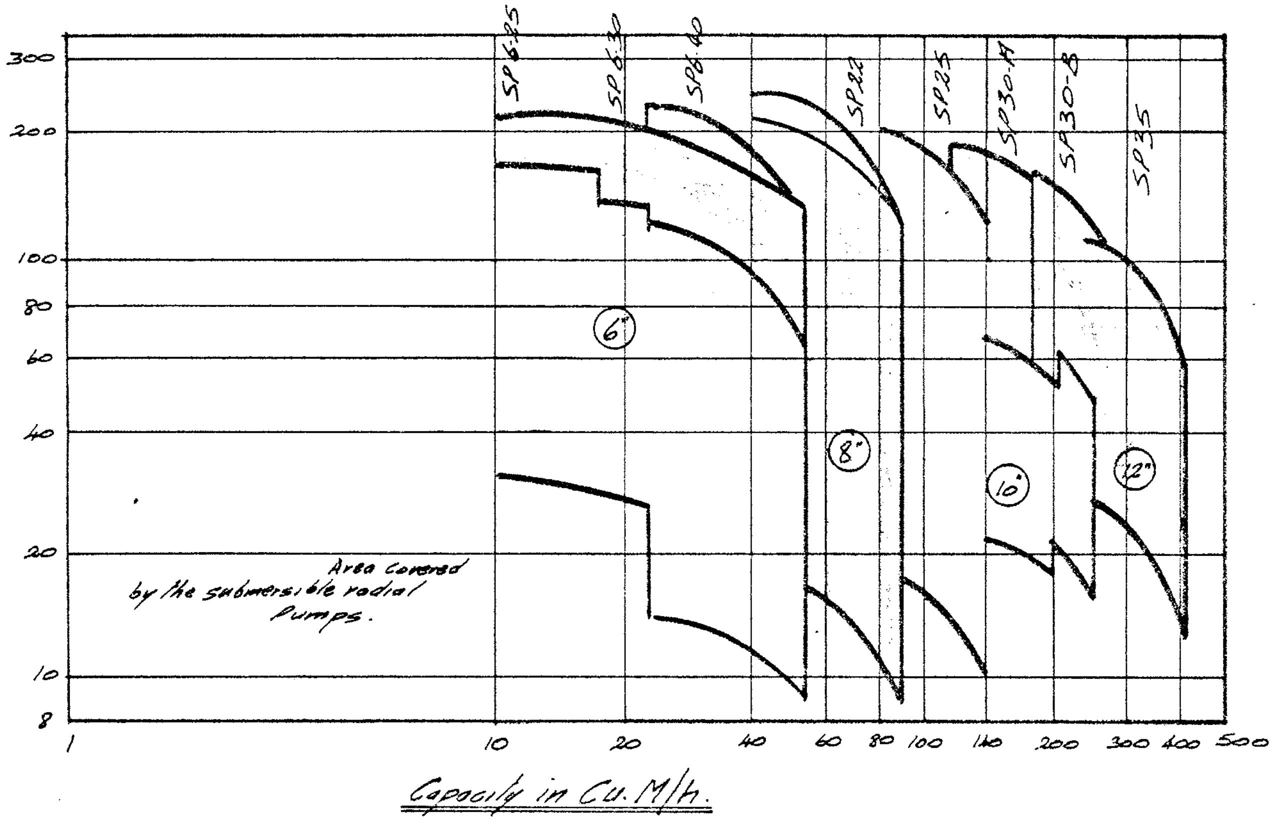
PUMP SELECTION:

Graph A2 illustrates typical overlap patters for submersible borehole pumps. This will coincide roughly with well yields, enabling the selection to be readily made.

The required head is obtained by having a number of impellers arranged in series. This can vary from 1 to approximately, 80, though normal standards would be 5 to 10 depending on the head required.

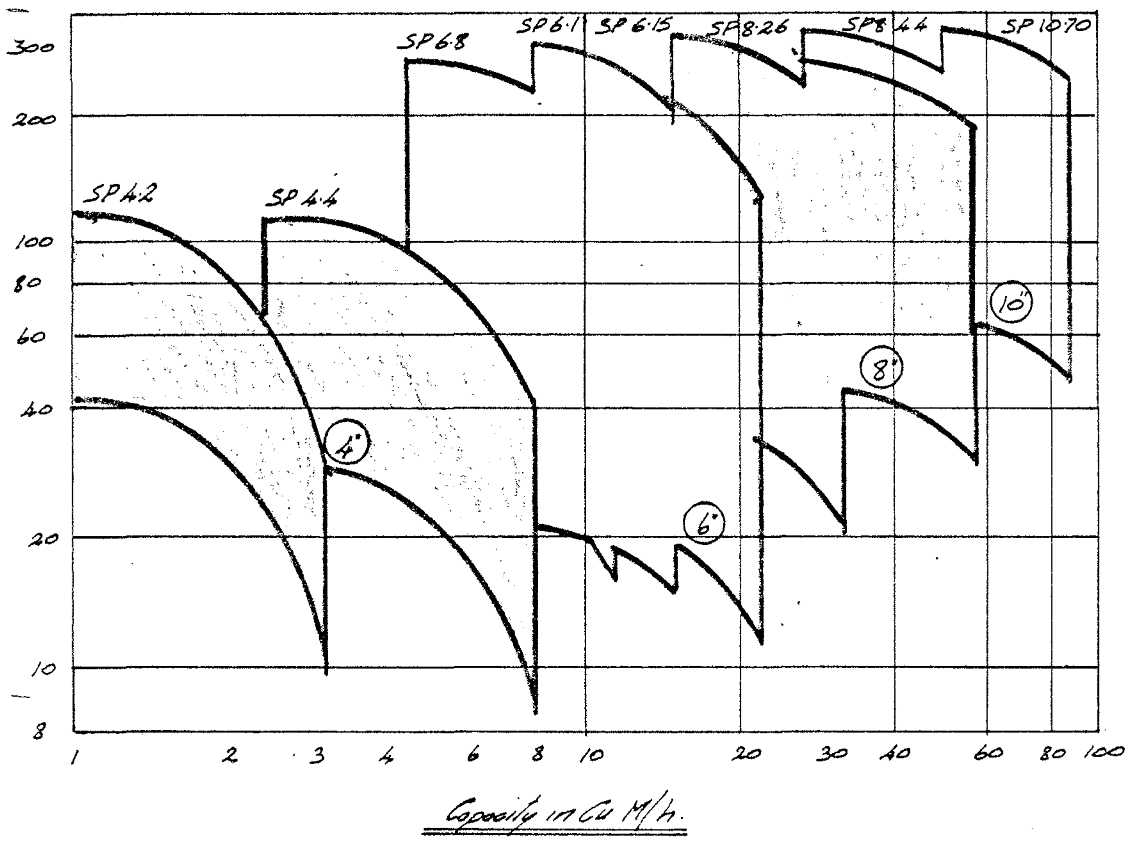
The smaller units are predominately radial flow impellers with a combined diffuser and guide vane system. The larger units can be either radial flow impellers with radial diffuser or a mixed flow impeller with an axial diffuser. The choice between the two can be decided by the well diameter and the flow required or the optimum number of stages desirable. Each pump manufacturer will have a different envelope of operation.

FIG A2

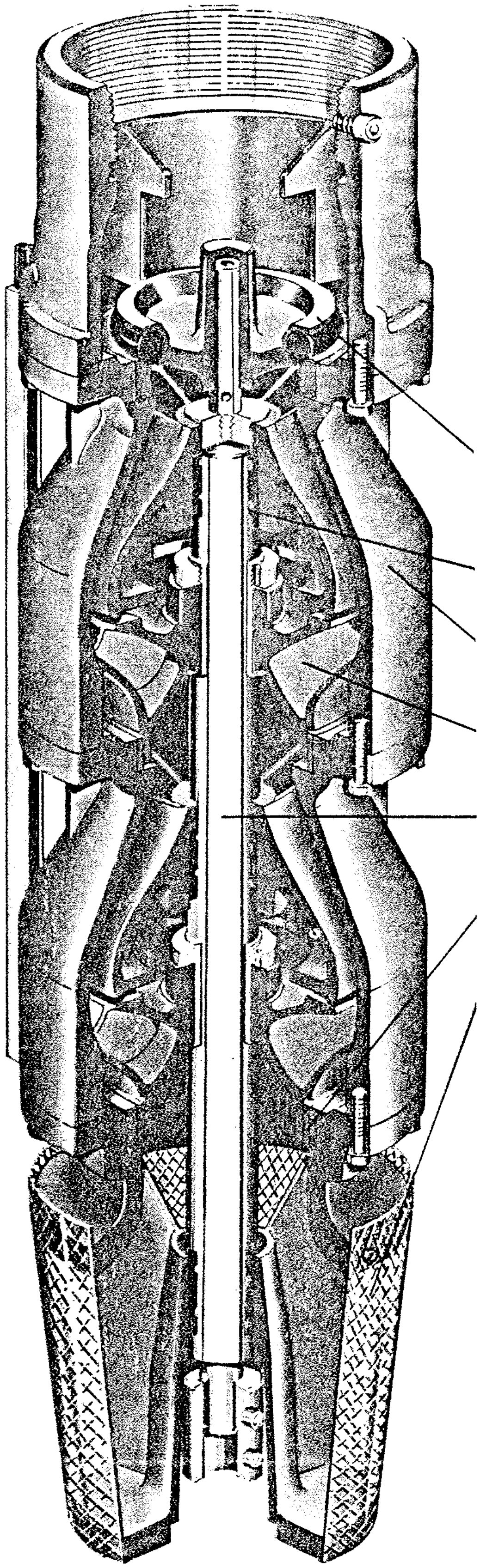


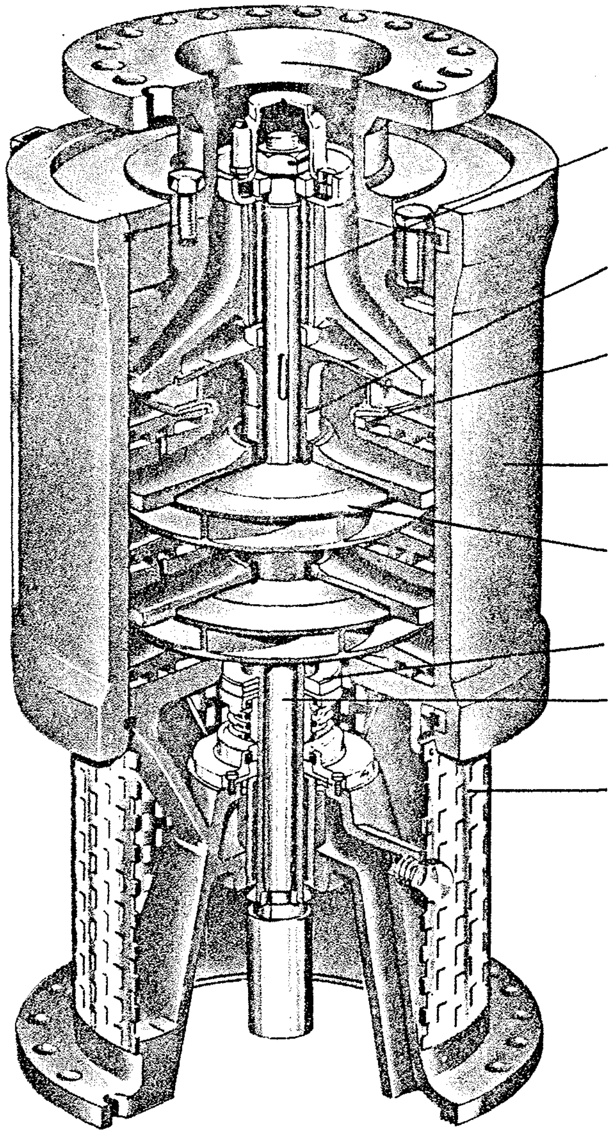
TYPICAL CHARACTERISTIC CURVES OF MIXED OR AXIAL FLOW SUBMERSIBLE PUMP UNITS

FIG A2



TYPICAL CHARACTERISTIC CURVES OF RADIAL FLOW PUMP UNITS


Check valve
Bronze with a positive sealing composition seat.
Bearings
Cutless rubber or bronze.
Bowls
Bronze or cast iron.
Impellers
Bronze.
Pump shaft
Stainless steel.
Wearing rings
Replaceable bronze.
Inlet strainer
Stainless steel or plastic coated steel.


Bearings
Cutless rubber with stainless steel journal sleeves.
Impeller spacers
Bronze or stainless steel.
Wearing rings
Replaceable bronze or stainless steel.
Outer casing
Bronze or stainless steel.
Impellers
Bronze or stainless steel.
Mechanical seal
Pump shaft
Stainless steel.
Inlet strainer
Stainless steel or plastic coated steel.

/6.

Pump and Motor Selection.

The pump unit should be selected to run at or near its best efficiency point. This will ensure that the flow conditions through the pump are at or near the optimum. Excess velocity by operating at high flow can increase wear, particularly where grit or sand is present. Running against throttle valve should be avoided due to wastage of energy and possible heating of the motor. It will also cause wear, and if throttling is severe, collapse the thrust bearing at base of motor.

INFORMATION REQUIRED.

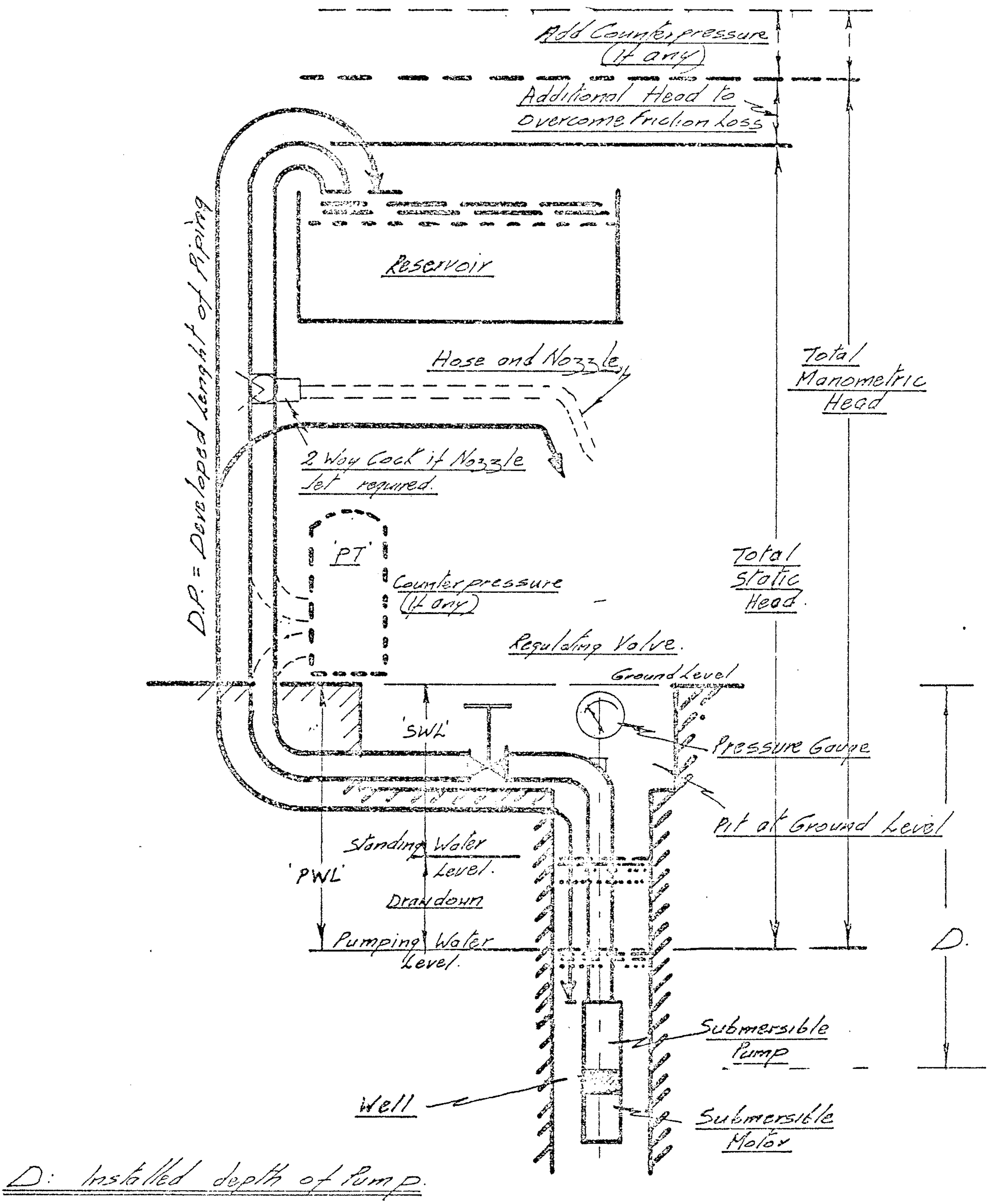
1. Pumping flow rate required.
2. Depth from ground level to water level while pumping.
3. Head required above ground level.
4. Well casing inside diameter.
5. Information on type of power unit required, i.e. electric motor, diesel driven unit, wind turbine or solar energy system, etc.
6. Pipework sizes proposed in borehole and above ground level.
7. Water quality, i.e. does it contain sand or corrosive elements, dissolved gas, its acidity, carbon dioxide and sodium chloride content.

Further information which would be useful also is as follows:-

(a) The depth from ground level at the well while not pumping.
(b) The depth to the top of the well screen.
(c) Particulars of the well screen.
(d) Details of the yield tests on the borehole, i.e. flow rates, drawdown levels, etc.
(e) Information about the aquafier.
(f) Is the water coming from sand and gravel beds, or from broken rock, or from limestone formation.
(g) Whether there are any slots or screens above the pump intake which could cause cascading.

This, of course, is a great deal of information which could be provided. However, not all is essential, but, if available, should be provided to ensure correct selection and operating conditions of the unit.

FIG A1



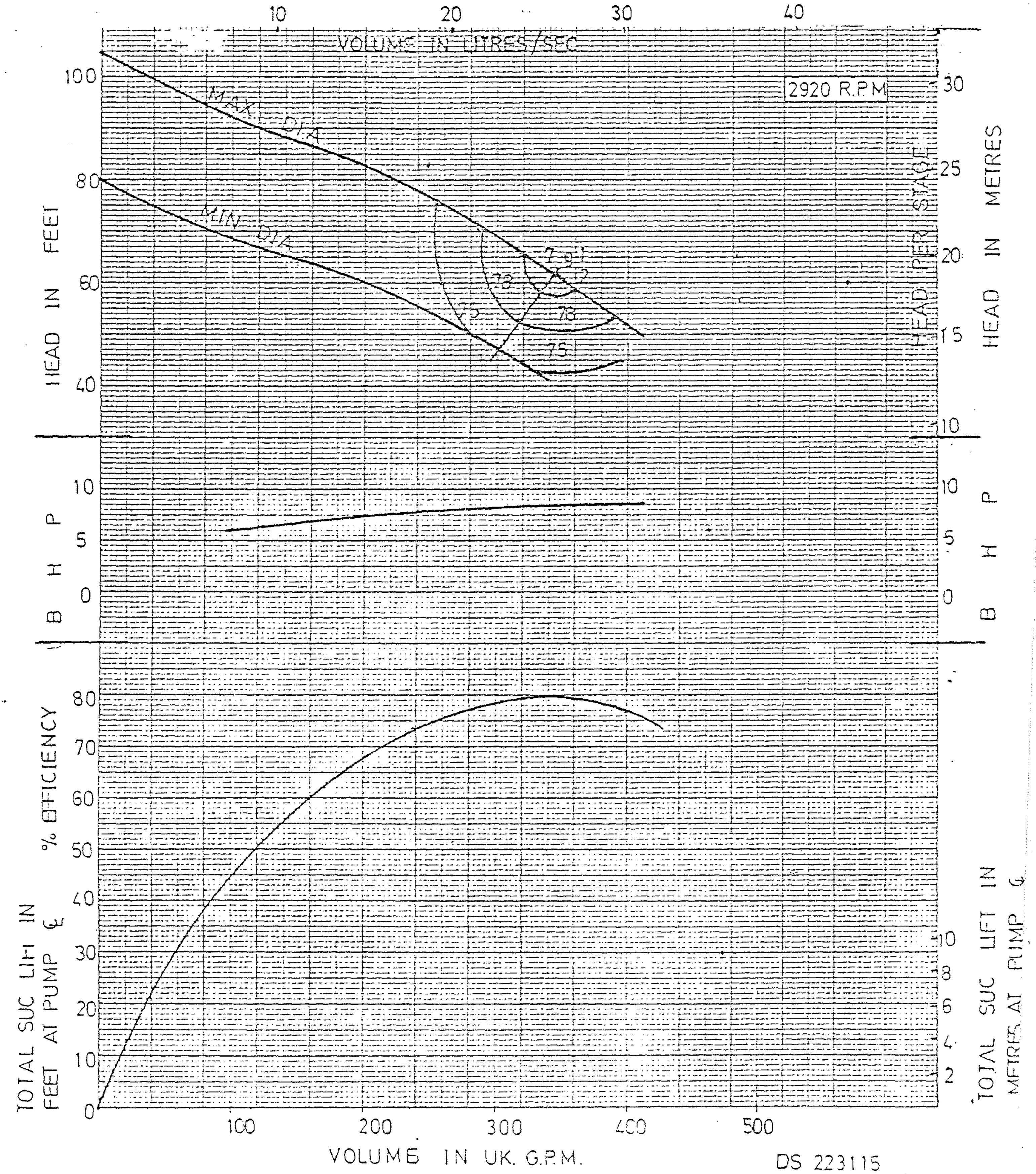
TYPICAL PUMP INSTALLATION

WEIR PUMPS LIMITED **DATA SHEET** 223115

Weougilde Pump

SBW 8 P.P.C.

Main Product Code	45	Sheet	1
		Issue	1
Circulation	08	Date	Dec.'66.



DS 223115

/7.

Total Pumping Head.

One of the most important things to know when selecting the pump for a given site, apart from flow, is the total head from all causes. In the case of a borehole pump, the total head is made up of several components.

(a) Static delivery head. This is the vertical height from the water level to the highest point from which the water is delivered.

(b) Friction head. This is the head generated through losses in the rising main pipework in the borehole and also in the distribution pipework from the borehole to the final discharge point.

(c) Counter pressures, if any, i.e. pressure head requirements in water softeners, pressure vessels, etc.

(d) Draw down level in the borehole from standing water level while pumping.

(e) System configuration, i.e. number of boreholes joining into common rising main.

The determination of total head, friction head and pump selection together with operation of a number of units into a common rising main is described on sketch A1

Well Water Conditions.

It is important that the pump manufacturer is given a well water specification to ensure that the correct materials are used in the construction of the pump. While most natural waters from wells in boreholes for domestic and industrial purposes do not cause any attack on standard pump materials, there are certain dissolved impurities which are met on occasion, and which can cause trouble. Possibly 10% of all boreholes produce water which is either aggressive causing corrosion or water which deposits a hard scale.

In assessing the water in general terms the expression P.H. is used. This is a measure of the acidity or alkalinity of the water. The neutral point is taken to be 7, below which the water is considered to be acid, and above considered alkaline. Knowing the P.H. value and its dissolved salts by analysis, enables the pump supplier to select the correct material to give a satisfactory service over a number of years.

Solids Content.

One must take into account any grit or sand present in the water as this will increase the wear in the water passage ways, but, more seriously, will considerably shorten the life of the bearings. Wells should be cleaned out by test pumping. Electrosubmersible pumps are not generally designed to pump large sand quantities. However, special adoption of pumps with rubber cutlass bearings can be employed in certain instances on wells to overcome this problem.

Boreholes with sand or silt.

As can be seen from the above, this is one of the major causes of problems with all bore pumps, particularly the electrosubmersible type. However, the Mono lift types of helical rotor borehole pump can pass certain volumes of sand without detriment to the pump unit, generally as set out overleaf. The helical rotor pump speed is adjustable and can run as low as 400 to 500 RPM., compared to 2900 RPM on submersibles. This also helps reduce wear on components when handling abrasive materials.

/9.

(a)	Maximum recommended particle diameter (millimetre) under continuous operation with constant concentration 50 gms. per litre.	Wells from 3" to 8".	0.35 up to 1.25

Particle diameter size within this range varies with type and size of borehole diameter.

(b)	Maximum recommended particle diameter (millimetres) of random solids under continuous operation.	Borehole diameter radius 3" to 8".	1.5 up to 6.25

Particle diameter size within this range varies with type and size of borehole diameter.

These are general figures and can be confirmed by the pump manufacturer on request depending on model selected and size of borehole. For short durations, i.e. bore clearing, particle diameters as set out above can be pumped in concentrations of 250 gms. per litre. The above sets of conditions apply only to the Mono range of helical rotor positive displacement pumps and not to the electrosubmersible range of pumps.

CASCADING.

Sometimes screening or slotting is placed halfway down the bore to allow water to enter from a higher aquafier and if the pumping level is below this entry, the water will cascade and entrain air in the water. This air is carried down and enters the pump, thereby reducing the performance of the pump and in the long term, causing corrosion and damage to the unit. This practice should be discourgaed if possible, i.e. by using a gravel packing outside the well casing to lead the upper water down to the screen at the bottom of the well. This may not always be practical, and if this conditions occurs, it may be worth considering vacuum sealing the well at the pump head.

PUMP SIZE.

Pumps should, if possible, be fixed centrally in the well. The pump should have a clearance of not less than 4% of the internal diameter of the casing. If the water is coming from above the pump, this clearance should not be less than 8% of the internal diameter of the casing. The clearance should be sufficient to avoid flow rates past the pump with velocities of more than 3 metres per second, otherwise, turbulent flow conditions may occur at the pump inlet.

/10.

BOREHOLE VERTICALITY AND ALIGNMENT.

Where possible, the well should be drilled as close as possible to the vertical and in straight alignment. Problems with verticality of alignment can cause problems with shafting or undue stress on pipework or problems with pump units rubbing against side walls of wells causing damage and overheating. The verticality and alignment of the well if critical should be tested by lowering a dummy into the well of at least 9 metres in length. Recommendations for testing borehole verticality and alighment are set out in the N.W.W.A. Guide on the Code of Good Practice for the Ground Water Industry, Para B3.

/11.

INSTALLATION AND MAINTENANCE OF SUBMERSIBLE PUMP UNITS.

A typical installation of a submersible pump unit is shown in sketch A3. The submersible is suspended by the rising main from the simple head piece which usually takes the form of a right angle swept bend with a suitable mounting plate.

If possible, the unit is suspended above the water inlet to ensure that the pumped water passes over the motor exterior. This will help dissipate electrical losses from the motor as quickly as possible, thus cooling the motor. If, due to the construction of the well, this is not practical, it is advisable (not always required depending on motor rating) to fit a flow shroud to direct the water over the motor. The minimum velocity of 0.15 metres per second is prefereable.

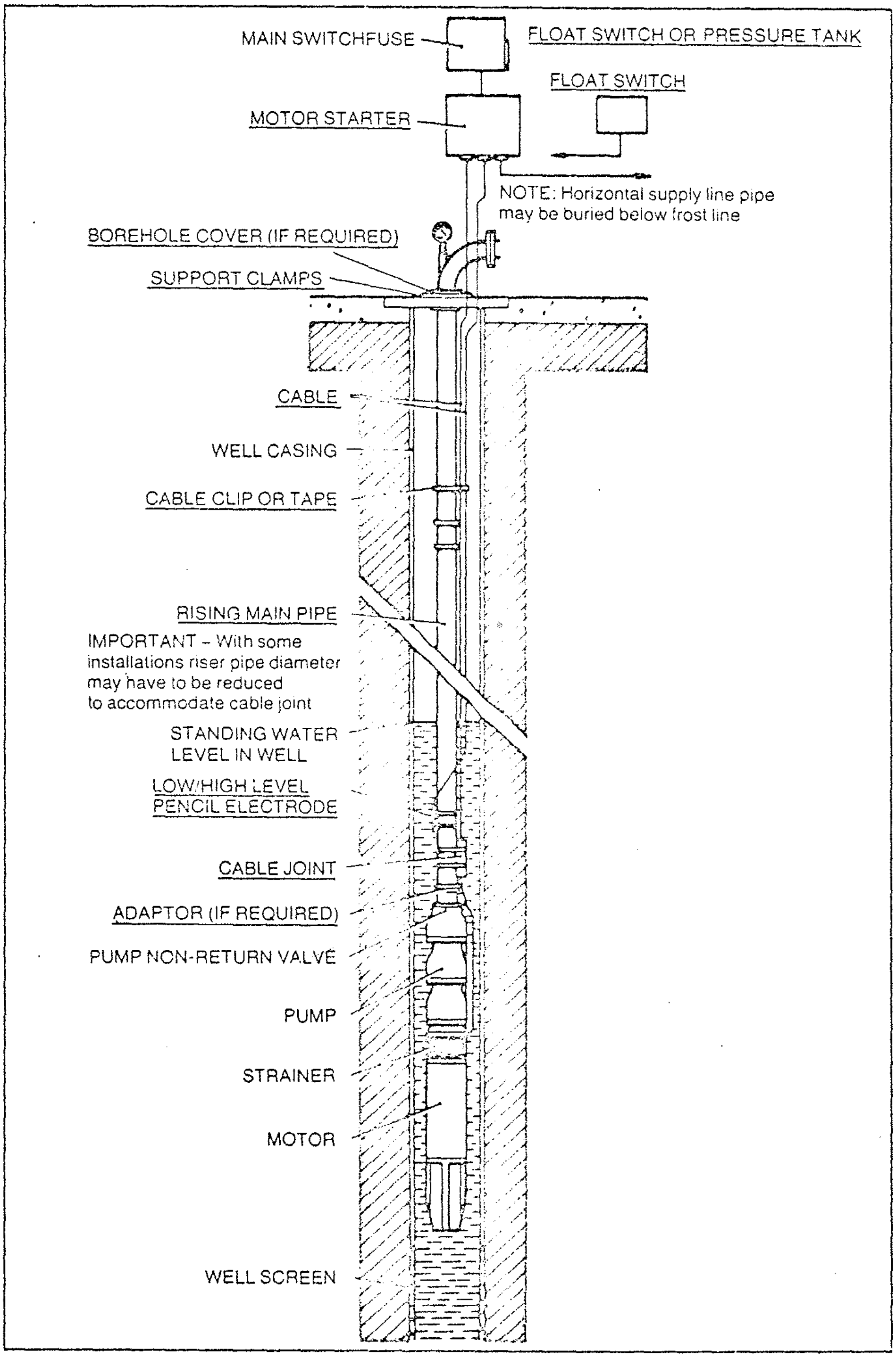
The unit should always be mounted clear of the bottom of the well to prevent any build up of sand, silt covering the bottom of the motor.

The electrical supply cable must be suitable for continuous use underwater at the temperature of the pumped water, and due attention must be paid to the motor rating which often have a rating of 30°C with some up to 40° C. Above these temperatures, a slight derating is required. The supply cable must be supported adequately as many failures occur due to cable slipping through poorly designed cable clips. This can cause earth faults and possible loss of the motor stator due to unbalanced supply conditions. Cable size is also important, as voltage drop is often neglected on cable lengths, and this can cause burn-out.

The pump and motor unit should be protected from low water conditions in the borehole by fitting electrodes positioned 1 or 2 metres above the pump. Dry running of the submersible must be avoided as the units are designed to live underwater. On small units where HDPE piping is used, the pump should be suspended from a nylon or steel rope.

ABOVE GROUND EQUIPMENT.

As a minimum safety requirement, overload trips should be fitted. Optional features, such as under and over voltage relays, earth leakage protection, lightning protection, etc. are desirable. On deep installation, interlocks should be used to prevent starting until the complete run back of water in the rising main has occured. To switch on when this is occuring, can lead to excessive transients.



MAIN SWITCHFUSE
FLOAT SWITCH OR PRESSURE TANK
FLOAT SWITCH
MOTOR STARTER
NOTE: Horizontal supply line pipe may be buried below frost line
BOREHOLE COVER (IF REQUIRED)
SUPPORT CLAMPS
CABLE
WELL CASING
CABLE CLIP OR TAPE
RISING MAIN PIPE
IMPORTANT – With some installations riser pipe diameter may have to be reduced to accommodate cable joint
STANDING WATER LEVEL IN WELL
LOW/HIGH LEVEL PENCIL ELECTRODE
CABLE JOINT
ADAPTOR (IF REQUIRED)
PUMP NON-RETURN VALVE
PUMP
STRAINER
MOTOR
WELL SCREEN

/12.

On the hydraulic part of the installation, the pipework must be capable of suspending the live weight of the unit. On smaller applications, a non-return valve is usually fitted at the pump discharge. Large units have this valve at the well head with an air release valve fitted also at the well head to allow air to enter the rising main on shut down. Failure to fit this item may lead to water surge with consequential damage to pipework or pump unit in the bore. Other points to look out for are:-

(a) Long discharge lines where the majority is not under the well, i.e. pumping across land to reservoirs.

(b) Pipelines having high points along their length, i.e. not continuously rising.

(c) Short vertical pipelines where the length can be less than twice the system static head.

(d) Closed valve condition. If this type of operation is entirely necessary due to system requirement, pressure relief and/or bypass flow valves should be fitted.

(e) If possible, some sets should be possible for reverse rotation. Where, for example, the pump internals or strainer openings at the pump entry tend to become blocked by deposits, the back flow on shut down provides an effective cleaning action in many cases.

/13.

SUBMERSIBLE MOTOR INSTALLATION

The essential requirements when installing this submersible motor are:-

1. There must be an adequate vent plug at the highest point of the motor to allow the air in the motor to be completely displaced by the filling medium.

2. The filling medium should be de-aerated and free from dissolved gases which could be liberated inside the motor as it warms up while running.

3. The filling of the motor should be as slow as is practical, possibly leaving overnight and then topping up completely just before installation as an optimum.

4. Cooling Flow.

   All submersible motors rely on a given rate of flow on them to ensure proper heat dissipation and hence avoid overheating. A small diameter motor in a large diameter borehole may not be provided with sufficient cooling velocity to take away the motor heat. A normal figure for rating of a motor is generally given as an output in kilowatts and with well water temperature at 30° C and a flow of 0.15 m per second velocity over the motor casing.

 /14.

CONCLUSION:

The very position of the submersible pump, deep in the ground, out of sight, completely neglected and expected to operate forever, puts an increasing need on the specifier, installer and operator to ensure that his part in the selection, installation and operation of the unit is of a high standard, thereby ensuring trouble-free operation and providing a product capable of operating under adverse conditions returning maximum efficiency and long life.

It is hoped that this paper will have assisted in achieving this goal.

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Acknowledgements: Sumo Pumps, Ltd.
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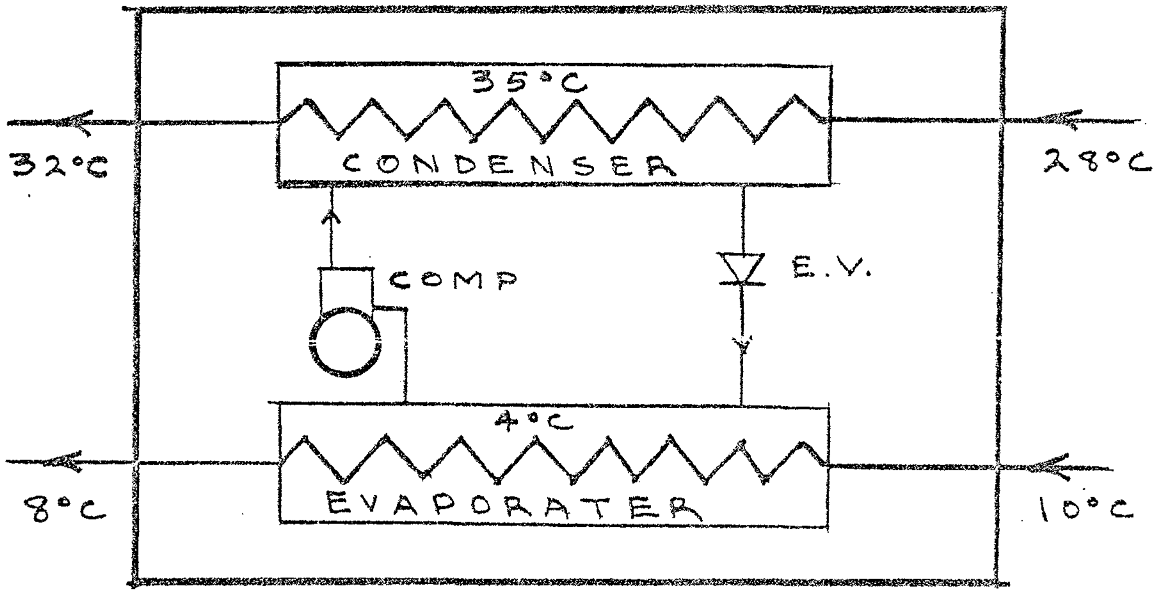
North West Water Authority Guide.

WATER SOURCE HEAT PUMPS

John Walls, Energy Management Contractors Ltd., Galway.

POTENTIAL IN IRELAND

A heat pump is a machine which takes low grade heat and upgrades it by raising the temperature, so that it becomes higher grade usable heat. In doing this, work has to be performed, i.e. energy is supplied.



EXAMPLE

Well flow 6,000 gals/hour at 10°C. Reduce the temperature by 2°C.

$$KW = \frac{6{,}000 \times 10 \times 2 \times 9/5\text{th}}{3{,}412}$$

	=	63 KW
Comp	=	21 KW
Total		84 KW

Co-efficient of Performance

$$C.O.P. = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{84}{21}$$

$$= 4$$

CAPITAL COST

Capital cost tends to be high and works out at roughly £1,000 per KW input.

RUNNING COSTS

Oil costs per KW 110/47	=	2.34p.
Assume boiler eff. of 75%	=	3.12/ KW hr.
Heat Pump Electric	=	7p per unit.
Assume C.O.P. of 4	=	1.75 per Kw hr.
Heat Pump electric (Night)	=	3.5
Assume C.O.P. of 4	=	0.875
Average cost (night & day)	=	1.276
Saving per KW 3.12 - 1.276	=	1.844
Savings per day 84 X 24 X 1.844	=	37.175
Annual savings 36.45 x 365	=	£13,569.

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WATER SOURCE/AIR SOURCE

ADVANTAGES:-

(1) Temp. does not vary with the seasons.
(2) No frosting problems.

DISADVANTAGES:-

(1) Cost of boring well & risk of no supply.
(2) Not as flexible as the air source heat pump, relative to location.

WELL YIELDS

The yield needed depends on the amo unt of energy required.

EXAMPLE

House requires 15 KW heat input at $-1^{\circ}C$ (design day) with a flow temperature of $55^{\circ}C$. Allow $2^{\circ}C$ drop.

C.O.P. should be about 3

5 KW input from compressor
10 KW input from well

$$10 \text{ KW} = \frac{X \text{ gals} \times 10 \times 2 \times 9/5\text{th}}{3412}$$

$$X = 947 \text{ gals / hour.}$$

The energy yield from a well also depends on the temperature available. If water is available at $20^{\circ}C$ its temperature could be dropped to $8^{\circ}C$ = $12^{\circ}C$ temperature drop. In this case:-

$$X = 158 \text{ gals / hour.}$$

/Cont.

OBSTACLES

The main obstacles to the introduction of heat pumps are:-

(1) High capital Costs.

(2) Lack of knowledge of their advantages & limitations.

(3) Some years ago the main obstacle was that other energy sources were too cheap.

LEASING

Leasing over a 5-year or 8-year period is the way to get over the capital cost disadvantage as the leasing cost can be put against the energy savings.

Heat pump, water source, to provide 1353 KW hours of water heating at 55°C. Take C.O.P. = 3.

Operate 8-hours at day rate - 7p per unit.
Operate 8-hours at night rate - 3.5p per unit.

Capacity of pump $\dfrac{1353}{16 \times 3} = 28$ KW

Capital Cost	Heat Pump	£28,000.
	Deep Well	5,000.
	Hot Water Storage	5,000.
	TOTAL	£38,000.

Lease cost over 5-years @ 8%	£10,640. per annum.
Oil costs 1353 X .0312 X 365	£15,407.

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Heat Pump $\frac{1353 \times .07 \times 365}{2}$ = £17,284.

$\frac{1353 \times .035 \times 365}{2}$ = 8,642.

TOTAL = £25,926.

Allow for C.O.P. of 3 = £8,642.

Assume energy cost escalation of 15% per year

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Oil	15,407	11,718	20,376	23,432	26,947	30,989
H.P.	8,642	9,938	11,429	13,143	15,115	17,382
Gross	6,765	7,780	8,947	10,289	11,832	13,607
Lease	10,640	10,640	10,640	10,640	10,640	-
Nett Savings	(3875)	(2,860)	(1,693)	(351)	1,192	13,607
Cumulative	(3875)	(6,735)	(8,428)	(8,779)	(7,587)	6,120

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MARKETS

The main market sectors are:-

Hotels -	Provision of hot water.
Industry -	Provision of hot water.
Horticulture -	Heating of glass houses with boiler assistance.
Recreation -	Heating of swimming pools & pool halls.