How to assess normal operating characteristics for pumps used in small water supply systems when no information on the pumps are available and when the technicians have little technical education.

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EVALUATING PUMP CHARACTERISTICS IN DEVELOPING COUNTRIES

The following is a common scenario in many developing countries: *Local Administrator:* "Our motorized pump set broke down four weeks ago and was sent to the capital city for repair. Since then we have had no water in the supply system for our town. We managed to borrow a pump which was in storage for many years. Now we need you, an expert in water supply, to tell us whether this pump can do the job and what motor we require to drive the pump."

Water Technician: "The pump no longer has an identification plate, and no one knows where the pump was previously used, since it has not been used since the departure of the colonial power seven years ago. Neither motors nor the ancillary equipment necessary for conducting pumping tests are available. Furthermore, the only pump workshop is in the capital city 1,000 miles away, and since transportation is irregular and unreliable, no expert help in determining the characteristics of the pump can be sought. How, then, can I determine the characteristics (flow, head and efficiency) of this pump, and, if the pump is appropriate, how can I determine the power and speed of the motor required to drive the pump?"

Since an immediate response is needed in such circumstances, an attempt was made to develop a simple field method for estimating the characteristics of the water pumps that were commonly encountered in such situations in developing countries. The only other published material addressing this problem (Karassik, 1959) was for centrifugal pumps only and gave rise to a method too complicated for use by the typical technician in a developing country. It was mandatory that the method depend only on physical measurements of the pump and that it be straightforward so that it could be used by the front-line water "technicians," who typically have about six years of formal schooling followed by a six-month technicians' training course.

THE METHOD

Functional forms relating pump parameters (such as rpm, impeller diameter, and discharge pipe diameter) to pump performance characteristics (flow and head) were developed from theoretical considerations. For instance, in a centrifugal pump, the principles of dynamic similitude (Moody, 1952) require that the pressure head developed by the pump must vary with the velocity head ($v^2/2g$). Since the velocity of the impeller is proportional to the product of speed of rotation and the diameter of the impeller, the pressure developed by the pump is proportional to the square of the rpm at which the pump operates and the square of the impeller diameter. Similarly, since the velocity in the discharge pipe of a centrifugal pump does not vary greatly (Babbitt et al, 1962), the flow is related to the square of the discharge pipe

On the basis of similar theoretical analyses, functional forms were developed for relating pump parameters to pump performance characteristics for the other

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TABLE I: FORMULAS FOR ESTIMATING HEAD, FLOW, AND EFFICIENCY IN SMALL WATER SUPPLY PUMPS

TYPE OF PUMP	R.P.M.	FLOW (m³/hr)	TOTAL PUMPING HEAD (m)	PUMP EFFICIENCY	OBSERVATIONS
Manual Reciprocating	variable	Q = 16/H in field conditions at optimal H	Optimal Head for: D < 75: 200 − 2 0D D ≥ 75: 94 − 0 63D		Choose the cylinder diameter using the following table For H < 50 m: D = 150 − 1 6H For H ≥ 50 m: D = 100 − 0 5H
Motor-driven Reciprocating	V strokes per minute	$Q = 50D^2LV/10^6$	$H_{max} = 580L - 1.4D$	40%	V is usually about 30 strokes per min
Simple Centrifugal	R	$Q = \frac{R\,(S-10)^2}{100{,}000}$	$H = \left[\frac{I \times R}{90{,}000}\right]^2$	For Q ≤20: 60% 20-100: 70% >100: 80%	
Multi-stage Pumps (including turbine pumps for boreholes)	R	$Q = \frac{R\,(S-10)^2}{150{,}000}$	$H = \left[\frac{I \times R}{110{,}000}\right]^2 \times n$	For Q ≤20: 50% 20-100: 55% >100: 60%	1 The flow in a pump of n stages is the same as the flow in a pump with the same impeller size, operating at the same rpm but with only one stage 2 The head developed in a pump with stages is n times the head developed in a similar pump with only one stage
Helical rotary Borehole pumps	R	$Q = \frac{R}{900}(0\ 0047S^2 - 2\ 5)$	Up to 150 metres, depending on the power of the motor	Q≤1 5 / Q>1 5 H≤50: 35% / 35% H>50: 35% / 65%	1 The rpm should not exceed 1000 rpm
Hydraulic Ram	— —	$Q = Q_e \times \frac{\text{pumping head}}{\text{working fall}} \times \text{efficiency}$	Diameter of drive pipe (E, mm) <38 / 39-76 / 77-120 H_{max}: 150 / 120 / 105	Pumping head/working fall <15 / 15-30 / >30 Working fall (m) <15: 40% / 40% / 35% 1 5-3 0: 50% / 45% / 35% >3 0: 60% / 50% / 35%	The flow entering the drive pipe (Q_e) will not be greater than Q_{max} but cannot be less than Q_{min}, where Diameter of drive pipe (E, mm): ≤65 / >65 Q_{min}: 0.65x (0 10E − 3 0) / 0 65x (0 22E − 10 3) Q_{max}: 1 35x (0 10E − 3 0) / 1 35x (0 22E − 10 3)

FORMULAE FOR CALCULATING THE NECESSARY SIZE OF MOTOR.
Electric motor: Installed horsepower $= \frac{Q \times H}{200 \times \text{pump efficiency}}$ Diesel motor: Installed horsepower $= \frac{Q \times H}{125 \times \text{pump efficiency}}$

NOTATION : D = dia. of cylinder in reciprocating pump (mm); E = dia. of drive pipe of hydraulic ram (mm); H = total pumping head (m); I = dia. of impeller of centrifugfal pump (mm); L = length of stroke in recriprocating pump (m); N = number of stages in a multistage pump; Q = flow delivered by pump (m³/hr.); Q_e = flow entering drive pipe of hydraulic ram (m³/hr.); R = revolutions per minute; S = dia. of discharge pipe (mm); V = strokes per minute in recriprocating pump.

pumps commonly used in small water supply systems in developing countries As indicated in Table 1, these include manual and motor-driven reciprocating pumps, simple centrifugal and multi-stage centrifugal (including submersible and vertical-turbine) pumps, helical rotary borehole pumps and hydraulic rams

Using manufacturers' information on a variety of makes of pump in each category, the theoretical functional forms were calibrated to give equations for estimating the rated characteristics (head, flow and efficiency) for each type of pump. These results are presented on Table 1.

In interpreting Table 1, it should be borne in mind that this is not intended to be a substitute for conventional methods for determining the characteristics of a pump (as presented, for example, by Walker, 1972), but is merely a guide in estimating these characteristics when it is not possible to follow the regular procedure. Thus Table 1 would never be used when it is possible either to obtain technical information from the pump manufacturer, or to conduct tests to determine the characteristics.

It should also be emphasized that pumps do not, as Table 1 suggests, have a unique operating point. In the case of centrifugal pumps, for instance, there is a trade-off between capacity and head for any particular pump While Table 1 gives only an estimate of the flow and head at which the pump would *normally* be operated, this estimate is useful because a pump should not be operated at a point very different from this "normal operation point"—due to considerations of pump efficiency and for protection of the motor and pump

APPLYING THE METHOD

MANUALLY-OPERATED RECIPROCATING PUMP (Reference: McJunkin, 1977)

Problem. We have a borehole with a yield of 3 cubic meters per hour (13 gpm) at a dynamic level of 60 meters (200 ft) We wish to install a hand pump. What diameter cylinder should be installed, and how many people could the pump serve?

Answer. From Table 1, for H ≥ 50 meters (164 ft), D = 100 − 0 5H. In this case, D = 100 − 0.5 × 60 = 70 mm (2 75 in.) That is, we would install a 70 mm (2¾ in.) cylinder. From Table 1, the flow will be about 16/H = 16/60 = 0.27 cubic meters per hour (1.19 gpm), which is substantially less than the capacity of the borehole. Assuming that each person requires 20 liters (5 3 gal.) of water per day, and that the borehole will be in use for 10 hours daily, then the borehole fitted with a hand pump with a 2¾ inch cylinder can provide water for 270 × 10/20 = 135 people. (*Note*: 20 liters is a design figure used in developing countries when water is supplied through hand pumps.)

MOTOR-DRIVEN RECIPROCATING PUMP (Reference: Babbitt et al, 1962)

Problem We have a reciprocating pump with a 75 mm (3 in.) diameter cylinder and a stroke of 0.45 meters (1.48 ft). We wish to use this pump in a borehole which yields 5 m^3/hour (22 gpm) at a dynamic level of 100 meters (330 ft). We want to know if the pump can be used and, if so, what size diesel motor should be coupled to the pump

Answer. From Table 1, we assume that the pump will operate at 30 cycles per minute and that the efficiency will be 40%. H_{max} = 580L − 1.4D = 580 × 0 45 − 1.4 × 75; i.e. H_{max} = 156 meters (512 ft), which is more than the 100 meters (330 ft) which we wish to pump. The yield of the pump is Q = $50D^2LV/10^6$ = 50 × 75^2 × 0.45 × $30/10^6$ = 3.8 m^3/hour (16 8 gpm), which is less than the yield of the borehole. We therefore conclude that the pump can pump against the required head, and that the pump will not pump the borehole dry. From the formula given in Table 1, installed horsepower = (Q × H)/(125 × pump efficiency). That is, the required horsepower = (3.8 × 100)/(125 × 0.4) = 7.6 hp. We would therefore install a 7½ horsepower diesel motor.

SIMPLE CENTRIFUGAL PUMPS (Reference: Walker, 1972)

Problem A village has a population of 3,000 people. In the village, a dug well has been constructed. A pumping test indicates that the well yields 12 cubic meters per hour (53 gpm) when the drawdown is 4 meters (13 ft) below ground level Next to the well an elevated storage tank 16 meters (53 ft) high with a capacity of 50 cubic meters (13,000 gal.) has been constructed. The village council has obtained an old centrifugal pump which no longer has an identification plate and wants to know if the pump can be used to pump the well water to the storage reservoir The diameter of the impeller of the pump is measured and found to be 200 mm (8 in.) The diameter of the discharge pipe is 32 mm (1.25 in.). If the pump can be used, the village council wishes to know the size of diesel motor necessary to drive the pump, and the details of the motor-pump coupling

Answer. It's estimated the villagers use 20 liters (5.3 gal.) per person per day. Thus, the present daily consumption will be about (3,000 × 20)/1,000 = 60 cubic meters (16,000 gal.) per day. There should be no problems on the suction side of the pump since the lift is less than 5 meters (16 ft.). Using the formulae in Table 1,

$$Q = R\,[S-10]^2/100{,}000 \text{ and}$$
$$H = (I.R./90{,}000)^2,$$

we can construct the following table.

		Q (m^3/h)	H (m)
R (rpm)	1,500	7.3	11.1
	2,000	9.7	19.8
	2,500	12.1	30.9
	3,000	14.5	44.4

Thus the pump can run at 2,000 rpm, pumping about 10 m^3/hour (44 gpm) against a 20 meter (66 ft.) head. To supply the 3,000 villagers, the pump would run about 6 hours per day.

From Table 1, we estimate an efficiency of 60%, where the installed capacity of the diesel motor is

$$(20 \times 10)/(125 \times 0.60) = 2.7 \text{ hp.}$$

That is, a 2½ or 3 horsepower motor would be adequate. To reduce maintenance requirements, it's best that relatively slow-running motors be used. If we use a motor operating at 1,500 rpm and have a pulley diameter of 15 cm (6 in.) on the pump, then the diameter of the pulley on the motor will be (2,000/1,500) × 15 = 20 cm (8 in.).

CENTRIFUGAL MULTI-STAGE PUMPS (Reference: Babbitt et al., 1962)

This category of pumps includes both horizontal-shaft pumps, which operate under conditions similar to those of simple centrifugal pumps (although the multi-stage pumps develop higher heads), and vertical shaft "turbine" pumps, which are used in boreholes. Included in the latter category are the so-called "submersible pumps," which are multi-stage centrifugal pumps. There, the electric motor and the pump itself operate below the water level in a borehole or other source

Problem We have a borehole that delivers 5 cubic meters per hour (22 gpm), with a dynamic level in the borehole of 45 meters (150 ft) below ground level A small town needs 20 cubic meters (5,300 gal.) of water per day. Alongside the borehole there is a 15-meter (50 ft.) high storage tank that holds 25 cubic meters (6,600 gal) of water. The town administration has obtained a vertical turbine borehole pump with 12 stages. The discharge pipe diameter is 25 mm (1 in.) and the turbines are 100 mm (4 in.) in diameter. We want to determine whether the pump can be used in the borehole and, if so, what electric motor is necessary to drive the pump.

Answer. From Table 1, we note the relevant formulae for this category of pump:

$$Q = [R(S-10)^2]/150{,}000 \text{ and}$$

$$H = \left[\frac{I \times R}{110{,}000}\right]^2 \times \text{number of stages}$$

In this case, for S=25, I=100, and 12 stages, we construct the following table:

R	Q (m^3/hr.)	H (m)
1,500	2.3	22.2
2,000	3.0	40.0
2,500	3.8	61.7
3,000	4.5	88.9

The pump can thereby develop the necessary head, 60 m. (200 ft.), if it operates at 2,500 rpm At this speed the pump will pump 3.8 cubic meters per hour (16.8 gpm), thus not exceeding the capacity of the borehole. It will be necessary to run the pump 20/3.8, i.e. about 5 hours daily.

The capacity of the electric motor required is $Q \times H/200 \times e_b = 3.8 \times 60/200 \times 0.50 = 2.28$ hp. We would therefore install a 2½ hp electric motor of 2,500 rpm directly coupled to the pump.

HELICAL ROTARY BOREHOLE PUMPS (Reference: Gibson and Singer, 1969)

Problem. We have a borehole that can supply 5 cubic meters per hour (22 gpm) at a dynamic head of 90 meters (295 ft). We want to know how much water can be pumped to ground level by a helical rotary borehole pump with a discharge pipe diameter of 38 mm (1.5 in.). We also wish to determine the size of the diesel motor necessary to drive the pump and to calculate the pulley diameters.

Answer We assume that the pump will function at 900 rpm, about the desirable speed for a pump of this sort. Use the relevant formula on Table 1:

$$Q = R/900\,(0.0047S^2 - 2.5)$$
$$= 900/900\,(0.0047 \times 38^2 - 2.5)$$
$$= 4.3 \text{ cubic meters per hour (19 gpm).}$$

For a helical rotary pump delivering more than 1.5 m^3/hour (6.6 gpm), the efficiency is about 65%, where the installed capacity of the diesel motor is to be

$$Q \times H/125 \times e_b = 4.3 \times 90/125 \times 0.65 = 4.8 \text{ hp.}$$

We would therefore install a 5 hp motor.

HYDRAULIC RAM (Reference: Wagner and Lanoix, 1959)

Problem. An isolated rural community with 100 inhabitants wants to examine the feasibility of using a hydraulic ram that has a 51 mm (2 in.) diameter drive pipe. A stream passes alongside the community and has a minimum flow of about 4 cubic meters per hour (18 gpm) The community has a 3-cubic-meter (800 gal.) prefabricated storage tank that they have installed on top of the community center. The top of the tank is 65 meters (213 ft) above the proposed site for the installation of the hydraulic ram. The working fall available at the proposed site is 4.5 meters (14.8 ft)

Answer From Table 1 we see that the maximum pumping head is 120 m (394 ft). Thus, there is no difficulty in pumping to 65 meters (213 ft). The minimum flow into the ram is

$$0.65\,(0.10 \times 51 - 3.0) = 1.4$$

cubic meters per hour (6.2 gpm) and the maximum flow is

$$1.35\,(0.10 \times 51 - 3.0) = 2.9$$

cubic meters per hour (12.8 gpm)

The flow into the drive pipe, Q_e, will therefore be 2.9 cubic meters per hour (12.8 gpm) (which is somewhat less than the minimum flow in the stream)

Since the pumping head/working fall = 65/4.5 = 14.4 and the working fall is 4.5 meters (14.8 ft), the energetic efficiency of the pump is 60%. Thus, the flow delivered by the ram is $Q = Q_e \times e_b \times$ pumping head/working fall $= 2.9 \times 0.6 \times 4.5/65 = 0.12$ cubic meters per hour (0.52 gpm). The ram can therefore deliver 120 × 24 = 2,800 liters per day (740 gal.), water for about 140 people.

While Table 1 may be useful to water personnel in developing countries, the approximations and limitations can only be understood by those who have attempted to derive such estimating questions. To avoid inappropriate use and to appreciate how the method relates to conventional methods for assessing pump characteristics, those responsible for the development of pedagogical material in water technicians' training institutions in developing countries should undertake a similar analysis, basing their empirical estimates on the pumps commonly found in their countries.

REFERENCES

(1) Babbitt, H E, J J, Doland, and J C Cleasby (1962) *Water Supply Engineering*, McGraw Hill, NY, pp. 175-214
(2) Gibson, U P and R D Singer (1969) *Small Wells Manual*, USAID, Washington, DC, p 120
(3) Karassik, I J (1959) "What are the Characteristics of the Unknown Pump?", *Public Works*, June 1959, p 1128
(4) McJunkin, F E (1977) *Handpumps*, WHO International Reference Center, The Hague, Netherlands, 230 pages
(5) Moody, L. F (1952) "Hydraulic Machinery", pp. 555-637 in *Handbook of Applied Hydraulics*, ed. C V. Davis, McGraw Hill, NY
(6) Wagner, E G and J. N Lanoix (1959). *Water Supply for Rural Areas and Small Communities*, WHO, Geneva, 340 pages.
(7) Walker, R (1972) *Pump Selection. A Consulting Engineer's Manual*, Ann Arbor Science Pub, Ann Arbor, MI, 120 pp

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