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North Bengal Terai Development Project, Phase III

Manual Pump Testing

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1 INTRODUCTION

1.1 Programme

This report presents the final results of the testing of manual pumps under controlled conditions. This testing was part of Action Plan 2 - Activity 2.2 "Testing of manually operated pumps" as described in the Inception Report of North Bengal Terai Development Project. The work is executed in the period November 1995 to May 1996 by Subrata Majumdar, of the Project Support Unit, under the guidance of David W. van Raalten, land and water management specialist and in direct consultation with Gert Jan Bom, pump technology specialist.

1.2 Background

In the first and second phase of the NBTDP, thousands of ***handpumps*** (Mo.6) with a GI pipe and brass filter were placed with considerable succes. These handpumps were generally used for drinking water supply and the cultivation of vegetables on the homesteads (about 1½ bigha = 0.17 ha) of the marginal and small landowners, who were the target recipients of the handpumps. These handpumps require substantial physical labour to operate. Another drawback is that they are prone to theft and hence generally not used outside the homesteads. Assumed is that this type of handpumps have a yield of 1 m^3/hour (0.3 l/s).

Outside the homesteads bamboo ***bucket pumps*** are common, lifting water from very shallow earthen digs (matir kua). A very tentative assessment showed that these traditional wells are comparatively easier to operate then the handpumps and would yield 2.5-3.5 m^3/hour (0.7 - 1.0 l/s). This is only possible if the well capacity would not be the constraint: the bucket pumps are generally limited by the fact that the earthen wells are extremely shallow, with a lot of sand intrusion and hence are rapidly depleted, which effectively limits their capacity to 0.5 m^3/hour (0.14 l/s) . These constraints may be overcome with the provision of concrete ringwells.

A third human-powered technology that has been popularized are the ***pedal pumps***. These pedal pumps have two iron cylinders, instead of only one in the case of a handpump. It is operated by foot, making it ergonomic much more suitable as a manual water lifting device. Different types are existing, with 3½" or 5" dia cylinders and with bamboo or iron pedal system. The 5" dia pedal pump is reported to give a yield of 1.5 l/s (5.4 m^3/hour) for shallow depths, which is five times more as the assumed yield of a handpump.
Given its higher ergonomic efficiency, the potential demand for pedal pumps in North Bengal may be substantial as the water table is generally within ten feet, whereas the pedal pump is suitable up to 7 metre (dependent on the model). Moreover, marginal and small landownership is common in the Terai, which can be served by small water lifting devices.

1.3 Objectives

The main objective of the action plan is to improve the efficiency of manual irrigation. In Phase III, again 15,000 handpumps are planned, and besides this the pedal pump is also promoted through the private sector. However, data on the functioning of these pumps is not available, making it impossible to compare the different manual irrigation technologies, and therefore to say anything about which pump is the most suitable manual pump for this region.

The objective of this controlled testing is therefore to get this lacking information on the functioning of the different manual irrigation technologies in use in the Terai region. Data on the flow rate and daily capacity, together with the ease of operation has to be determined for different water depths. After this data collection a proper comparison between the different technologies can be made and the most efficient type can be selected.

2 METHODOLOGY

2.1 Test variables

2.1.1 Pumps

The different water lifting devices that were tested are:

⇒	handpump:	cast-iron lever-type, Mo.6		
⇒	pedal pump:	3½" dia	steel pedal system	9" cylinder
		3½" dia	bamboo pedal system	12" cylinder
		3½" dia	bamboo pedal system	14" cylinder
		5" dia	steel pedal system	9" cylinder
⇒	bucket pump:	bamboo spring lever		
		bamboo counter-balance		

The tested 14-inches pedal pump is also called the Ambay model and is widely in use in Bangladesh, having a flap check valve, like the other pedal pumps.
The volume of the buckets used for by the bucket pumps is 8 litre.
See annex A for some photographs of these types of pumps.

2.1.2 Depth

The flow rate of the pump and the ease of operation is closely related to the total depth over which the water has to be lifted. That is why different depths have been included in this test, as also different depths will be found in the different areas of the project. At the following depths the testing is done:

⇒ 2½ metre
⇒ 5 metre
⇒ 7 metre

The depths are measured from the pump outlet to waterlevel in the well. In the test configuration the pump outlet is about 50 cm above groundlevel.

2.1.3 Test persons

This test is about water lifting devices which are manually operated, so for this testing test persons were needed. To get a good comprehensive result, an average size male, female and child did the testing. Because body weight is important, especially in case of the pedal pumps, the person's weight was measured.

⇒	male	52 kg
⇒	female	42 kg
⇒	child (boy)	34 kg

2.2 Test criteria

To determine the efficiency of every water lifting device, the following criteria were established, for every depth and testperson:

⇒ flow rate
⇒ daily capacity
⇒ ease of operation

The *flow rate* is the discharge that the water lifting device gives when it is in use, excluding any breaks, expressed in l/s.
The *daily capacity* is the amount of water that can be lifted during a working day of 8 hours. In the test these 8 hours were divided in a morning session of 4 hours, then a one hour lunch break, followed by an afternoon session of another 4 hours. Breaks within these 4 hours-sessions have been included in the calculations of the daily capacity, but the 1 hour lunch break is excluded.
For the *ease of operation* criteria are the time that one person can continuously operate the pump before a rest is required, the number of breaks that are required and for how long. This might differ for every test person, therefore the decision to take a break was completely according to the choice of the test persons themselves. Whenever they felt the need for a break, they could take it. Another criteria is the opinion of the test persons themselves about which technology is more or less easy to operate and which pump they prefer at which depth.

2.3 The different types of tests

2.3.1 Preliminary testing

Preliminary testing was done before the real testing was started. This preliminary testing was needed for:

a. Giving the test persons chance to practise operating the different technologies, so that they get experience, in order to avoid incorrect test results.
b. Estimating the time schedule that will be applied during the final testing; how long can a system continuously be operated? What is the length and frequency of breaks for rest? (finally no fixed time schedule was used; it remained the testperson's choice)
c. Practising the methods of measuring the discharges, in order to judge if these methods are suitable.
d. Checking of the proper functioning of the installed pumps and the closed well.

The test persons operated for one hour, during which they were given the chance to decide for themselves when they need a break and for how long (appendix 5 gives a form). After finishing this first round, a second round of one hour was done. The results of these testing are not included in this report, as during this round the test persons did not yet have enough experience and therefore the results were not representative.

2.3.2 1-hour testing

After the preliminary testing, in which the testpersons got used to all the different types of water lifting devices, the 1-hour testing started. The test persons operated the pumps for one hour at what they consider a normal rythm. During operation the discharge was measured with the following the methods (see annex C for measurement forms):

⇒ pedal pumps and handpump
For the pedal pumps and the handpump a 500 litre tank was used. This tank was placed into a concrete basin, constructed below groundlevel and which was connected through a drain tube

to the closed well. In this way after checking the time needed to fill the tank, the water could easily flow back into the well and the water level in the well remained relatively stable. The lifted water by the pumps was conveyed into the tank with the help of 2½" and 3" flexible tubes. Before and after filling of the tank the tube was directly diverted into the well, so that the test persons were able to continue pumping. In this way the flow rate was measured twice in one hour and breaks were noted down.

⇒ bucket pumps
For the bamboo bucket pumps the number of buckets were counted over the time. Volumes of representative filled buckets were measured. In this way all the buckets were counted during one hour, together with the time needed for breaks.

2.3.3 8-hour testing

During the 1-hour testing it became clear that it was impossible to get a clear picture of the ease of operation. The testpersons were able to run the pedal pumps and the handpump continuously for 1 hour, while for the bucket pumps already within one hour breaks were needed. Besides this is was expected that if someone has to pump for eight hours continuously the speed of operation would reduce. In order to get a good estimation of the discharge during a day, it was decided to go for 8-hour testing, after which the daily capacity could also be calculated.

As this testing takes much more time, the number of test persons and water lifting devices was reduced. Only the four following types of water lifting devices were selected, being the most interesting ones, based on the results of the 1-hour testing:
⇒ 5" steel pedal pump
⇒ 3½" bamboo pedal pump (standard 12" height cylinder, but with disk check valve),
⇒ handpump
⇒ counter balance bucket system

The test persons were only the female and the child, as the results of the 1-hour testing showed that the results for male and female were nearly the same. During this 8-hour testing the flow rate was measured every hour and the frequency and length of breaks were closely monitored. The choice to go for a break remained to the discretion of the test person.

2.4 Location

The location where the testing is done is Mohit Nagar State Farm, in Jalpaiguri Block, about 8 kilometres from Jalpaiguri. Behind the office of the Farm Manager a site was found where already a 2 feet dia ringwell was present and a closed well could be constructed (see annex A for a overview).

A closed well was installed which acted as a kind of reservoir in which different ground water tables could be simulated. This well has a depth of 26 feet and a diameter of 3 feet. It has a closed bottom and all the joints were sealed properly, in order to avoid leakage (annex B: design with some details). Around the well the different water lifting devices were installed.

On a distance of only a few metres another well was present, needed for filling the closed well to the desired water depths, for which a pedal pump with flexible suction pipe was used.

In between these two wells a lined brickwork basin was constructed into the soil in which a 500-litre tank was installed. This basin was directly connected through a drain tube with the closed well, so that water could easily flow back into the well.

2.5 Instruments

Basically for the testing a closed well and the already present ringwell were needed. The different water lifting devices where connected through PVC and GI pipes to the well, and the pedal pumps were sligthly modified at the pump outlet side, in order to collect the water into a tube. Besides this the following instruments and materials have been used during the testing:

⇒ stopwatch
⇒ 500 litre tank, with a stop-cock at the bottom
⇒ 4" tube for drainage of tank
⇒ 3 tubes for diverting the discharge of pedal pumps and handpump (2½" and 3" dia, 10 feet length)

3 RESULTS OF TESTING

3.1 Testing during 1-hour

3.1.1 Flow rates

The flow rates measurements of the 1-hour testing are presented in the following tables 1,2 and 3 and graphs 1,2 and 3, for female, male and child test person respectively. These flow rates are all without any breaks.

Table 1 - Flow rates for female test person (l/s)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	0.69	0.59	0.42
Pedal pump steel 3½"	0.64	0.51	0.36
Pedal pump bamboo 3½"	0.54	0.42	0.31
Pedal pump steel 5"	1.12	0.63	0.41
Ambay bamboo 3½"	0.68	0.61	0.45
Bamboo counter balance	0.69	0.35	0.25
Bamboo spring lever	0.64	0.31	0.17

Table 2 - Flow rates for male test person (l/s)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	0.74	0.53	0.41
Pedal pump steel 3½"	0.74	0.59	0.50
Pedal pump bamboo 3½"	0.67	0.54	0.37
Pedal pump steel 5"	1.29	0.85	0.49
Ambay bamboo 3½"	0.65	0.58	0.48
Bamboo counter balance	0.72	0.40	0.25
Bamboo spring lever	0.72	0.36	0.21

Table 3 - Flow rates for child test person (l/s)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	0.49	0.38	0.34
Pedal pump steel 3½"	0.57	0.44	0.33
Pedal pump bamboo 3½"	0.53	0.27	0.18
Pedal pump steel 5"	1.06	0.44	0.29
Ambay bamboo 3½"	0.65	0.50	0.36
Bamboo counter balance	0.49	0.27	0.19
Bamboo spring lever	0.46	0.22	-

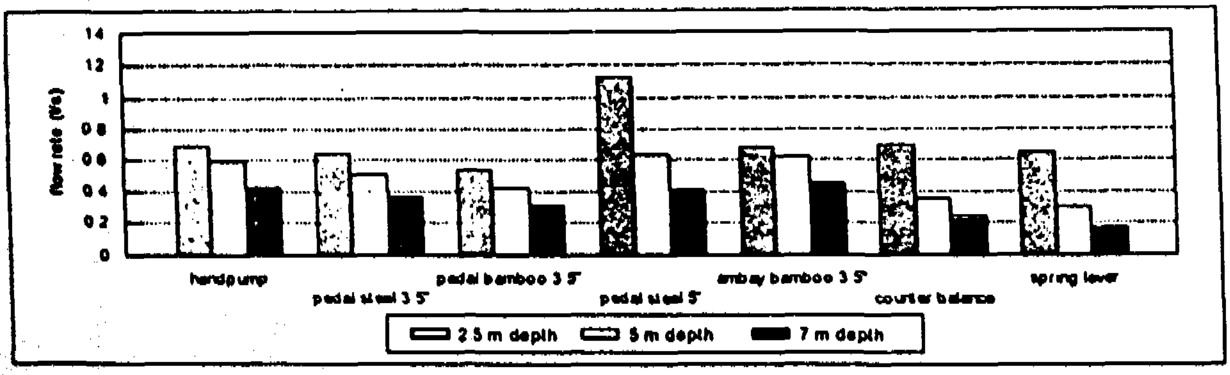


Figure 1 - Flow rates for female test person (l/s)

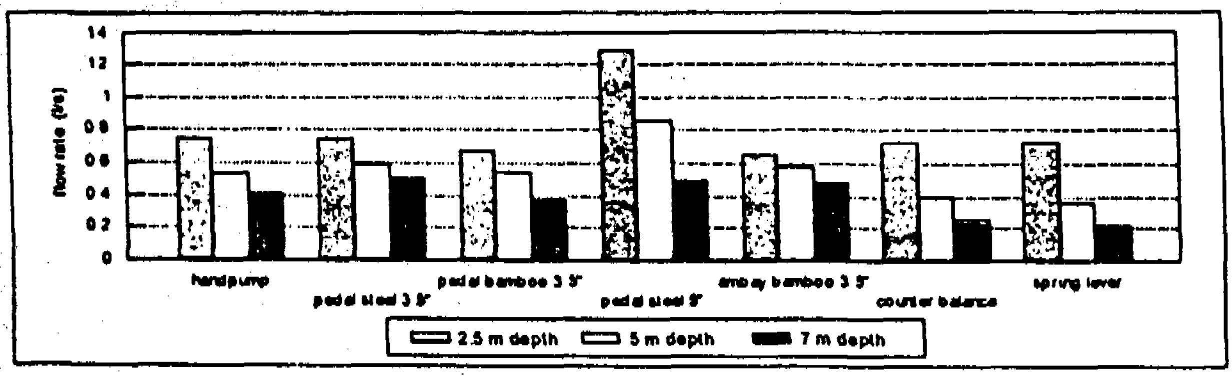


Figure 2 - Flow rates for male test person (l/s)

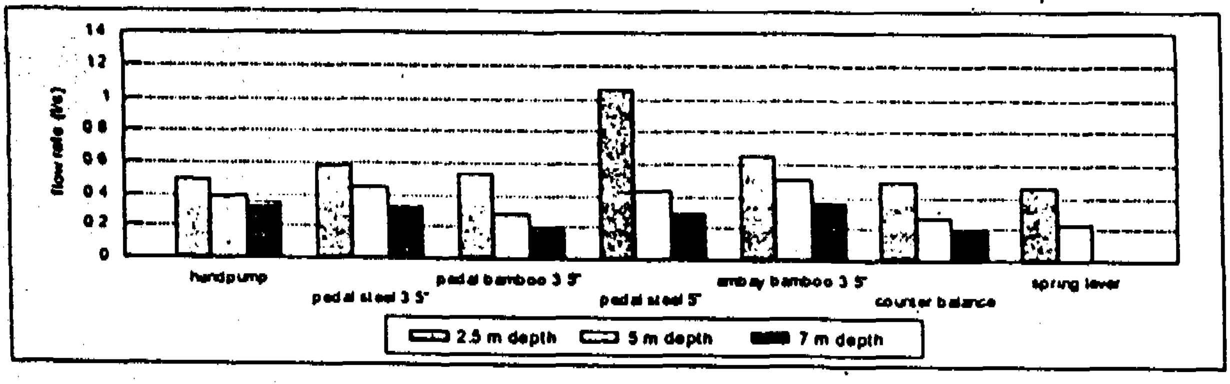


Figure 3 - Flow rates for child test person (l/s)

First of all it is interesting to see that the flow rates of all the types of devices are quite in the same range. Initially it was assumed that the pedal pump would give up to five times more water as the handpump (paragraph 1.2 Background). Now it seems only in the most extreme case a factor two. However the pedal pumps are still doing good, compared with the other devices.

Regarding the testpersons, in general it can be concluded that the male person can lift more water. However it is clear that the difference between male and female is very marginal, whereas the difference with the child is more significant. Especially in case of the 5" pedal pump, body weight seems to be a limiting factor.

At shallow water depth, i.e. *2½ metre*, for all the test persons the *pedal pump* with the 5" diameter and steel pedal is absolutely superior to the other types of water lifting devices. It is interesting to see that the flow rates of the handpump compared with the bamboo counter balance are for all the test persons about the same.

When the water level goes to *5 metre*, the difference is minimized, as it becomes more heavy to operate the 5" pedal pump, causing a tremendous drop in flow rate of 50% for the child and female, and 35% for the male test person. However, for the male test person the 5" pedal pump remains superior. At this depth the child can lift more water with the 3½" Ambay bamboo type, being followed by the two steel pedal (5"and 3½") pumps. For the female the flow rates of Ambay, handpump and 3½" bamboo are about the same.

At *7 metre* depth the differences become very mariginal. However the female and child test persons can pump more with the 3½" Ambay bamboo type, closely followed by the handpump. For the man there is hardly any difference between the 5" and the 3½" steel and Ambay pedal pumps.

The 3½" bamboo *pedal pump* is in generally giving less water, while the Ambay model, also with bamboo and 3½" dia, is doing better, both in case of the child and female test persons. Diameter is an important factor for the flow rate, as can be seen in the differences between the 5"steel and 3½" steel pedal pumps. The type of pedal does have some influence, but a factor of more importance seems to be the length of the cylinder, as can be seen in the differences between the 3½" pedal pumps. The steel pedal has only 9" height, the bamboo one 12" and the ambay bamboo 14", the latter giving the best results. A theoretical explaination is that a larger stroke gives relatively more effective pumping time, therefore causing an increase in flow rate. Besides this the type of check valve seems to play a role (see 8 hour testing)

Interesting is that at shallow water depth the *bucket systems* are able to compete with the other types of devices. However, when the water level is deeper, the flow rates drops down more quickly. At greater depth, i.e. 7 metre the child was during this testing too scared to operate the bamboo spring lever bucket system, that is why no measurements could be taken. In general the counter balance gives slightly more than the spring lever.

3.1.2 Ease of operation

During the testing it became clear that on the pedal pumps and the handpump both the female as the male could continue for at least one hour. After one hour they expressed that they could easily continue for another hour. The child required sometimes a break on the 5" pedal pump at greater depth. The test persons expected that in general they could even easily continue operating the pedal pumps for four hours.
For the handpump their expectation was roughly two hours, while for the bucket system they took breaks within 1-hour. Related to the depth they expected that more breaks would be required as the water level would be deeper.

3.2 Testing during 8-hours

3.2.1 Flow rates

In the 8-hour testing only four types of devices have been tested:

⇒ handpump:	cast-iron lever-type, Mo.6		
⇒ pedal pumps:	3½" dia	bamboo pedal system	12" cylinder
	5" dia	steel pedal system	9" cylinder
⇒ bucket system:	counter balance		

The difference between the two pedal pumps is in diameter (3.5" and 5"), pedal type (steel and bamboo) and cylinder height (9" and 12"), both promoted by IDE on the local market. The flap check valves of the 1-hour testing, have been replaced by a better system of disk check valves. For the bucket system the counter balance has been tested, according to the preference of the test persons. The results for respectively child and female are presented in the following tables 4,5 and in the figures 4,5.

Table 4 - Flow rates for female test person - 8 hour testing (l/s)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	0.50	0.30	0.27
Pedal pump bamboo 3½"	0.51	0.41	0.32
Pedal pump steel 5"	0.77	0.59	0.22
Bamboo counter balance	0.45	0.29	0.17

Table 5 - Flow rates for child test person - 8 hour testing (l/s)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	0.33	0.25	0.19
Pedal pump bamboo 3½"	0.50	0.44	0.22
Pedal pump steel 5"	0.94	0.38	0.21
Bamboo counter balance	0.41	0.26	0.17

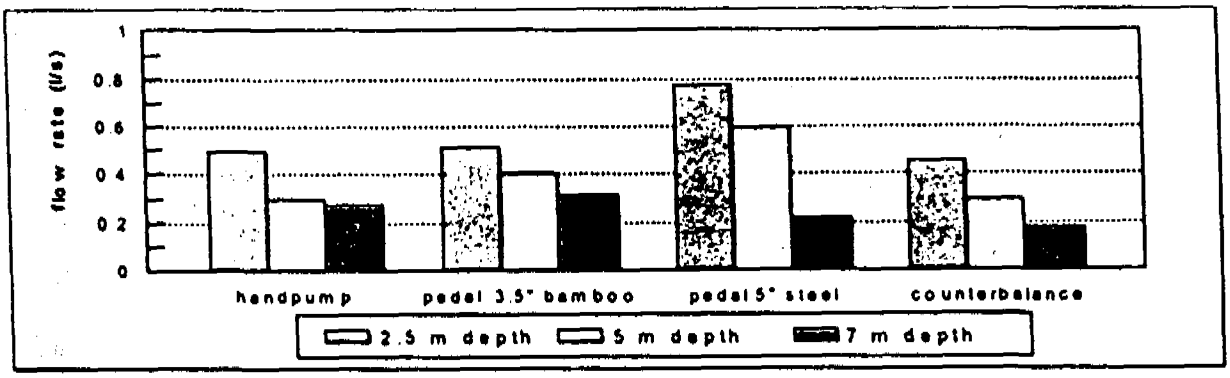


Figure 4 - Flow rates for female test person - 8 hour testing (l/s)

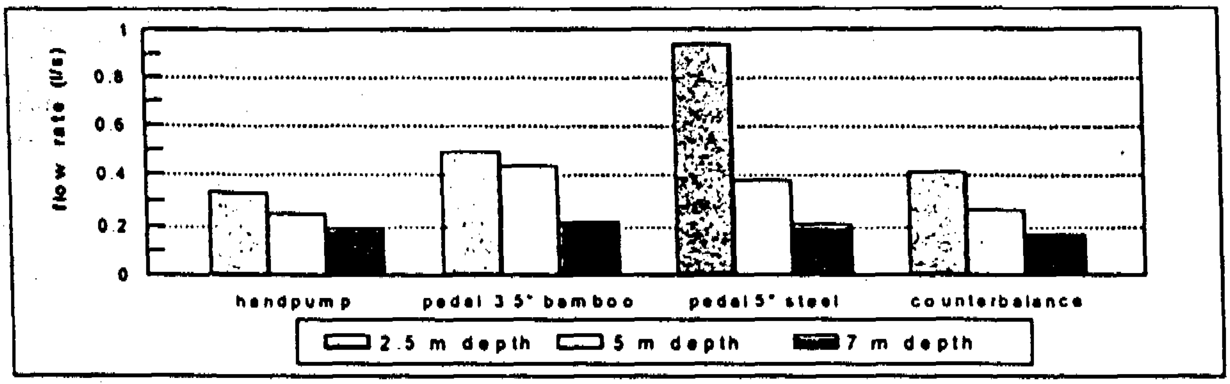


Figure 5 - Flow rates for child test person - 8 hour testing (l/s)

The flow rates are in general considerably lower for the 5" pedal pump and the handpump, than in the case of the 1-hour testing. This decrease in flow rate is present from the very first minute, while during the day the flow rate remains quite constant, as can be seen in annex D. It seems that the fact that you have to operate it for a whole day, makes people operate it a lower speed directly from the beginning. For the 3½" pedal pump however, the flow rate is about the same, or even more in case of the boy. This is probably due to a better check valve system and the fact that this type of pump is more easy to operate. At least the difference in discharge between the 3½"pedal pump and the handpump has increased.

The pedal pump with 5" diameter is again doing tremendously good at ***2½ metre water depth***, but this was to be expected. However, this is still lower as was initially expected and claimed (1.5 l/s). For the female the flow rates for the handpump and the 3½" pedal pump are the same. For the boy the 3½" pedal pump is a doing better than the handpump and the counter balance is giving a higher yield than the handpump.

At ***5 metre water depth***, in the case of the child the flow rate of the 5" pedal pump drops incredibly (by 60%) and ends below that of the 3½" pedal pump, while for the female also a drop is there, but not so significant (23%) and remains still more than the 3½" pedal pump. The drop in flow rate of the handpump is more in her case (40%).

For the female only at a *depth of 7 metre* the 3½" pedal pump gives more, with the handpump as a good runner-up. While for the child it hardly becomes possible to make any distinction between the different devices.

In the comparison between the *handpump* and the *counter balance* system, it can be concluded that they give more or less the same discharge. Operated by the boy the handpump gives less discharge at 2.5 metre water level, equal at 5 metre and slightly more at 7 metre. In case of the female the handpump performs slightly better on all depths.

3.2.2 Ease of operation

Criteria for the ease of operation were the number of breaks, together with the time required for every break. With this data the total break time and average break length are calculated.

Table 6 - Frequency and time of breaks for female testperson (sec)

Water lifting device	2½ metre			5 metre			7 metre		
	no. of break	total time	avg. break	no. of break	total time	avg. break	no. of break	total time	avg. break
Handpump	0	-	-	6	2245	374	3	1068	356
Pedal pump bamboo 3½"	0	-	-	0	-	-	2	666	333
Pedal pump steel 5"	2	922	461	0	-	-	3	1107	396
Bamboo counter balance	4	2100	525	4	2100	525	3	1620	540

Table 7 - Frequency and time of breaks for child testperson (m^3/day)

Water lifting device	2½ metre			5 metre			7 metre		
	no. of break	total time	avg. break	no. of break	total time	avg. break	no. of break	total time	avg. break
Handpump	2	2025	1013	2	899	450	2	746	373
Pedal pump bamboo 3½"	2	156	78	0	-	-	2	774	387
Pedal pump steel 5"	0	-	-	0	-	-	4	1380	345
Bamboo counter balance	5	2100	420	5	2280	456	4	1320	330

In the analysis of these data it becomes clear that the human factor is a difficult factor to quantify. For instance; the boy did require a break on the 3½" pedal pump at a depth of only 2½ metre. When the water was deeper, at 5 metre, he did not require any break, while on 7 metre again breaks were required. The same happens in the case of the pedal pump 5" for the female. In her case the handpump is even more interesting; at 2½ metre no breaks, at 5 metre 6 breaks, where on 7 metre she took only 3 breaks.

Anyhow, the general impression is that:

- the number of breaks increases with increased depth, at 7 metre depth all the pumps require breaks,
- the pedal pumps needs less breaks at 2½ and 5 metre depth, where it seems possible to continue for 4 hours, whereas at 7 metre depth it is reduced to only 2 hours,

- the 5" pedal pump needs more breaks at 7 m depth than the 3½",
- the handpump requires after 2 hours a break, different depth does not seem to have that much influence in case of the child,
- the counter balance needs always breaks, after 1 to 1.5 hour, regardless of the waterdepth,
- the length of a break is relatively constant and is not increasing with increased depth.

The test persons indicated that all the devices become more difficult to operate at greater depth, but especially in the case of the 5" pedal pump and the bucket system it is becoming very difficult.

3.2.3 Capacity in a day

After knowing the required break times, the capacity for one day can be calculated. A day is defined as 8 working hours, divided in two sessions by a lunch break of 1 hour. In the following daily capacities the operational breaks of paragraph 3.2.2 are included, but the lunch break is excluded.

Table 8 - Day capacity for female testperson (m^3/day)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	14.3	7.8	7.5
Pedal pump bamboo 3½"	14.7	11.7	8.9
Pedal pump steel 5"	21.5	17.0	6.0
Bamboo counter balance	12.0	7.7	4.7

Table 9 - Day capacity for child testperson (m^3/day)

Water lifting device	2½ metre	5 metre	7 metre
Handpump	8.9	6.8	5.4
Pedal pump bamboo 3½"	14.3	12.6	6.0
Pedal pump steel 5"	27.0	10.9	5.7
Bamboo counter balance	10.9	6.9	4.6

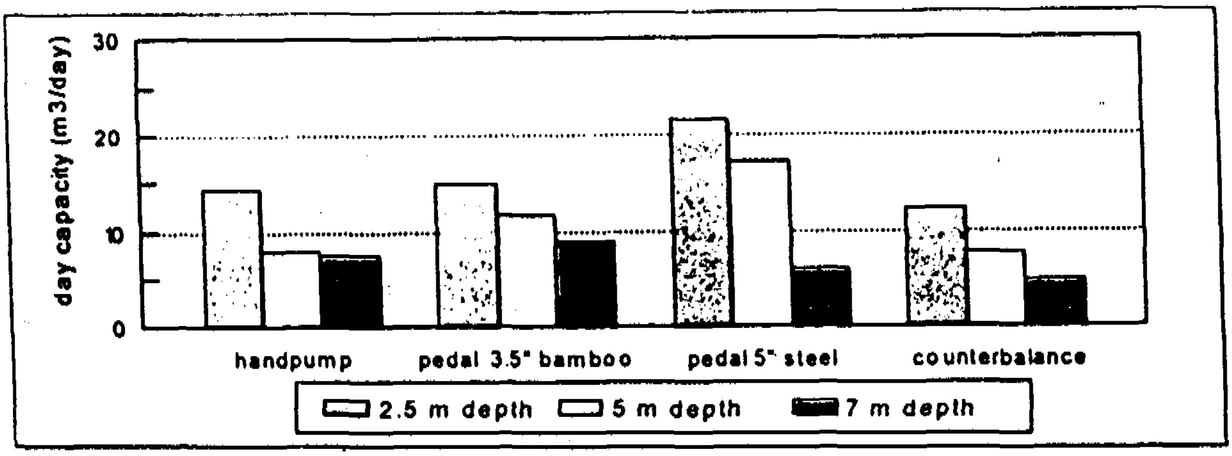


Figure 6 - Day capacity for female test person (m^3/day)

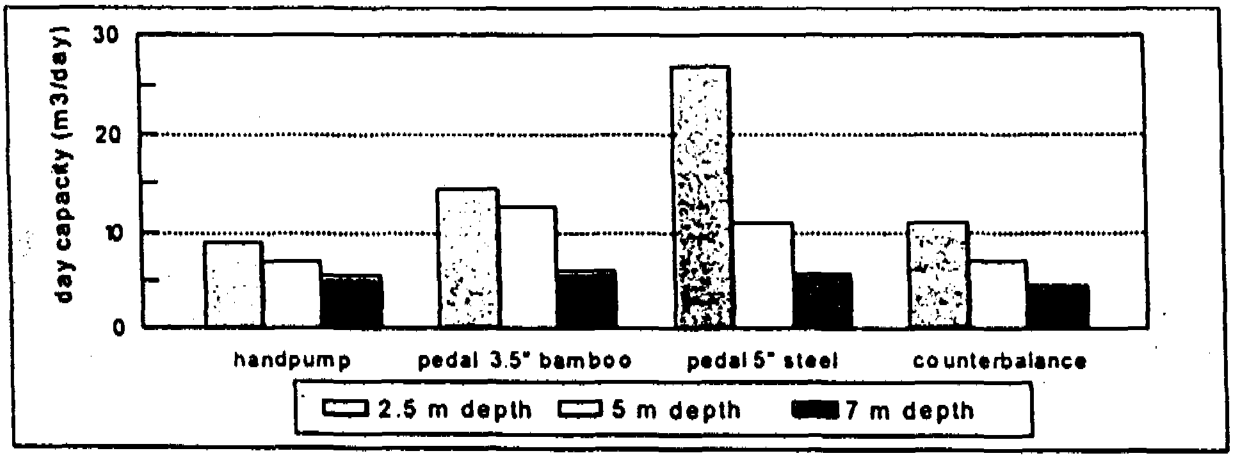


Figure 7 - Day capacity for child test person (m^3/day)

In general it can be concluded that:

- the day capacity is much more influenced by the flow rate, than by the number of breaks, as the patterns of the graphs for flow rates and daily capacity are about the same,
- the pedal pump 5" gives at 2½ metre depth much more for both test persons, but drops incredibly at 5 and 7 metre depth,
- for the female the capacity of the handpump and the 3½" pedal pump at a depth of 2½ is about the same, deeper the handpump gets a lower capacity,
- at 5 metre depth the 3½" gives the best results for the boy, but for the female it is still the 5" pedal pump that yields more,
- at 7 metre depth the 3½" version of the pedal pump becomes more interesting, for both the test persons,
- the counter balance is giving a reasonable capacity, in case of the boy even more at 2½ metre depth than the handpump, in case of the female in general slightly less than the handpump, but at 7 metre the handpump is clearly better.

The following table gives the results in percentages, which makes it easier to compare. The drop of the 5" pedal pump is tremendous. But also the drop in flow rate of the handpump, for the female, from 2½ metre to 5 metre is considerable.

Table 10 - Day capacity expressed as percentages for female testperson

Water lifting device	2½ metre	5 metre	7 metre
Handpump	97	53	51
Pedal pump bamboo 3½"	100	80	61
Pedal pump steel 5"	146	116	41
Bamboo counter balance	82	52	32

Note: 2½ metre, pedal pump bamboo 3½" is index (100%)

Table 11 - Day capacity expressed as percentages for child testperson

Water lifting device	2½ metre	5 metre	7 metre
Handpump	62	48	38
Pedal pump bamboo 3½"	100	88	42
Pedal pump steel 5"	189	76	40
Bamboo counter balance	76	48	32

Note: 2½ metre, pedal pump bamboo 3½" is index (100%)

3.2.4 Preference of test persons

At the end the test persons were asked to give their preference at different depths. In this case a distinction has to be made between drinking water and irrigation water. Drinking water can in the social context of this area not be lifted up by means of feet. To present this water to someone is considered as very impolite.

The preferences of all the test persons (F = female, M = male and C = child) for irrigation purpose were as follows:

Table 12 - Preference of test persons for the purpose of irrigation water (m^3/day)

	2.5 metre			5 metre			7 metre		
Water lifting device	F	M	C	F	M	C	F	M	C
Handpump	5	3	3	4	4	4	3	4	3
Pedal pump bamboo 3.5"	2	2	2	- 1 -	2	- 1 -	- 1 -	2	- 1 -
Pedal pump steel 3.5"	6	6	5	5	6	5	4	5	4
Pedal pump steel 5"	- 1 -	- 1 -	- 1 -	2	- 1 -	2	6	- 1 -	6
Bamboo spring lever	4	5	6	6	5	6	5	6	5
Bamboo counter balance	3	4	4	3	3	3	2	3	2

All the persons preferred on ***2½ metre water depth*** the 5"pedal pump, as according to their words it is easy to operate and gives a high flow rate. Their second choice is the 3.5" pedal pump. Male and child then prefer the handpump, while the female prefers the bucket systems.

When the waterdepth goes to ***5 metre***, still the two pedal pumps get the preference, but for both the child as the female, the 3½" has become no. 1 choice, with the 5" as a second choice.

Interesting to see is that all the test persons at this depth prefer the counter balance above the handpump.

On *7 metre depth*, both the child and the female consider the 5" pedal pump as too difficult to operate and put it in the last position. The 3½" pedal pump gets their full support at this depth. However, the male still prefers the 5" type.

The preference for the 3½" steel pedal pump is very low, as the stroke of this type is very limited, compared with the 3½" bamboo pedal pump. If the stroke of the steel one can be improved, they prefer a steel pedal system.

The test persons all together told that operating the bucket system the whole day at a depth of 2½ to 5 metre is no problem, but when the water is deeper it becomes too difficult.

In the preference two factors are possibly playing a role, one is the ease of operation, another is the capacity. In case that you have to pump the whole day, the ease of operation will be more important, while if you have to irrigate a plot, the capacity might be of more importance as the time factor will also play a role.

The preferences for the purpose of drinking water is presented in table 13. The pedal pumps are completely excluded because of the earlier mentioned reason. However, if the pedal pump is used by hand, which is easily possible in the case of the bamboo type, this problem does not arise. People also already use the bamboo pedal pump at their homesteads, when not required in the field, by using only one cylinder and having an increased standpipe to comfort the operation.

Table 13 - Preference of test persons for the purpose of drinking water (m^3/day)

	2.5 metre			5 metre			7 metre		
Water lifting device	**F**	**M**	**C**	**F**	**M**	**C**	**F**	**M**	**C**
Handpump	3	3	2	3	3	2	3	- 1 -	- 1 -
Pedal pump bamboo 3.5"	-	-	-	-	-	-	-	-	-
Pedal pump steel 3.5"	-	-	-	-	-	-	-	-	-
Pedal pump steel 5"	-	-	-	-	-	-	-	-	-
Bamboo spring lever	2	2	3	2	2	3	2	3	3
Bamboo counter balance	- 1 -	- 1 -	- 1 -	- 1 -	- 1 -	- 1 -	- 1 -	2	2

The test persons in general prefer the bucket system, instead of the handpump, as this latter is giving according to them a bad taste to the water due to high iron content. They think that the quality of water from a open well is better. The counter balance is always preferred above the spring lever bucket system.

When the water gets too deep, the handpump is getting the preference of both the boy and the male. The boy clearly indicated that at this depth it becomes too hard operate the bucket system and children of his age will be scared to do this kind of job.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Technical performance

4.1.1 Earlier assumed yields

In paragraph 1.2 (Background) assumed was that the handpump would yield 1 m^3/hour, which is 8 m^3 for 8 hours. Now we can conclude that this assumption was quite right, at shallow water depth (2½ metre) it is in the range of 9-14 m^3, for medium depth (5 metre) 7-8 m^3, and for deep depth (7 metre) 5-8 m^3.

In case of the bucket pump the estimation was too high, expected was that when the well would not be a limiting factor, the yield could be 2½-3½ m^3/hour, i.e. 20-28 m^3 for 8 hours. The test results however show that it will only yield 11-12 m^3 in the case of shallow water, at medium 7-8 m^3 and 5 m^3 for deep ground water.

Only for the 5" pedal pumps some data was available, saying that 6 m^3 per hour was possible, so 48 m^3 for 8 hours. The results however show that it is considerably lower; in case of the 5" pump 22-27 m^3 for shallow water depth, 11-17 m^3 for medium depth and 6 m^3 for deep depth. While the 3½" pump yields 14-15 m^3 for shallow water depth, 12-13 m^3 for medium depth and 6-9 m^3 for deep depth.

4.1.2 Actual performance

In the analysis of the results the incredible drop in discharge for the 5" pedal pump is on first sight remarkable. For instance in case of the boy, if we go from 2½ metre to 5 metre, the water depth increases by 50%, but the flow rate reduces by 60%, and another 2 metre more depth (40% deeper), gives an decrease of 45%.
In case of other pumps these kind of drops are not occuring, which is even more remarkable, as one expects that when the water has to be lifted over twice as much heigth, the flow rate will also reduce twice times, under optimal conditions.

A rule of thumb is that a person can get an output of its own weight in Watts. So that means for the boy 34 Watt and for the female 42 Watt. If we compare this with the outputs (lift head x flow rate x 9.81) given by the pumps we get the following interesting results, see the following tables 14 and 15 and efficiencies can be calculated.

Table 14 - Output in Watts for female testperson

Water lifting device	2½ metre	5 metre	7 metre
Handpump	12.3	14.7	18.5
Pedal pump bamboo 3½"	12.5	20.1	22.0
Pedal pump steel 5"	18.9	28.9	15.1
Bamboo counter balance	11.0	14.2	11.7

Table 15 - Output in Watts for child testperson

Water lifting device	2½ metre	5 metre	7 metre
Handpump	8.1	12.3	13.0
Pedal pump bamboo 3½"	12.3	21.6	15.1
Pedal pump steel 5"	23.1	18.6	14.4
Bamboo counter balance	10.1	12.8	11.7

If we take the case of the female testperson, the highest output she gets with the 5" pedal pump at 5 metre depth; 28.9 Watt, so an efficiency of 69%. On 2½ metre depth the efficiency is only 45%, whereas at 7 metre it is only 36%. For the 3½" pedal pump it is at 7 and 5 metre depth, resp. 48% and 52%, whereas at 2½ metre it is only 30%.
The boy also has the highest efficiency (68%) for the 5" pedal pump, but at 2½ metre depth. It is interesting that every pump reaches its highest efficiency at different depths, and that it differs per test person.

A possible theory for the fact that the flow rate is not so directly related with the the lifting head, and the fact that the highest efficiency is reached at diffent depths, could be that we are dealing with different kind of efficiencies, let's say:

- ergonomic efficiency; which is increasing with depth, because when the water is not so deep, not all input is required, while at greater depth all manual input can be given.
- mechanical efficiency: which is decreasing with depth, as for instance more friction will be there.

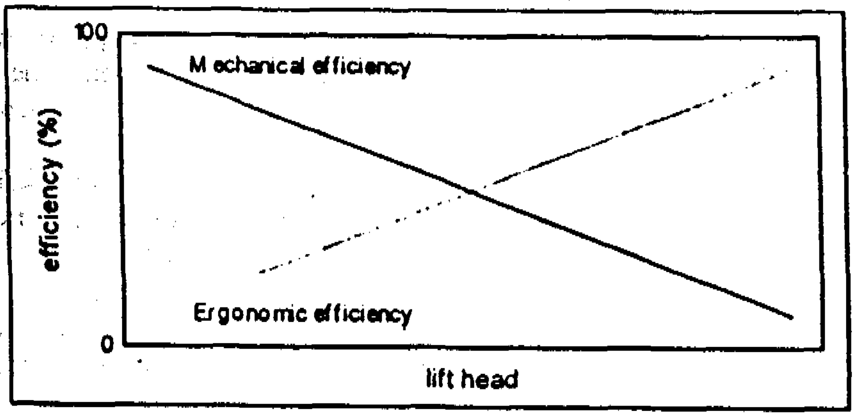


Figure 8 - Theoretical efficiencies

This might explain why every pump will have its highest efficiency at a different depth. The optimum of the two efficiency's will differ for every type of lifting device.
It can be concluded that the 5" pedal pump has the highest efficiencies, but there is still scope for improvement.

4.1.3 Scope for improvement

With the 5" pedal pump the highest efficiencies have been reached. It seems that this pump has highest potential for improvement. This pump can be improved in different ways. Mechanically the check valves have already been replaced, and the stabiliser also has been improved. Another type of washer, with less resistance can again reduce the friction and increase the efficiency.

The manual input can probably be used more efficient by:

- using another (longer) type of pedals. In case of the bamboo pedal pumps a big advantage is that the test persons can change his/her position on the pedals and in that way increase or decrease the momentum.
- increasing the cylinder height, at this time only 9" is present, because more height will increase the stroke and therefore the effective pumping time (relatively less time is necessary for the change from downward movement to upward movement).

4.2 Selection of most suitable pump

4.2.1 Flow rate and capacity

In drawing final conclusions for this project and to come with recommendations, the local factors are playing a very important role, if we look into the technical results of this testing, i.e. the flow rates and the daily capacity, can conclude that:

- at 2½ metre depth the 5" steel pedal pump is superior
- at 5 metre the 5"steel and the 3½" bamboo pedal pumps perform the best
- at 7 metre depth the 3½" bamboo pedal pump gives the highest yield

The average ground water depth in the North Bengal Terai Region is about 3 metre, that means that the 5" steel will give the best results, followed by the 3½" bamboo pedal pumps.

4.2.2 Ease of operation

If we take into consideration the ease of operation, the pedal pumps are more user friendly, both the 5" and 3½" type, especially at the waterdepths that we have in the Terai region. On this kind of pumps someone can continue operating the pump for 4 hours, and can in that way easily operate it for a whole day, which is required if someone wants to irrigate a whole field. At 7 metre depth only the 3½" bamboo pedal pump remains ergonomically the best.

4.2.3 Investment costs

Initial investment costs are a factor that should not be excluded. In the following table an indication of the costs involved are given. All prices are according to present market rates. In the case of the handpump it is a tubewell of G.I.-pipe of approximately 40 feet and a concrete basement (Rs. 500). In case of the pedal pumps a tubewell of bamboo ([b]) is possible and a G.I.-pipe ([g]) is possible, and only 20 feet is in use. For the bucket system the well consists of concrete rings, up to 22 feet depth.

Table 16 - Costs of water lifting devices

Water lifting device	cost of well	cost of device	total cost
Handpump	Rs. 2000	Rs. 600 + 500	Rs. 3100
Pedal pump bamboo 3½"	Rs. 150[b] - 1000[g]	Rs. 300	Rs. 450 - 1300
Pedal pump steel 3½"	Rs. 150[b] - 1000[g]	Rs. 700	Rs. 850 - 1700
Pedal pump steel 5"	Rs. 150[b] - 1000[g]	Rs. 1200	Rs. 1350 - 2200
Bucket system	Rs. 1250	Rs. 150	Rs. 1400

The pedal pump with bamboo pedals and 3½" diameter and with bamboo tubewell, or even with G.I.-boring is the cheapest option. The 5" pedal pump, with bamboo tubewell follows. This makes the pedal pumps economically the most interesting option. The question is of course how long a bamboo tubewell can last, but this is reported to be up to three years. The bucket system is from economically point of view also more interesting.

4.2.4 Purpose of use

A distinction in purpose of use can be made between irrigation water and drinking water. For the purpose of irrigation water, the capacity and the ease of operation are most important parameters. In that case the pedal pumps are simply the best option.
For drinking water the quality of water is mainly the only factor. Ease of operation is also of importance, but for domestic use a person does not operate a pump for a very long time. In that case the quality of water of tubewells is better than open wells. The pedal pump has the problem of lifting water by means of foot, which can not be given as drinking water to socially higher placed persons. This problem can be solved by operating the pump by hand, but the question is if that will be generally accepted. The test persons were having no problem with that and in the field it is observed that people use the bamboo pedal pump at home at a higher standpipe, for the purpose of drinking water, and when they go to their field they bring the pump with them. However, the handpump seems to be the best option for the purpose of drinking water.

4.2.5 Other factors

Placing handpumps in the middle of the field has the risk of theft. Removing and fitting the handpump is a laborious job and therefore handpumps are always permanently placed in the homestead, where it can easily be used for domestic use, but the distance to field is increased. The bucket systems can be placed in the field as they are not prone to theft, only the bucket has to be brought home. However, the main expenditure is the ringwell and that can be constructed at only one place.
The pedal pumps, especially in case of a bamboo tubewell can easily be removed at the end of the day and fitted the next day. In the case of the 3½" type, with bamboo pedals, the whole bamboo construction can remain in the field and only the two cylinders have to be carried home, for which nowadays these pumps even have a handle. Even more borings in different fields can be made, for which the same pump can be used. This makes this pump again very interesting for irrigation use, as in this way the distance to the field can be reduced and therefore the losses minimized.

4.3 Recommendations

Initially the objective was "to collect data in order to be able to make a comparison between the different technologies in order to select the most efficient type". However, now it becomes clear that the already installed handpumps, and the newly introduced pedal pumps are not competitors, but have their separate working range. If the objective is to provide irrigation water the pedal pump is the best option, but if the objective is to provide drinking water, the handpump is better.
Although the handpumps are installed by the department of Agriculture, with the main purpose of providing irrigation water, they are actually also used for drinking water as well. The latter being a very positive side effect, that also contributes to the objective of the project to

"improve the standard of living of small and marginal farmers". So in this way this choice for handpumps is justified.
However, if a technology has to be chosen with the only objective of providing irrigation water, the pedal pumps are recommended. As second choice recommended is the counter balance bucket system, as this is more cost effective and giving nearly the same yield as a handpump.

Annex A

Pictures of testing site

A.1 Pictures of testing site

Annex A.1 - Pictures of testing site

Overview of testing site.
Male test person is operating the 5" pedal pump and the flow rate is measured.
In front on the right side is the 3.5" bamboo pedal pump.
In front, centre is the closed well, thereafter the tank and then the open well.

Female testperson on Ambay pedal pump

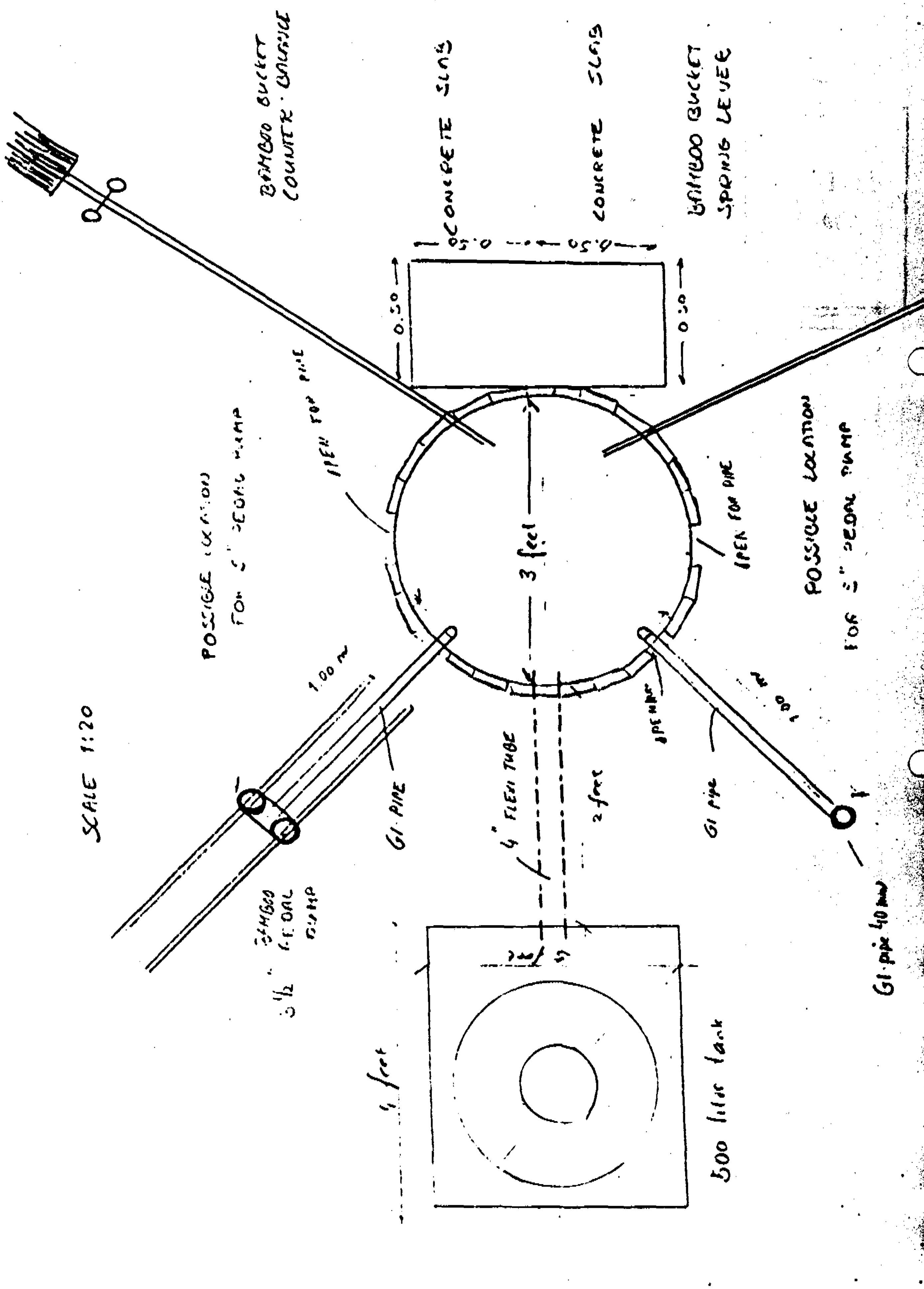
Male test person with counter balance system.

Annex B

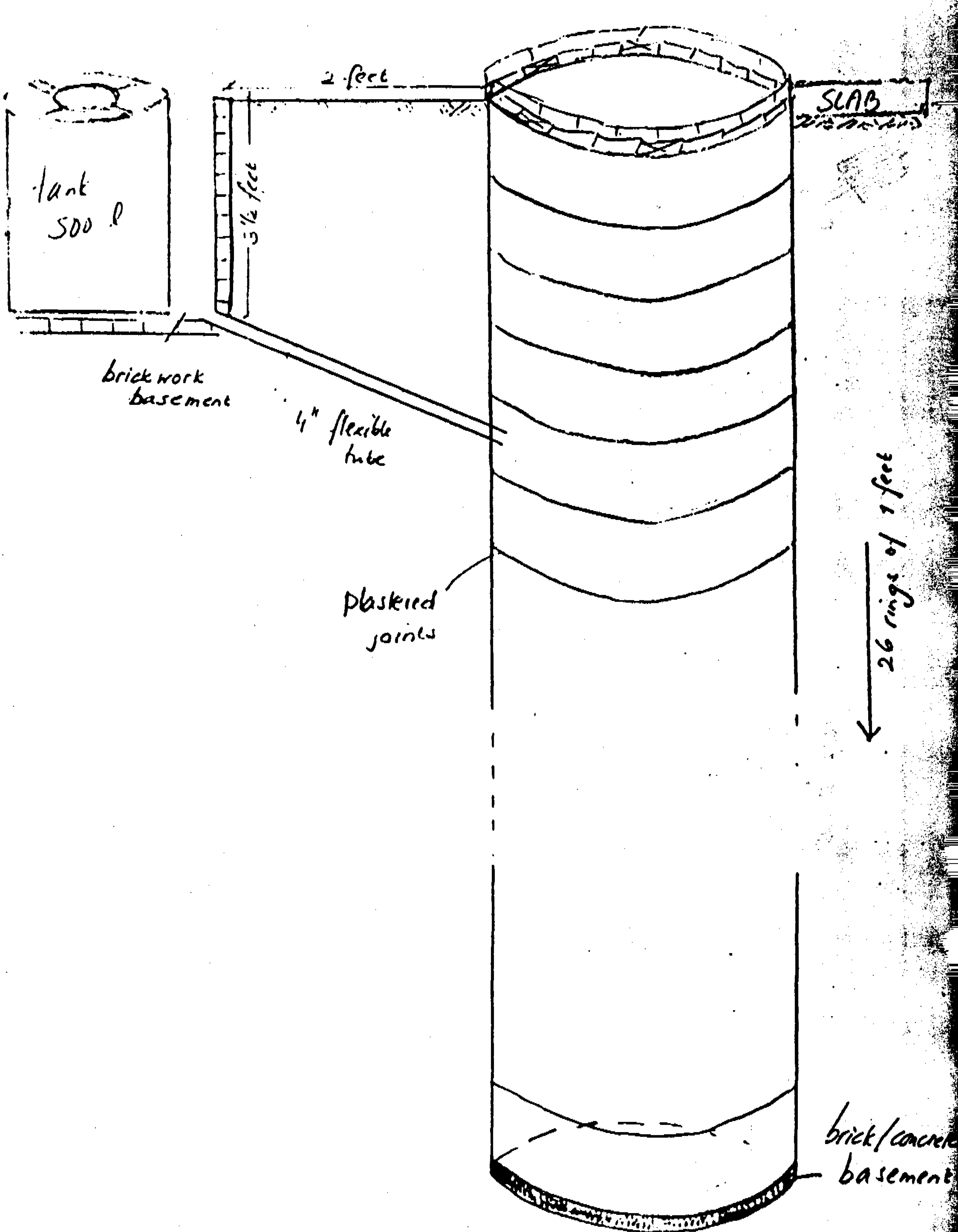
Design sketches

B.1 Plane view of closed well with pumps
B.2 Side view of closed well
B.3 Connection of pumps to well

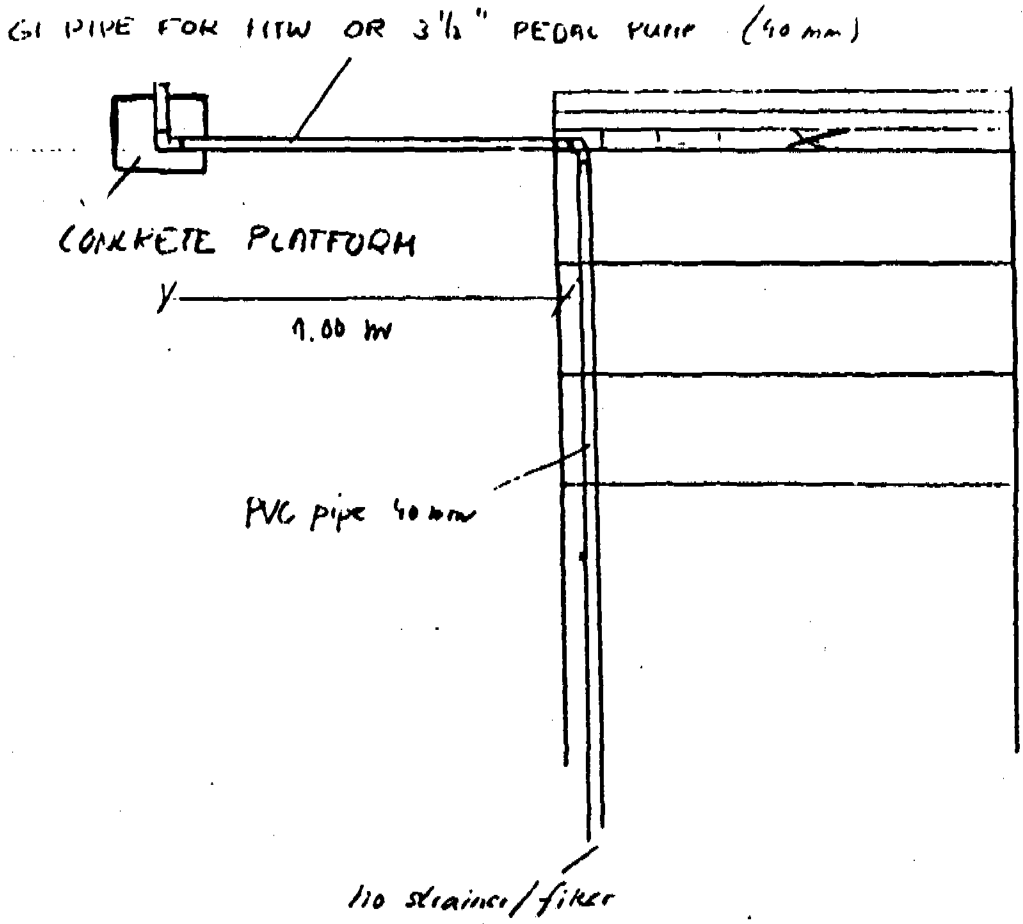
Annex B.1 - Design sketches: plane view of closed well with pumps



Annex B.2 - Design sketches: side view of closed well



Annex B.3 - Design sketches: connection of pumps to well



Annex C

Measurement forms

- C.1 - Discharge measurement form for cylinder pumps
- C.2 - Discharge measurement form for bucket pumps
- C.3 - Time schedule measurement form

Annex C.1 - Discharge measurement form for cylinder pumps

DISCHARGE MEASUREMENT FORM FOR CYLINDER PUMPS			
State of measurement:	1. preliminary 2. final		
Date:			
Day time:			
Done by:			
Type of pump:	1. handpump 2. pedal pump 3½" dia 3. pedal pump 5" dia		
Test person:	1. Bimul Roy .... male 2. Vijoya Roy .... female 3. Shamal Roy .... child		
Water depth when tank is half full:	.... metre below ground level		
Starting time of operation:			
Discharge measurements:	Start	Stop	Total
Filling time:			
Rest break:			
Filling time:			
Rest break:			
Filling time:			
Total filling time:			
Total break time:			
Volume of water in tank:			
Remarks:			

Annex C.2 - Discharge measurement form for bucket pumps

DISCHARGE MEASUREMENT FORM FOR BUCKET PUMPS		
Date:		
Day time:		
Done by:		
Type of pump:	1. bamboo counter-balance 2. bamboo spring lever	
Test person:	1. Bimul Roy .... male 2. Vijoya Roy .... female 3. Shamal Roy .... child	
Water depth:	.... metre below ground level	
Starting time of operation:		
Operation schedule for 1 hour:	No. of buckets	Avg. volume of bucket
Operation time:		
Rest break:		
Operation time:		
Rest break:		
Operation time:		
Total operation time/hour:		
Total break time/hour:		
Remarks:		

Annex C.3 - Time schedule measurement form

TIME SCHEDULING MEASUREMENT FORM			
Date:			
Day time:			
Done by:			
Type of pump:	1. handpump 2. pedal pump 3½" 3. pedal pump 5" 4. bamboo counter-balance 5. bamboo spring lever		
Test person:	1. Bimul Roy .... male 2. Vijoya Roy .... female 3. Shamal Roy .... child		
Water depth:	.... metre below ground level		
Starting time of operation:			
Operation schedule for 1 hour:	**Start**	**Stop**	**Total**
Operation time:			
Rest break:			
Operation time:			
Rest break:			
Operation time:			
Total operation time/hour:			
Total break time/hour:			
Remarks:			

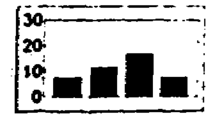
Annex D
Results of testing

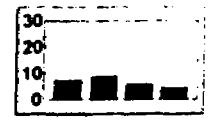
D.1 Data of 8-hour testing

MANUAL PUMP TESTING TOTAL RESULTS

TESTPERSON female

DEPTH	PUMP-TYPE	FLOW RATE MEASUREMENTS 1	2	3	4	5	6	7	8	average	BREAK TIME MEASUREMENTS total time	breaks	avg time	DAILY CAPACITY FOR 8 HRS capacity
2.5 m	*handpump*	0.49	0.46	0.46	0.45	0.55	0.48	0.59	0.48	0.50 l/s	0 sec	0 no.	- sec	14.3 m3/d
	pedal 3.5" bamboo	0.51	0.49	0.50	0.52	0.54	0.53	0.50	0.50	0.51 l/s	0 sec	0 no.	- sec	14.7 m3/d
	pedal 5" steel	0.79	0.74	0.74	0.71	0.77	0.65	0.66	1.10	0.77 l/s	922 sec	2 no.	461 sec	21.5 m3/d
	counterbalance	0.50	0.51	0.45	0.38	0.44	0.42			0.45 l/s	2100 sec	4 no.	525 sec	12.0 m3/d
5 m	*handpump*	0.28	0.28	0.38	0.32	0.27	0.28	0.27	0.28	0.30 l/s	2245 sec	6 no.	374 sec	7.8 m3/d
	pedal 3.5" bamboo	0.39	0.40	0.40	0.47	0.42	0.44	0.36	0.37	0.41 l/s	0 sec	0 no.	- sec	11.7 m3/d
	pedal 5" steel	0.66	0.62	0.57	0.56	0.62	0.58	0.54	0.57	0.59 l/s	0 sec	0 no.	- sec	17.0 m3/d
	counterbalance	0.35	0.30	0.27	0.29	0.24	0.27			0.29 l/s	2100 sec	4 no.	525 sec	7.7 m3/d
7 m	*handpump*	0.28	0.28	0.28	0.27	0.29	0.25	0.24	0.26	0.27 l/s	1068 sec	3 no.	356 sec	7.5 m3/d
	pedal 3.5" bamboo	0.35	0.32	0.30	0.31	0.35	0.30	0.30	0.31	0.32 l/s	666 sec	2 no.	333 sec	8.9 m3/d
	pedal 5" steel	0.20	0.18	0.24	0.22	0.21	0.24	0.21	0.24	0.22 l/s	1107 sec	3 no.	369 sec	6.0 m3/d
	counterbalance	0.17	0.17	0.17	0.19	0.17				0.17 l/s	1620 sec	3 no.	540 sec	4.7 m3/d





TESTPERSON child

DEPTH	PUMP-TYPE	FLOW RATE MEASUREMENTS 1	2	3	4	5	6	7	8	average	BREAK TIME MEASUREMENTS total time	breaks	avg time	DAILY CAPACITY FOR 8 HRS capacity
2.5 m	*handpump*	0.33	0.34	0.31	0.31	0.29	0.42	0.35	0.32	0.33 l/s	2025 sec	2 no.	1013 sec	8.9 m3/d
	pedal 3.5" bamboo	0.47	0.44	0.50	0.51	0.50	0.45	0.60	0.51	0.50 l/s	156 sec	2 no.	78 sec	14.3 m3/d
	pedal 5" steel	0.91	0.85	0.90	0.95	1.00	0.76	1.11	1.02	0.94 l/s	0 sec	0 no.	- sec	27.0 m3/d
	counterbalance	0.51	0.45	0.40	0.39	0.38	0.32			0.41 l/s	2100 sec	5 no.	420 sec	10.9 m3/d
5 m	*handpump*	0.26	0.28	0.24	0.21	0.23	0.24	0.25	0.25	0.25 l/s	899 sec	2 no.	450 sec	6.8 m3/d
	pedal 3.5" bamboo	0.47	0.46	0.41	0.40	0.44	0.43	0.42	0.48	0.44 l/s	0 sec	0 no.	- sec	12.6 m3/d
	pedal 5" steel	0.42	0.35	0.36	0.38	0.41	0.38	0.35	0.37	0.38 l/s	0 sec	0 no.	- sec	10.9 m3/d
	counterbalance	0.27	0.28	0.28	0.29	0.28	0.19	0.24		0.26 l/s	2280 sec	5 no.	456 sec	6.9 m3/d
7 m	*handpump*	0.19	0.17	0.19	0.20	0.18	0.21	0.19	0.22	0.19 l/s	746 sec	2 no.	373 sec	5.4 m3/d
	pedal 3.5" bamboo	0.23	0.22	0.20	0.18	0.23	0.23	0.23	0.20	0.22 l/s	774 sec	2 no.	387 sec	6.0 m3/d
	pedal 5" steel	0.25	0.20	0.21	0.23	0.24	0.19	0.17	0.18	0.21 l/s	1380 sec	4 no.	345 sec	5.7 m3/d
	counterbalance	0.15	0.16	0.18	0.17	0.18	0.16			0.17 l/s	1320 sec	4 no.	330 sec	4.6 m3/d