Epidemiology

Water & Sanitation

The Rope and Washer Pump

Compilation of articles related to epidemiology and water & sanitation which composed the scientific impulse for the later development and introduction of the rope and washer pump.

Bombas de Mecate S.A.
Division Technology Transfer
Apartado Postal 3352
Fax: 00-505-2784045
E-mail: sdc-agua@ibw.com.ni
Managua, Nicaragua.

Produced in cooperation with the National Drinking Water Institute (INAA) and the Swiss Development Cooperation (SDC Central America, COSUDE).

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INTRODUCTION

In this document a series of articles are inserted related to water & sanitation and epidemiology of the rural population in the municipality in Nicaragua where later the introduction of the rope pump started as a hardware solution to the problems encountered.

These studies justified and still justify the development and introduction of the rope pump as it is now a days widely known in Nicaragua and other countries.

Policies on the introduction of hand-pumps go together with technical and managerial discussions in which however knowledge on the current water & sanitation and epidemiological situation is to be considered indispensable in order to make an estimate on the cost effectiveness of such a policy.

Each article inserted describes in some way the daily living situation of the rural population, how it can be influenced or how this influences in their water & sanitation situation.

The last five articles are related to the introduction of the rope pump in Nicaragua, as a hardware solution to the epidemiological problems encountered, and the evaluation of the experiences with this rope pump in Nicaragua by IRC in march 1995.

The next pages present a small summary of the most relevant results of each of the articles. The articles are included with exception of the IRC evaluation of the rope pump of which the executive summary and references are included.

This document has been prepared for distribution within the Project "Technology Transfer of the Rope Pump Technology". The Governments of the Republics of Nicaragua and Switzerland (through COSUDE) signed a Bilateral Agreement for a period of three years to be executed by the national drinking water institute (INAA). Within this agreement important support is foreseen for the technology transfer of the rope pump. The Division Technology Transfer of Rope Pumps Ltd is in Charge of the execution of these activities.

CONTENTS

GENERAL INFORMATION ON THE ZONE.

The study site Villa Carlos Fonseca is a rural municipality on the Pacific lowlands at about 30 km from Managua, the capital of Nicaragua. Within its area of 500 square kilometers there are approximately 30.000 (1990) inhabitants distributed amongst 35 communities. A census in the municipality showed a total of 1200 handdug wells, which means one handdug well on each 25 persons. The depth of the wells is normally in the range of 8 to 25 meters although deeper wells up to a hundred meters can be found. The inserted articles are all related to this zone.

I) Sandiford P, Gorter AC, Davey Smith G and Pauw JPC, Determinants of drinking water quality in rural Nicaragua, *Epidemiology and Infection* 1989; 102:429-438.

153 water samples were examined for the presence of faecal coliforms during both wet and dry periods. A population-based survey was made on a random sample of the households on record with the Ministry of Internal Commerce, the most up to date census available.

Table: Geometric mean faecal coliform counts by water source for each weather period.

Water source	Population served %	Wet Period	Dry Period
Rivers and streams	2.5	14.700	11.100
Unprotected wells and springs	26.3	15.250	179
Protected bucket wells	52.5	4.300	1.410
Protected wells with pumps	2.0	No samples taken	22
Public standpipes	1.7	19	11
House connections.	15	2	0

- More then 80 % of the population depends on an extremely contaminated water source.
- Unprotected wells and springs deliver in the dry season relative clean water while they are extremely polluted in the wet season.
- A mean of 2.2 families per source or well.

In this article the discussion is reopened on water-borne and water washed transmission. Diarrhoea, like all faecal-oral diseases, can be transmitted by both water-borne or water-washed mechanisms. Water-borne transmission occurs when the pathogen is in water that is drunk by a person or animal which may then become infected. Improvements in drinking water quality will reduce water-borne transmission. In water-washed transmission, domestic and personal hygiene plays a key role and therefore disease is prevented by increasing the quantity of water used for hygiene purposes, irrespective of the quality of that water. It is still not known which of these transmission mechanisms is more important for diarrhoea. Although most work suggests that improvements in water quantity are more likely to reduce the incidence of diarrhoea than improvements in microbiological quality, at least one study has shown a greater benefit from water quality improvements, especially in younger children.
It is now becoming clear that it is beyond the economic ability of most developing nations to provide sophisticated water supplies to entire populations.

II) Sandiford P, Gorter AC, Orozco JG and Pauw JPC, Determinants of domestic water use in rural Nicaragua, *Journal of Tropical Medicine and Hygiene* 1990; 93:383-389.

An analysis was performed of water consumption estimates from 1020 different households in Nicaragua, collected between may 1986 and december 1988.

Some of the conclusions:

Distance to source 1000 m => 10 m	20 % more water
Mother's level of schooling (6 years)	17 % more water
Father's level of schooling (6 years)	12 % more water

Water consumption was in the range of 15 to 30 liters per person per day.
Other factors such as, ownership of cattle, type of flooring in the house, do have some influence but not significant.

Increasing domestic water use in many settings is believed to be at least as effective in preventing diarrhoea morbidity and mortality in children as improving the microbiological quality of drinking water. In fact some of the spectacular failures of water supply interventions to improve child health and survival can be attributed to the absence of any significant increase in domestic water consumption by the intended beneficiaries.

III) Gorter AC, Sandiford P, Davey Smith G and Pauw JPC, Water supply, sanitation and diarrhoeal disease in Nicaragua: Results from a case-control study, *International Journal of Epidemiology* 1991; 20(2):527-533.

A case-control study of risk factors for child diarrhoeal disease was undertaken. Some 1229 children in the age of under-five were matched with an equal number of children of the same age presenting with other illnesses unrelated to water and sanitation.

Some of the conclusions:
Only water availability, the level of maternal education and the number of under five year old children living in the house were significantly associated with diarrhoea morbidity. There was no indication that the presence of a latrine or the type of water source (a reasonable proxy for bacteriological water quality), were risk factors for diarrhoea.

- Children in houses with water sources 500 metres away had 34 % more diarrhoea than in houses adjacent to their water supply.
- Children of women with primary school education had 18 % less diarrhoea than those of women with no formal schooling. The children of women with secondary school suffered 26 % less diarrhoea. There was no correlation between the incidence of diarrhoea and father's level of education. The rate of diarrhoea in houses with more than four children under five years was 70 % higher than in houses with just one under five year old.
- Relative incidence rate of diarrhoea is in the range of 1 to 3 a year.

The results presented support the notion that access to water is an important risk factor for diarrhoea. Most studies have not attempted to obtain separate estimates for the impact of water quality and water availability, (indeed the two are often highly correlated making this difficult to achieve in practice), but there are two review papers which divide health impact evaluations of water supply into those where improvements were predominantly in water quality, and those where the improvement was mainly in water availability. The first of these found a median percentage reduction in diarrhoea incidence for studies where the improvement was mainly in water availability was 25% compared with 16% for those studies where the improvement was predominantly in water quality. The second paper which reviewed many of the same studies, showed that the highest proportion of studies reporting a positive impact were those where the intervention resulted in increased water availability. Our findings are consistent with these results as it was found that high rates of diarrhoea occur in the houses with water sources mare than 500 metres away.

IV) Well Water study, A consultancy undertaken for COWATER International INC, By Dr. P Sandiford and Dr A Gorter, Liverpool Associates in Tropical Health, september 1992

* Literature review to identify any studies which have measured the health impact of moderate reductions in levels of faecal coliform contamination of wells, waterholes or surface water.

* Literature review to identify which interventions (both in terms of hardware and

community education) are most likely to bring about such reductions in the level of contamination of these sources.

A total of 73 studies were reviewed.

Summary of part 1.

Although there have been numerous health impact studies of water supply and sanitation, very few have looked at the potential health impact of moderate reductions in the faecal contamination of water sources and many of the studies which have been undertaken have suffered from serious methodological flaws. There is however, a reasonable consensus that water quality improvements do not generally have as great an impact on health as providing excreta disposal facilities or interventions which increase water availability. From the small amount of relevant literature that is available, and taking into account the studies of major water quality improvements, it would appear that a water quality intervention is more likely to have a positive health impact through reducing contamination from very high levels to moderate levels than from moderate levels to low levels. However, one should not expect more than a 15-20% reduction in diarrhoeal disease morbidity. It should be noted too, that such improvements are likely to be more effective where many families share a water source, than where the water source is used by just one or two households.

Summary of Part 2

While the theory of water contamination is well developed, there is a general lack of empirical support for the effectiveness of the numerous potential interventions to improve microbiological water quality. The few published studies which are available suggest that upgrading wells through improvements such as a windlass, bucket cage, drainage system, lining, headwall and cover are effective when provided as a combination. It is not known however, how effective individual components of the upgrading are in reducing contamination nor whether their combined effect is greater or smaller than the sum of the separate effects. The provision of pumps seems to be useful in settings with gross contamination, and tubewells are consistently cleaner than hand dug wells. There is a need for a rigorous assessment of the potential impact of 'software' interventions such as health education on well water quality.

Part 3 is not included.

V) Gorter AC, Alberts JH, Gago JF and Sandiford P, A randomized trial of the impact of rope-pumps on water quality, *Journal of Tropical Medicine and Hygiene*, 1993; 98: 247-255.

Thirty wells in 14 different communities were selected for the study and randomly assigned to three groups of ten wells each: one group to be fitted with a rope-pump and concrete cover, a second group with only a rope pump and the third group not receiving a rope-pump until the end of the study.

The data are adjusted for the parameters used in the water quality model; method of extraction, rainfall, number of families/well, distance well to nearest kitchen and amount of water extracted.

A reduction of 62 % was seen in the geometric mean of the coliform contamination of the well water as a result of the installation of a rope-pump in the intervention group which was originally equipped with a rope and bucket; no reduction was seen in the group originally equipped with a windlass.

No difference was shown in faecal contamination for rope-pumps with or without a concrete cover.

An important relation between the contamination of the well and the distance of the well to the nearest kitchen is shown. This information can be used as a design parameter without additional costs in water and sanitation infrastructure projects.

Impact of the distance of the well to the nearest kitchen on the level of water contamination of the well.

Distance well/ kitchen (varas)	Number of samples	GM FC/100ml
1 - 9	77	260
10 - 19	87	200
20 - 29	26	176
> 30	64	143

(data corrected for other influences.)

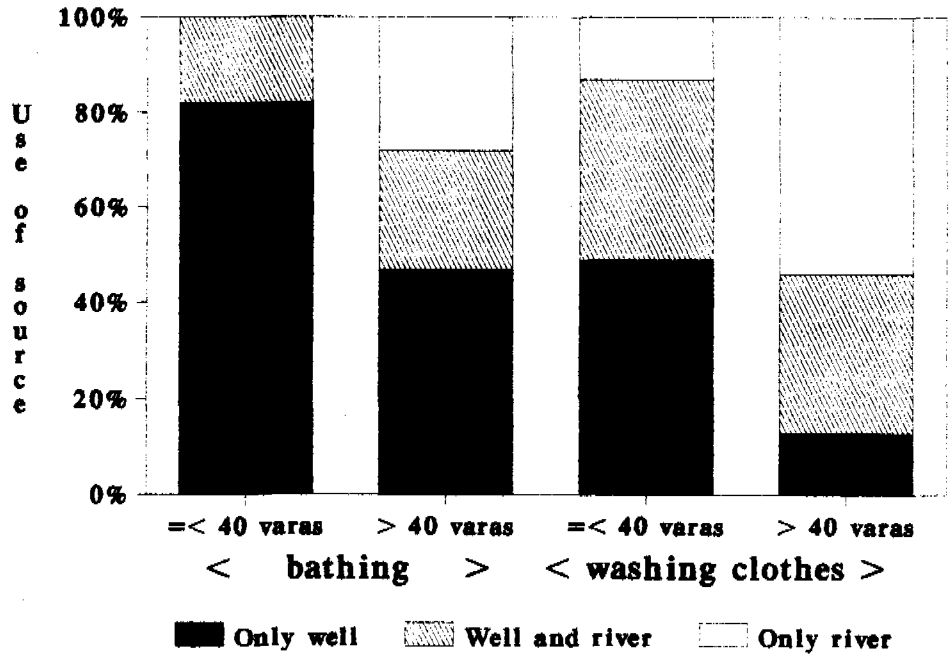
When assigning the faecal contamination of the bucket wells to groups of very high, moderate and low levels of contamination, all counts at the very high level are eliminated after intervention and part of the moderate counts is reduced to the low level.

Proportion of very high, moderate and low readings before and after intervention in the group originally equipped with rope and bucket.

	Low level 0 - 100 FC/100ml	Moderate level 101 - 1000 FC/100ml	Very high level > 1000 FC/100ml
Before	12 %	80 %	8 %
After	31 %	69 %	0 %

The figure on the choice of water source for bathing or washing clothes in relation to the distance to the well is included as the rivers are generally highly contaminated. (article I) The use of rivers for bathing and washing clothes should be prevented. These customs can be influenced by improving the water availability.

Figure: Choice of water source for bathing or washing clothes in relation to the distance to the well.



VI) Experiences at Rope Pump Ltd with a handdug well with concrete well-cover and drainage apron at one meter distance of a drilled well. Both with a rope pump installed.

Handdug well:
Concrete cover.
Water cannot drip back into the well.
Well lining up to two meters depth.
Concrete drainage apron.
Rope-pump installed.
Water depth about 10 meters.
Daily high turn-over of water content.
Contamination in the range of 30 to 100 Faecal Coliforms per 100 milliliter.

Drilled Well:
Drilled well made through persecution.
Casing of 4 inch PVC. (Tubewell).
Casing at the top sealed with a PVC cover.
Water inlet through small holes in the last meter of the casing at the bottom of the well

Sealed around with concrete.
Rope-pump installed.
Water depth the same at about 10 meters at one meter distance from the handdug well.
Almost exclusively used for drinking-water.
Contamination in the range of 0 to 3 Faecal Coliforms per 100 milliliter.

Similar results of none or very low contamination were found in much deeper drilled wells with rope pumps installed.

Conclusions:

* Ground water at this depth under these circumstances is not, or almost not, contaminated.
* The rope-pump as technical device does not, or almost not, contaminate the water.
* Causes of low level contamination (range up to 100 FC/100ml) must be sought in small animals such as ants, wood-louses or black-beetles, which commonly can be found around handdug wells. Dripping water around well-lining still cannot be excluded completely as cause of contamination.
* At places where hand-drilling or persecution can be performed easily it is an easy and cheap technology to separate surface water from ground water to prevent contamination of family wells. Primarily in sandy or clay areas.
* In Nicaragua the rope pump is already used at community level in relatively expensive drilled wells up to 50 meters depth.

VII) Sandiford P, Alberts H, Orozco JG and Gorter A, The Nicaraguan rope pump, *Waterlines* 1993; 11(3):27-30.

History on the introduction of the rope pump in Nicaragua from 1983 up to 1992. Recalls how an Appropriate Technology Research Centre started the introduction of the rope pump in 1983. War and institutional politics plagued this initiative. The Environmental Engineering Programme of the National University restarted this initiative in 1987 making significant advances. In the initial stage a number of technical improvements were made to the prototype pumps, effectively transforming them from a 'Heath Robinson' endeavor into a truly appropriate technology, although still lacking in important respects. Philosophical differences led to the complete collapse of the relationship between the producing Co-operative and the Environmental Engineering Programme. Two promoters or fieldworkers of the former programme, started in february 1990, what was later to be known in Nicaragua as Rope Pump Ltd. (Bombas de Mecate S.A.)
The drawings in this article do not represent the actual technological state of the art.

VIII) Alberts H, Meza R, Solís D and Rodríguez M, How the rope pump won in Nicaragua, *Waterlines* 1993; 12(3):3-5

Describes the history on the technological and company development and its constraints of the rope pump in Nicaragua. Contains especially technical and economic data on the initial phase. Information on technological development and very important the promotional campaigns through agriculture fairs, radio and newspapers.

IX) Evaluation report Nicaraguan experiences with the rope pump. Evaluation undertaken by the IRC (International Water and Sanitation Centre, WHO collaborating Centre) The Netherlands, September 1995.

Executive summary and references included.

X) *Water Newsletter* ; Number 243, August 1996: 1-2.
Lift Water by Rope Pumps.

Article which presents state of the art, August 1996. Makes reference to the support of COSUDE to the international technology transfer of the rope pump.

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Determinants of drinking water quality in rural Nicaragua

P. SANDIFORD[1], A. C. GORTER[2], G. DAVEY SMITH[3] AND J. P. C. PAUW[4]

[1] *Instituto Nicaraguense de Acueductos y Alcantarillados, Managua, Nicaragua*
[2] *Centro de Investigaciones y Estudios de la Salud, Managua, Nicaragua*
[3] *Department of Community Medicine, University College, London*
[4] *Departamento de Higiene Ambiental, Universidad Nacional de Ingeneria, Managua, Nicaragua*

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SUMMARY

One hundred and fifty-three water samples from rural Nicaragua were examined for the presence of faecal coliforms during both wet and dry periods. A linear model was fitted by analysis of covariance with the logarithm of the faecal coliform count as the dependant variable. As expected, traditional water sources were grossly contaminated at all times whereas piped water sources were much cleaner. Hand-dug protected wells had significantly higher levels of faecal contamination than unprotected riverside wells and springs during the dry season. The possible reasons for this unexpected finding are discussed. A close association between rainfall and faecal contamination was demonstrated but the effect of rainfall depended on the type of water source. An association between water quality and the size of the community served by the source was also detected. The finding that stored water was usually more contaminated than fresh water samples is consistent with the results from other studies. Since it is unusual for water quality to be inversely correlated wth accessibility, this study site would be suitable for investigating the relative importance of water-borne versus water-washed transmission mechanisms in childhood diarrhoea.

INTRODUCTION

It is generally believed that the use of inadequate water supplies relates closely to the high incidence of childhood diarrhoea in most developing countries, in spite of the difficulties that have been encountered in measuring this relationship (Blum & Feachem, 1983; Esrey & Habicht, 1986). Diarrhoea, like all faecal–oral diseases, can be transmitted by both water-borne or water-washed mechanisms (Cairncross & Feachem, 1983). Water-borne transmission occurs when the pathogen is in water that is drunk by a person or animal which may then become infected. Improvements in drinking water quality will reduce water-borne transmission. In water-washed tansmission, domestic and personal hygiene plays a key role and therefore disease is prevented by increasing the quantity of water used for

Correspondence: Dr G. Davey Smith, Department of Community Medicine, 66-72 Gower St, London WC1E 6AE.

hygienic purposes, irrespective of the quality of that water (Cairncross & Feachem, 1983). It is still not known which of these transmission mechanisms is more important for diarrhoea (Feachem *et al.* 1978). Although most work suggests that improvements in water quantity are more likely to reduce the incidence of diarrhoea than improvements in microbiological quality (Esrey & Habicht, 1986; Briscoe, 1978; Esrey *et al.* 1985; Freij *et al.* 1978; Schliessman, 1959), at least one study has shown a greater benefit from water quality improvements, especially in younger children (Herbert, 1984).

The relative importance of these two transmission mechanisms has major implications in the design and construction of rural water supplies. Although water supply projects often increase both the quality and quantity of water used, such interventions are usually very expensive. It is now becoming clear that it is beyond the economic ability of most developing nations to provide sophisticated water supplies to entire populations (Schneider *et al.* 1978; Walsh & Warren, 1979).

On the other hand, there are several relatively inexpensive interventions which might independently improve either water quality (e.g. simple chlorinators or filtration systems) or increase water consumption (e.g. hand pumps and well digging). This paper presents the results of a study of the microbiological quality of drinking water sources in rural Nicaragua which will be used in the analysis of a case-control study of the relationship between water quality, water accessibility and childhood diarrhoea.

MATERIALS AND METHODS

The study site was Villa Carlos Fonseca, a rural municipality on the Pacific coastal lowlands with a population of approximately 20000 spread amongst 35 communities. A population-based survey of the zone was made from a random sample (stratified by community) of 244 (6·7%) of the households on record with the Ministry of Internal Commerce whose consumer census is the most up-to-date population census available. Ministry officials estimate its completeness to be approximately 95%. Each of the houses selected was visited by a trained interviewer who interviewed the female head of household. The water supply for the household was ascertained and inspected. It was thereby possible to classify the different types of water source and to estimate the proportion of the population using each of them.

Sites for monthly water-sampling were chosen at random for each type of water-supply identified in the population-based survey. Additional water samples were also randomly selected at different times to provide sufficient statistical power to test diverse hypotheses. Water samples were collected in sterile glass bottles and transported to the laboratory in a cold box containing freezer packs. In all cases, analysis by the multiple tube method was commenced within 8 h of collection. The glassware and media were sterilized the day before in an autoclave at 121 °C for 15 min. Five sets of five tubes were inoculated with 10, 1, 0·1, 0·01 and 0·001 ml of each sample. Samples were incubated first in lauryl tryptose broth (Gibco Laboratories no. 28300) for 24 h at 37 °C in a warm-air incubator. Positive tubes were confirmed by inoculating a further set of tubes containing *E. coli* medium

Table 1. *Population and water sample distribution by water source*

Water source	Population served (%)	No. of sources tested	No. of samples taken: Wet period	Dry period	Total
Rivers or streams	2·5	5	3	16	19
Unprotected wells and springs	26·3	13	6	25	31
Protected bucket wells	52·5	15	5	37	42
Protected wells with pumps	2·0	7	0	11	11
Public standpipes	1·7	3	3	21	24
House connections	15·0	7	3	23	26
Total	100	50	20	133	153

Table 2. *Parameters included in the water quality model*

Variable name (and type)	Range of values
Main effects	
Type of water source*** (categorical)	1 = rivers/streams 2 = unprotected wells 3 = protected bucket wells 4 = protected wells with pumps 5 = public standpipes 6 = house connections
Rainfall period** (dummy)	0 = dry period (July–December) 1 = wet period (mid-May–June)
Community size* (dummy)	0 = small (≤ 1500 inhabitants) 1 = large (> 1500 inhabitants)
Storage*** (dummy)	0 = fresh sample 1 = sample from storage vessel
Interactions	
Type of water source by rainfall**	

*$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}0001$.

Table 3. *Geometric mean faecal coliform counts by water source for each weather period*

Water source*	Weather period: Wet period	Dry period
Rivers and streams	14700	11100
Unprotected wells and springs	15250	179
Protected bucked wells	4300	1410
Protected wells with pumps	No samples taken	22
Public standpipes	19	11
House connections	2	0

* Does not include stored water samples

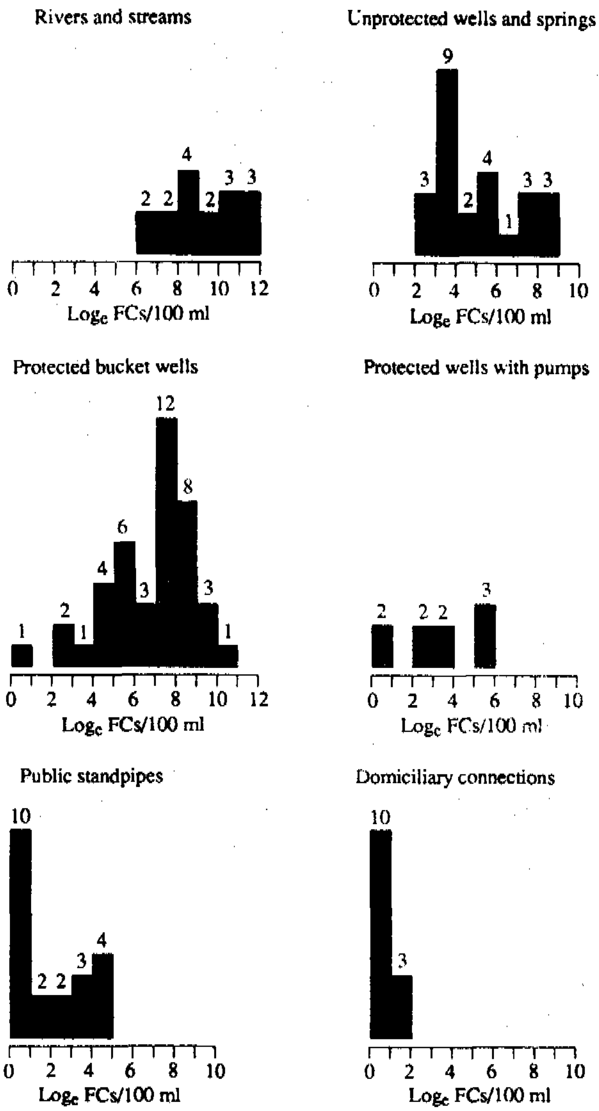

Fig. 1(*a*). Histograms of geometric mean faecal coliform counts by water source for the dry period.

(Difco Laboratories no. 0314-01-0) and incubating these at 44·5 °C in a water-bath for an additional 24 h. Most probable number faecal coliform (FC) counts were calculated from the proportion of tubes at each dilution confirmed as positive, that is gas-producing (APHA, 1981).

A linear model was fitted by analysis of covariance with the natural logarithm of the FC counts as the dependent variable. The independent variables considered were: type of water source, recent rainfall, time of sampling (morning or afternoon), presence of a windlass on protected wells, whether the sample was 'fresh' or stored and size of the community from which the sample was taken. The latter was considered large if communities were of greater than 1500 inhabitants.

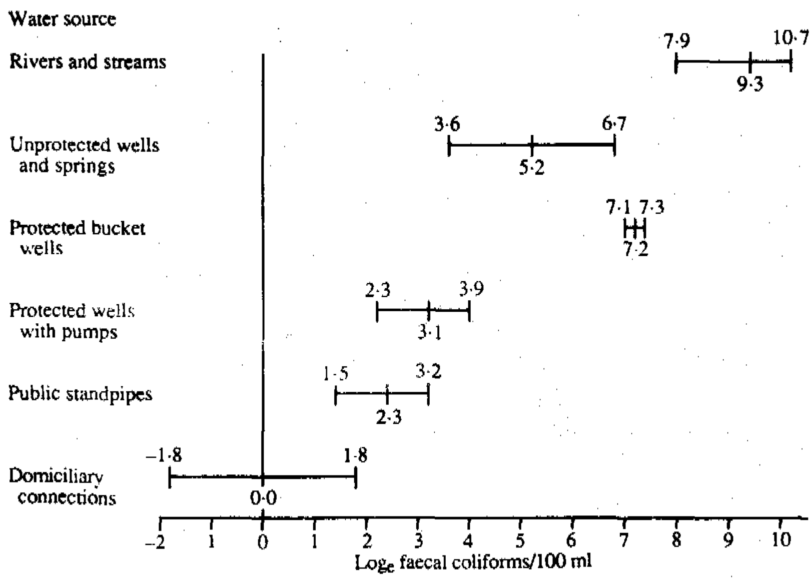

Fig. 1(*b*). Geometric mean faecal coliform counts with 95% confidence limits by water source for the dry period. N.B. Does not include wet period or stored water samples.

It was thought that this might be an adequate surrogate for population density, especially since the houses in the communities of this size were arranged in street blocks whereas smaller communities consisted of a single main road with occasional side streets. Pairwise comparisons were made using the Tukey–Kramer studentized range test to control for type I experimentwise error (Einot & Gabriel, 1975).

RESULTS

Trained field-workers were successful in interviewing female heads of household at 240 (98%) of the homes selected. Water supplies were classified into five main types: domiciliary connections, public standpipes, protected wells, unprotected wells and springs, and rivers or streams. The domiciliary connections in one area functioned for less than 4 h per day, but the rest provided water virtually all day and were quite reliable. All public piped water came from boreholes, there being three different boreholes providing water to standpipes and another two different boreholes supplying the networks of domiciliary connections. The protected wells were hand-dug, generally to a depth of about 4 m, and were surrounded by a precast concrete headwall. As a rule they were partially lined by stone which was sometimes joined to the headwall by mortar. Water was drawn in a bucket on a rope supported by a crossbar and pulley. Many were roofed and some had a windlass, but none incorporated a drainage apron. They were usually privately owned and sited in the yards of peoples homes. Springs and unprotected wells were shallow holes in the ground usually adjacent to rivers in which water accumulated either by filtering up from below or by seepage from above (or both). They were

Table 4. *Geometric mean faecal coliform counts by water source and community size*

Water source*	Community size†	
	Large	Small
Rivers and streams	27 800	5760
Unprotected wells and springs	767	83
Protected bucked wells	1450	977
Protected wells with pumps	16	39
Public standpipes	No samples taken	7
House connections	0	5

† There were 3 communities considered to be large and 16 communities classified as small.
* Does not include wet period or stored water samples.

often carved out from sandstone. As the springs and unprotected wells formed an indistinguishable continuum they will both be referred to as unprotected wells. None of the water supplies were treated.

The proportion of houses with each type of water source is shown in Table 1 together with the number of water samples taken from each. The number of samples taken during the wet period is low due to the drought in 1986 which greatly reduced the length of the wet season.

The complete model fitted is shown in Table 2, together with the significance level for each variable. Only those interactions found to be statistically significant are shown. In fitting the model, each monthly measurement of a single source is considered as an independent sample as it was noted that there was almost as much water quality variation for repeated samples from the same site as there was for different samples from different sites.

Geometric mean FC counts of each water source for the wet and dry periods are shown in Table 3. All mean values quoted are 'least squares means' which adjust the estimates to allow for the unbalanced design. There were not enough samples taken during the wet period to permit pairwise comparisons but the quality of piped water is obviously much better than that of traditional sources. It would be interesting to obtain sufficient samples during this period to test whether protected wells are less contaminated than the unprotected sources. For the dry period, the distribution of FC counts by water source is plotted in Fig. 1*a*. Pairwise comparisons were made using the Tukey–Kramer studentized range test (Fig. 1*b*).

The nature of the water source/rainfall interaction can be seen in Table 3. While the quality of water drawn from springs and unprotected wells improves strikingly in the dry period, the quality of other sources did not change greatly. Unprotected wells and springs seem to be more contaminated than protected wells during the wet period, but they are significantly less contaminated during the dry period.

Table 4 shows for each type of water source how the quality depends on the size of the community from which the water was sampled. The quality of piped water sources does not depend on the community size but it appears that the quality of traditional water sources does. In fact for piped water, quality seemed to improve in the larger communities but this difference is unlikely to be significant.

As indicated in Table 2, water stored in homes is significantly more contaminated than water drawn directly from the source. The geometric mean FC count of stored water from domiciliary connections was 94 compared with 0 for the unstored samples. There were not enough samples to determine how domestic storage affects water drawn from other sources.

Of the 42 samples taken from protected bucket wells, 6 were taken from wells incorporating a windlass. It was hypothesized that the presence of a windlass on a protected well would reduce the contamination since the rope does not drag on the ground. In fact, the (least squares) geometric mean FC count of those wells with a windlass was 1420 compared with 1100 for those without ($P = 0{\cdot}77$), though caution should be excercised in interpreting this result owing to the small number of samples from wells with a windlass.

DISCUSSION

In many ways this analysis confirms the results obtained from several other studies in that the quality of water was found to depend greatly on the type of water source from which it is drawn, the weather prior to the time of sampling, and whether it was taken directly from the source or from a storage vessel in the home (Freij *et al.* 1978; Schneider *et al.* 1978; Shiffman *et al.* 1978; Young & Briscoe. 1987; Muhammed & Morrison. 1975; Torun, 1982; Barrell & Rowland, 1979). It does not pretend to take into account all the variables that have been considered in other work (e.g. soil type, well diameter, depth, distance to the nearest latrine, etc.) and there are other variables which might affect the water quality of domestic wells which have not generally been considered in this type of study (e.g. literacy, presence of domestic animals, etc.).

As in other studies, there is a very high level of contamination in the traditional water sources. The unexpected finding was that protected domestic wells were significantly more contaminated than unprotected riverside wells and springs during the dry period. Most studies of rural water quality have found that protected sources are generally less polluted than unprotected sources. Tomkins *et al.* (1978) and Wright (1982) both found that protected wells were less contaminated than unprotected wells during the dry season. Isely (1978) and Lehmusluoto (1987) also both found protected springs to be less contaminated than unprotected springs though in the latter study the difference was not statistically significant. On the other hand in Nigeria Blum *et al.* (1987) found significantly lower faecal streptococci counts in ponds and unprotected springs than in traditional wells during the period of lower contamination, but it was not clear how well protected their 'traditional wells' were.

There are two possible explanations for the observed difference in water quality between the protected and the unprotected sources. One is that the protected wells are exposed to greater faecal contamination in spite of their protection. The other is that a structural difference tends to make the unprotected water sources less polluted during the dry period.

The first hypothesis is supported by the fact that protected wells in this part of Nicaragua are almost all privately owned and located close to houses where children and domestic animals defecate openly. Also, 72% of these wells are in homes with latrines although most of them are situated at least 10 m from the well (Sandiford *et al.* unpublished results). In contrast, the unprotected wells are usually dug beside rivers and streams 50–100 m from the nearest houses.

It would seem unlikely that a structural difference could explain why unprotected wells have lower FC counts during dry weather than protected wells. Protected wells all have parapets at least one metre high, they usually incorporate a crossbar and pulley, and often have a roof, a cover, and/or a windlass, while unprotected wells are much shallower and do not have parapets. One important feature of the unprotected well though, is the small volume of water which it holds (usually only 20–40 l). As each generally serves several families, the high demand for water creates a rapid turnover which would readily eliminate externally introduced contaminants. It has been observed that some families empty these wells and allow them to refill each time they collect water (Pauw *et al.* in preparation). The protected wells on the other hand, contain a much greater volume of water which is emptied by their owners only once or twice a year.

Though more research is needed to determine the relative importance of these two explanations the quality of water from protected wells does appear to be more variable than that from unprotected wells (Fig. 1*a*) suggesting that certain factors in the domestic environment may give rise to contamination. Not all protected wells had higher counts than unprotected wells.

It is notable that the presence of a windlass appeared to have no effect on the water quality of domestic wells. Those with an electric pump to extract the water were significantly less contaminated than those using a bucket and rope, in spite of being virtually identical in other respects. It is possible that much of the contamination of protected bucket wells originates from water spilt around the parapet seeping back into the well. Pumps which pipe water away from the well clearly avoid this problem. The complete absence of drainage aprons in the Nicaraguan wells studied makes them rather susceptible to this type of pollution (Cairncross & Feachem, 1983).

The poor quality of springs and unprotected wells during periods of rainfall is probably due to run-off into the wells. Similar problems have been noted with unprotected springs in other studies (Moore, de la Cruz & Vargas-Mendez, 1965; Barrell & Rowland, 1979). It would be interesting to investigate the impact of spring protection during the rainy periods. A modest drop in the quality of domestic well water was also noted with the rainfall which is consistent with other studies (Voelker & Heukelekian, 1960; Barrell & Rowland, 1979).

Community size was found to be significantly associated with water quality and this was particularly noticeable in the rivers, springs and unprotected wells. An association between water contamination and proximity to towns has previously been reported (Muhammed & Morrison, 1975; Bradley & Emurwon, 1968) but only for rivers and streams. It may be that the more families using a source, the greater the potential for contamination. In fact the mean number of houses using unprotected wells and springs in large communities is 4·2 compared with 2·9 in smaller communities (Sandiford & Gorter, unpublished results).

Community size did not seem to affect the quality of protected well water where an average of 2·2 families are served by each well in both small and large communities.

This study has shown that water quality in protected wells is not always better than that in unprotected wells, though the reasons are not entirely clear. More research is needed to determine the most cost-effective means of protecting hand-dug wells. If cheap but effective structural modifications to traditional water sources can be found, these may prove to be appropriate interventions for the prevention of water-borne illnesses.

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Determinants of domestic water use in rural Nicaragua

P. Sandiford,* A. C. Gorter,† J. G. Orozco† and J. P. Pauw†

**Department of International Community Health, Liverpool School of Tropical Medicine, Liverpool, UK and †Programa de Ingeneria Ambiental, Universidad Nacional de Ingeneria, Managua, Nicaragua*

Summary

In order to investigate the factors affecting domestic water use in rural areas of developing countries, an analysis was performed of water consumption estimates from 1029 different households in Nicaragua collected between May 1986 and December 1988. Eight of the 22 variables hypothesized to be related to per capita domestic water consumption, were included in the final multiple regression model. These were; household size, site of clothes washing, the type of water source, mother's and father's levels of schooling, distance to the water source, wealth, and ownership of cattle. According to this model, a decrease in the distance to the water source from 1000 to 10 m is associated with an increase in per capita water consumption of 20%. Similarly, families where the mother has 6 years of schooling use 17% more water than families where the mother has had no formal education. The same difference in the father's schooling is associated with 12% greater per capita water consumption. A better understanding of the factors affecting domestic water use is needed to improve the design of interventions aimed at reducing the transmission of water-washed disease in developing countries.

Introduction

It has now become apparent that the quantity of water used for the purposes of domestic and personal hygiene is an important factor in the control of diarrhoea (and possibly other faecal–oral diseases) (Esrey & Habicht 1986; Esrey *et al.* 1985; Victora *et al.* 1988; Sandiford 1989). Increasing domestic water use in many settings is believed to be at least as effective in preventing diarrhoea morbidity and mortality in children as improving the microbiological quality of drinking water (Cairncross 1987). In fact, some of the spectacular failures of water supply interventions to improve child health and survival can be attributed to the absence of any significant increase in domestic water consumption by the intended beneficiaries (Kawata 1978; Schliessman 1959).

There is therefore clearly a need to develop water supply and health promotion interventions which raise per capita domestic water consumption and/or increase the proportion of domestic water used for purposes of domestic and personal hygiene. A review of the published literature revealed a poverty of information on the factors related to domestic water use in rural areas of developing countries.

Given the well recognized public health importance of childhood diarrhoea in developing countries, such a gap in our knowledge is of some significance. This paper presents an investigation of the variables related to water consumption obtained from a large case-control study of diarrhoea performed in rural Nicaragua from May 1986 until December 1988. It is not intended to be a definitive study of all the possible factors which combine to determine behavioural patterns of water use. Rather, it is an exploratory analysis of certain correlates of rural domestic water use, with a view to contributing to the design of health promotion programmes which maximize the quantity of water used for domestic and personal hygiene, with or without structural improvements in rural water supplies.

Correspondence: P. Sandiford, Department of International Community Health, Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK.

Materials and methods

The study was carried out in Villa Carlos Fonseca, a rural municipality on the Pacific coastal plains of Nicaragua with a population of approximately 30 000. Children under the age of 5 years who presented with diarrhoea to health facilities in the study zone were matched by age and clinic to children presenting with non-diarrhoeal illnesses (mainly acute lower respiratory tract infections). A total of 1228 episodes of diarrhoea and 1228 control illnesses were recruited to the study. Trained interviewers collected data on a variety of factors from female heads of household at their homes. These included reported daily water consumption, the types of water source, distance from the house to the water source(s), the ownership of cattle and presence of domestic animals, the parents' occupations and levels of education, indicators of socioeconomic status, and household size including the proportion of inhabitants under the age of 5.

Water consumption estimates were not collected from houses with piped water as the precision of the data was likely to be low. Therefore water consumption figures were available for only 1962 of the 2456 interviews. The selection procedure used for the case-control study was such that children could be recruited on more than one occasion so some homes were visited more than once. The 1962 figures for water consumption were thus obtained from a total of 1455 separate interviews, of which 1029 were initial visits and 426 were repeat visits (after an interval of at least 3 months). The repeatability of the mothers' water consumption estimates was assessed by comparing the rates given at the initial visit with those obtained in the repeat interview. Only the first home visits were used in the analysis of the factors relating to domestic water consumption.

Per capita daily domestic water consumption (PCWC) was obtained by dividing total daily water consumption by the number of household inhabitants. The total water consumption was calculated by the computer program for data entry which multiplied the volume of each water container by the number of times it was filled in a day. The fact that there is little variety in the bucket size used for water collection in Villa Carlos Fonseca made it a simple matter for field workers to estimate the volumes. The result was then tested for association with 22 factors which could potentially influence it, using a linear regression model.

Following the recommendations of Maclure and Willett (1987), the measurement of repeatability for the continuous and ordinal scale variables was evaluated by the intraclass (i.e. within household) correlation coefficient. For indicator variables, repeatability was measured using the kappa score which takes into account the degree of concordance to be expected by chance alone (Fleiss 1981). Negative kappa scores indicate less concordance than would be expected by chance. Positive kappa scores suggest better concordance than that expected by chance, with kappa scores of 1 representing perfect agreement between the repeated measurements. For dichotomous variables, it is generally accepted that values below 0.40 imply poor repeatability, 0.40 to 0.75 good repeatability, and values above 0.75 indicate excellent repeatability (Fleiss 1981). It is important to bear in mind that kappa scores for variables with more than two categories tend to be lower than those for dichotomies. In the statistical analysis, the natural logarithm of daily per capita domestic water consumption log (PCWC) was used as the dependent variable in fitting a linear model by analysis of covariance. The transformation was performed in order to make the variance of log (PCWC) approximately the same for each value of the independent variables and to normalize the distribution of the residuals. The final model was arrived at by stepwise inclusion of the variable which at each stage gave rise to the greatest statistically significant ($P<0.05$) improvement in the goodness of fit. At the same time, any variable whose exclusion did not significantly reduce the goodness of fit was removed from the model at each stage. Interactions between the hypothesized factors were also assessed for statistical significance.

Results

Table 1 lists the 22 factors hypothesized to be related to PCWC and presents the repeatability estimates for each.

Table 1. Repeatability of measurement of the parameters studied

Variable	Intraclass correlation coefficient
Continuous variables	
Total daily water consumption	0.57
Household size	0.64
Per capita water consumption	0.45
Log (per capita water consumption)	0.44
Mother's level of schooling	0.89
Father's level of schooling	0.79
Distance to the water source	0.65
Log (distance to water source)	0.73
No. houses sharing water source	0.71
No. of under 5-year-olds	0.51
Frequency of drawing water*	
children	0.45
women	0.41
men	0.44
Indicator variables	Kappa score
Type of water source	0.84
Site of clothes washing	0.58
Site of bathing	0.59
Presence of a latrine	0.75
Literacy of mother	0.77
Literacy of father	0.67
Mother's occupation†	0.56
Father's occupation†	0.68
Type of flooring in house	0.74
Electric power	0.76
Domestic animals owned	
pig	0.47
horse	0.57
poultry	0.32
cattle	0.66
Ownership of land (yes/no)	0.60
Drinking water protection	0.31

*Ordinal variables with three levels corresponding to 'usually', 'sometimes' and 'never'.
†These variables each have four levels of classification. All others are dichotomous.

The variables included in the final regression model are shown in Table 2. Although it was found that PCWC is greater when men contribute to water collection, this variable was not included in the final regression model because it was felt that the involvement of men in water collection may be a consequence of high rates of PCWC rather than a cause. None of the interactions tested was found to be statistically significant. In particular, the likelihood of the child suffering from diarrhoea was found to be unrelated to per capita domestic water consumption whether as a main effect or as an interaction term.

As the dependent variable in the regression model was the natural logarithm of PCWC, the coefficients obtained represent relative rather than absolute differences. The effect of each variable is therefore best expressed in terms of the associated percentage increase or decrease in PCWC. These differences are summarized in Table 3 which shows mean values and the percentage change in PCWC for each level of the variables included in the final model. The effect of water *availability* (as *measured* by the distance from the home to the main water supply) on PCWC is portrayed in Figure 1. It was found that a logarithmic transformation of the distance from the home to the water source improved the fit of this variable in the regression model. The crude PCWC rates (and their 95% confidence limits) were calculated by taking the geometric mean PCWC within log-distance intervals of equal size.

Discussion

The repeatability of the mother's daily per capita domestic water consumption estimates was not very high, perhaps owing to the fact that PCWC is calculated as the ratio of two other variables (total daily household water consumption and the number of household inhabitants), each of which is subject to measurement error. As no objective measure of PCWC was obtained, it is uncertain to what extent these estimates reflect actual rates of water consumption. Cairncross and Cliff (1987) found that observed domestic water consumption was quite similar to reported water consumption in a study performed in Mozambique, though the estimates were obtained from different samples of the population. No published research has been identified which directly compares observed with reported rates of water consumption. It would be valuable to know how accurately women estimate their household water consumption. This would permit comparisons of the relative efficiency of observation versus interview as data collection methods for studies of water use.

Table 2. Variables included in the final regression model of water consumption

Variable	Coefficient	Std error	*t*-Value
Household size	−0.0761	0.0059	12.82***
Site of clothes washing	−0.2461	0.0517	4.77***
Type of water source	−0.1731	0.0472	3.66***
Mother's level of schooling (years)	0.0267	0.0083	3.22**
Father's level of schooling (years)	0.0190	0.0073	2.67**
Log (distance to the water source)	−0.0401	0.0156	2.56*
Type of flooring in the house	−0.1147	0.0503	2.28*
Ownership of cattle	0.0785	0.0386	2.04*
Constant term	4.0186	0.0842	47.75***

*$P<0.05$; **$P<0.01$; ***$P<0.0005$.

Table 3. Levels and changes in PCWC associated with the indicator variables included in the regression model

Variable	Mean PCWC (l/person day)	Crude % change	Adjusted % change
Site of clothes washing			
in the home	32.8		
at the river	20.7	−36.9	−21.8
Ownership of cattle			
not owned	24.0		
owned	23.1	−3.8	8.2
Flooring of house			
tile or concrete	29.7		
clay	22.4	−24.6	−10.8
Type of water source			
protected well	27.7		
river/spring/unprotected well	18.2	−34.3	−15.9
Mother's level of schooling*			
nil	19.9		
3 years	23.1	16.1	8.3
6 years	27.5	38.2	17.4
9 years	37.2	86.9	27.2
Father's level of schooling*			
nil	20.5		
3 years	23.4	14.1	5.9
6 years	28.0	36.6	12.7
9 years	23.9	16.6	18.7
Household size*			
4 persons	32.9		
8 persons	23.3	−29.2	26.2
12 persons	18.8	−42.9	45.6
16 persons	23.7	−28.0	59.9

*Crude and adjusted percentage change is in relation to the minimum level shown in the table.

Of the total variance explained by the regression model (28.7%), a large proportion (12.3%) was attributable to just one variable, namely household size. The inverse correlation between PCWC and household size can be explained by the economies of scale in certain activities requiring water, such as cooking and cleaning the house. Only a minority of water uses (e.g. drinking and bathing) can be expected to increase in direct proportion to the number of

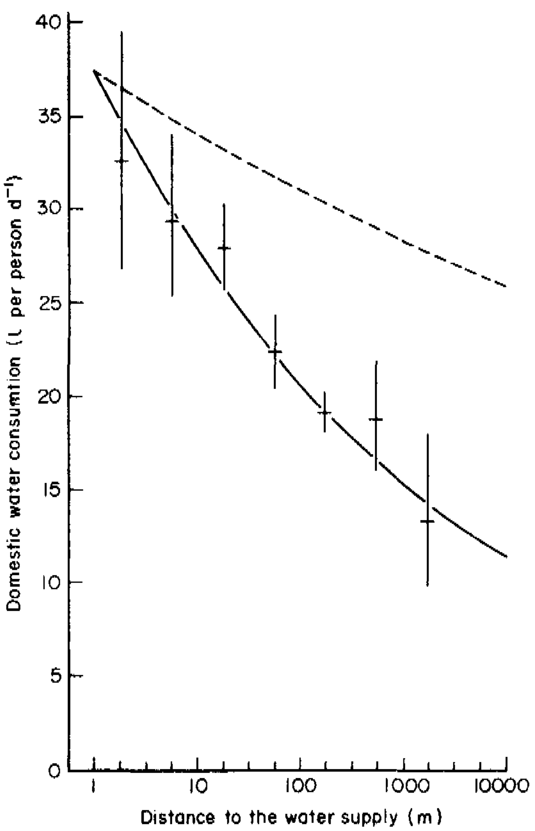

Figure 1. The relationship between water consumption and the distance from the house to the water supply. ——, Crude regression line; – – –, adjusted regression line. Bars represent mean and upper and lower 95% CI.

people living in the house. Household size has consistently been found to be inversely related to PCWC in previous studies (Darr *et al.* 1975; Feachem *et al.* 1978; White *et al.* 1972; Wong 1987).

The importance of the site of clothes washing is mostly a consequence of the way PCWC was measured. Water consumption estimates by female heads of household pertain only to water carried home. They do not include water which is used for washing clothes at source. Furthermore, those families which wash clothes at the river generally bathe there too. Though the site of bathing was also included in early regression models, it became statistically insignificant when the site of clothes washing was introduced. Obviously, the high level of collinearity existing between the site of clothes washing and the site of bathing makes it difficult to separate the independent effects of one from another. The 21.8% lower PCWC in households washing clothes at the riverside compared with those who perform their laundry at home is thus an indication of water used for bathing as well as for clothes washing.

A statistically significant relationship was identified between water availability and PCWC. This is consistent with results from research in Thailand (Frankel & Shouvanavirakul 1973), but not all investigations have demonstrated such a correlation. In studies performed in Lesotho (Feachem *et al.* 1978) and in East Africa (White *et al.* 1972), per capita water use did not decrease significantly for unpiped rural areas until the source was at least 1 km from the home. The constraints of linear regression modelling prevent one from defining the shape of the adjusted distance/PCWC curve, but it is interesting that the crude relationship shows some similarity to the model postulated by Cairncross (1987) on the basis of studies in Africa. According to this model, PCWC increases sharply when water is supplied to the home or yard but flattens out for return journey times from 10 to 30 min and then decreases gradually for distances greater than 1 km. The crude rates plotted in Figure 1 offer some support for this model. For water sources up to 18 m from the house, PCWC varies little. From 18 to 180 m PCWC drops from 27.9 to 19.1 l per person d^{-1}. There is then virtually no change in PCWC for distances up to 560 m. PCWC falls again from 18.7 to 13.2 l per person d^{-1} between 560 and 1800 m.

It should be recognized, however, that these are crude rates which do not allow for factors such as the change in site of clothes washing which could partly explain the observed falls in PCWC. It is for this reason that the slope of the unadjusted regression line is much steeper than the adjusted regression line. It seems that as distance from the house to the water source increases, people change their patterns of water use; more families bathe and wash clothes at the river rather than carry the water to their homes. Nevertheless, there remains a small but statistically significant, independent effect of water availability on PCWC. This was also found by Frankel and Shouvanavirakul (1973) who noted that when public standpipes were far from villagers' houses (they do not state how far), washing and bathing occurred at the site of water collection, but even allowing for this change in the pattern of water use, PCWC was still higher in the villages with closer water sources.

A close relationship was found between water consumption and the type of household flooring (clay versus concrete or tile), a variable found to be a good indicator of wealth in this setting (Sandiford *et al.* 1989). The correlation between wealth and PCWC persisted even after controlling for water availability, education levels, the ownership of cattle, household size and the site of clothes washing (although the relationship was weaker). Other studies have also observed associations between water consumption and socioeconomic indicators (Darr *et al.* 1975; White *et al.* 1972; Wong 1987). There are several reasons why poor people might consume less water. On the one hand they may have fewer tools or equipment associated with water use, smaller gardens, or fewer containers and less time to draw water. On the other hand, there may be cultural factors such as differences in hygiene practice between the wealthy and the poor. The relative importance of cultural factors in domestic water use is supported by the associations which have also been noted with parental schooling (Darr *et al.* 1975; Wong 1987) and race (Darr *et al.* 1975) and by White and colleagues' finding that PCWC 'seems to be more sensitive to gross differences in material wealth from one area or culture to another than within such groups'.

Parental schooling emerged as a particularly strong determinant of PCWC in this analysis. The mother's and the father's levels of education each independently predicted PCWC. Other studies have either found no relationship with schooling (White *et al.* 1972) or have not distinguished between male and female levels of education (Darr *et al.* 1975; Wong 1987). In Nicaragua, the father's level of schooling is probably a reasonable proxy for family income while the mother's level of schooling may indicate more cultural family characteristics such as hygiene practice. More work is needed to identify the precise mechanism by which education affects PCWC.

PCWC was significantly higher in households drawing water from protected wells than from unprotected shallow wells, springs or rivers. One reason may have been the limited capacity and flow of water from unprotected wells and springs. It is customary to 'clean' these wells by emptying them with a small basin before and allowing them to refill before drawing water (Sandiford *et al.* 1989). This takes about 30 min in the dry season and thus adds considerable time to daily water collection. Another possible reason for the lower PCWC associated with these sources is that the riverbeds where they are found are often at the bottom of steep paths. The importance of terrain has been mentioned by White *et al.* (1972).

No significant variation in water consumption between the dry and wet seasons was detected in this study. This is consistent with results from East Africa (White *et al.* 1972), but in Thailand, rainwater collection during the wet season reduced the demand from piped water sources. In contrast, rainwater use is not common in this area of Nicaragua.

Families with cattle had higher rates of PCWC than those without, but only after controlling for the other variables in the model. The 8.2% difference in PCWC is likely to be an underestimate as in some cases cattle were watered from a different source so their consumption was not included as a part of domestic water use.

The multiple regression model developed in this analysis, while a useful first approximation, is undoubtedly deficient in several respects. Only a small proportion of the total variance in water consumption estimates was explained by the various factors tested. Although much of the residual variance could be accounted for by measurement error associated with the rather low repeatability of the mother's water consumption estimates, there are also factors which have been found to be significant in other studies which were not tested in this analysis. They include the size of the water container, the number of baths per day, and family income.

One should note that PCWC was found to be unrelated to the case-control status of the child suggesting that water consumption may not be an important risk factor for childhood diarrhoea in rural Nicaragua. However, in another analysis it was found that the distance from the house to the water source (i.e. the availability of water) was significantly associated with diarrhoea (Sandiford 1989). A likely explanation for this is the low repeatability of water consumption estimates (as measured by the intraclass correlation coefficient), compared with the repeatability of water availability measurements. This could mean that the distance from the house to the water source is actually a better proxy for the quantity of water used in hygiene-related activities than the per capita domestic water consumption estimate itself, especially since the water used by a family for the practice of hygiene may be only a small proportion of total daily water consumption.

It is clear from this analysis that several factors are important determinants of domestic water consumption. Those most likely to be related to the amount of water used for hygiene practice (and therefore to diarrhoea morbidity) are the mother's and father's level of schooling, the distance from the home to the water source, and the type of water source. Given the strength of the association between water supply and schooling, it may prove more cost-effective, in some settings, to increase domestic water consumption for hygiene (and thereby reduce child diarrhoea morbidity) by educational interventions than by structural improvements in water supplies.

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Water Supply, Sanitation and Diarrhoeal Disease in Nicaragua: Results from a Case-Control Study

ANNA C GORTER,* PETER SANDIFORD,** GEORGE DAVEY SMITH† AND JOHANNA P PAUW*

Gorter AC (División de Ingenería Ambiental, Universidad Nacional de Ingenería, Managua, Nicaragua) Sandiford P, Davey Smith G and Pauw JP. Water supply, santitation and diarrhoeal disease in Nicaragua: Results from a case-control study. *International Journal of Epidemiology*, 1991; **20**: 527–533.
A case-control study of risk factors for child diarrhoeal disease was undertaken in a rural area of Nicaragua. Some 1229 children under the age of five were matched with an equal number of children of the same age presenting with other illnesses unrelated to water and sanitation. The main types of water supply were sampled at monthly intervals and tested for the presence of faecal coliforms in order to characterize their microbiological quality. In spite of marked differences in water quality between the different types of water supply, no relationship was found with diarrhoea morbidity. In contrast, there was a statistically significant association between water availability and diarrhoea morbidity. Children from homes with water supplies over 500 meters from the house had incidence rates of diarrhoea 34% higher than those of children from houses with their own water supply. Owning a latrine was not found to be significantly related to diarrhoea morbidity. A mother's level of schooling was inversely correlated with the frequency of diarrhoea in her children. A significant association was also found between the number of children under the age of five living in the house and the incidence of diarrhoea. These effects remained significant after controlling for confounding variables by conditional logistic regression.

It is well known that acute diarrhoeal disease is one of the most important causes of morbidity and mortality in children under five years of age. Mortality rates of over 20 per 1000 children in their first two years of life have been reported in Latin American countries and average morbidity rates are estimated at two episodes per year.[1]

The use of oral rehydration therapy has been promoted to reduce diarrhoea mortality, recognizing that other strategies are necessary to reduce diarrhoeal morbidity.[2] In 1982, the Diarrhoeal Diseases Control Programme of the World Health Organization commenced a systematic study of the strategies that might play a role in the control of diarrhoea. One of the seven strategies considered to be viable was the improvement of water supplies and sanitation.[3]

However, the relationship between improvements in water supply or sanitation and diarrhoeal disease is still not completely understood. Although reviews of more than 50 investigations on the relationship between diarrhoea and environmental sanitation found positive impacts in the majority,[4,5] there was considerable variation in the magnitude of the effects observed. For example, while there was a median reduction of 25% associated with improvements in water availability, the impact ranged from 0% to 100%. Similarly, they found that the reduction in morbidity associated with water quality improvements ranged from 0 to 90% (median 16%).[4]

The presence of design faults in many of these studies could explain the lack of consistency in the results. Blum and Feachem[6] identified eight important methodological flaws in the designs of 44 published studies and concluded that 'while most of the studies do claim to show an improvement in one or more health indicators, critical review of the papers raises serious doubts as to the validity of their conclusions'.

Since then, efforts have been made to develop rigorous methodologies to measure the health impact of strategies aimed at reducing diarrhoeal morbidity.[7] The outcome of this has been the application of case-control designs whose superior efficiency in comparison with cohort studies, even for investigating common

*División de Ingenería Ambiental, Universidad Nacional de Ingenería, Managua, Nicaragua
**Department of International Community Health, Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK.
†Department of Epidemiology and Population Sciences, London School of Hygiene and Tropical Medicine, London WC1E 7HT, UK.
Reprint requests to: Dr P Sandiford.

diseases, allows data of higher quality to be collected.[8] This article presents results from one application of the case-control method to the study of the relationship between acute diarrhoeal disease and environmental risk factors.

METHODS

This study was undertaken in Villa Carlos Fonseca, a rural municipality located on the Pacific coast about 30 km from Managua, the capital of Nicaragua. Within its area of 500 square kilometres there are approximately 30 000 inhabitants distributed amongst 35 communities. There is one health centre (with a small laboratory but no beds) and six smaller health posts.

A random sample of houses registered with the Ministry of Internal Commerce's consumer census was visited in order to determine the prevalence of the different types of water supply and sanitation. A subsample was then selected of sites representative of each type of water source from which monthly samples were taken to measure microbiological water quality by faecal coliform count. The results from a multivariate analysis of the water quality data have been published elsewhere.[9]

Cases and controls were recruited from the health centre and five of the six health posts, matched by age and the health care facility where they were first seen. All children under the age of five presenting with diarrhoea (defined as four or more liquid motions per day, with or without mucus, fever or blood), were recruited as cases, provided that they had not been included in the study as cases or as controls within the previous seven days. Children presenting with other symptoms in addition to diarrhoea were included as *cases* as long as they fulfilled the criteria. A child could be recruited on more than one occasion as either a case or a control irrespective of the previous diagnosis, provided that it had not been included in the previous seven days. Each case was matched to one control, which was defined as the next child of the same age group presenting to that clinic with one or more of the following conditions:

(a) Acute respiratory tract infection	(b) Measles
(c) Otitis	(d) Mumps
(e) Non-specific fever	(f) Skin disorders
(g) Malaria	(h) Conjunctivitis
(i) Urinary tract complaints	(j) Chickenpox
(k) Oral candidiasis	(l) Allergy

Specifically excluded from the control group were children diagnosed as having hepatitis, typhoid or parasitosis, or presenting with nausea, stomach pains, breast-milk intolerance or mild diarrhoea. Children with any form of trauma were also excluded from the control group because it is believed that they may be drawn from a different population than those who present with diarrhoea and thus their inclusion would introduce selection bias.[8]

At the health centre and each of the five health posts, a research assistant was employed to fill in the data forms, measure the child's height and weight, and to match controls with cases. Seven age categories were used for the purpose of matching (<1 month, 1–5 months, 6–11 months, 1 year, 2 years, 3 years and 4 years). The doctors and nurses staffing the clinics were responsible for making the diagnosis so they were also taught the selection criteria. Clinic data forms recorded a variety of information about the child, including its date of birth, age, sex, weight, height, type of feeding and diagnosis. Ownership of a latrine and drinking water supply were also noted to permit cross-checks with home visit data.

Field workers unaware of the subject's diagnosis were sent to the home of each child in order to verify by direct observation the type of water supply and presence or absence of a latrine. They reinterviewed the mother, asking once again the child's age and type of feeding but questions were also added to ascertain the parents' levels of schooling, their employment, and the number of household inhabitants (including the proportion under five years of age). Interviewers noted the distance from the house to the water supply and certain indicators of socioeconomic status such as the floor and roof construction materials, the types of domestic animal owned, and the possession of a radio, television, refrigerator, car, horse or cattle. If the child was normally cared for by someone other than the mother, data was collected from that person and if the mother or guardian was not at home a repeat visit was arranged. Where a family had already been visited within the three preceding months, the visit was not repeated unless the family had changed their address.

Least-squares linear models were fitted to identify the determinants of bacteriological water quality[9] and household water consumption.[10] The ratio of discordant pairs was used as an estimator of the incidence rate ratio for the different levels of each risk factor. The rate ratio was tested for statistical significance using McNemar's test in the first place and then by conditional logistic regression while controlling for confounding variables. The 95% confidence intervals were estimated by maximum likelihood.

RESULTS

Water Quality

The six main types of water supply identified in the population survey were rivers and streams, unprotected wells, protected wells, wells with mechanical

TABLE 1 *The distribution of diarrhoea cases and controls by exposure with crude and adjusted relative rates*

Risk factor	Cases	Controls	Odds ratios Crude	Odds ratios Adjusted†	95% confidence Intervals
Type of water source					
piped water supply	214	201	1.00	1.00	
protected well	521	562	0.86	0.92	(0.69–1.24)
unprotected well	407	382	1.01	1.11	(0.80–1.55)
river/stream	10	9	1.08	1.17	(0.37–3.67)
χ^2 (3 df)‡			3.16	4.32	
Distance to water source					
< 50 metres	713	751	1.00	1.00	
50–149 metres	249	230	1.12	1.16	(0.91–1.47)
150–249 metres	85	85	1.05	1.06	(0.74–1.50)
250–349 metres	38	44	0.93	1.00	(0.62–1.62)
350–449 metres	28	27	1.12	1.12	(0.63–1.98)
450–749 metres	12	4	3.79	3.61	(0.98–13.3)
750–1249 metres	14	8	1.78	1.80	(0.73–4.44)
≥1250 metres	13	5	2.69	3.29	(1.13–9.61)
χ^2 (1 df trend)			6.55*	7.24**	
Presence of a latrine					
no latrine	462	459	1.00	1.00	
latrine	690	695	0.98	0.99	
χ^2 (1 df)			0.05	0.01	
Maternal schooling					
nil	351	307	1.00	1.00	
primary school	687	720	0.84	0.82	(0.67–0.99)
secondary school	114	127	0.78	0.74	(0.54–1.02)
χ^2 (1 df trend)			4.01*	4.74*	
No. children under five years					
1	302	349	1.00	1.00	
2–4	810	778	1.20	1.22	(1.00–1.48)
≥5	40	27	1.68	1.70	(1.02–2.85)
χ^2 (1 df trend)			6.09*	6.00*	

†Matched analysis adjusting for potential confounders and all other main effects. The confounding variables controlled for were feeding practice, possession of a latrine, type of water source, socioeconomic status, access to health facilities and distance to health services.
‡The χ^2 statistic used is the score test.
*$p<0.05$; **$p<0.01$.

the type of water supply (which may be a proxy for water quality) but these were not analysed by logistic regression.

In a case-control study performed in Sri Lanka, diarrhoea morbidity was significantly related to the type of water source both before and after adjusting for confounders.[15] The authors believe that this is an effect more of water quality than of water availability. When disease status was compared with geometric mean faecal coliform counts (adjusting for source and area) there was a small but statistically insignificant difference between cases and controls.

It is difficult to make any general statement about the relative importance of water quality, water availability or sanitation from these studies. Their importance may actually vary from one country to another according to differences in geographical setting, behaviour patterns, transmission routes of the common aetiological organisms, or the nature of the water supplies and excreta disposal facilities. It is also possible that the inconsistencies derived from biases in one or more of the studies.

Our results suggest that the transmission of diarrhoea in Nicaragua is predominantly water-washed rather than water-borne. Where the prevention of diarrhoea is an important consideration in the design of water supply projects, the main focus should be on improving water availability and not water quality. It implies that the practice of boiling drinking water (advice frequently included in health education materials in Nicaragua) may be of little benefit. Taking into account the cost for the family of boiling water and

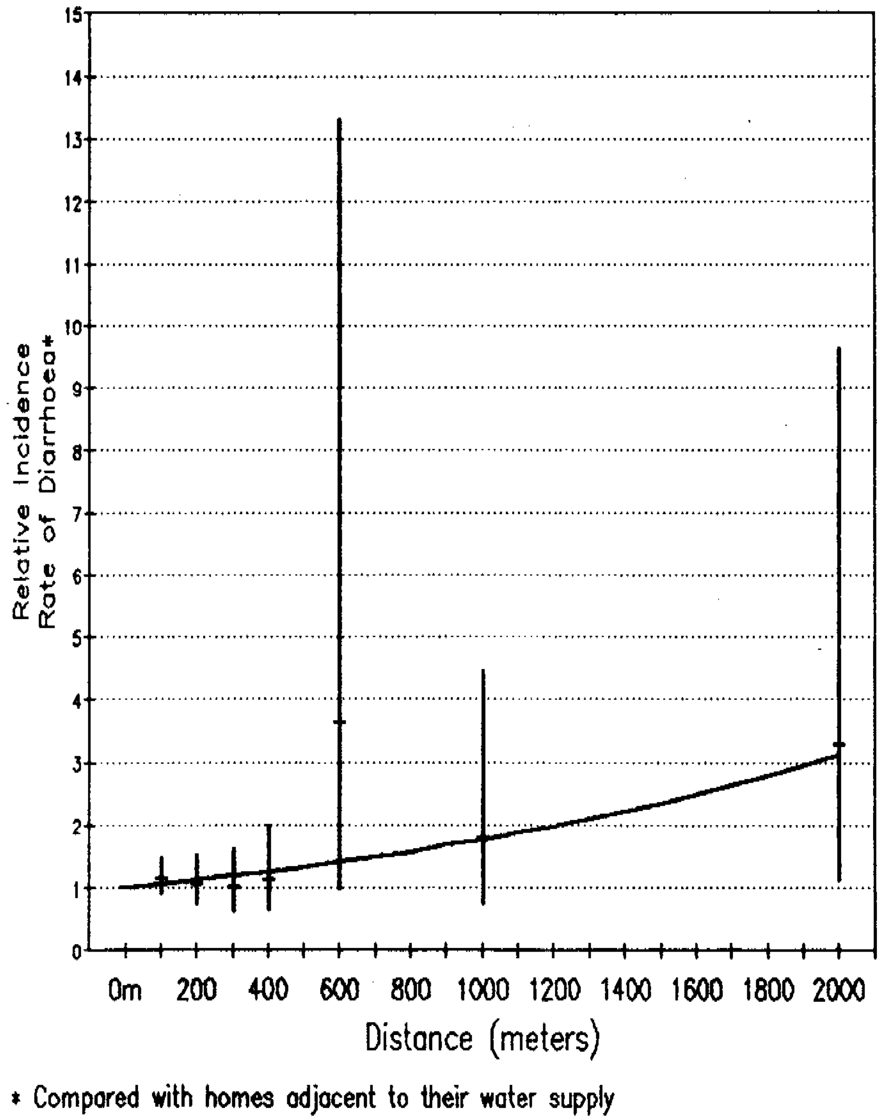

FIGURE 3 *Relative rates of diarrhoea morbidity by distance from the home to the water source (point estimates, 95% confidence limits and trend line).*

its other disadvantages.[16] it may be wise to reconsider the inclusion of this advice in health education programmes. On the other hand, it was not possible in this study to assess whether the lack of an association between water quality (at the source) and diarrhoea was in part due to the practice of boiling water in the home. Recent observational studies performed in Villa Carlos Fonseca however, suggest that drinking water for infants is not usually boiled (unpublished results).

The strong association between maternal schooling and child health has been demonstrated previously in Nicaragua[17,18] and elsewhere.[19] Although the precise mechanism by which child health depends on a mother's level of education is unknown, it is plausible that hygiene practice is important.[20] This is supported by the correlation found between per capita domestic water consumption and maternal schooling.[10] It is possible that as well as using more water, educated mothers also dedicate a greater proportion of the water they collect to hygiene-related activities.

At this stage however, there is only indirect evidence for an association between hygiene practice and maternal schooling. Education is a complex social variable and its relationship with health could have several pumps, public standpipes and domiciliary connections. Unprotected wells include springs and generally consist of shallow holes dug at the bank of a river or gully. Protected wells are usually at least seven metres deep and are surrounded by a parapet with the water drawn in a bucket on a rope.

The (geometric mean) faecal coliform counts obtained from each type of water source are shown in Figure 1. There was a marked difference in the degree of contamination of piped water compared with water from wells or other traditional sources. It was surprising to discover that during periods of low rainfall, the water quality of the unprotected wells was better than that of protected wells. Water quality was worse during wet periods, especially in the unprotected wells. The results of the water quality analysis have been presented elsewhere.[9]

Relationships between Water Supply and Diarrhoea Morbidity

A total of 1229 cases-control pairs were recruited between May 1986 and March 1988. The recruitment of cases by month is shown in Figure 2. There is seasonal variation such that during the rainy season more cases of diarrhoea were recruited than during the dry season. The majority of cases were less than one year old and 80% were under two years of age. Home visit data was obtained for 2436 of the 2458 subjects (99.1%).

Table 1 shows the relative rates of diarrhoea for the risk factors investigated. Of these factors, only water availability, the level of maternal education and the number of under five year old children living in the house were significantly associated with diarrhoea morbidity. There was no indication that the presence of a latrine or the type of water source (a reasonable proxy for bacteriological water quality), were risk factors for diarrhoea.

Water availability was significantly associated with diarrhoea when included in the logistic regression model as a continuous variable, implying that the frequency of diarrhoea increases exponentially with unit increases in the distance from the house to the water source (Figure 3). Thus, in houses with water sources 500 metres away, children had 34% (95% CI 2–56%) more diarrhoea than in houses adjacent to their water supply.

Child diarrhoea morbidity was found to depend on the mother's level of schooling. Children of women with primary school education had 18% less diarrhoea than those of women with no formal education. The children of women with secondary school education suffered 26% less diarrhoea than those who had not attended school. There was no correlation between the incidence of diarrhoea and a father's level of education once the other variables had been included in the model.

It was also discovered that the rate of diarrhoea in

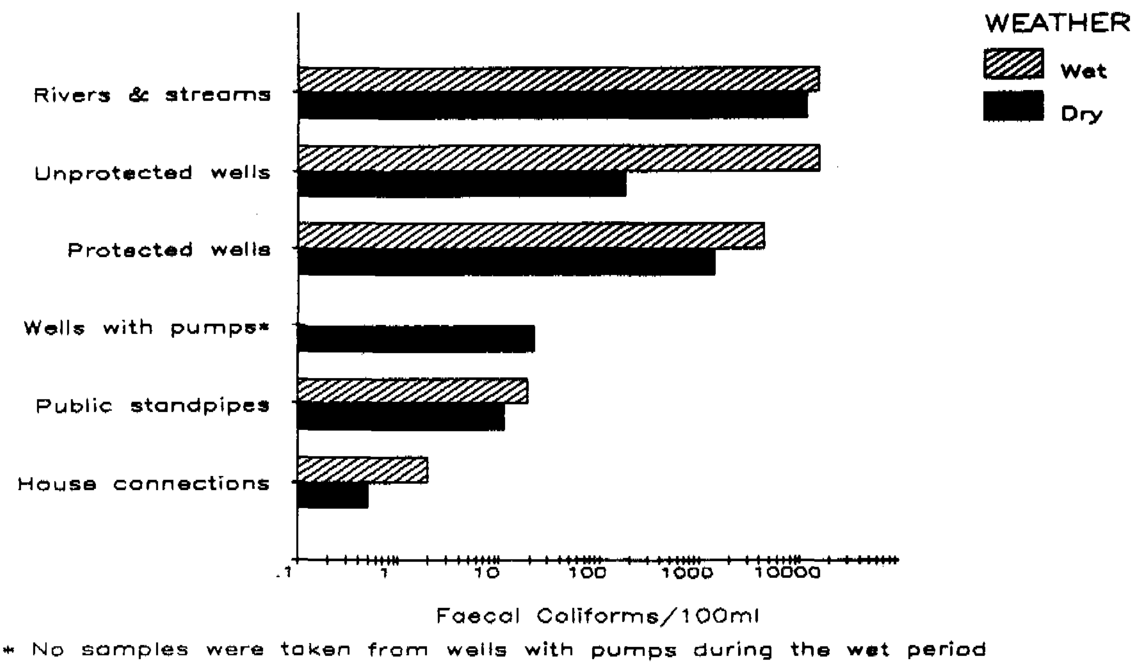

FIGURE 1 *Geometric mean faecal coliform counts by type of water source during wet and dry weather (months with >200 mm rain defined as wet).*

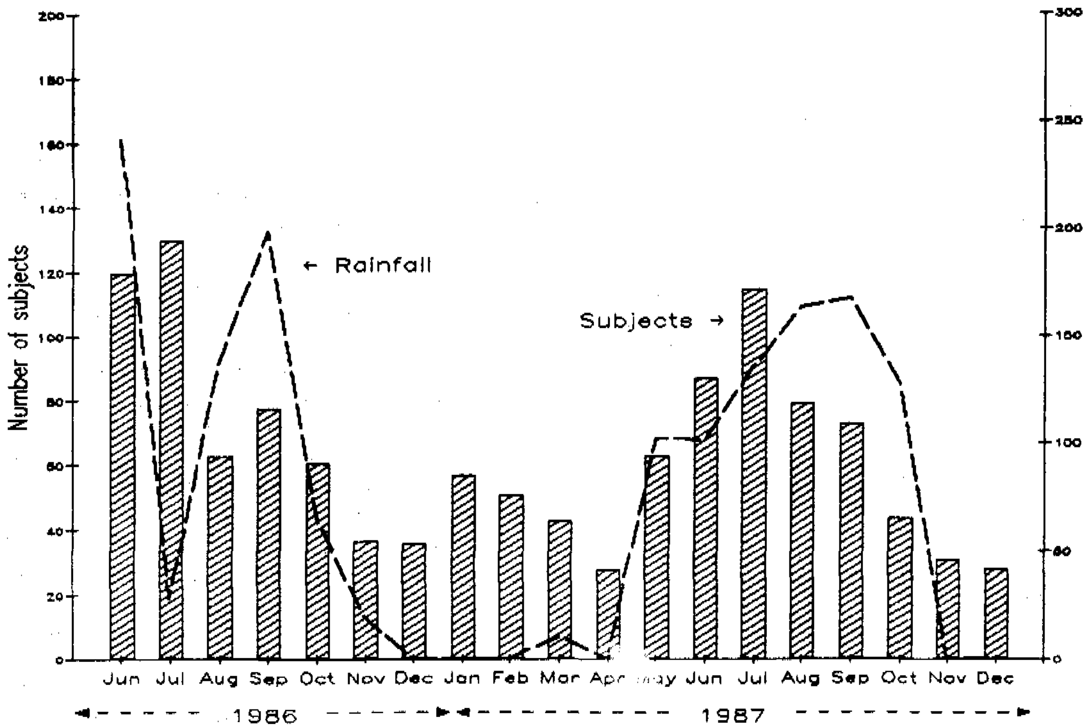

FIGURE 2 *Monthly rainfall and recruitment of subjects.*

houses with more than four children under five was 70% higher than in houses with just one under five year old. In houses with two to four children under five, the rate was 22% higher.

DISCUSSION

The results presented support the notion that access to water is an important risk factor for diarrhoea. Most studies have not attempted to obtain separate estimates for the impact of water quality and water availability, (indeed the two are often highly correlated making this difficult to achieve in practice), but there are two review papers which divide health impact evaluations of water supply into those where the improvement was predominantly in water quality, and those where the improvement was mainly in water availability. The first of these found that the median percentage reduction in diarrhoea incidence for studies where the improvement was mainly in water availability was 25% compared with 16% for those studies where the improvement was predominantly in water quality.[4] The second paper which reviewed many of the same studies, showed that the highest proportion of studies reporting a positive impact were those where the intervention resulted in increased water availability.[5] Our findings are consistent with these results as it was found that high rates of diarrhoea occur in the houses with water sources more than 500 metres away. At distances under 500 metres, however, the effect of water availability is small.

Since these reviews there have been several case-control studies of diarrhoea and environmental sanitation.[11-15] Two of them[11,12] assessed the joint impact of improved water supply (mainly water quality) and excreta disposal facilities compared with neither or just one of these interventions. These studies did not report statistically significant effects although they were the earlier case-control studies with rather small sample sizes.

Another study[13] used mortality from diarrhoea as the outcome measure and detected a significant association with water availability. They also observed a lower mortality rate in families using treated water but this was not significant after controlling for confounding variables. Diarrhoea mortality was unrelated to sanitation.

The Lesotho case-control study[14] showed an association between diarrhoea morbidity and latrine ownership which was statistically significant in crude analyses but not in the logistic regression analysis (although the odds ratio remained 0.76). Diarrhoea also showed crude associations with water consumption and with components. A mother's education is closely associated with socioeconomic status, with access to health services, with intrafamilial power relationships, and with her health-seeking behaviour when the child is ill. The lack of a significant relationship between diarrhoea morbidity and paternal education in this study suggests that the effect of the mother's education is not merely a reflection of socioeconomic status. However, the influence of education on the behaviour of the mothers with their sick children could explain the observed relationship with diarrhoea. For example, if educated mothers give home-based oral rehydration therapy while uneducated mothers tend to seek professional help, diarrhoea morbidity will appear lower in the group of educated mothers. More research is needed to clarify the importance to child health of maternal literacy and education.

The higher rate of diarrhoea morbidity in houses with more children under the age of five requires little explanation. Secondary transmission of diarrhoea is obviously facilitated by person to person contact between the children in the house. Family planning programmes or improved housing may have some impact on diarrhoea incidence but the effect observed in this study was small except where more than four children under five years old lived in the house.

The results obtained from this study do not allow comment on the efficacy of other methods for preventing diarrhoea recommended by the World Health Organization, such as the promotion of breastfeeding, measles immunization or improvements in weaning practice.[3] The study does suggest that improvements in water availability and hygiene education can be effective interventions for the prevention of child diarrhoea.

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(Revised version received October 1990)

Well Water Study

A Consultancy Undertaken for COWATER International INC

by

Dr Peter Sandiford and Dr Anna Gorter

Liverpool Associates in Tropical Health

September, 1992

CONTENTS

Executive Summary

Although there have been numerous health impact studies of water supply and sanitation, very few have looked at the potential health impact of moderate reducations in the faecal contamination of water sources and many of the studies which have been undertake have suffered from serious methodological flaws. There is however, reasonable consensus that water quality improvements do not generally have as great an impact on health as providing excreta disposal facilities or interventions which increase water availablity. From the small amount of relevant literature that is available, and taking into account the studies of major water quality improvements, it would appear that a water quality intervention is more likely to have a positive health impact through reducing contamination from very high levels to moderate levels than from moderate levels to low levels. However, one should not expect more than a 15-20% reduction in diarrhoeal disease morbidity. It should be noted too, that such improvements are likely to be more effective where many families share a water source, than where the water source is used by just one or two households.

While the theory of water contamination is well developed, there is a general lack of empirical support for the effectiveness of the numerous potential interventions to improve microbiological water quality. The few published studies which are available suggest that upgrading wells through improvements such as a windlass, bucket cage, drainage system, lining, headwall and cover are effective when provided as a combination. It is not known however, how effective individual components of the upgrading are in reducing contamination nor whether their combined effect is greater or smaller than the sum of the separate effects. The provision of pumps seems to be useful in settings with gross contamination, and tubewells are consistently cleaner than hand dug wells. There is also a need for a rigorous assessment of the potential impact of 'software' interventions such as health education on well water quality.

The third section of this document consists of a study protocol using a randomised factorial design to quantify the impact on water quality of five potentially effective interventions. These are:

- health education
- headwall and well lining construction
- installing a windlass
- fitting a well cover
- building a drainage apron

Terms of reference and budget guidelines for the consultancy component of the study are provided.

Terms of Reference

1. Undertake a literature review to identify any studies which have measured the health impact of moderate reductions in levels of faecal coliform contamination of wells, waterholes or surface water.

2. Undertake a literature review to identify which interventions (both in terms of hardware and community education) are most likely to bring about such reductions in the level of contamination of these water sources.

3. Take into account in the above the work being done by Dr Peter Morgan of the Blair Research Laboratories in Zimbabwe for the World Bank.

4. Design a study to be undertaken in Sri Lanka which would measure the reduction in faecal contamination that can be expected from specific hardware and software interventions. The likely interventions will be identified from the literature review but would also include any suggested by Cowater.

5. Produce Terms of Reference and a budget, suitable for retaining consultants to carry out the work, for the above study.

Part 1. A literature review of the health impact of moderate reductions in levels of faecal coliform contamination of wells, waterholes and surface water

1.1. The Relationship between Health and Water

The intimate relationship between human health and disease is manifest. Water is not only an essential element for the sustenance of human life but also a cause of much death and disease particularly in the developing world. Most of morbidity and mortality related to water is due the role it plays in the transmission of a variety of communicable diseases. Bradley[1] developed a classification of water-related illness based on four different transmission routes:

1. **Water-borne transmission.** This occurs when water is drunk containing pathogens which subsequently infect the host. All water-borne diseases with the exception of Guinea worm (dracunculiasis) are faecal-oral. That is, they pass from the faeces of one host to the mouth of another.

2. **Water-washed transmission.** Here water serves as a positive factor through its use for personal and domestic hygiene. Faecal-oral pathogens are washed away thus preventing person to person transmission. Skin and eye diseases are also preventable with increased availability of water for personal and domestic hygiene purposes.

3. **Water-based transmission.** This occurs when certain parasitic worms such as schistosomiasis reside in water and infect their hosts directly through the skin.

4. **Water-related insect vector transmission.** Many insect vectors such as mosquitos breed in water or bite near water (e.g. tsetse flies). By preventing breeding in water or human contact with breeding sites, this form of transmission can be controlled.

1.2. The Importance of Water-borne Transmission

Improvements in water quality will obviously impact on health only in those cases where the transmission route is water-borne. There are a several factors which determine the importance of the water-borne transmission route.

1.2.1. Other transmission routes

Firstly, there is the relative importance of other transmission routes. Briscoe[2] has argued that for diseases such as diarrhoea where there are multiple transmission routes, reducing transmission by the dominant route will not necessarily produce a corresponding reduction in the incidence rate of that disease. However, this notion was refuted by Cairncross[3] who pointed out that Briscoe's case rested upon the assumption that the multiple transmission routes were operating simultaneously which is clearly not the case for any given illness episode. Nevertheless, even if an intervention which prevents 50% of water-borne transmission, reduces the number of cases from that route by the full 50%, it may have an insignificant overall effect if that route contributes only a small proportion of the total number of cases.

1.2.2. Survival of the pathogen in water

Secondly, the importance of the water-borne route also depends upon the ability of the pathogen in question to survive outside of its host. Table 1 shows the estimated time for 50% of a bacterial population to die in a stable well water supply. There is considerable variation in the survival of different pathogens in water, with some such as V. Cholera sensitive to the level of salinity and pH.[4] Resistance to chlorine affects survival treated water supplies and indeed, some viruses are known to be able to withstand bactericidal concentrations of chlorine.

Table 1. Survival of various pathogens in a stable well water supply

Pathogen	Survival time (T_{50})
Shigella flexneri	26.8
Shigella sonnei	24.8
Shigella dysenteriae	22.4
Enterococci	22.0
Coliform bacteria	17.0
Salmonella enteritidis	16.0
Vibrio cholera	7.2
Salmonella typhi	6.0

Source: Feachem R et al, 1987[5]

1.2.3. Variation in Pathogenicity

Differences in pathogenicity also determine the relative importance of the water-borne route for any given aetiology. Pathogenicity of infectious agents is usually measured by the infective dose. This is the number of pathogens which when ingested, gives rise to illness in 50% of cases. In water, the concentration of pathogens tends to be rather low and therefore it may be difficult to imbibe an infective dose merely by drinking. On the other hand, if contaminated water comes in contact with food, the bacterial pathogens may breed in that medium until an infective dose is reached. The infective dose for viruses is generally less than 100.[6] Infective doses of bacteria tend to be higher[7], however there is considerable variation between the different species. Shigella needs a relatively small dose (about 1000).[6]

An interesting suggestion[8] has been put forward that reducing waterborne transmission puts evolutionary pressure on organisms tending to reduce their pathogenicity. Although Ewald has attempted to provide some empirical support for this hypothesis which is large based upon theoretical considerations, his success has been limited by the quality of available historical data. The traditional health impact evaluation would not, of course, measure benefits of this type.

1.2.4. Epidemiologic profile

Obviously if the importance of water-borne transmission depends upon pathogen-specific factors, then the impact of water quality improvements will vary according to the relative incidence of these different agents. However, the converse is also true, that is, the distribution of disease will depend upon the various transmissions routes open to pathogens. Moreover, if Ewald's hypothesis is correct, control of waterborne transmission will tend to reduce the prevalence of the more virulent species as well as reducing virulence within the population of a given species of pathogen.[8]

1.2.5. Degree of water contamination

One would expect that the importance of water-borne disease transmission increases with increasing levels of faecal contamination. This is not just because a higher level of contamination implies a greater probability of encountering a pathogen, but also, a greater probability of imbibing a pathogenic dose of the agent.

It is important however, to point out that faecal contamination per se does not imply water-borne transmission of disease. Unless the faeces contain a pathogen to which the potential host is susceptible, no infection will be transmitted. There is not doubt that a large amount of faecal matter is consumed by humans without any risk of them developing an illness, simply because the faeces contain no pathogens. Even if infectious agents are present, it is possible that the potential host has already been exposed to them. There are several important implications from this point. Firstly, a given level of water supply contamination may have more epidemiologic significance where that water supply serves a large population than where it serves just one or two families, because in the latter case, any pathogen in the water, may already have been transmitted to family member via other routes. Secondly, in-house contamination of stored water, may not be as significant as contamination of source water. Thirdly, apparent health impacts due to improved water availability do not necessarily imply reduced water-washed transmission. When an intervention lowers the number of families served by a water source, it may actually decrease water-borne transmission more that water-washed transmission because the frequency of pathogen exposure and size of the susceptible population is reduced.

1.3. Evidence for the Health Impact of Water Quality Improvements

1.3.1. Methodological Issues in Health Impact Evaluations of Water Supply Interventions

The failure to be able to demonstrate a positive health impact of several major water supply interventions[9,10,11,12,13] led some scientists to reexamine the methods which were being used. Water supply interventions are expensive, politically sensitive and often serve entire communities. These peculiarities often make it impossible to use the epidemiologically rigorous randomised controlled trial design. Most studies that have been performed are therefore observational, and frequently are designed as <u>post hoc</u> evaluations. In a review of 44 published studies of the impact of water supply and sanitation facilities on diarrhoeal disease, Blum and Feachem[14] identified 8 major methodological flaws. While none of the studies reviewed were entirely free from these flaws, some were much worse than other. The eight major flaws were:

1. Use of inadequate control groups
2. Comparison of one intervention with one control
3. Unsatisfactory control of confounding
4. Recall bias in ascertaining disease status
5. Imprecise disease definition
6. Failure to analyze by age
7. Failure to record facility usage
8. Insufficient consideration of seasonal variation

In addition to these deficiencies in study design, the evaluation of water supply interventions was hampered by the enormous cost of carrying out longitudinal studies of the size necessary to satisfactorily address the key issues. Hence, in 1976, an expert panel to the World Bank published a paper discouraging any further studies of this type.[15]

Nevertheless, this paper did lead investigators to look at alternative methods to carry out health impact evaluations of water supply and sanitation interventions. Attention focused on the case-control design, mainly because it offered the promise of low sample sizes and the ability to make retrospective evaluations of successfully functioning water supply programmes.[16,17]

Since then, various health impact evaluations employing the case-control design have been carried out in a wide variety of settings[18,19,20,21,22,23,24]. Although these studies generally have been able to define disease status more precisely, it has to be said that their results are really no more consistent than those of the earlier designs. The advantages of the case control study in terms of sample size and statistical power are probably not as great as was initially expected and many of the problems previously identified remain unresolved such as the difficulty in documenting exposure and the selection of an appropriate control group.

Moreover, there are two problems which observational studies will always find difficult to deal with. One is the fact that water supplies are not allocated randomly within the study population and therefore tend to correlate strongly with other health-related social and economic factors. Some of these factors are very difficult to measure and hence control for during the analysis stage. The second problem is that these studies are based on an assumption that individuals behave passively with regard to the putative risk factors.[25] In reality though, it is possible for example, that a household with a contaminated water supply will be more likely to boil a child's drinking water than a household with an uncontaminated water supply. Unless such practices are measured and taken into account, traditional analyses will yield misleading results.[26]

1.3.2. Reviews of the health impact of water supply and sanitation improvements

There have now been three definitive reviews of the many health impact evaluations of environmental sanitation that have been performed over the last fifty years.[6,27,28] Each of these reviews classified the studies according to whether the interventions improved water quality, water availability, excreta disposal or combinations of the three. The most recent of these reviews[28] updates the findings of the others and is therefore the one will be discussed most thoroughly. Since this review, seven further studies have been published in which the impact of water quality is assessed, either alone or in combination with other improvements.

Although the 1991 Esrey et al review[28] considered the potential health impact of water supply and sanitation on trachoma, schistosomiasis, hookworm, dracunculiasis, diarrhoea and ascariasis, it is only the latter 3 diseases which improved water quality for drinking might be expected to prevent. The others are therefore not considered here. Table 2, reproduced from Esrey et al,[28] shows the median reduction in morbidity and mortality for each disease taking all of the studies combined. It appears from this table that dracunculisasis and schistosomiasis are particularly amenable to water and sanitation interventions. It also seems that mortality is more greatly reduced than morbidity but this could be due to the difficulties in measuring the latter.

1.3.3. The health impact of combined water supply and excreta disposal improvements

In four well-conducted studies, the prevalence of ascariasis was reduced among those with water supplies and latrines, the greatest

Table 2. Expected reduction in morbidity and mortality from improved water and sanitation for selected diseases

	All studies		Rigorous studies	
	n	Median reduction (%)	n	Median reduction (%)
Ascariasis	11	28 (0–83)	4	29 (15–83)
Diarrhoea				
Morbidity	49	22 (0–100)	19	26 (0–68)
Mortality	3	65 (43–79)	-	-
Dracunculiasis	7	76 (37–98)	2	78 (75–81)
Hookworm	9	4 (0–100)	1	4
Schistosomiasis	4	73 (59–87)	3	77 (59–87)
Trachoma	13	50 (0–91)	7	27 (0–79)
Child mortality	9	60 (0–82)	6	55 (20–82)

Source: Esrey et al, 1991[28]

reductions being observed in those settings where household water supplies were provided rather than community standpipes. There was a greater reduction in the intensity of infection (as measured by egg counts) than in the prevalence.

For diarrhoea, studies of combined water supply and sanitation improvements showed a 20% median reduction in morbidity with the better studies having a 30% median reduction (table 3). In the only study to examine the impact on mortality, an 82% reduction was observed in those with toilets and water compared with those without such facilities. One recent study from Bangladesh[29] which was not included in the review articles reported a 25% reduction in diarrhoea incidence in areas with a water supply, sanitation and hygiene education intervention compared with control areas (table 4).

1.3.4. The health impact of combined water quantity and/or water quality improvements

In many of the studies published, it is difficult to determine whether the water supply improved quantity, quality or both and hence the review grouped them together. Two studies found that water supplies alone reduced Ascaris spp. prevalence by 30% and 37% respectively. However, for diarrhoea morbidity, only modest reductions (16-17%) were observed (table 3). In the nine rigorous studies which looked at diarrhoea mortality, a positive impact was observed only in certain age groups. The studies reporting positive impacts tended to be ones where the water supply was piped into the homes as opposed to protected wells, tubewells and standpipes. A recent study from

Table 3. Expected reduction in diarrhoeal disease morbidity from improvements in one or more components of water and sanitation

	All studies		Rigorous studies	
	n	Reduction (%)	n	Reduction (%)
Water & sanitation	7[a]/11[b]	20	2[a]/3[b]	30
Sanitation	11/30	22	5/18	36
Water quality & quantity	22/43	16	2/22	17
Water quality	7/16	17	4/7	15
Water quantity	7/15	27	5/10	20
Hygiene	6/6	33	6/6	33

[a] The number of studies for which morbidity reduction calculation could be made.
[b] The total number of studies that related the type of facility to diarrheoal morbidity, nutrition and mortality studies.

Source: Esrey et al, 1991[28]

China[30] not included in the review articles (table 4), found that deep well tap water in the house or yard (average total coliform count 0.23/100cc) was associated with a lower incidence of diarrhoea, hepatitis and cholera but not *Shigella*, compared with those using surface water at 10 to 40 meters from the home (average total coliform count 77/100cc).

1.3.5. Studies evaluating the impact of water quality alone

Of the sixteen studies which examined the health impacts of pure versus contaminated water supplies, 10 reported positive effects and the median reduction in diarrhoea morbidity was 17%. Among the seven more rigorous studies, the median reduction was 15%. There are several recent studies in which it has been possible to separate out the effect of water quality (table 4). In one of them, carried out in Sri Lanka,[18] there was a 29% reduction in diarrhoea associated with a ten-fold drop in faecal contamination. In contrast, studies in Egypt,[31] Nicaragua,[23] Nigeria[32,33,34,35] and Malaysia[19] were unable to detect any effect of water quality although in the case of the latter, the small sample size may have prevented detection of a significant effect.

Table 4. Recent studies examining the health impact of water quality

Country	Type of improvement	Comparison	Observed impact	Ref. No.
Bangladesh	Sanitation, water quantity, and water quality	Intervention area with handpumps, latrines and hygiene education vs control areas	25% reduction in incidence of diarrhoea. No impact on nutritional status	29
	Quality only	Exclusive wet season use of handpump water	Not significant	29
China	Quality & quantity	Deep well tap water in house or yard vs surface water at 10-40m	Reduction of 38% in diarrhoea incidence, 73% in hepatitis, 88% in El Tor cholera and 0% in <u>Shigella</u>	30
Egypt	Quality	Tap water versus well water for drinking	Nil	31
Malaysia	Quality	Absence vs presence of faecal coliforms in water source	Insignificant 23% reduction in diarrhoea	19
		Absence vs presence of faecal coliforms in drinking water	Insignificant 31% reduction in diarrhoea	19
Nicaragua	Quality	Piped water versus protected wells versus unprotected wells	Nil	23
Nigeria	Quality	Boreholes versus traditional sources	Reduced incidence of dracunculiasis. Nil effect on diarrhoea.	32 33 34 35
Sri Lanka	Quality	Faecal coliform counts	29% reduction in diarrhoea per ten-fold drop in FC contamination	18

1.3.6. Studies evaluating the impact of moderate water quality improvements

The vast majority of evaluated water supply interventions which specifically address the issue of water quality, have taken as their reference point, watersupplies with faecal coliform (FC) counts of, or close to zero, as have the review articles. The median health impact of even such significant reductions in levels of contamination was small compared with those reported for sanitation and water quantity improvements. Clearly one would expect the impact of moderate reductions to be even lower.[1]

Only four studies were identified which enable an empirical assessment of this issue. One of these from the Philippines[36] found little difference between the illness rates of children drinking good quality source water (<1 E. coli per 100ml) and those drinking moderately contaminated water (2-100 E. coli per 100ml). Children drinking water with over 1000 E. coli per 100ml had significantly higher rates of diarrhoeal disease than those drinking less contaminated water.

Trivedi et al in India[37] studied the effect of 4 different levels of chlorination of highly polluted open shallow wells. Seventy four percent of these wells had 'MPN counts' over 1,800 per 100ml (table 5). The results demonstrate a clear dose response between the level of contamination and the incidence rate of diarrhoea. One must realize that chlorination of water also means that handwashing will be more effective since presumably the chlorinated water not only removes faecal material but kills or debilitates pathogens.

Table 5. Water quality and incidence rate of diarrhoeal disease

		Control	I	II	III	IV
Residual chlorine		0	0.5	0.4	0.3	0.2
Average MPN count	Before	820	953	1089	1100	880
	After	727	17	41	49	82
Diarrhoea incidence rate	Before	19.0	20.0	22.2	20.3	10.7
	After	29.5	1.1	1.7	2.1	3.0

Source: Trivedi et al, 1971[37]

In a study in Indonesia[38] water sources were classified as either 'safe' (uncontaminated piped water, protected springs and treated water), 'less safe' (springs, deep well pumps, shallow well pumps, dug wells,

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[1]Moderate reducation as used here means from thousands down to around one hundred faecal coliforms per 100cc of water.

and rain water) and 'unsafe' (rivers, streams, and ponds). In a cross-sectional 8600 household survey of diarrhoea, 3.8% of children in the 'safe' group had diarrhoea compared with 4.0% in the 'less safe' and 6.3% in the 'unsafe' ($p<0.05$).

The authors' case-control study in Nicaragua[23] compared diarrhoea rates in users of piped water sources with users of protected wells and users of unprotected wells. Piped water sources generally had low levels of contamination (<100 FCs / meal), while protected wells had high levels of contamination (geometric mean FC counts over 1000 per ml). Unprotected wells (which were mostly small waterholes dug beside rivers and streams) had relatively low mean FC counts during dry periods (179 per 100 ml) but very high levels after rain had fallen (15,000). No difference was detected in diarrhoea incidence between the different water sources.

1.4. Summary of Part 1

Although there have been numerous health impact studies of water supply and sanitation, very few have looked at the potential health impact of moderate reducations in the faecal contamination of water sources and many of the studies which have been undertake have suffered from serious methodological flaws. There is however, a reasonable consensus that water quality improvements do not generally have as great an impact on health as providing excreta disposal facilities or interventions which increase water availablity. From the small amount of relevant literature that is available, and taking into account the studies of major water quality improvements, it would appear that a water quality intervention is more likely to have a positive health impact through reducing contamination from very high levels to moderate levels than from moderate levels to low levels. However, one should not expect more than a 15-20% reduction in diarrhoeal disease morbidity. It should be noted too, that such improvements are likely to be more effective where many families share a water source, than where the water source is used by just one or two households.

Part 2. A literature review to identify which interventions are most likely to reduce faecal contamination of wells, waterholes and surface water.

2.1. The Mechanism of Faecal Contamination of Water Sources

Fresh water is essentially distributed between three different compartments - rain, surface water and ground water. Rain water is normally free from faecal contamination, at least until it is collected.[39] Surface water, on the other hand is typically highly contaminated in developing countries. The faecal contamination of surface water implies that at some stage in the water cycle, faecal has been mixed with the rain water. Ground water, like rain water, is also usually free from faecal contamination. The relative purity of ground water compared with surface water is due to (a) the death of microbiological contaminants and (b) the filtering effect of soil.[40,41]

Coliform bacteria have a half life of about 17 hours[5] and bacterial half-lives in wells and laboratory groundwaters are mainly in the range of 8 - 24 hours.[41] This implies that without replenishment, FC contamination of water sources will decrease by a factor of 100 in less than 11 days. However, this process is highly dependent on temperature and survival is therefore possibly lower in warm climates. On the other hand, as has already been pointed out, the survival of different pathogens varies greatly (table 1).

Soil filters bacteria best when the particles are fine (<1mm), when the unsaturated zone in the water table lies at more than 2m below the surface, and when groundwater flow velocities are low. Faecal bacteria in soil are also eliminated by antagonistic aerobes and anaerobes.[41] The risk of groundwater contamination is therefore greatest where the water table is shallow and where fissured non-porous bedrock is overlaid by shallow soils. Lateral migration of faecal bacteria generally does not exceed the 10m. Older latrines pollute less, because of pore clogging of the walls. In general the distance between a water supply and an on-site sanitation unit for safe lateral separation should be 15m. It depends however, on the aforementioned factors and in some areas 5m is probably sufficient.

From a public health point of view, groundwater contamination in developing countries is of much less significance than surface water contamination. The level of contamination of rivers, streams, canals, pond depends primarily on:

1. The degree of environmental surface contamination which itself is determined by a multitude of factors such as population density, number of people using the source, the way people fetch the water, sources of pollution around water supply (eg animals), bathing and defecation practices, ambient temperature, humidity, rainfall and wind.

2. The amount of water in which the pollution becomes diluted. This in turn will depend on the exact amount of water present at the moment of pollution and the turnover of the water. The more water is extracted or streaming away and the more water there is, the more dilution of contamination is taken place.

For scoop holes, waterholes and hand-dug wells the level of contamination is a function of groundwater quality, the rate of introduction of faecal contaminants, the rate of water extraction, the volume of water in the well, and the survival of the microorganisms.

2.2. Determinants of the Level of Faecal Contamination

2.2.1. Water source

There are many different studies which have documented water quality.[1,36,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59] The highest levels of faecal contamination of drinking water sources are usually found in rivers where they range from less than 10 FCs per 100ml up to 2 million FCs per 100 ml. Ponds and canals can be equally contaminated while streams tend to be a little less contaminated.

Springs, waterholes and hand-dug wells have lower levels of faecal contamination with values typically ranging from 0 to 10.000 FC/100ml. In some cases however, levels as high as one million FCs per 100ml can be found. The variation in contamination of these sources is enormous. Springs are usually less contaminated than waterholes and hand dug wells. As stated earlier, rainwater is inherently clean but can readily be contaminated depending on the way it is collected.[39,56]

2.2.2. Season

The marked seasonal variation in water quality is well known[60,61] and is closely related to rainfall.[51,62] It tends to affect surface water and unprotected well water more than water from protected wells and boreholes.[59] There are two factors giving rise to the seasonal variation in water source contamination. One is the run-off effect whereby rain washes faecal matter into water sources. The other is the concentration/dilution effect in which dry weather reduces the volume of water and hence concentrates the existing level of contamination. Support for the importance of this effect was provided by Wright,[55] who in Sierra Leone noted increasing levels of faecal contamination during the dry season.

Blum[50] in Imo State, Nigeria found that contamination peaked during transition from the dry to the wet season when the mean FC counts for all sources except rivers were 2.5 to 7.2 times greater than during the rest of the year. The lowest FC counts occurred at the height of the wet season. A similar pattern has been observed in Costa Rica,[63]6 Papua New Guinea,[64] and the Gambia.[65] Blum's explanation takes both the run-off effect and concentration effect into account. 'The first rains wash the faecal matter into the water source, progressing the wet season there develops a rain induced dilution. At the onset of the dry season, bodies of water again begin to shrink and counts rise.'[50] That there are still considerably higher levels of contamination during the wet season than during the dry season is because the water levels of the wells during rain rise, but not enough to counter the increased rate of pollution due to run-off.[51]

2.2.3. Other factors

Most of the microbiological pollution of water sources is due to the external introduction of contaminants through either poor design or unhygienic methods of water extraction. Interventions to reduce this cause of pollution are discussed below. There are several additional factors however which relate to water contamination.

One of these is the number of households using the source. In a Kenyan study, 70% of wells used by only one family had FC counts below 100 per 100ml compared with 15% when one to five families used the well.[58] In the latter case, each family used its own bucket and rope which were frequently placed on the ground.

A marked variation between countries in the contamination levels of water sources can be observed from the literature. Low contamination was found in a study from Zambia[57] where none of the shallow wells had over 50 FCs per 100ml. In Sri Lanka[60] the geometric mean FC count for protected hand-dug wells was also low (93/meal). Higher levels were seen in a study in Kenya where 68% of hand dug wells and 19% of springs had more than 100 FCs per 100ml[58] and in Gambia contamination of hand dug wells was around 20,000 FCs per 100ml during the dry season and up to 500,000 FCs per 100ml during the wet season.[65] While there are many possible explanations for this variation, population density is one factor which may be important. In Nicaragua, there was a significantly lower level of FC contamination in rivers, streams, unprotected wells, springs, and protected wells for small communities compared with large communities.

2.3. Interventions to Reduce or Prevent Faecal Contamination of Water Sources

In discussing the various interventions which can reduce or prevent faecal contamination of water sources, only those involving relatively simple and inexpensive construction have been considered.

2.3.1. Interventions to Reduce Surface Water Contamination

Rivers, streams, canals, ponds are often heavily contaminated by run-off and defecation by animals and people in and around the water. Often people attempt to protect themselves from the effects of river and stream water contamination by taking their drinking water upstream of their village or by digging holes alongside the river, and sometimes even protected by a parapet. Water seeps into the hole and in doing so is filtered by the soil. In Nicaragua it was observed that people completely empty the water from these little wells and allow them to refill each time they collect water.[59] Interestingly, during dry periods the quality of water in these unprotected wells was significantly higher than in domestic wells protected with a lining and parapet and often less than one hundredth of the level in the adjacent river.

Another possibility is filtering the water within the source, for example Jempeng stone filter used in canals in Indonesia or sand-filtering wells developed in China.[66] Filtering the water in the home is also an option. For example, there is winnowing sieve, the cloth filter, clay vessels, plant material, and the family sand filter.[62,66] It is claimed that these sorts of filters yield water of a very high microbiological quality (presumably FC counts of less than 50 per 100ml) although no data were found to verify this.

Spring water, which is often relatively clean anyway, can be improved by constructing a spring box consisting of a headwall, outlet pipe and backfill cover.[67,58] One study[67] found that only 20% of protected springs tested positive for E. coli compared with 62% of unprotected springs. Rain jars with mosquito nets placed on the rooves of houses are a safe way of collecting rainwater with mean FC counts of less than ten per 100ml.[39]

2.3.2. Interventions to Reduce Well and Waterhole Contamination

Four basic strategies can be used to reduce well and waterhole contamination. These are (a) diluting the pollutants (b) preventing groundwater contamination (c) preventing surface contamination and (d) treating the water.[68]

Preliminary results from a study by the authors in Nicaragua, show that the degree of contamination of hand-dug protected wells is inversely related to the amount of water in the well. This is presumably because of a dilution effect. One option for improving water quality would therefore be to increase the depth of water in the well or by widening the well.

However, another way to dilute the contaminants is to increase water turnover. Presumably this is why riverside waterholes can have better water quality than large, protected, hand-dug wells.[59] It may also partly explain why pumps on hand dug wells are associated with better water quality.[59] Pumps generally increase the amount of water used and hence increase turnover. Morgan[62] has demonstrated that this 'flushing effect' can be very significant in an experiment with a Bucket Pump installed on a tubewell. At normal rates of extraction, the total content of the tubewell is completely replaced within ten minutes. In the sense that turnover is greater with smaller volumes of water in the well, this flushing effect will be less if the amount of water in the well is increased as suggested above. The impact of pumps on water quality in the Zimbabwe study is illustrated in table 6. In Nicaragua where electric or wind pumps are installed on traditional hand dug wells, the geometric mean FC count was only 22 per 100ml compared with 1,410 for wells without pumps. Expressed another way, 90% of wells without pumps had over 50 FCs per 100ml compared with 33% in those with electric or wind driven pumps,[59] and 55% in traditional wells with handpumps.[69] Another study in Nicaragua found 26% and 23% of wells fitted with Dempster pumps and rope pumps respectively had FC counts over 50/100ml.[70]

Table 6. Bacteriological quality of water taken from wells and handpumps

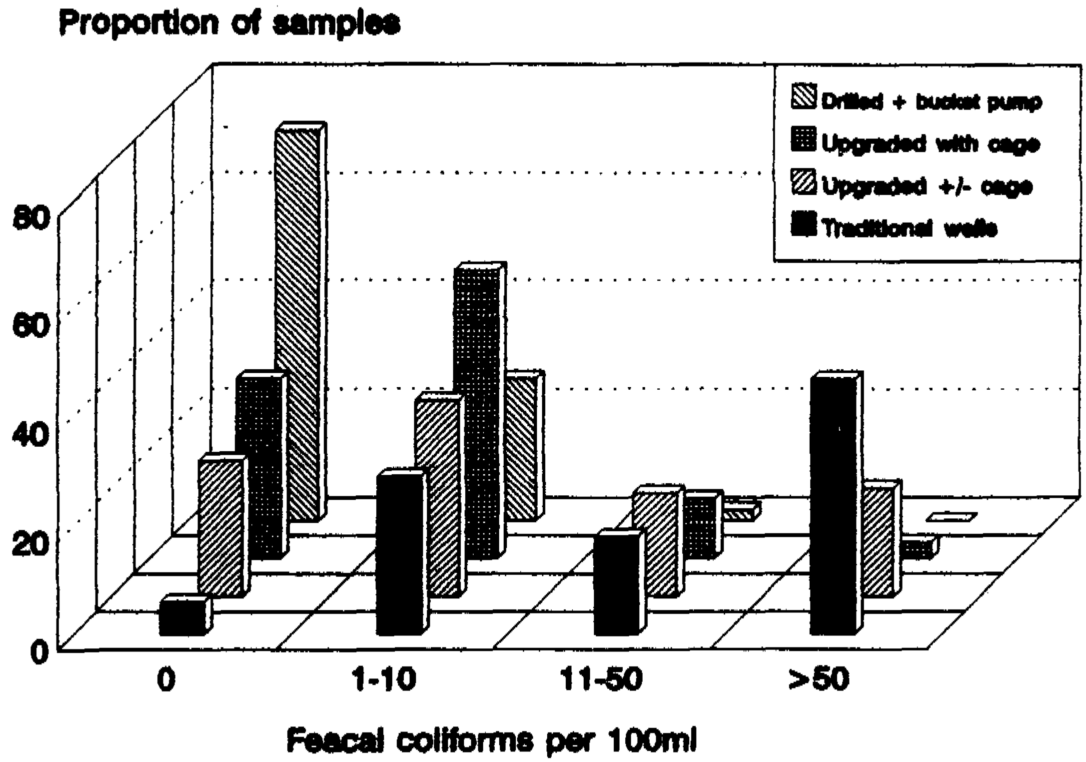
Source	Mean E. coli/100ml	No. samples
Poorly protected well	266.42	233
Upgraded wells	65.94	234
Bucket Pump (overall)	33.72	338
Blair Pump (tubewells)	26.09	248
Bush Pump (tubewells)	6.27	281

Source: Morgan, 1990[62]

Groundwater pollution is usually a minor source of contamination in most wells and therefore interventions to prevent it are unlikely to have a major impact on faecal coliform counts. A study in Nigeria for example[53] in which 20 wells were studied found no correlation between water quality and the distance between the well and the latrine, nor with the depth of the water table. This result is supported by another study in Sri Lanka's Kandy District where no relationship was found between the level of contamination and the distance of the latrine from the well. Tracer tests to investigate if surface water might enter the hand dug wells were negative, perhaps due to the nearly ideal soil material in the unsaturated zone.[71] In Sri Lanka[60] 95% of the protected open hand dug wells were contaminated. In contrast, only 5% of deep tubewells with handpumps were contaminated when mouth of tap was sterilised but 52% were contaminated when mouth of tap was not sterilised. Mertens et al concluded that ground water contamination is negligible if it occurs at all, the contamination occurs at the periphery of the system. However, in cases where groundwater pollution is suspected to be significant, then all nearby latrines and cesspits should be removed to a safe distance (15 to 30 metres) and the lining of the well upgraded, replaced or installed as necessary.

Several design features of the protected well are intended to reduce contaminants from the surface entering the well. A headwall/parapet with a cover will prevent faecal material, dirt and debris from falling into the well and helps to keep animals and people away from the well water. A concrete apron around the base with a sanitary seal to the headwall and lining, a drainage channel and sump at some distance from the well will prevent spilt water and rainwater run-off seeping into the well. It also keeps the area dry which reduces breeding of bacteria, which grow better in a moist environment. Improvements in the water lifting device, such as a windlass or handpump will decrease or eliminate contamination of the water via the bucket and rope. A study of the faecal contamination of upgraded wells compared with unimproved wells showed that the latter had over four times the concentration of faecal E. coli, and over five times the concentration of faecal Streptococci (table 6). In this case the upgrading was extensive and consisted of installing a windlass, well cover, drainage apron and lining.[62] Another study in Zambia[72] found significantly better water quality by upgrading the wells, but drilling the wells produced even better results (figure 1). Hand dug wells were upgraded with a lining, concrete cap, drainage channel and a windlass. A special cage around the bucket was developed to protect the bucket against stealing. Some wells were hand augured and a bucket pump was installed. Water quality was then compared between traditional wells, improved hand dug wells some with a bucket cage and some without, improved hand dug wells with a bucket cage and augered wells with a bucket pump.

Figure 1. Relationship between water quality and well type



Source: Lacey (1990)[71]

When a rope and bucket are used the cover should be designed in a way that prevents water from spilling back into the well. This means the cover should have a raised collar around the extraction port. However, a study in Kenya[58] found that the presence of a cover and well lining had no effect on water quality. Similarly, the study in Nigeria by Adesiyun et al[53] did not detect any difference in water quality between the wells with a cover and those without. Likewise, a study in Indonesia found no improvement in faecal contamination when hand dug wells were upgraded by fitting a handpump and a sanitary cover. Among the improved wells with handpumps, 20% had contamination levels over 100 FCs per 100ml compared with 22% in the unimproved open dug wells.[56] Other studies however, have shown that a coverplate can make some difference. In a study from Cape Verde, 53% and 23% respectively of traditional hand dug wells without and with coverplates contained E. coli. For coliforms the proportions were respectively 100% and 80%.[67]

Surface contamination is considerably reduced when wells are augured as the first few meters of the well is then protected by the casing which always goes with a drilled well. In addition, the opening of the well will be smaller and therefore easier to protect. The lifting device will also tend to be more hygienic. In the aforementioned Indonesian study, only 7% and 9% respectively of the shallow and deep drilled tubewells with handpumps had more than 100 FCs per 100ml compared with 20% for among upgraded hand dug wells and 22% among the unimproved hand dug wells.[56]

Another way to reduce faecal contamination is by chlorification. This is normally done by periodic disinfection of the well but several methods of gradual chlorine infusion have also been experimented with. Table 6 illustrates the potential improvement in water quality made possible by chlorination. However, there are problems with chlorination such as the often unacceptable taste, the difficulty in determining and maintaining an appropriate dosage schedule, and the problems of guaranteeing a regular supply of chlorine.

2.3.3. `Software' Interventions to Reduce Faecal Contamination of Water

Certain behaviours may increase or decrease the level of contamination of a well. For example, placing the bucket and rope on the ground, defecating in the area near the well or allowing animals to do so, bathing or washing clothes close to the well may introduce surface contaminants. It is also conceivable that handwashing might prevent well water pollution by reducing the contact of bacteria with the rope or bucket. Hence, health education directed at modifying potentially harmful practices and promoting beneficial behaviours in addition to explaining how contaminants are introduced into wells, should in theory, give rise to water quality improvements. Health education may be particularly effective where there is private ownership of wells. However, no studies have been identified which demonstrate whether health education can lead to improved water quality and if it can, by how much.

2.3.4. Summary of Part 2

While the theory of water contamination is well developed, there is a general lack of empirical support for the effectiveness of the numerous potential interventions to improve microbiological water quality. The few published studies which are available suggest that upgrading wells through improvements such as a windlass, bucket cage, drainage system, lining, headwall and cover are effective when provided as a combination. It is not known however, how effective individual components of the upgrading are in reducing contamination nor whether their combined effect is greater or smaller than the sum of the separate effects. The provision of pumps seems to be useful in settings with gross contamination, and tubewells are consistently cleaner than hand dug wells. There is a need for a rigorous assessment of the potential impact of 'software' interventions such as health education on well water quality.

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A randomized trial of the impact of rope-pumps on water quality

A.C. GORTER[1], J.H. ALBERTS[1], J.F. GAGO[1] & P. SANDIFORD[2]

[1]Fundación DESEAR, Villa Carlos Fonseca, Nicaragua
[2]Liverpool School of Tropical Medicine, UK

SUMMARY

Rope-pumps are now widely promoted as a low cost, easily maintained means to improve water availability in developing countries. However, in some instances their acceptance has been limited by concerns over the microbiological quality of the water. This study looked at the well water quality under a variety of conditions, comparing unimproved bucket and rope wells with wells with a windlass and rope-pump wells with and without a concrete cover. Other factors influencing the water quality were also examined.

Results indicate a 62% reduction of the geometric mean of the faecal coliform contamination of the well water as a result of the installation of a rope-pump with or without a concrete cover. Other factors found to influence the level of contamination of water in hand-dug wells were rainfall, number of households using the well, amount of water extracted daily and the distance of the well from the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well.

The installation of a simple rope-pump on family wells improves the water quality and availability at a favourable cost/benefit ratio.

Keywords: rope-pumps, hand-dug wells, family wells, water quality, water quantity, diarrhoeal diseases

INTRODUCTION

The use of inadequate water supplies relates closely to the high incidence of childhood diarrhoea in most developing countries. Both quality and quantity of water used are believed to play a role. There is a reasonable consensus that interventions which increase water availability have a greater impact than those which improve the quality of water, but combined interventions have been associated with the greatest reduction in disease (Esrey *et al.* 1991).

From the small amount of relevant literature available, it would appear that reduction of faecal contamination from very high levels to moderate levels is more likely to have a positive health impact than reductions from moderate to low levels (Moe *et al.* 1991; Sutomo 1987; Trivedi *et al.* 1971). Reductions of faecal contamination from very high levels are likely to be more effective where many families share a water source than where it is used by just one or two households.

In rural Nicaragua the preferred type of water supply is the family hand-dug well (Gorter *et al.* 1991). Sharing of a hand-dug well mostly occurs between families who are relatives or in cases where the economic and/or geological factors have made it impossible to dig more wells. In the rural municipality of Villa Carlos Fonseca, more than half of the population is served by these private wells which are almost entirely

Correspondence: Anna GORTER, Apartado Postal 2691, Managua, Nicaragua.

equipped with a bucket and rope or a windlass. An earlier study (Sandiford *et al.* 1989) showed that these wells have high levels of contamination which rise after the rains, though not as much as other traditional water sources.

Improvements in water quality and availability for this type of rural population can be made at a favourable cost/benefit ratio only by upgrading the private wells and improving the method of water extraction. The few published studies of the effectiveness of the numerous potential interventions to improve microbiological water quality of hand-dug wells suggest that upgrading of wells through improvements such as a headwall, apron, drainage channel, lining, cover, handpump, windlass or bucket cage are effective when provided as a combination (Buchrieser *et al.* 1989, Lacey *et al.* 1990, Morgan 1991). It is not known, however, how effective are the individual components of the upgrading in reducing contamination or whether their combined effect is greater or smaller than the sum of the separate effects. In order to design an effective cost/benefit intervention on hand-dug family wells the impact of the individual components of upgrading should be known.

In Nicaragua the rope-pump (Figure 1), based on the simple chain and washer pump (Lambert 1990), was introduced in 1983 (Sandiford *et al.* 1993). Extensive modifications have enabled rope-pumps to be produced which are easy to operate, have a high efficiency, low cost, and are easy to maintain (Alberts *et al.* 1993). More than 3000 are installed in the private and project sectors and recently the first 50 were introduced in Honduras.

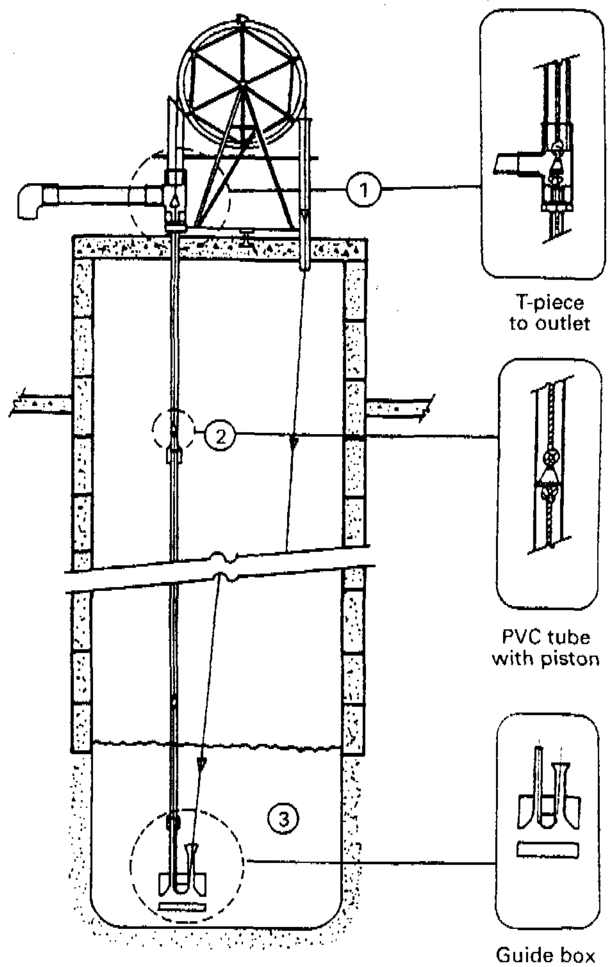

Figure 1. Cross-section of a rope-pump on a well.

MATERIALS AND METHODS

The study was carried out in Villa Carlos Fonseca, a rural municipality on the Pacific coastal plains of Nicaragua with a population of approximately 30 000. The area can be characterized as a tropical dry zone with small rivers which tend to dry up during the dry season. Thirty wells in 14 different communities were selected for the study and randomly assigned to three groups of 10 wells each: one group to be fitted with a rope-pump and concrete cover, a second group with only a rope-pump and the third group as a control group, not receiving a rope-pump until the end of the study.

To determine the baseline level of faecal contamination, two or three water samples were taken weekly from each well in the dry season and less than one month before the installation of rope-pumps and covers began. A baseline interview and observation were carried out to identify behavioural, structural and socioeconomic factors which might influence faecal contamination. Days of rainfall were registered. Seven water samples were taken from each well every 3 weeks following installation for a total of 5 months.

The Oxfam Delagua portable water quality testing kit was used to measure faecal coliform counts by the membrane filtration method. The water quality laboratory of the water and sewage Ministry prepared the cultures and trained the research assistant to prepare the kit, take the samples and perform the water quality tests. At the study midpoint the kit was taken to the national laboratory after incubating and samples were

Table 1. Characteristics of the study wells and their users

Characteristics of the wells		
Presence of a headwall	100%	
Upper section lined with masonry	100%	
Equipped with a windlass	53%	
Some sort of cover on headwall	43%	
Cover is complete and in use	20%	
Apron around headwall	10%	
Drainage system	0%	
Protection against animals	0%	
Presence of a corral in the yard	43%	
Cattle watered from the well	37%	
Well has been cleaned	93%	
Average time since well was cleaned (years)	0.5	
Average age of the wells (years)	17	(1–70)
Average depth of the wells (m)	14	(6–27)
Average water depth in the well (m)	1.1	(0.2–3.3)
Average distance to kitchen (m)	16	(0.85–70)
Average distance to corral (m)	19	(1–80)
Average daily water extraction (gallons)	134	(25–330)
Average number of families/well	2.1	(1–9)
Average number of persons/well	13.7	(3–65)
Characteristics of the users		
Average schooling heads families (years)	3.1	(0–11)
Proportion of family heads illiterate	21%	
Average number of members/family	6.5	(2–16)
Average age of children start drawing (years)	10	(6–15)
Average time to draw water (minutes)	40	(15–120)
Average distance family/well (m)	40	(0.7–170)
Average distance family/river (m)	650	(17–2000)
Average daily water use/family (gallons)	67	(10–330)
Usual drawers of water		
Women	63%	
Men	19%	
Children	10%	
Children together with women or men	5%	
Men and women together	3%	

counted independently by the research assistant and the head of the laboratory. No differences in counts were found. The temperature reading of the incubator was also checked. Samples of 50 ml were taken from the wells using the existing method of water extraction. The samples were incubated within 6 hours of sampling at 44°C for 16–18 hours, on pads impregnated with lauryl sulphate broth.

Data were entered in Epi-info and analysed using Epi-info and SPSS programs. A water quality model was fitted by analysis of covariance with the natural logarithm of the faecal coliform counts as the dependent variable. The independent variables considered were method of water extraction, design of the well, protection and distance from a source of contamination, amount of water extracted daily, amount of water in the well, and various socioeconomic factors.

RESULTS

Description of wells and users

Table 1 lists the characteristics of the 30 wells, and those of the well users. The latrine to well distance averaged 28 m (range 8–67 m), which means that, for the type of soil existing in the area (ocean sediments of clay and limestones, sometimes covered by volcanic sand), no lateral contamination of the water from latrine to well is likely (Lewis *et al.* 1981). The 61 families had a total of 396 members. Almost a quarter of the heads of families are illiterate. The vast majority are farmers though some work in the nearby capital.

Figure 2 shows that the more water is needed and the greater the well distance, the more people shift from the well to the river. For drinking, cooking and washing dishes, all families used only well water. In 25% of cases well water was also used to irrigate their premises and in 26% of cases to water the cattle.

Water quality

Table 2 shows the number and type of wells in each group. The Nicaraguan rope-pump company Bombas de Mecate SA installed 30 rope-pumps. Due to an initial misunderstanding between the research group and the company 3 wells in the intervention group with only a rope-pump received their rope-pump in error before the baseline measurements could be made and were therefore shifted to the control group. Of the rope-pump group with covers, 2 wells did not receive their rope-pump due the very low water levels in the wells after 3 years of severe drought in the study area

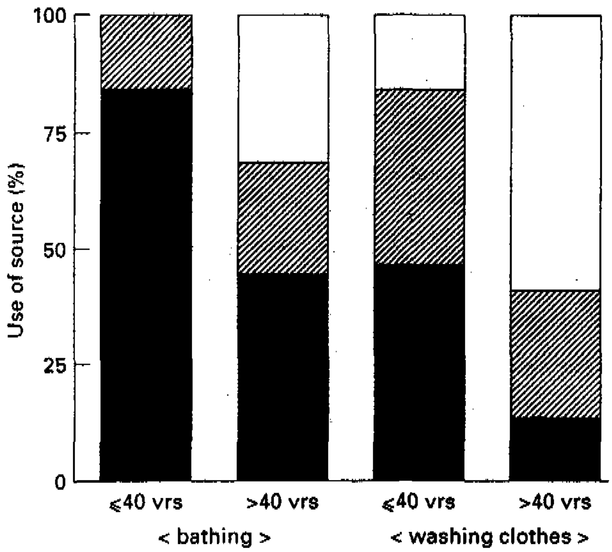

Figure 2. Choice of water source for bathing or washing clothes in relation to the distance to the well. □, Only river; ▨, well and river; ■, only well. vrs, Varas; 1 vara=0.8539 metres.

Table 2. The number and type of well in each group

Baseline type	Baseline wells	After modification: Control wells	Only pump wells	Pump/cover wells
Bucket	14	4	5	5
Windlass	13	8	2	3
Rope pump	3	3	—	—
Total	30	15	7	8

and thus were also shifted to the control group. Eventually the control group consisted of 15 wells as did the intervention group.

During a total of 283 visits 273 water samples were taken. Ten samples could not be taken because 4 wells were dry on 1–4 occasions. Of these 273 samples 15 were discarded because of an error in the culture and 4 because of well construction or cleaning activities in the week before sampling, leaving a total of 254 samples for analysis.

Rainfall commenced shortly after intervention and just one sample was taken in the dry period after intervention. Table 3 shows the effect of the rainfall on the level of contamination of the control group.

Table 3. Effect of rain on the geometric mean of faecal coliform contamination of the 15 control wells

	GM FC/100 ml	*N*
Dry season (February–mid May)	189	48
First rains (mid May–end July)	268	42
After first rains (end July–September)	221	32

Table 4 shows the geometric mean faecal coliform contamination of the different methods of extraction of the 30 wells during the baseline measurements and the entire study. The third column shows the results when adjusted for all the parameters included in the water quality model. Comparison of these values gave better results for the intervention with a rope-pump and concrete cover than for the rope-pump alone. Also it gives the impression that rope-pump wells are associated with better water quality than wells with a windlass.

However, the results of faecal contamination of the different subgroups before and after intervention as presented in Table 5 show no difference for rope-pumps with or without a concrete cover. A reduction of 62% in contamination was seen in the intervention group which was originally equipped with a rope and bucket; no reduction was seen in the group originally equipped with a windlass. Overall reduction of the faecal coliform counts of all the wells supplied with a rope-pump was 47%.

Figure 3 shows the frequency distributions, before and after intervention, of the natural logarithm of faecal coliform counts of the group originally equipped with a rope and bucket.

When assigning the faecal contamination of the bucket wells to groups of very high, moderate and low levels of contamination, all counts at the very high level are eliminated after intervention and part of the moderate counts is reduced to the low level (Table 6).

Other factors influencing water quality

The complete model, fitted on the water quality results of the entire study, is shown in Table 7, together with the significance level for each variable. In fitting the water quality model, each measurement of a single well

Table 4. Geometric means of faecal coliform contamination for different methods of extraction during the baseline measurements and the entire study

Method	Baseline study Crude FC/100 ml	*n*	Entire study Crude FC/100 ml	Adjusted[1] FC/100 ml	*n*
Bucket	323	34	288	324	56
Windlass	165	32	215	196	79
Only rope-pump	81	7	174	169	72
Rope-pump/cover	—		131	136	47
Total		73			254

[1]Adjusted for the parameters used in the water quality model; rainfall, number of families/well, distance of well/kitchen and amount of water extracted.

Table 5. Geometric mean faecal coliform counts before and after the intervention for the different types of baseline wells modified and for the control group

Type of baseline well	Before intervention Crude FC/100 ml	*n*	After intervention Crude FC/100 ml	Corrected for rain[1] FC/100 ml	*n*	Change (%) (95% CI)
Control group	189	35	238	189	87	0% (−28/40)
Bucket modified with only rope-pump	455	13	211	167	33	−63% (−78/−39)***
Bucket modified with rope-pump/cover	196	12	99	79	30	−60% (−82/−10)*
Windlass modified with only rope-pump	108	5	147	116	14	+7% (−66/250)
Windlass modified with rope-pump/cover	171	8	213	169	17	−1% (−54/114)
All modified bucket well	304	25	147	117	63	−62% (−77/−37)***
All modified windlasses	143	13	180	143	31	0% (−48/91)
All modified wells	235	38	158	125	94	−47% (−65/−20)**

*$P<0.05$; **$P<0.005$; ***$P<0.0001$.

In order to compare the counts before and after intervention, the effect of rainfall was removed. Differences between the means of the natural logarithm of FC counts in the dry period and the other two weather periods (see Table 3) were calculated and subtracted from the natural logarithm of each FC count of the corresponding weather period.

is considered as an independent sample as there was almost as much water quality variation for repeated samples from the same well as there was for different samples from different wells. No interactions were seen for the main effects. No difference in results of the fitted model was seen when those wells which mistakenly received their rope-pump too early and/or the wells which did not receive the planned intervention because of the drought, were excluded.

Contamination of the wells increases when more families are using the well and when more water is extracted daily, although these effects are less significant than the distance of the well from the nearest kitchen (Table 8). Structural factors such as a wooden cover and its use, the age or depth of the well, the presence and distance from a latrine or corral, and socioeconomic factors such as schooling, type of water-drawer and possessions of user families had no effect on water contamination. The effect of an apron, a good drainage system and protection against animals could not be assessed because none or almost none of the study wells possessed one. Neither could the effect of

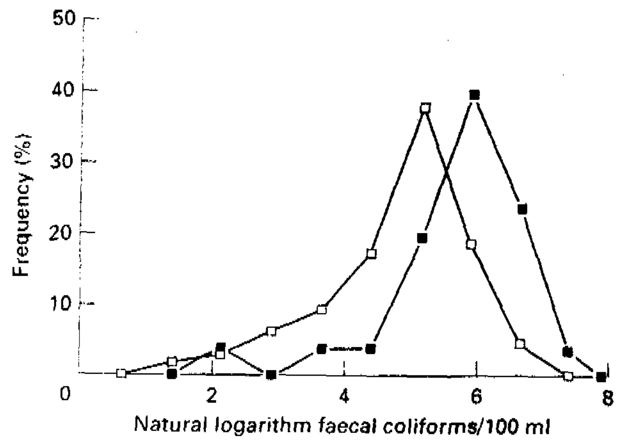

Figure 3. Frequency distribution of the $\log_e$ counts of the whole bucket group ■, before and □, after intervention. (After intervention corrected for rain.)

cleaning the well be determined, since the vast majority had cleaned their well within the last half year.

Table 7. Parameters included in the water quality model

Variable name (and type)	Range of values
Main effects	
Method of extraction*** (categorical)	1 rope-pumps 2 windlass 3 rope/bucket
Rainfall period* (categorical)	1 dry period (February-mid May) 2 first rains (mid May-end July) 3 after first rains (end July-September)
Number of families/well* (dummy)	1 = 1 2 >1
Covariates	
Distance well/kitchen**	continuous
Amount of water extracted*	continuous

*$P<0.05$; **$P<0.01$; ***$P<0.001$.

DISCUSSION

Results of this study indicate that faecal coliform counts are reduced by an average of 62% when a rope-pump is installed in place of a bucket and rope. A concrete cover appeared to effect no additional improvement, but the concrete covers in this study were of a poor design and did not seal the headwall hermetically. A better design is needed and its impact should be investigated.

The effect of a simple windlass seemed almost as great as that of a rope-pump, although pre and post-installation measurements were not made. The effect of a rope-pump or windlass must be ascribed to the elimination or reduction of contamination of the rope and bucket being dragged on the ground and touched by the hands. Improvement of water quality by installing a windlass and upgrading the well with a cover, drainage apron and lining has been reported in other studies (Morgan 1991; Lacey *et al.* 1990).

Other factors found to have an impact on contamination of the wells included rainfall, number of households using the well, amount of water extracted daily and the distance of the well from the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well. The association with the number of households using the well has been described in Kenya (Nyangeri 1986). The amount of water within the well may have some influence, reflecting dilution of the faecal contamination introduced daily into the well and its subsequent die-off. The fact that contamination of wells peaks during the start of the rainy season and returns to normal levels after the first rains is consistent with studies in other regions (Barrell & Rowland 1979; Blum *et al.* 1987; Feachem 1974; Mertens *et al.* 1990b; Moore *et al.* 1965; Wright 1985).

In developing countries, only around 40% of the rural population have access to good quality water

Table 6. Proportions of very high, moderate and low readings before and after intervention in the group originally equipped with rope and bucket

	Low level 0–100 FC/100 ml (%)	Moderate level 101–1000 FC/100 ml (%)	Very high level >1000 FC/100 ml (%)
Before	12	80	8
After	31	69	0

Table 8. Impact of the distance of the well to the nearest kitchen on the level of water contamination of the well

Distance well/kitchen (varas)	Crude GM FC/100 ml	Adjusted* GM FC/100 ml	*n*
1–9	251	260	77
10–19	201	200	87
20–29	177	176	26
>30	150	143	64
Total			254

1 Vara=0.8359 m.
*Adjusted for the parameters used in the water quality model; method of extraction, rainfall, number of families/well and amount of water extracted.

(Huttly 1990). The other 60% use traditional water sources of generally poor quality, among which the protected hand-dug well is one of the less contaminated; only springs are usually cleaner (Feachem 1980; Lindskog & Lindskog 1988; Sandiford *et al.* 1989; Tensay 1991; Utkilen & Sutton 1989; White *et al.* 1972; Wright 1985). Geological, socioeconomic and ethnographic factors determine the type of water supply and, in the case of hand-dug wells, the density of these wells. Where water depth makes it possible, people dig their own private or communal wells and this remains the most common method of groundwater exploitation, probably even more important than drilled wells (Clark 1988). To improve water and sanitation for this rural population, hundreds of programmes have been developed to drill, dig or upgrade communal wells and to equip them with a hand-pump. Many programmes failed due to abandoning of wells because of frequent breakdowns of the pumps and insufficient maintenance and hygiene education. Maintenance and hygiene education have now become a central feature of these programmes (Reynolds 1992; Kerr 1990). Besides, studies of water quality have shown that hand-pumps do not always yield the expected water quality improvement (Lloyd & Suyati 1989; Mertens *et al.* 1990b; Wedgwood 1989). Consequently a shift has taken place and programmes to upgrade the old-fashioned family wells and equip them with an improved method of extraction have gained in popularity (McIntosh 1989; Morgan & Chimbunde 1991; Utkilen & Sutton 1989).

Such programmes could have an important impact on the incidence of diarrhoeal disease. In the first place, the amount of water used for hygiene purposes will increase as availability increases through a decrease in the distance to the water source, improvement of the method of extraction or a decrease in the number of users per water source (Cairncross & Cliff 1987; Frankel & Shouvanavirakul 1973; Hoque *et al.* 1989; Sandiford *et al.* 1990; White *et al.* 1972). Secondly, the level of contamination of the well will decrease from high to moderate and eliminate very high levels of water contamination. Finally, protected hand-dug wells are used by fewer families than most unimproved sources. Since disease transmits readily by person-to-person contact in such households, water quality is less important. Many studies of in-house contamination of stored drinking water found no relation with diarrhoeal disease (Han *et al.* 1991; Henry & Rahim 1990; Mertens *et al.* 1990a; Moore *et al.* 1965). The same could account for the family well, in contrast to the community well where contaminating pathogens can come from all the families using the water source and where the source could be an important transmission route. Whether a persisting low level of faecal contamination of family well water still poses a serious risk for diarrhoeal diseases remains to be investigated.

Simple, cheap rope-pumps can yield a significant improvement in water quality while simultaneously increasing availability. Upgrading the well with a drainage system, a well designed cover or an extra large tube (to shift domestic activities around the wells to a point some 10–20 m from the well) and hygiene education programmes may further improve water quality. The low cost and easy maintenance of the rope-pump makes it appropriate for family wells.

CONCLUSIONS

Results indicate a 62% reduction in the geometric mean of the faecal coliform contamination of the well water due to the installation of a rope-pump with or without a concrete cover. Other factors found to influence the level of contamination of water in hand-dug wells were rainfall, number of households using the well, amount of water extracted daily and the distance of the well from the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well.

The installation of a simple rope-pump on family wells improves the water quality and availability at a favourable cost/benefit ratio. They can be considered a viable option for rural water and sanitation programmes in developing countries and a good adjunct to the traditional family wells. Additional programmes of upgrading the wells and hygiene education may improve the water quality, but their impact remains to be investigated.

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The Nicaraguan rope pump

by Peter Sandiford, Hans Alberts, Juan Guillermo Orozco, and Albert Gorter

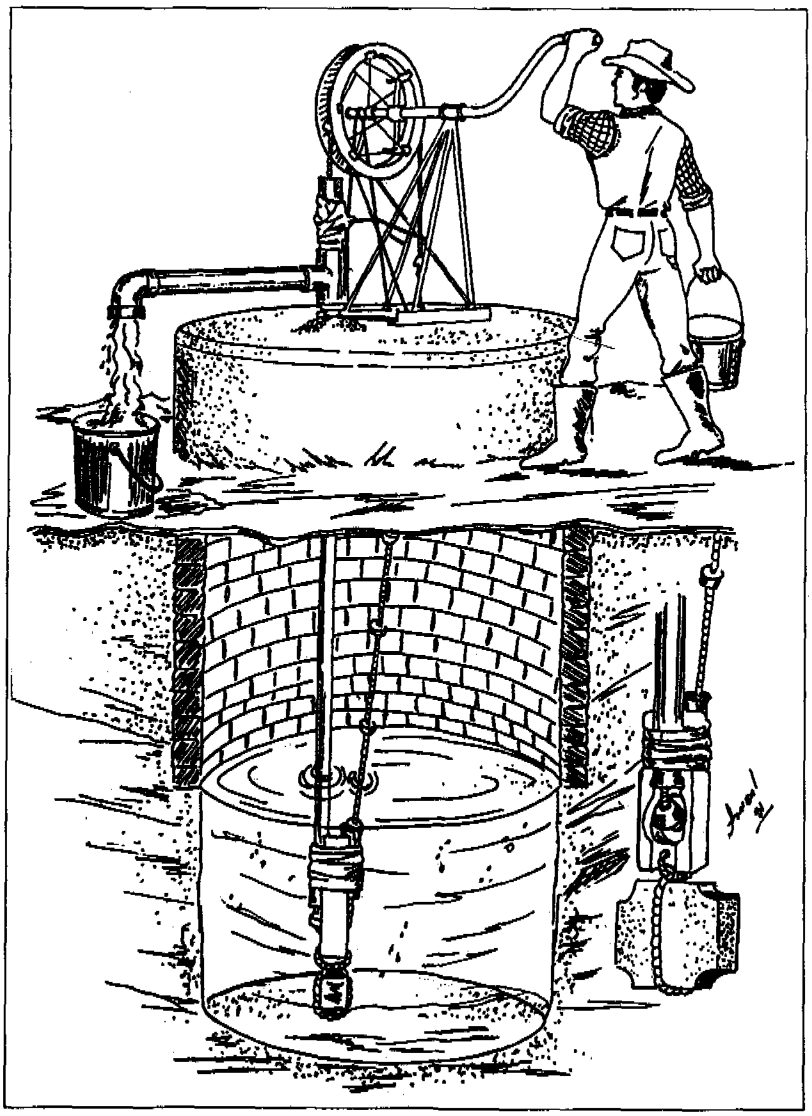
Despite numerous setbacks, the rope pump's development in Nicaragua has finally fulfilled its promoters' expectations. Even pumps installed during an emergency in an area without access to spare parts are still working.

ALTHOUGH THE FIRST rope-and-washer pumps appear to have been introduced into Nicaragua about 20 years ago, it was not until 1983 that a Belgian technician named Jan Haemhouts seriously began to develop the rope pump in Nicaragua. He had been involved with a peasant self-development project in Haiti in which the rope pump was one component, but the political situation there finally made further work impossible and he left the country. He believed that the rope pump, a technology that could be produced by peasants themselves, could serve as a catalyst around which the people could organize themselves to resolve their problems and improve their lives. His experience in Haiti, however, had convinced him that such a process could only be successful when set within a supportive political environment.

He turned instead to revolutionary Nicaragua, which at the time seemed to be the ideal setting to try out these ideas. He felt that before the rope pump could gain acceptance it needed to be developed to a stage where it could be presented as a highly reliable yet inexpensive water supply — in other words, as an appropriate technology. The development of the rope pump began in Nicaragua at the Appropriate Technology Research Centre of the Agrarian Reform Institute (CITA-INRA). CITA-INRA brought together professionals who were enthusiastically promoting a whole host of technologies including biogas, windmills for both electricity generation and water pumping, and hydraulic rams, and put them to work on the rope pump. Nicaraguan versions of the rope pumps evolved and a major effort was made to demonstrate that peasants were both interested enough and capable of building the pumps themselves. Training materials, including a video and a cartoon booklet, were produced at this time.

Despite some notable successes, CITA-INRA was disbanded in 1985, as civil war began to take its toll on the country's fragile economy. By that stage serious limitations had become evident. Too much effort had been put into the scientific development of technologies, while insufficient attention had been given to their dissemination within the ministries and the institutions responsible for their application on a large scale. Nevertheless, the experience in CITA-INRA had demonstrated the acceptability of the rope pump within the Nicaraguan peasantry, and those who had been involved with it from the early stages continued to seek opportunities for its further promotion as a component of the rural development projects being undertaken at that time.

The fact that rope pumps are still being made by local carpenters in the



The Nicaraguan rope pump has overcome numerous setbacks and is now a popular and reliable technology.

Readers interested in more information should contact Hans Alberts. Peter Sandiford is in the International Health Division, Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK; Hans Alberts and Albert Gorter are at Bombas de Mecate S.A., Apartado Postal 3352, Managua, Nicaragua; and Juan Guillermo Orozco is at UNDP, Managua, Nicaragua.

This one rope pump provides more than enough water for this Nicaraguan family.

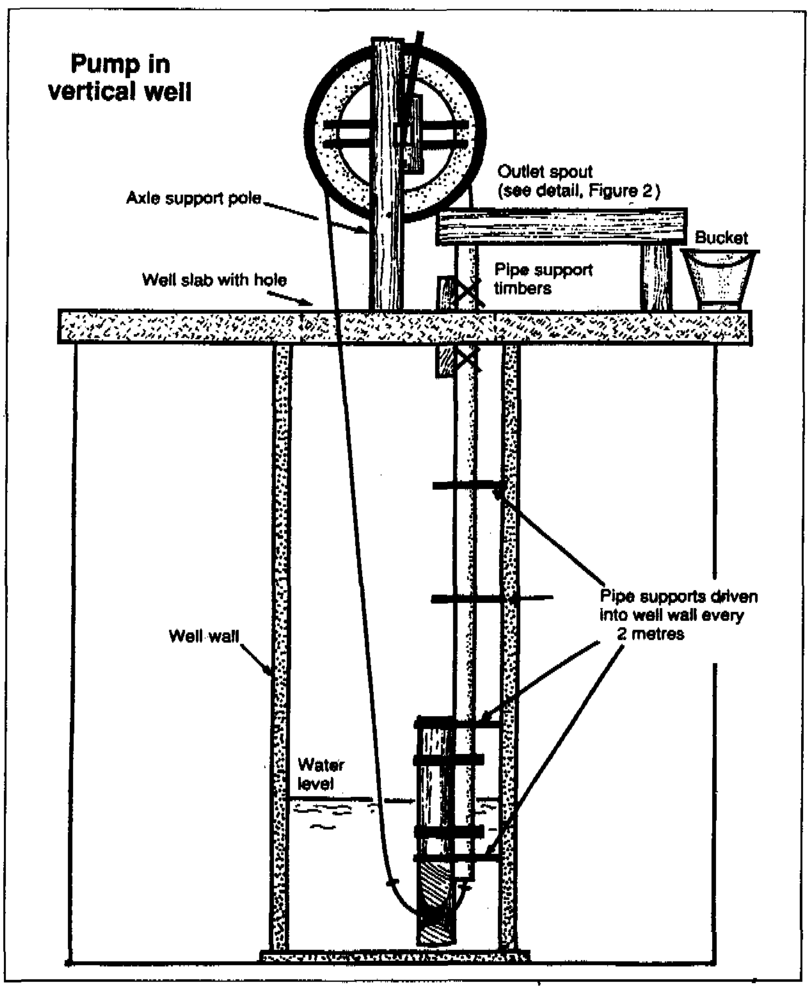


Figure 1. A typical design for a rope pump for use in a vertical well. (Figures 1 to 4 are from How to make a rope-and-washer pump, *IT Publications, 1990.)*

area surrounding the CITA-centre, without any institutional promotion since 1985, demonstrates the impact of those activities during that period. An accurate estimate is impossible to obtain because the pumps were installed all over Nicaragua and made by different people, but well over a hundred pumps must have been produced by these artisans.

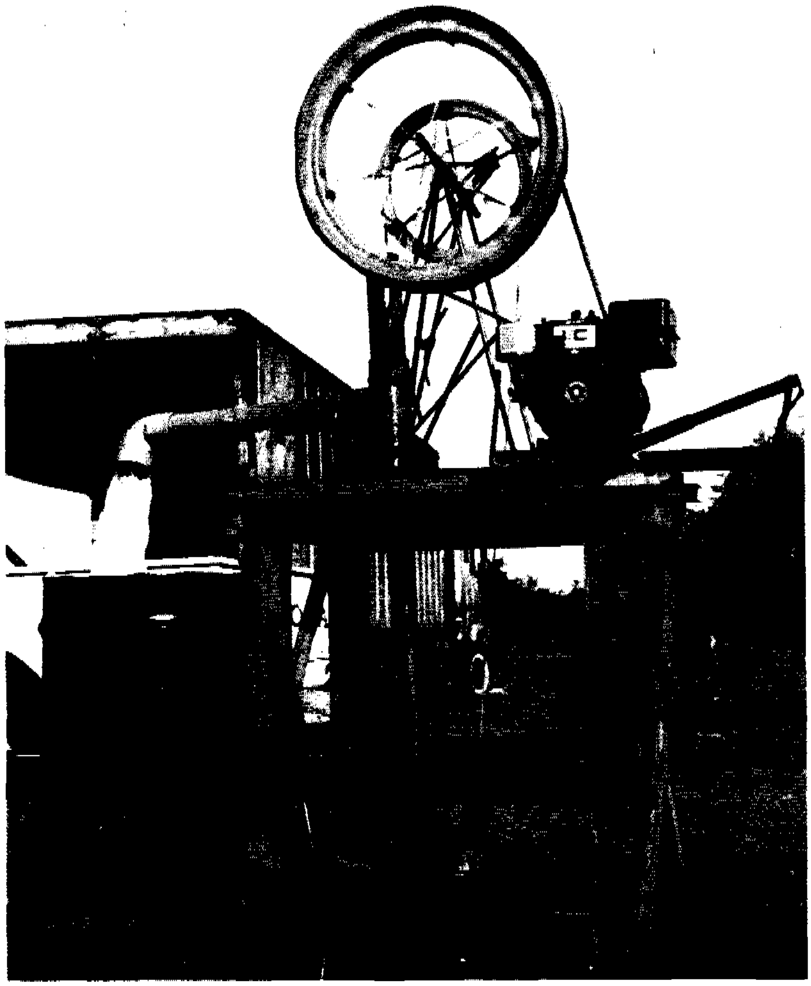
Try again

A significant turning point in the fortunes of the rope pump took place in 1987. Juan Guillermo Orozco, a Colombian sanitary engineer working as a consultant in the recently established Environmental Engineering Programme (INGAM) of the National Engineering University, together with Haemhouts, was looking for opportunities to continue to promote the rope pump in a setting without the problems of war and institutional politics which had plagued the project in CITA-INRA. They started work again with a small family-based co-operative in Monte Fresco, a village some 30km from the capital, Managua. The setting appeared to be perfect — the San José co-operative had been founded by peasants who did not have sufficient land to work on, and who had therefore taken to producing brooms, brushes, and other domestic articles. The co-operative had some equipment and staff and it seemed that, with a little training and investment, it could produce rope pumps and perhaps even realize Haemhouts' vision of peasant self-advancement. The idea was that the rope pump would be just one, though the first, of several technologies which would be developed and then produced on a larger scale in the co-operative.

Seeding finance of about $10 000 was obtained from the governments of New Zealand and Holland. The intention was to use this money to develop, produce, and install one thousand pumps in the hand-dug wells in the surrounding area. Once built, it would be possible to study and perfect the pump.

The project quickly made some significant advances. In the initial stage a number of technical improvements were made to the prototype pumps, effectively transforming them from a 'Heath Robinson' endeavour into a truly appropriate technology, although still lacking in important respects. The project was starting to stagnate in much the same way that it had in CITA-INRA, however — over 50 prototypes had been made without anyone daring to take the plunge and start production on a commercial scale.

It was an ill wind, however, that blew good fortune to the project. In September 1988 hurricane Juana struck Nicaragua, devastating much of the Atlantic coast of the country. A total of about 200 rope pumps were sold to the international organizations which were providing emergency aid to the victims of the disaster on the eastern seaboard. For the first time, the co-operative was forced to enter into production of the rope pump on a significant scale.



The rope pump can even be attached to a small engine if large quantities of water are needed.

Work under pressure

It did so with considerable success. Interestingly, at least 75 per cent of those pumps were still functioning perfectly two years after their installation, despite the fact that no backup had been provided and that the supply of replacement parts to the isolated Atlantic coast is notoriously difficult. The causes of failure in those that did break down have now been identified and have been resolved in the more recent improvements to the design.

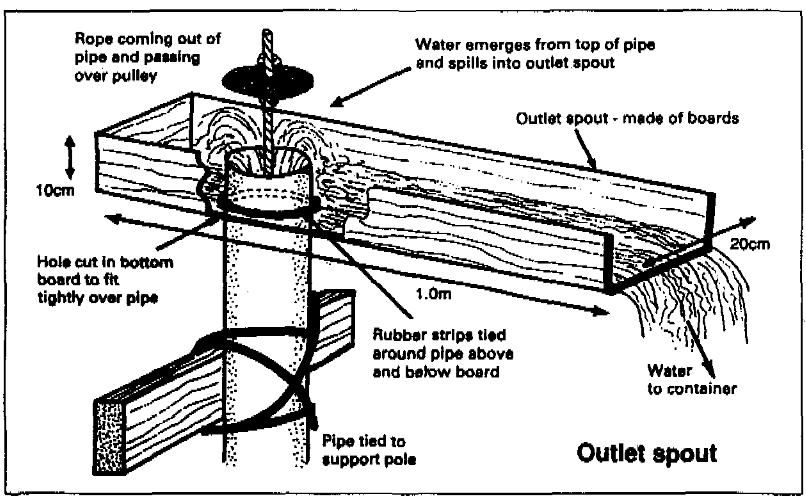


Figure 2. If used in a vertical lined well, the pump will need a suitable outlet spout. If a pre-formed spout is not available, this design can be used.

Unfortunately success does not always breed success. At this point, there emerged a serious rift between the philosophies of the two key protagonists of the rope pump project: one saw a role for the university in providing technical assistance and an opportunity for the environmental engineering students to learn from the practical application of appropriate technologies, while the other felt that technical assistance was unnecessary and that the peasants themselves had sufficient innovative ability to develop the pump to its final stage. According to the latter view, the involvement of the students would only detract from potential innovation. While one felt that the future for the project lay in selling pumps on a commercial basis, the other thought that this would destroy the potential of the rope pump to serve as a catalyst for peasant self-advancement. In the end, these philosophical differences led to the complete collapse of the relationship between the San José Co-operative and the Environmental Engineering Programme.

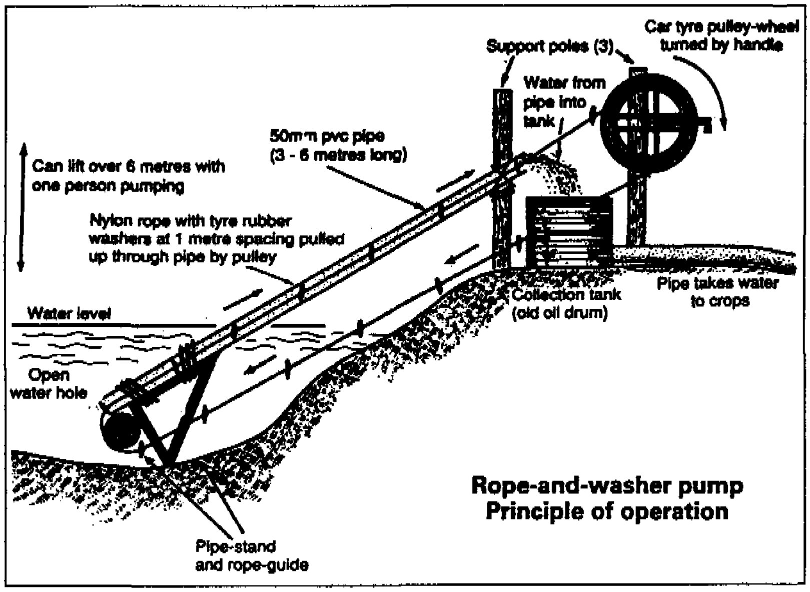


Figure 3. The rope pump can be used to deliver water for irrigation to nearby fields.

New supporters

Before that took place, however, both UNICEF and a Dutch volunteer organization had seen the potential success of the rope pump project. The Dutch group, who were undertaking a water and sanitation development project in one of the regions of Nicaragua, opted to use the rope pumps rather than the imported handpumps that they had originally intended to use. In this project the pumps were to be installed on communal wells, and the organization felt it important to ensure that microbiological quality was adequate. They therefore focused on ways to prevent the introduction of external contaminants through, for example, the use of well-head covers.

Meanwhile, UNICEF planned a new project which was to be executed by the Environmental Engineering Programme. The rope pump was initially a key component of this project, but in time it was relegated to an increasingly peripheral role as it was considered inappropriate for a university to be involved in industrial production. The university's role was restricted to one of determining guidelines and producing prototypes.

By this stage the co-operative was no longer producing rope pumps — it had never developed the skills to market the pump — and the university had effectively lost interest in working with the co-operative. Formal agreements between the co-operative and the university had failed to provide an adequate foundation for further work. Neither the co-operative nor the university had the skills required to market the pump effectively, to provide the backup services, or to manage the resources involved in production.

Unable to rely on the continued supply of the rope pumps, the INGAM/UNICEF project decided in early 1990 to discontinue promoting the pump and to concentrate on their new role in developing policy guidelines. This left two rope pump promoters without jobs and a number of disgruntled families in the area who had been promised rope pumps by the UNICEF/INGAM project.

In February 1990 an historic meeting took place between the two pump promoters, the UNICEF/INGAM's project administrator (who had also been laid off), and a Dutch physicist who had previously worked in Nicaragua producing wind-driven water pumps. The feeling which pervaded this meeting was 'let's do it ourselves — independently of any bureaucracy'.

Here started what became, in August 1992, Bombas de Mecate S.A. (Rope Pumps Ltd), a small cottage industry producing rope pumps for the Nicaraguan population. Beginning on a small scale it placed a heavy emphasis in the initial stage on promoting the pump, taking advantage of the various fairs and exhibitions about the country to demonstrate its worth and thereby obtain sales. Advertisements in newspapers and on the radio were also used. Now it employs a dozen workers and installs on average 60 rope pumps each month. As the pump became better known, the need for active marketing diminished and most sales are currently derived from the recommendations of other pump owners. Sales have increased steadily and Bombas de Mecate is now operating commercially without any external subsidies. There are plans to establish branches in different parts of the country and perhaps even outside of Nicaragua. The Dutch group has also had some success. Following the example of Bombas de Mecate, they have started to sell the pumps on a commercial basis. Some of the components of their rope pumps are sold to them by Bombas de Mecate.

So what are the lessons from this story? Why has the rope pump proved such a successful technology while other hand pumps have been such dismal failures? Why has the rope pump so stubbornly re-emerged from the institutional mires which have threatened to sink it? Surely this is the test of a truly appropriate technology — one which overcomes the inevitable obstacles which are placed in its path. The ease of operation, low cost, simplicity of maintenance, ready availability of spares, and high efficiency are undoubtedly important factors. They have perhaps ensured that the rope pump did not fade into obscurity in Nicaragua. ●

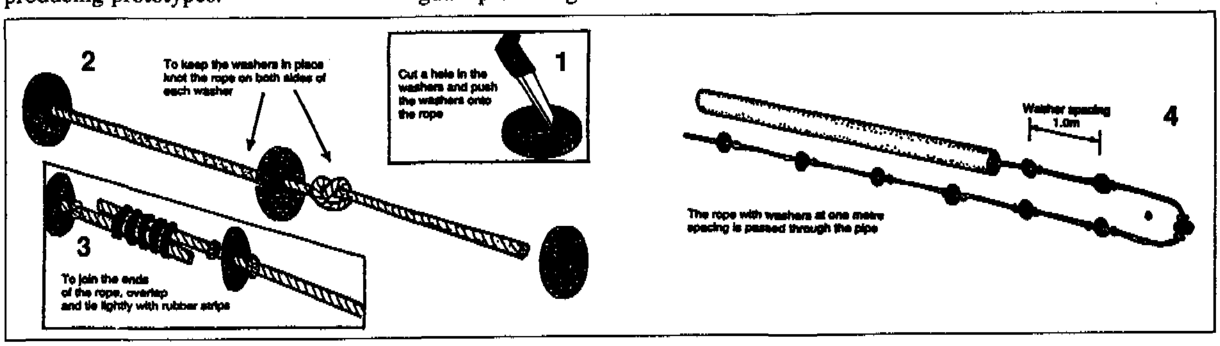


Figure 4. Tips for constructing your own rope-and-washer pump.

How the rope pump won in Nicaragua

by Henk Alberts, René Meza, Denis Solís, and Marvin Rodríguez

Following on from a previous article, the founding members of Bombas de Mecate tell the story of the further adventures of the rope pump.

AFTER A TEN-YEAR development process in Nicaragua, the rope-and-washer pump has proven its efficiency, low breakdown rate, low price, and very high social acceptance. The pump is used in wells up to 40 metres deep, and it costs about US$75. Current sales of up to eighty pumps a month indicate the extent of the success. In a previous *Waterlines* article[1] the story was told of the institutional struggles around the development of the rope pump and the start of the enterprise 'Bombas de Mecate S.A.' This article describes the conditions which led to the introduction of the rope pump, focusing on the organizational and technical matters related to this development.

The integrated development approach, taking into account local customs, economic constraints, and the adaptation of high technology to local capacities, has been the key to reaching the present stage of development.

History

The technology behind the rope-and-washer pump goes back hundreds of years, but recent literature reveals that the development of the pump in the last ten years has been based on appropriate technology.[2,3,4,5] All the studies are enthusiastic about the pump, but the focus on the use of appropriate technology based on locally available technology and materials has led to designs that are less efficient than they could be, and efficiency is one of the main priorities for users.

The rope pump was introduced to Nicaragua several decades ago. In 1983, however, attention was again given to its development by an appropriate technology project in the north of the country. (The project closed a few years later.) In 1986, the National Engineering University took the initiative to continue its development, but lack of proper management soon caused this initiative to collapse.

At the beginning of 1990, local technicians involved in the earlier project started a private workshop. At that time, the main problems affecting the rope pump in Nicaragua — mainly the guide, the brake, and the level of efficiency — had not been resolved. The continued on-the-job development of different parts of the pump acquired during production, installation, and use, resulted in a high-efficiency product with very low breakdown rates. Its low price, about $75, makes the pump available to most of the rural population in Nicaragua.

Local organization

The rope-pump firm Bombas de Mecate S.A. began operations in February, 1990, when its four founding members decided to set up in business by themselves, outside the framework of a funded project. Each of them had several years' experience working on projects funded by governments and NGOs, and they felt that the chance of benefits from these projects really reaching the rural population were slight. They had also donated their time and experience to co-operative and small enterprises, many of which failed because of poor administration.

It took about three months to gather together stock of the different parts to begin producing the rope pump in its basic, rudimentary form. Only two of the four members were working full-time at Bombas. A start-up loan from the local foundation DESEAR (Foundation for Social and Economic Development of the Rural Areas) was used as capital for investment and recurrent costs. Sales grew to about twenty pumps a month, and by the end of 1990, the firm's sales were covering their costs. The total capital invested was about $5000, of which $4000 was spent on stocks and materials, and $1000 was used to cover initial expenses. In December 1990, a promotional campaign was begun at industrial and agricultural fairs throughout the country, on the radio, and in newspapers. During 1991 and 1992 about $15 000 of the proceeds of rope pump sales was invested in these promotional activities, and this strategy of selling directly to farmers has been fundamental and successful: half of the rural population now knows about the rope pump.

Sales figures have risen to 80 pumps a month, and a total of 1800 pumps have been installed. The business is not making a profit because of the heavy investment in promotion and development activities. The total amount of capital invested in stock has increased to about $8000, funded through a loan by the same foundation. In 1993, a total of 20 people were engaged directly or indirectly in the

The company built up customer awareness by promoting the pump widely and selling directly to farmers.

The rope pump has recently been introduced into Honduras by Bombas, who are working through both an NGO and the private sector.

production and installation of rope pumps.

Specifications

The technical development of the pump has been a continuous search for cheap methods that can be implemented on a large scale. Some raw materials are imported, but the pump is manufactured entirely in Nicaragua. The components of the rope pump, such as the wheel, the guide, the washers, the old cut-up car tyres, and even the rope itself, were produced by independent workshops. Each of the components was developed in close and continuous co-operation with these workshops. Initially the firm only assembled and installed the pump. In this way no capital investment was necessary for production, although the costs were relatively high. The costs of the raw materials of the pump is in the range of $30 for each pump. At the end of 1992, as the market for the pump became stable, the firm took on pump production, including ceramic production, injection of the plastics, welding, and other processes.

A typical rope pump is made of the following parts:

- The wheel: iron rods, tubing, and concrete steel, using an old cut-up tyre for the pulley wheel.
- The pumping tube: PVC tubing, with the diameter depending on the depth of the well.
- The rope: 5mm polypropylene rope.
- The washers: the washers or pistons are made of polyethylene or high-density polythene. Great attention was paid to this part of the pump in order to achieve high efficiency and durability. High efficiency is especially necessary to permit pumping from deep wells and to allow children to be able to pump water.
- The discharge tube: PVC tubing, but with a larger diameter. The discharge tube is coupled to the pumping tube with a tee and a reduction piece.
- The guide box: glazed ceramic fired at high temperature (2300°F). Without any doubt, one of the most sensitive parts of the pump.

The capacity of the rope pump is shown in Table 1. (1 vara = 33 inches = 0.83m) The figures are based on results in practice. An adult can easily pump at a capacity of about 80 watts for 15 minutes. Children have a capacity of about 40 watts. Thanks to the high efficiency of the rope pump, children as well as adults are able to pump water, an important condition for getting the pump to be accepted.

The diameter of the pumping and discharge tubes vary according to the depth of the well. Table 2 indicates the tubes used in relation to the depth of the wells, based on experience with clients to date.

Pumping tubes of 45mm and 60mm are also used in shallow wells with good results. (ASTM D-2241 standards are used in the tube diameters.) The pump's washers were traditionally made by knotting the rope, or from old tyres, inner tubes, old foam plastic sandals, or wooden rings. The first rubber washer, formed by injecting rubber into moulds, was made in a workshop called HUTECNIC in Nicaragua in 1984.

Table 1. Pumping capacity of rope pump at different depths

Depth (varas)	Depth (m)	Adult (litres per minute)	Child (litres per minute)	Time necessary for an adult to fill a barrel (min)
5	4	83.27	45.4	2.5
10	8	41.6	22.7	5
15	12	26.5	15.1	7.8
20	17	18.9	11.7	11
25	21	15.1	9.5	14
30	25	13.2	7.9	16
35	29	11.7	6.8	18
40	33	10.2	5.7	21
45	37	9.1	5.3	23
50	42	8.3	4.5	25

Table 2. Tube diameters in relation to depth of wells

Depth of tube (m)	Pumping tube diameter (mm)	Discharge tube diameter (mm)
0-11	30	60
11-19	23	45
19-40	18	30

Efficiency

It was felt that the efficiency of the rope pump, and the significance of that efficiency, had not been understood.

The literature frequently supposes that each washer takes with it some water and some air.[6] The theoretical description of rope pump efficiency, based on fluid mechanics, using a model similar to the 'rotameter' (a floating flowmeter in a conical tube), and taking into account the volume of rope and washers, gives results within a 5 per cent error of the practical test results. Tests have been executed in wells from 8 to 40 metres deep using a watch and a bucket as laboratory instruments. A constant factor has been encountered concerning water losses around the washers. This factor depends on the form of the washers and tube diameter and ranges from 0,6 to 0.9 using hard plastic conical washers. A turbulent flow can be assumed around the washers.

There is a very easy way to test this volumetric efficiency. Turn the wheel at a velocity at which it just begins to yield water; losses are equal to the energy input. Thereafter, define the rotation velocity at which the pump is normally used (this depends on the strength of the user, and the depth and diameter of the tube). The losses are almost constant, so the volumetric efficiency can be estimated under the assumption of relatively small friction losses. For example: 15rpm does not yield any water, while 60rpm is normal use and volumetric efficiency is about 75 per cent. A child turning at 30rpm achieves an efficiency of 50 per cent in this case, which is not acceptable. Tests can be performed over the whole range of velocities, static heads, etc. The mechanical losses are quite constant, ranging from 10 to 20 watts. The torque necessary to move the pump handle can also be measured easily. These results are in agreement with those found by Faulkner.[7] Friction between the washers and the tube has to be avoided. The viscous resistance and kinetic energy of the water column are negligible in relation to pumping energy.

Hygiene

Compared to the rope and bucket, the rope pump can lead to better hygiene practices. There exists a strong association between water availability and diarrhoea-related deaths.[8] Clients are advised to install a concrete cover on their wells, and to make aprons around them. In many cases the acceptance of the concrete cover is low because it is too heavy to take away while the well is cleaned or deepened. Water quality can be increased by taking precautions such as this cover which prevent water from dripping back into the well, but economic reality results in the use of wooden covers. A study begun at the end of 1991, and financed by the British Embassy in Nicaragua, is investigating the impact on water quality of both the rope pump alone and the rope pump with a concrete cover compared with the traditional well with wooden tap and bucket. Preliminary results indicate that the rope pump lowers contamination and coliform concentration by 60 per cent.

Types of rope pumps

A range of different pump types has been developed. There is a normal rope pump, used for family drinking-water, cattle watering, and small-scale irrigation. This pump is usually installed on wooden covers or beams. In perforated wells with diameters from 4 to 12 inches virtually the same pump is used, but with an extra tube to guide the washers downwards. A special pump has been developed and marketed to fill water tanks directly from the well for running water applications. A similar design was later found in the literature.[9]

Another very interesting development is a rope pump coupled to a small gasoline motor. Its economical application for irrigation purposes is gaining widespread use, as traditional gasoline or diesel pumps can be used with static heads up to about only 6 metres. The gasoline rope pump can open up a large area to farming in tropical dry zones, where water is found at depths between 5 and 25 metres. An initial investment of around $1000 for all the equipment is relatively low, and alternatives at these static heads are much more expensive. Capacities of 200 litres per minute from a depth of 10 metres are easily attainable.

The horticultural activities of 'Rope Pump Ltd.', whose main objective is pump promotion, have actually become an important business, employing up to ten people during the harvest season. (The same rope pump coupled to a tractor was developed by a local farmer for use in watering cattle.) A windmill with a rope pump has been developed in an independent workshop, but in co-operation with Bombas de Mecate SA. The first prototypes have been installed and show promising results.

The future of the rope pump

Bombas de Mecate S.A. has established a firm base in Nicaragua, helping rural areas to solve their water supply problems with cheap and easy methods. Although the firm is not making a profit, the tremendous dedication of its members has made it a totally self-sufficient success. A total of 2000 rope pumps will have been installed by the end of 1993, but as there are about 200 000 wells in Nicaragua, there is still a long way to go to cover them all!

Without any doubt the rope pump has a great future in other countries with similar economic and natural conditions. The main problem will be how to convince policymakers at international levels that the rope pump is a viable option. ●

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Bombas de Mecate S.A. now has a firm administrative structure capable of establishing branches in other countries. Development organizations interested in or wishing to cooperate in manufacturing the rope pump in other countries can contact Bombas de Mecate S.A. at Apartado Postal 3352, Managua, Nicaragua. Fax: 010 505 2 784045 or 780167.

IX) Evaluation report Nicaraguan experiences with the rope pump. Evaluation undertaken by the IRC (International Water and Sanitation Centre, WHO collaborating Centre) The Netherlands, September 1995. (executive summary and references included.)

Executive summary.

There is a continuing need to develop and introduce appropriate technologies for water supply in developing countries. On the other hand, there are reported successes of the rope pump development and applications in Nicaragua. This matching of need and reported success resulted in an evaluation mission to assess the potential of this technology. The mission was fielded in the period 8-14 March 1995. The evaluation was jointly financed by the Royal Netherlands Embassy in Costa Rica, the SNV-supported PASOC Program in Nueva Guinea (Nicaragua), and the IRC.

The Evaluation Team consisted of five experts comprising two IRC staff, one Dutch consultant and two Nicaraguan consultants. Their expertise covered mechanical engineering; institutional issues; community participation and social issues; water supply technology; and the economic and financial issues.

The overall objective of the evaluation was to assess the short- and long-term performance of the rope pump in Nicaragua in view of its potential for wider application and active promotion outside Nicaragua.
The specific objectives related to the technical functioning and performance; the materials used and manufacturing quality; comparison with other handpumps; success factors for introduction in Nicaragua; technical and financial sustainability; affordability; cost-effectiveness; acceptance; private sector involvement; replication of private sector involvement in other countries.

The evaluation was preceded by a literature review financed by the IRC on world-wide experiences with rope pump technologies. The review document was used by the Evaluation Team as a briefing paper.

The Evaluation Team held and half-day briefing workshop on evaluation issues, and ESAs[1)] and agencies experiences with the rope pump in Nicaragua. The Team had discussions with local organizations, mechanical workshops, communication and users. Major rope pump workshops were visited to evaluate the production process, and technical aspects of the pump were assessed in the field. At the end of the short mission, an half-day participatory workshop was held to present and discuss the Evaluation Team's preliminary findings, conclusions and recommendations.

<u>The major conclusion is that the rope pump has a great potential to be introduced in other countries to add an appropriate option to the range of groundwater lifting technologies.</u>

For many countries the rope pump has the potential to be locally manufactured, marketed and installed by the private sector, including smaller local mechanical workshops. Operation and maintenance requirements are relatively low and simple, and therefore, users, with some minimal support from the local private sector (e.g.

through some repairs, spare parts support), can take care of this. This is particularly attributed by the absence of piston, foot and piston valves, pump rods etc. However, there is a need for constant attention on simple but regular maintenance requirements. The rope pump is for many conditions a sustainable technology.

The relatively low level of investment (approximately US$ 80) makes the technology accessible for individual households and farmers, although for the poorer sections of the society the rope pump will not be affordable on a private basis. In that case, either the communal rope pump or the self-made rope pump could be considered as an option. For both, the O&M care and costs will be feasible.

Although the rope pump has been under continuous technical development in Nicaragua since 1983, the pump still needs technical improvements. Particularly, as no standardized designs and manufacturing processes are described, the individual workshops differ in their design and product quality. ESAs demand such design criteria and standards, and quality control of the product.

The success of the rope pump in Nicaragua is the result of (i) the initial interest of the individual families to install the pump for farm activities (cattle watering; small scale irrigation) and also for domestic water uses, and (ii) the interest of national technical institutions and the private companies (small workshops) to experiment with design and to improve the parts of the pump. The role of ESAs has also been substantial, particularly in the development of the communal rope pump. One company has been very active in the promotion and commercialization of the manufacturing and installation of the pump. Surely, this promotion and commercialization has substantially contributed to the popularity and high coverage of the rope pump in Nicaragua.

The recommendations include activities to promote internationally the proven appropriate technology. These activities include development of promotional materials (publications, video), and organization of a workshop in Central America, publication of articles for sector journals, dissemination of the technology in conferences etc. and development of pump selection criteria, standard designs, manufacturing processes and quality control procedures for the rope pump.

A series of recommendations are made on how to introduce the rope pump in a specific country.

For Nicaragua, a number of recommendations are made with regard to technical, manufacturing, community organizational, and training aspects. Thereby, a division is made between the 'industrial' pump, the 'self-made' pump and other types. A special attention is paid to the problem of the affordability of the pump for the poorer sections of the country.

As a first follow-up of the evaluation, the potential funders for the most important recommended activities will be approached to discuss and agree on actions and budgets.
This was not possible in the time-frame of the evaluation.

1) ESA = External Support Agency

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Lift Water by Rope Pumps

Lifting water from a well is not an easy job. If you install mechanical handpumps, most break down soon after installation; if you leave the well open there are serious risks for contamination. What is a good technology that will continue working in a poor rural village far from town, with little risk of contamination of the well water? And, how can a lifting technology reduce women and children's heavy job of getting the water from deep down -sometimes as much as 40 metres- into their buckets and jars?

The solution was introduced in Nicaragua 13 years ago. It is called the "rope pump". In 1983 the first prototype of the rope pump was installed, and was further developed with inputs from technical institutions and farmers. It was particularly these farmers who indicated that this water lifting device would make their irrigation work easier. They could manufacture it themselves with local materials (timber and rope) and it was socially acceptable and financially sustainable. Farmer-to-farmer workshops spread the technology.

The drinking water supply sector became interested, and with contributions from government departments and Nicaraguan and international organizations, the technology was further adapted and improved to make it sufficiently strong and durable for community water supply. The Nicaraguan private sector further improved, but particularly *promoted* the rope pump. One leading workshop, Bombas de Mecate S.A., has sold some 3500 rope pumps.

Before spreading the good news to the rest of the world, this reported success had to be evaluated. To be assessed were the technical functioning and performance, materials used and manufacturing quality, comparison with other "hand"pumps, success factors in Nicaragua, technical and financial sustainability, affordability, cost effectiveness, acceptance, private sector involvement, and potential for replication by the private sector in other countries.

The Netherlands Government, the SNV-Netherlands Development Organization and IRC provided funds to send a multi-disciplinary expert team to Nicaragua. They listened, they asked, they observed and they saw with their own eyes that the rope pump is truly a water lifting technology that is sustainable at the low-income community and household level. Why? First of all its O&M is relatively simple and cheap because the rope pump does not have complicated mechanical parts. While the rope pump needs constant attention and simple but regular maintenance, users can do it themselves with some minimal support from the private sector e.g. through some repairs and spare parts. The evaluation also saw that the rope pump technology is accepted all over Nicaragua.

The evaluation team concluded that the rope pump has great potential as an appropriate option to the range of groundwater lifting technologies in other countries. It was concluded that also in other countries the rope pump can be manufactured locally, marketed and installed by the private sector, including smaller mechanical workshops. Because the rope pump is relatively cheap to buy (in Nicaragua US$ 80), it is affordable for community users groups, individual households and farmers, where groundwater is not deeper than some 50 metres below ground level. A cheaper model, the self-made rope pump (in Nicaragua US$ 25) could be considered as an alternative for small groups of users.

The conclusion of the evaluation does not mean the end of other water lifting technologies. It does add a low-cost, effective and sustainable technology for several rural water supply conditions.

Follow-up workshops were held in Nicaragua to discuss what could be done with the recommendations of the evaluation. This resulted in a new three-year Water Supply and Sanitation Programme in Nicaragua funded by COSUDE (SDC: Swiss Development Cooperation).

including the support for international technology transfer of the rope pump. Activities include the publishing of technical production manuals in different languages and the establishment of a training centre to teach people how to manufacture a strong rope pump. The rope pump is already gaining popularity in neighbouring countries such as El Salvador and Honduras.

The interest in the evaluation results is great; from all over the world support agencies and projects want to know more about "this" rope pump. Therefore IRC plans to publish a promotional document, to convince policy/decision makers and planners at the international and national level of the great potential of the rope pump as a sustainable water lifting technology that can be locally manufactured. Funders for this publication, which will be available in English, French, Spanish and Portuguese are being approached.

In the meantime, parties interested in getting acquainted with this technology can contact:
The Technology of Transfer of the Rope Pumps Co. Ltd.
Bombas de Mecate S.A.
PO Box 3352
Managua
NICARAGUA