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 post hoc 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 Shigella	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 a either 'safe' (uncontaminated piped water, protected springs and treated water), 'less safe' (springs, deep well pumps, shallow well pumps, dug wells,

[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

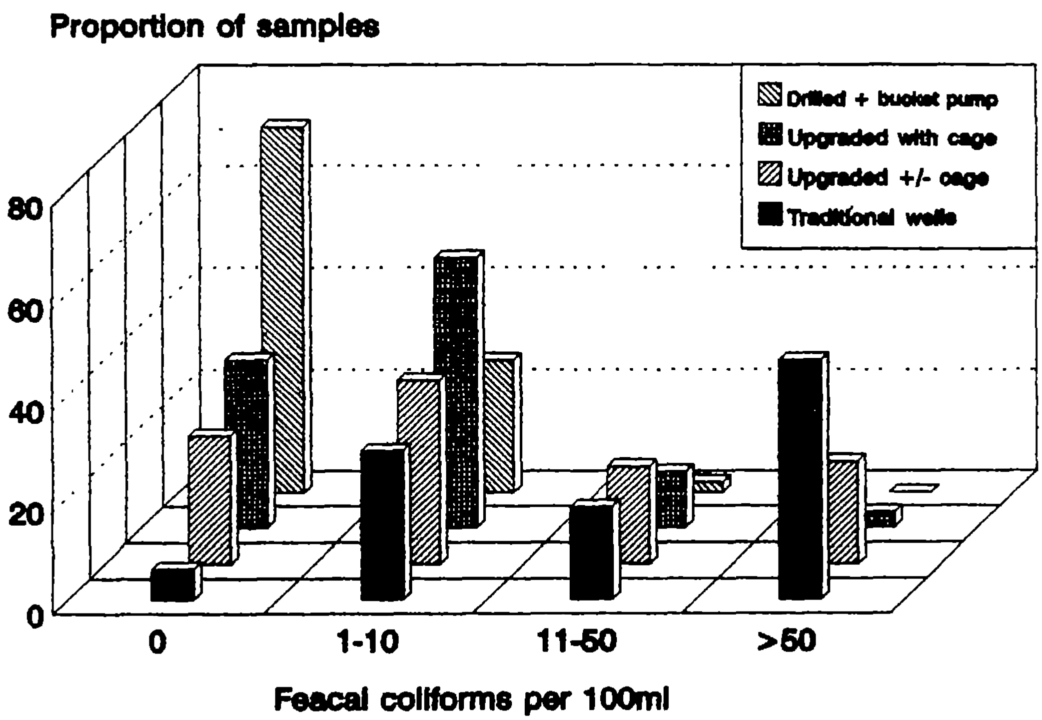
Source: Morgan, 1990[62]

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.

References

1. White GF, Bradley DJ, White AU, Drawers of Water: Domestic water use in East Africa, University of Chicago Press, Chicago, 1972.

2. Briscoe J, Intervention studies and the definition of dominant transmission routes, American Journal of Epidemiology 1984; 120:449-455.

3. Cairncross S, Ingested dose and diarrhea transmission routes, Lancet 1984; 125:921-922.

4. Miller CJ, Feachem RG and Drasar BS, Cholera epidemiology in developed and developing countries: new thoughts on transmission, seasonality, and control, Lancet 1985; Feb 2:261-263.

5. Feachem R, McGarry M and Mara D (editors), Water, Wastes and Health in Hot Climates, 1987, English Language Book Society and John Wiley & Sons, Chichester, UK.

6. Esrey SA, Feachem RG, Hughes JM, Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. Bulletin of the World Health Organization 1985; 63:757-772.

7. Pinfold JV, Horan NJ, Mara DD, Seasonal effects on the reported incidence of acute diarrhoeal disease in Northeast Thailand, International Journal of Epidemiology 1991; 20:777-786.

8. Ewald PW, Waterborne transmission and the evolution of virulence among gastrointestinal bacteria, Epidemiology and Infection 1991; 106:83-119.

9. Weir JM, An evaluation of health and sanitation in Egyptian villages. Journal of the Egyptian Public Health Association, 1952; 27:55-114.

10. Kourany M, Vasquez MA and Mata LJ, Prevalence of pathogenic enteric bacteria in children in 31 Panamanian communities. American Journal of Tropical Medicine and Hygiene 1971; 20:608-615.

11. Levine RJ, Khan MR, D'Souza S and Nalin DR, Failure of sanitary wells to protect against cholera and other diarrhoeas in Bangladesh, Lancet 1976; 2:86-89.

12. Feachem RG, Burns E, Cairncross S, et al, Water, Health and Development: An Interdisciplinary Evaluation, Trimed Books, London 1978.

13. Shiffman MA, Schneider R, Faigenblum JM, et al, Field studies on water, sanitation and health education in relation to health status in Central America. Progress in Water Technology, 1978; 11:143-150.

14. Blum D and Feachem R, Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology, International Journal of Epidemiology 1983; 12:357-365.

15. International Bank for Reconstruction and Development. Measurement of the health benefits of investments in water supply: Report of an Expert Panel, Public Utilities Department Report No. PUN 20, World Bank, Washington DC, 1976.

16. Briscoe J, Feachem RG and Rahaman MM. Measuring the impact of water supply and sanitation facilities: prospects for case-control methods, WHO/CWS/85.3. World Health Organization, Geneva, Switzerland, 1985.

17. Briscoe J, Feachem RG and Rahaman MM. Evaluando el impacto en salud: agua, saneamiento y educacion sanitaria. Centro Internacional de Investigaciones para el Desarrollo, Ottawa, Canada, 1987.

18. Mertens TE, Fernando MA, Cousens SN, et al, Childhood diarrhoea in Sri Lanka: a case-control study of the impact of improved water sources, Tropical Medicine and Parasitology 1990; 41:98-104.

19. Knight SM, Toodayan W, Caique WC, et al, Risk factors for the transmission of diarrhoea in children: A case-control study in rural Malaysia, International Journal of Epidemiology 1992; 21:812-818.

20. Daniels DL, Cousens SN, Makoae LN and Feachem RG, A case-control study of the impact of improved sanitation on diarrhoea morbidity in Lesotho, Bulletin of the World Health Organization, 1990; 68:455-463.

21. Young B and Briscoe J, A case-control study of the effect of environmental sanitation on diarrhoea morbidity in Malawi, Journal of Epidemiology and Community Health 1988; 42:83-88.

22. Baltazar J, Briscoe J, Mesola V, et al, Can the case-control method be used to assess the impact of water supply and sanitation on diarrhoea? A study in the Philippines, Bulletin of the World Health Organization 1988; 66:627-635.

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

24. Victora CG, Smith PG, Vaughan JP, et al, Water supply, sanitation and housing in relation to the risk of infant mortality from diarrhoea, International Journal of Epidemiology 1988; 17:651-654.

25. Briscoe J, Akin J and Guilkey D, People are not passive acceptors of threats to health: Endogeneity and its consequences, International Journal of Epidemiology 1990; 19:147-153.

26. The Cebu Study Team, Underlying and proximate determinants of child health: The Cebu Longitudinal health and nutrition study, American Journal of Epidemiology 1991; 133:185-201.

27. Esrey SA and Habicht JP, Epidemiologic evidence for health benefits from improved water and sanitation in developing countries, Epidemiologic Reviews 1986; 8:117-128.

28. Esrey SA, Potash JB, Roberts L and Shiff C, Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma, Bulletin of the World Health Organization 1991; 69:609-621.

29. Aziz KMA, Hoque BA, Huttly SRA, et al, Water supply, sanitation and hygiene education, Report of a health impact study in Mirzapur, Bangladesh, Water and Sanitation Report Series of the UNDP-World Bank Water and Sanitation Program 1990; 1.

30. Zeng-sui W, Shepard DS, Yun-cheng Z, et al, Reduction of enteric infectious disease in rural China by providing deep-well tap water, Bulletin of the World Health Organization 1989; 67:171-180.

31. Wright CE, El Alamy M, DuPont HL, et al, The role of home environment in infant diarrhea in rural Egypt, American Journal of Epidemiology 1991; 134:887-894.

32. Huttly SRA, Blum D, Kirkwood BR, et al, The epidemiology of acute diarrhoea in a rural community in Imo State, Nigeria, Transaction of the Royal Society of Tropical Medicine and Hygiene, 1987; 81:865-870.

33. The Imo State Evaluation Team, Evaluating water and sanitation projects: lessons from Imo State, Nigeria, Health Policy and Planning 1989; 4:40-49.

34. Blum D, Emeh RN, Huttly SRA, et al, The Imo State (Nigeria) drinking water supply and sanitation project, 1. Description of the project, evaluation methods, and impact on intervening variables, Transactions of the Royal Society of Tropical Medicine and Hygiene 1990; 84:309-315.

35. Huttly SRA, Blum D, Kirkwood BR, et al, The Imo State (Nigeria) drinking water supply and sanitation project, 2. Impact on dracunculiasis, diarrhoea and nutritional status, Transactions of the Royal Society of Tropical Medicine and Hygiene 1990; 84:316-321.

36. Moe CL, Sobsey MD, Samsa GP and Mesolo V, Bacterial indicators of risk of diarrhoeal disease from drinking-water in the Philippines, Bulletin of the World Health Organization 1991; 69:305-317.

37. Trivedi BK, Gandhi HS and Shukla NK, Bacteriological water quality and incidence of water borne diseases in a rural population, Indian Journal of Medical Science 1971; 25:795-801.

38. Sutomo S and Tilden R, Water supply and sanitation are good predictors of diarrhea. Water supply and diarrheal disease in rural areas of Indonesia, Bul Penelit Kesehat 1987; 15:1-14.

39. Pinfold JV, Horan NJ and Wirojanagud, The bacteriological quality of water collected in rainjars in rural northeast Thailand with respect to drinking water quality guidelines, submitted to Water Research 15/3/1990.

40. Lewis WJ, Foster SSD and Drasar BS, The risk of groundwater pollution by on-site sanitation in developing countries, A literature review, IRCWD-Report No.01/82, 1982.

41. Lewis WJ, Foster SSD, Read GH and Schertenleib R, The need for an integrated approach to water-supply and sanitation in developing countries, Science of the Total Environment 1981; 21:53-59.

42. Feachem R, Bacterial standards for drinking water quality in developing countries, Lancet 1980; August 2, 255-256.

43. Molbak K, Hojlyng N and Jepsen S, Bacterial contamination of stored water and stored food: a potential source of diarrhoeal disease in West Africa, Epidemiology and Infection 1989; 102:309-316.

44. Lonergan S and Vansickle T, Relationship between water quality and human health: a case study of the Linggi river basin in Malaysia, Social Science and Medicine 1991; 33:937-946.

45. Jiwa SFH, Mugula JK and Msangi, Bacteriological quality of potable water sources supplying Morogoro municipality and its outskirts: a case study in Tanzania, Epidemiology and Infection 1991; 107:479-484.

46. Feresu SB and Van Sickle J, Coliforms as a measure of sewage contamination of the River Zambesi, Journal of Applied Bacteriology 1990; 68:397-403.

47. El-Zanfaly HT, and El-Tonssy MD, Studies of the bacteriological water quality for the intakes of different water treatment plants in greater Cairo, Zbl Hyg 1989; 188:303-310.

48. Barabas S, Monitoring natural waters for drinking-water quality, World Health Statistics Quarterly 1986; 39:32-45.

49. Graham N and Hartung H, Performance of slow sand filters in refugee water supplies in Somalia, Waterlines 1988; 6:19-22.

50. Blum D, Huttly SRA, Okoro JI, et al, The bacteriological quality of traditional water sources in north-eastern Imo State, Nigeria, Epidemiology and Infection 1987; 99:429-437.

51. Lindskog RUM and Lindskog PA, Bacteriological contamination of water in rural areas: an intervention study from Malawi, Journal Tropical Medicine and Hygiene 1988; 91:1-7.

52. Lindskog PA and Lindskog RUM, The importance of hygiene education in obtaining a health impact through improved water supply and sanitation, with examples from Malawi. Paper presented at the International Council Scientific Unions Committee on Teaching of Science Conference, 6-14 August 1985, Bangalore, India.

53. Adesiyun AA, Adekeye JO and Umoh JU, Studies on well water and possible health risks in Katsina, Nigeria, Journal of Hygiene 1983; 90:199-205.

54. Tensay ZW, Bacteriological quality of drinking water in Kaffa administrative region, south west Ethiopia, Journal of Hygiene, Epidemiology, Microbiology and Immunology 1991; 35:251-258.

55. Wright RC, The seasonality of bacterial quality of water in a tropical developing country (Sierra Leone), Journal of Hygiene Cambridge 1985; 96:75.

56. Lloyd B and Suyati S, A pilot rural water surveillance project in Indonesia, Waterlines 1989; 7:10-13.

57. Utkilen H and Sutton S, Experience and results from a water quality project in Zambia, Waterlines 1989; 7:6-8.

58. Nyangeri EEN, Rehabilitation of hand-dug wells and protected springs in Kisii, Kenya, Report Tampere University of Technology in co-operation with Finnida 1986; No 29.

59. 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.

60. Mertens TE, Fernando MA, Marshall TF de C, et al, Determinants of water quality, availability and use in Kurunegala, Sri Lanka, Tropical Medicine and Parasitology 1990; 41:89-97.

61. Nichter M, From Aralu to ORS: Sinhalese perceptions of digestion, diarrhea, and dehydration, Social Science and Medicine 1988; 27:39-52.

62. Morgan P. Rural Water Supplies and Sanitation: A Text from Zimbabwe's Blair Research Laboratory, 1990; London: Macmillan.

63. Moore HA, de la Cruz E and Vargas-Mendez O, Diarrheal disease studies in Costa Rica: IV. The influence of sanitation upon the prevalence of intestinal infection and diarrheal disease, American Journal of Epidemiology 1965; 82:162-184.

64. Feachem R, Faecal coliforms and faecal streptococci in streams in the New Guinea Highlands, Water Research 1974; 8:367-374

65. Barrell RAE and Rowland MGM, The relationship between rainfall and well water pollution in a West African (Gambian) village, Journal of Hygiene 1979; 83:143-150.

66. Vigneswaran S, Tam DM, Visvanathan C, et al, Water Filtration Technologies for Developing Countries, Environmental Sanitation Reviews 1983; No12, Environmental Sanitation Information Center, Bangkok, Thailand.

67. Buchrieser V, Brosch R, Buchrieser C, et al, On the drinking water situation on the Cape Verde Islands (Island of Santiago), Journal of Hygiene Epidemiology Microbiology and Immunology 1989; 33:35-43.

68. Anon. A workshop design for well improvement: protecting open wells. WASH Technical Report No. 34, Arlington, Virginia, May 1988.

69. Wedgwood K, Nicaragua: rural water quality surveillance and improvement, Waterlines 1989; 7:20-23.

70. van Hemert B, Solis O, Haemhouts J and Amador O, La Bomba de Mecate, El Desafío de la Tecnología Popular, Editorial Enlace, 1991, Managua, Nicaragua.

71. Taka M and Aapola R, Study on bacteriological contamination in hand pump wells, Kandy district water supply and sanitation project, Soil and Water Ltd, September 1988.

72. Lacey E, Eng BEC and Eur Eng MIEI, Comparison between hand dug and hand augered wells. Report based on experiences in Zambia and Zimbabwe, 1990, IRC 212.5.

73. Loevinsohn BP, Health education interventions in developing countries: A methodological review of published articles, International Journal of Epidemiology 1990; 19:788-794.