



INSTITUTE OF WATER AND ENVIRONMENT

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CHLORINATION FOR HAND DUG WELLS IN PERI-URBAN MONROVIA, LIBERIA

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ABSTRACT

The Liberian conflict has led 180,000 Internally Displaced Persons (IDPs) to flee to the capital Monrovia. It has also resulted in the destruction of much of the watsan infrastructure. In peri-urban Monrovia, communities and IDPs mostly drink water from unprotected hand dug wells and seriously lack sanitation infrastructure. Water, sanitation and hygiene are below SPHERE standards, and the risks of a cholera outbreak are high.

Well chlorination can be used as an emergency response to prevent outbreaks of waterborne diseases such as cholera. However, information on how to chlorinate different wells in an effective and appropriate way is variable and imprecise. This research therefore evaluated various well chlorination systems and assessed the needs for chlorination training and awareness in these peri-urban Monrovia communities.

Oxfam floating pot chlorinators and trichloroisocyanuric acid tablets, pot chlorinators made with local materials and chlorination with liquid bleach, both at the well and household levels, were evaluated. Oxfam chlorinators can be fairly effective, and so is daily chlorination with liquid bleach, but both have drawbacks. Local pot chlorinators consisting of pierced plastic jerrycans filled with layers of gravel, sand and HTH were found little effective, and so was household chlorination. The most effective and appropriate system seemed to be a pot chlorinator made with locally pressed HTH tablets placed in pierced plastic bags packed with sand.

In these communities, most people are already aware of the benefits of well chlorination but do it in a very empirical way. Well chlorination campaigns should therefore include trainings for the watsan committees and well owners. Adequate sensitisation software (drama, songs, discussions) on the importance of chlorination and contact time, coupled with hygiene messages (hand washing, safe water abstraction and storage), should be delivered to women and children (women groups, markets, schools) by the committees' health motivators.

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This research was carried out for Oxfam GB



The opinions in this work are the opinions of the author and do not necessarily represent Oxfam policy

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LIST OF ABBREVIATIONS AND SYMBOLS

ACF	Action Contre la Faim
ASAH	Association for Social Advancement and Health
cm	Centimetre
ECHO	European Commission Humanitarian Office
FRC	Free Residual Chlorine
g	Gram
HTH	High Test Hypochlorite
IDP	Internally Displaced Person
IFRC	International Federation of the Red Cross and Red Crescent Societies
INGO	International Non-Governmental Organisation
kg	Kilogram
L	Litre
L/day	Litre per day
L\$	Liberian Dollar (L\$ 60 = US\$ 1)
LRRRC	Liberian Refugee, Repatriation and Resettlement Commission
LURD	Liberian Union for Reconciliation and Democracy
mbgl	Metre below ground level
mL	Millilitre
mg	Milligram
mg/L	Milligram per litre
MSF	Médecins Sans Frontières
m³	Cubic metre
NTU	Nephelometric Turbidity Units
Oxfam	Oxford Famine Relief Committee
O&M	Operation and Maintenance
PC	Pot Chlorinator
Pers./day	Person per day
TNC	Too Numerous to Count
UN	United Nations
UNICEF	United Nations International Children and Education Fund
UNMIL	United Nations Military Intervention in Liberia
US\$	American Dollar (US\$ 1 = L\$ 60)
Vol.	Volume
Watsan	Water and sanitation
WEDC	Water Engineering and Development Centre
WHO	World Health Organisation
WHY	World Hunger Year
°C	Celsius degree
∅	Diameter
£	Great Britain Pound

1. INTRODUCTION

1.1. General context in Liberia and Monrovia

Liberia has experienced serious politico-economic disruption and intermittent civil war from 1989 to August 2003. In June 2003, heavy fightings between Government Forces and the Liberian Union for Reconciliation and Democracy (LURD) created massive displacement. An estimated 450,000 people fled their homes (ECHO, 2003), either to neighbouring countries or to Monrovia. An estimated 180,000 Internally Displaced Persons (IDPs) now live in difficult conditions in and around the Liberian capital (Liberian Reconciliation, Repatriation and Resettlement Commission figures (LRRRC), cited in Oxfam GB Liberia, 2003a). Some IDPs live in camps run by International Non Governmental Organisations (INGOs) while others live with relatives or squat empty buildings, in the city centre but mostly in peri-urban districts. The country is now relatively stable thanks to the United Nations Military Intervention in Liberia (UNMIL) and to on-going disarmament, but tension remains high and IDPs will not return home before security stops to be an issue.

1.2. Public health in peri-urban Monrovia

1.2.1. Water, sanitation & hygiene

Successive conflicts have destroyed much of the infrastructure of the country, especially in and around the capital. As a result, water, sanitation and health infrastructure is very poor in peri-urban Monrovia. Moreover, communities have seen scarce resources depleted as a result of hosting IDPs.

Oxfam's public health assessment reports (Oxfam GB Liberia, 2003b) of the peri-urban communities in Gardnersville and Paynesville (East and South-East of Monrovia, see map of Liberia in appendix 1) described the following:

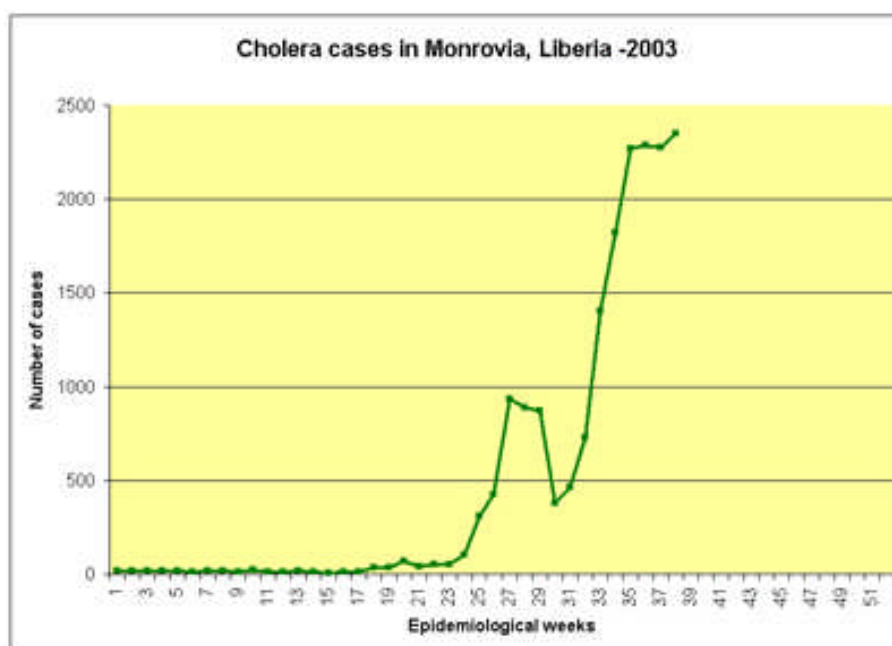
- Most people abstract their water from community shared shallow unprotected hand-dug wells. Groundwater is very high during the rainy season, but wells can dry during the dry season. Protected wells with handpumps are very scarce, most were installed by INGOs.
- There is an enormous lack of sanitation infrastructure. Few private latrines exist but most people defecate in the bush, using paper or leaves for anal cleansing. Men, women and children are reported to go to the same places. At night, some people defecate in plastic bags which they throw away after. Open defecation is also practiced by children.
- Hygiene is poor. Existing latrines do not have any hand washing facilities and most people do not wash their hands after defecation. Safe water abstraction, transportation and storage are also an issue, as well as safe food handling.

Oxfam (Oxfam GB Liberia, 2003c) concluded that watsan infrastructure and hygiene were far below Sphere standards in these communities, creating high public health risks for the IDPs and their hosts.

1.2.2. Associated Public Health risks

Oxfam's public health assessment of the peri-urban communities (Oxfam GB Liberia, 2003b) reported the most common diseases are diarrhoea, typhoid, skin diseases and malaria. Most of them originate from inadequate water supply and sanitation and poor hygiene behaviour.

In addition to these problems, the difficulty in accessing health care facilities and the general impoverishment (lack of education and basic assets, financial, nutritional, etc.), combined with the fact that the population is highly mobile, make the risk of a cholera epidemic high. INGOs and the World Health Organisation (WHO) reported non-laboratory confirmed cholera cases in the city centre and peri-urban areas of Monrovia during the rainy season of 2003. Epidemiological surveillance shows a total of 17,500 cases since the beginning of the epidemics in June, with over 2,250 cases per week at the end of September (Oxfam GB, 2003a ; WHO, 2003, see graph 1).



Graph 1: Cholera epidemiological surveillance in Monrovia (WHO, 2003)

1.2.3. Oxfam's Public Health projects in peri-urban Monrovia

Cholera and acute diarrhoea tend to have two peaks, at the beginning (May - June) and at the end (October - November) of the rainy season. In October and November 2003, Oxfam's efforts at reducing cholera included well chlorination campaigns throughout the city, the provision of IDP centres with emergency sanitation, potable water and health promotion and the setting up of primary health facilities and cholera treatment units. However, this has had little impact on the overall number of cases (Oxfam GB Liberia, 2003a). Well chlorination especially was difficult to implement, due to the fact that different wells had different chlorine demands and abstraction rates, and because Free Residual Chlorine (FRC) and contact time were difficult to control, requiring intensive monitoring (Oxfam GB, 2004).

More recently, Oxfam implemented integrated water, sanitation and health promotion projects in peri-urban communities where cholera hotspots had been identified (Chicken Soup Factory and Struggle Island in Gardnersville ; Duport Road, Police Academy and Soul Clinic in Paynesville). These included the construction of community and institutional protected wells with handpumps and VIP latrines, as well as the training of watsan committees and health motivators. However, because of the massive displacement and the volatile situation in Liberia, these projects were difficult to implement and Sphere standards are still largely not met (Oxfam GB, 2004). Oxfam therefore decided to carry out a research on hand dug well chlorination to prevent cholera or other waterborne diseases outbreaks in these peri-urban communities.

1.3. Objectives of the research

The overall aim of this research was to provide recommendations and guidelines for Oxfam GB to establish a sustainable community managed chlorination system for hand dug wells in peri-urban Monrovia. The terms of reference of the research (Oxfam GB Liberia, 2004, see appendix 6) also listed the following specific objectives:

- Evaluate and adapt Oxfam's pot chlorinator and chlorine tablets to hand dug wells chlorination in peri-urban Monrovia.
- Evaluate and improve other hand dug wells chlorination systems already existing in Liberia (UN agencies, international and local NGOs, local water institutions).
- Research the feasibility of simple, efficient and cost-effective hand dug wells pot chlorinators using local materials.
- Compare the previous chlorination systems between each others, make technical recommendations to Oxfam GB Liberia, and provide practical guidelines to establish a sustainable community managed hand dug wells chlorination system in peri-urban Monrovia, using the technologies previously evaluated and adequate software.

2. HAND DUG WELL CHLORINATION

2.1. Water chlorination & public health

Pathogens (bacteria, spores, viruses, cysts, protozoa, helminths, etc) in drinking water can cause diseases to humans (cholera, dysentery, typhoid, hepatitis, etc). For instance, cholera is caused by ingestion of the bacteria *Vibrio cholerae* in faecally contaminated water, food, fingers, etc (Rowe et al., 1998). These pathogens should primarily be reduced by protecting the source (e.g. lined wells with handpumps) or by adequate treatment (e.g. filtration, coagulation and sedimentation), while remaining pathogens can be eliminated through disinfection (Oxfam Guide for chlorination, undated). However, in case of emergencies (such as high cholera risk or epidemic), disinfection on its own can offer a much quicker response than protection and/or treatment (Wisner et al, 2002). Various disinfection methods can be used (solar disinfection, ultra-violet, ozone, etc), but chlorination is the most common one for emergencies (Davis and Lambert, 2002). Table 1 shows the assets and drawbacks of chlorine as a disinfectant.

Assets of chlorination	Drawbacks of chlorination
<ul style="list-style-type: none"> • Chlorine is available almost anywhere in one form or another: HTH calcium hypochlorite granules (65% available chlorine), bleaching powder or chlorinated lime (35%), sodium hypochlorite or bleach (5%), trichloroisocyanuric chlorine tablets, etc. • Chlorine is usually cheaper, simpler, quicker and more reliable than other disinfectants • When used properly, chlorine can kill all bacteria and viruses • Free Residual Chlorine (FRC) will also protect water from post-disinfection contamination. WHO recommends $0.2 < \text{FRC} < 0.5 \text{ mg/L}$, but sometimes up to 1.0 mg/L in case of cholera epidemic. • Chlorine concentration is easy and quick to measure in the field using a pool tester (colour comparator) 	<ul style="list-style-type: none"> • Chlorine needs a specific range of chemical and physical water quality to be effective. WHO recommends $6.5 < \text{pH} < 8.0$, turbidity $< 5 \text{ NTU}$, low organic, iron, ammonia, manganese contents = low chlorine demand) • Chlorine needs a contact time to be effective (depending on pH and temperature). The minimum is 30 minutes • Chlorine does not kill all pathogens (e.g. some species of protozoa and helminths are resistant, against which source protection is the most effective) • Used improperly, chlorine can be harmful to humans (high concentrations, disinfection by-products such as trihalomethanes) • People might dislike chlorinated water ($>0.5 \text{ mg/L}$) and prefer contaminated sources • Chlorine is corrosive and volatile and must be used and stored safely

Table 1 : Assets and drawbacks of chlorine as a disinfectant
(CCC, 1997 ; Oxfam guide for chlorination, undated ; Davis and Lambert, 2002 ; WHO, 1997)

In spite of some drawbacks, the availability of chlorine in Monrovia and its effectiveness at killing most pathogens, including *Vibrio cholerae*, made it an obvious choice for Oxfam to disinfect hand dug wells in cholera hotspots around Monrovia.

2.2. Parameters influencing chlorination in hand dug wells

Water chlorination is mainly a matter of water quantity and quality. Figure 1 presents the parameters that influence water quantity and quality, hence chlorination, in hand dug wells.

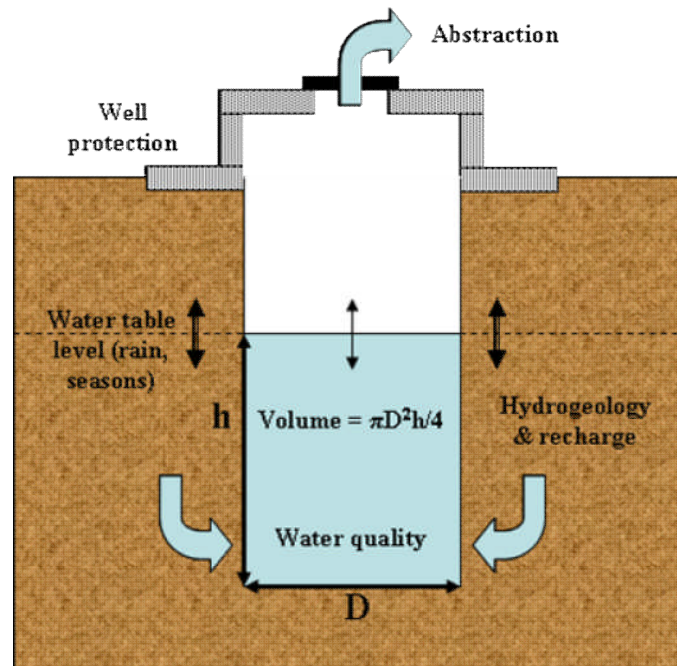


Figure 1 : Parameters influencing chlorination in hand dug wells

Quantitatively, the volume of the well is obviously important. It will vary according to the water table level (seasons, rainfall, abstraction, etc). Qualitatively, the water pH and temperature have to be considered, as well as the presence of organic matter (vegetal fragments, faecal contamination), iron, ammonia, manganese, as these will be oxidised by chlorine, hence creating a chlorine demand (e.g. the amount of chlorine needed, in mg/L, for all these elements to be oxidised). The water quality will vary according to the hydrogeology, recharge, and the protection of the well. Figure 2 illustrates the interrelationship and variability of these parameters influencing chlorination in hand dug wells.

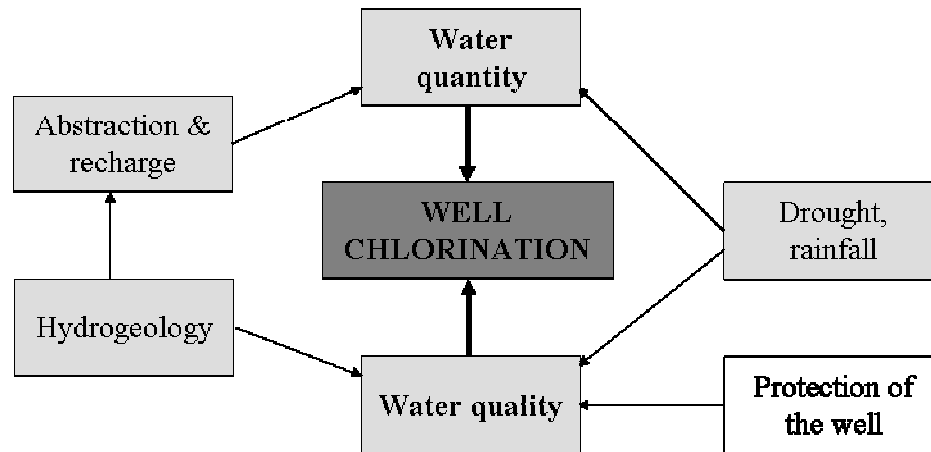


Figure 2 : Interrelationship and variability of the parameters influencing chlorination in hand dug wells

Since well chlorination seems complex and influenced by numerous, interrelated and variable parameters, what systems are available to chlorinate hand dug wells effectively ?

2.3. Well chlorination systems

2.3.1. Pot chlorinators and solid chlorine

A pot chlorinator is a pierced container (clay pot, plastic bucket, etc), filled with a chlorine powder and sand/gravel mixture and hung in a well, alone or in a larger pierced container (see figures 3 and 4).

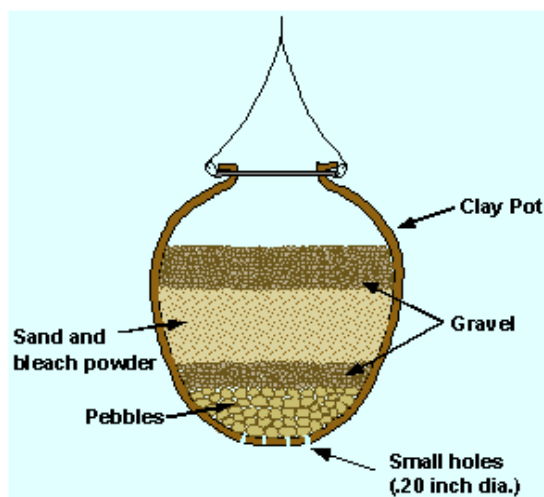


Figure 3 : Simple pot chlorinator (Svadlenka, 2003)

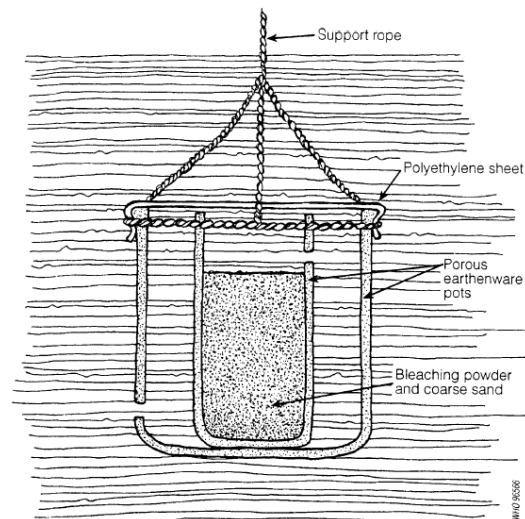


Figure 4 : Double pot chlorinator (WHO, 1997)

The chlorine slowly disperses from the pot into water. The aim is to protect against direct contamination in the groundwater and provide a protective chlorine residual. The number and size of holes, the type and quantity of chlorine used and the parameters discussed in 2.2 determine the dose of chlorine released and left into the well. The difficulty is to ensure a more or less constant chlorine dose in the well. The first water drawn in the morning may have a very high level of chlorine (because chlorine will have dissolved during the night, when nobody draws water), but if a well has certain periods of very high use, the dose may become too low (because chlorine may not dissolve quickly enough to balance the quantity and quality of new water coming into the well). This system requires some monitoring to operate effectively (IFRC, 2004).

Table 2 describes various pot chlorinator designs found in the scarce literature about this technique or during interviews with current or former aid workers.

Source	Design description	Effectiveness
Nerdatabank, 2004	8 holes of 5 mm are made at the bottom of a 7-8 L container. The holes are covered with stone pebbles and then with a layer of pea gravel. A dry mixture of 1.5 kg bleaching powder and 3 kg of coarse sand is spread over the gravel. The pot is then filled with pebbles or stones to the neck	Chlorination for a 2-3 weeks period with a daily abstraction of 900-1300 L
IFRC, 2004	The pot is a 1 L pierced plastic bottle, filled with a chlorine powder and gravel mixture and placed in a larger pierced container (4 L)	Not cited
Svadlenka, 2003	A clay pot with small holes at the bottom is filled with layers of pebbles, gravel, mixture of bleaching powder and sand (1.5 kg of powder for 3 kg of sand) and finally another layer of pebbles.	Chlorination for 1 week with 1000 L drawn daily
Feachem et al., 1977	Chlorination pots are charged with an equal-weight mixture of bleaching powder and sand. The simple or double containers are pierced (6-10 mm holes)	Not cited
Cairncross and Feachem, 1993	Clay pot with 6-8 holes of 5 mm diameter at the bottom and mouth open, filled with layers of 20 to 40 mm stones, gravel, 1.5 kg of bleaching powder mixed with 3 kg of sand, and finally stones again	Chlorination for 60 people for two weeks
	A container is pierced on the side, at the top (10 mm diameter), filled with 1 kg of bleaching powder and 2 kg of sand, then placed in a larger container pierced on the side, at the bottom (10 mm diameter)	Chlorination for 20 people for three weeks.
Benjamin Daye, ex-MSF France during a chlorination campaign in Monrovia in 1997	Local pot chlorinators were made with recycled plastic jerrycans (Chlora), filled with various layers of gravel, sand, sand and HTH mix, and pierced around 30 times with a needle. MSF France said they now stopped and do not plan to implement pot chlorination again in Liberia	"High chlorine residual"

Mr Coleba, Watsan Engineer, ACF Liberia	75 g of HTH granules compressed with a drilling rig to make a tablet, used in rice bags full of sand	"Never monitored in the field"
Libessart and Hammache (2000), ex-ACF during a chlorination campaign in Mogadishu	Pierced 5L recycled jerrycans with different levels of gravel, sand, sand/chlorine mix, sand and gravel again	60% of wells have FRC > 0.1 mg/L for 12 to 15 days
	Chlorine tablets were pressed locally with a manual press (125 g of HTH), and inserted in pierced pipes	95% of wells have FRC > 0.1 mg/L

Table 2 : Various pot chlorinator designs (Sources cited in the table)

2.3.2. Daily injections of liquid bleach

Some other well chlorination systems use liquid bleach. They usually consist in daily or weekly injections of 1% or 5% bleach in the wells, doses being calculated or estimated with chlorine demand and/or volume. The following table describes some techniques found in the literature or during interviews with aid workers.

Source	Design description	Effectiveness
Rowe et al, 1998	Shock chlorination with liquid bleach, estimating doses with the wells volume to bring the FRC up to 30 mg/L, closing the well for 24 hours before people drink	"FRC are short-lived and variable"
Week (2004), Head of the Watsan Department at UNICEF Liberia, Flaboe Gabrael (2004), Watsan Engineer at the LWSC, Tebutt (2004)	UNICEF, in coordination with the EU and the LWSC, chlorinated several hundreds of wells using bleach, estimating doses with volumes to bring FRC up to 50 mg/L, twice a month (see guidelines in appendix 2)	"It was a huge and expensive waste of chlorine"
Roger (2004), Watsan Team Leader at Oxfam GB in Liberia	Daily chlorination of hand dug wells with bleach made from HTH, calculating doses with volumes (5 mg/L), see procedure in appendix 3	"Fairly accurate and effective"
Sam Godfrey (2003a, 2003b, 2004), ex-Oxfam GB in Angola during chlorination campaigns	Weekly well chlorination up to 0.5 mg/L with dissolved HTH, calculating the dose with volume and chlorine demand, mixing with an Oxfam floating pot chlorinator for 30 minutes	"Faecal contamination reduced from TNC to within Sphere standards"
Das (2004), Director of ASAH India	Daily well chlorination up to 0.7 mg/L with dissolved bleaching powder, calculating the dose with volume and chlorine demand, mixing with a bucket and leaving a contact time of an hour	Not cited

Table 3 : Various well chlorination techniques using liquid bleach (Sources cited in the table)

2.3.3. Household chlorination

As it appears difficult to design technologies able to disinfect effectively different wells, some organisations have also looked at the possibility of chlorinating water from wells at the household level. The following table describes two techniques that have been implemented in Monrovia.

Source	Design description	Effectiveness
Hydrosan, undated	Household chlorination based on dissolved HTH granules, with instruction for households to dose around 0,8 mg/L, by drops or using a syringe (see instructions in appendix 4)	Not cited
UNICEF, undated	Household chlorination based on commercial 5% bleach, with instruction for household to dose around 2,5 mg/L by drops (see instructions in appendix 5)	Not cited

Table 4 : Household chlorination techniques (Sources cited in the table)

What is striking in the tables 2, 3 and 4 is the variation in the chlorination techniques, the generally quite high doses, and the variability of the results sought and achieved. There are no precise guidelines indicating in which kind of wells different pot chlorinator designs are effective. Some methods using bleach aim at continuously leaving FRC in the wells, while others aim at reducing source contamination through periodical chlorination. The two household chlorination methods use significantly different chlorine doses.

Research and monitored field-tests could help to determine the effectiveness and appropriateness of these very different techniques.

2.4. Chlorination awareness & training

Readings and discussions also highlighted the fact that chlorination projects necessitate a certain level of public awareness and training in the community.

- Rowe et al (1998), chlorinating wells in Guinea-Bissau, asked their owners how long they thought a one-off chlorination would provide safe water. Answers varied between two weeks and six months, highlighting the need for awareness and training.
- Oxfam coupled its well chlorination campaign in Angola with hygiene promotion, including messages about contact time, protection of wells and safe abstraction and storage practices in community discussions and drama (Godfrey, 2003a, 2004).
- In Mogadishu, ACF coupled a well chlorination campaign with public awareness (to well owners and users) and health education programmes (to mothers and children),

coordinating with cholera treatment centres to identify areas of the city where chlorination hardware/software were needed (Libessart and Hammache, 2000).

People in different communities or countries might have different knowledge, habits or fears about water chlorination. Chlorination projects should therefore include appropriate software, such as awareness campaigns and trainings, based on the existing local knowledge. Moreover, cholera or diarrhoea outbreaks must be fought on several fronts. Providing safe water might not be enough and improving hygiene practices through promotion might help to reduce the impact of the outbreak. Even in emergencies, all interventions should aim at being integrated and coordinated.

As for chlorination systems, research could help to determine which kind of software would be appropriate during a well chlorination campaign.

3. METHODOLOGY

This research was carried out in Liberia during 9 weeks, between June and August 2004. The methodology was drafted before the field work, but evolved progressively as the results were obtained.

3.1. Meeting communities and ensuring participation

As the research was to be done mainly in the field in peri-urban Monrovia, agreement and participation from the communities was needed. The first step was therefore to visit the peri-urban communities identified by Oxfam, UN agencies and other INGOs as cholera hot spots. These visits included:

- Meetings with the community leaders and watsan committees, to explain the purpose of the research, ask the permission to do it, explain the need for volunteers to help, as well as make the respective roles of the researcher, Oxfam and the communities clear.
- Brief visit of the communities (different districts, markets, schools) and their watsan infrastructures with members of the watsan committees, to get an idea of the general public health situation.
- Discussions with well owners to introduce the research and determine their willingness to participate.

In addition, communities were visited almost daily throughout the field research, to get a better understanding of living conditions and local practices, as well as to ensure continuous observation, discussion and participation.

3.2. Selecting representative wells

3.2.1. Selecting the wells

After having met the communities, the volumes of various protected and unprotected hand dug wells were measured. A sample of 12 wells was selected, in different communities and with a range of different volumes and protections, to get a sort of representative sample as well as to lead to a better understanding of how chlorination can work in different environments. This sample is relatively small, as the communities have numerous hand dug wells (for instance, over 60 wells in Chicken Soup Factory and around 50 in Police Academy according to Oxfam, 2003b), but the time available and distances between the communities made it impossible to select more wells. Permission was asked to each owner to use their well for the experiments, clearly explaining the possible inconvenience. Once people agreed, other parameters influencing chlorination were measured in the selected wells.

3.2.2. Measuring well parameters

Table 5 lists the parameters influencing chlorination presented in 2.2., and explains how they were measured in the field.

Parameters		Measurement	Remarks
<i>Volume of the well</i>		Tape to measure the diameter D and the water column h (m), volumes were then calculated with $V = \pi D^2 h / 4$ (m ³)	This is just an estimation of the volumes. As they are variable, they were measured several times during the tests
<i>Protection of the well</i>		Direct observations	Protections like headwall, apron, cover, lining, hand pump, fence, rope and bucket were important
<i>Hydrogeology</i>		None	Impossible to assess (pumping tests would be necessary).
<i>Water abstraction and recharge</i>		Water abstraction rate was monitored in each well by volunteers (see abstraction rate form in appendix 8), noting time and estimating the volume drawn by each user during one or two days	Water recharge could not be measured
<i>Drought and rainfall</i>		Direct observation	Observations by volunteers and/or by the researcher
<i>Water quality</i>	pH	pH colour comparator and phenol red tablets ("pool tester" Palintest SP610, Oxfam code FPO/1)	pH, temperature and turbidity were measured several times throughout the research, after and before rain
	Temperature (°C)	Thermometer	
	Turbidity (NTU)	Turbidity tube (Palintest PT513, Oxfam code FTT/1)	
	Faecal pollution (therm. col. /100 mL)	Delagua water testing kit (Oxfam code FK/2)	Faecal pollution was tested twice before the chlorination tests
	Chlorine demand (mg/L)	Field dosing method, see detailed procedure in appendix 7	Chlorine demand was measured three times in each well, before chlorination, at different steps of the research
	Free Residual Chlorine (mg/L)	FRC colour comparator and DPD1 tablets ("pool tester" Palintest SP610, Oxfam code FPO/1)	FRC was measured prior to the chlorination, then 2 to 5 times a day while chlorinating, by the researcher and/or volunteers

Table 5 : Measurement of the parameters influencing chlorination in wells

Table 6 also gives an approximate schedule of measurements and tests throughout the research (dots represent one-off or periodical measurements while arrows represent continuous monitoring or observation).

Measurements and tests	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
Volume	•					•		•	
Protection	•								
Temperature, pH, turbidity	•		•		•		•		
Faecal pollution	•	•							
Chlorine demand		•				•		•	
FRC			←—————→						
Water abstraction rates		•							
Rainfall	←—————→								

Table 6: Schedule of measurements and tests throughout the research

3.3. Designing, testing & evaluating chlorination systems

3.3.1. Available materials

Various local markets, small shops and supermarkets were visited in Central Monrovia and peri-urban communities, to determine the availability and prices of local materials that could be used to design well chlorination systems similar to those described in 2.3. The following materials were sought:

- *Chlorine*: bleaching powder or chlorinated lime, HTH granules, bleach, chlorine tablets, etc.
- *Containers*: new clay pots and plastic buckets, recycled plastic containers, plastic bags, etc.
- *Gravel and sand*
- *Other equipment*: rope, syringes

3.3.2. Chlorination systems design and field tests methodology

Readings and discussions described three types of well chlorination systems: pot chlorinators, chlorination with bleach and household chlorination. It was decided to try and evaluate all of them, with a special focus on pot chlorinators (to provide continuous chlorination). Various designs of local pot chlorinators were to be tested (simple, double, using chlorine powder or tablets), but Oxfam also wanted to test its own equipment.

3.3.2.1. Oxfam floating pot chlorinator

Oxfam floating pot chlorinators (Oxfam code FFP/1) and 200 g trichloroisocyanuric acid tablets (FCT/1) are standard equipment used by Oxfam in emergency watsan interventions. The chlorinators consist of a sealed plastic chamber filled with air to make them float. In the middle of this chamber is a tube to put chlorine tablets. This tube is closed at the top by a lid, and pierced at the bottom, with a kind of valve to control the size of the holes, hence contact between the chlorine tablets and water. There is also a small plastic handle at the top to attach the chlorinator to the container in which it is installed. Photograph 1 shows a similar floating pot chlorinator.



Photograph 1 : Floating pot chlorinator, similar to Oxfam one (Pool Supplies, 2004)

As this technology is normally intended for swimming pools or water tanks of a much larger volume than shallow hand dug wells, it was decided to use only one chlorine tablet per well for the field tests. The valves would first be opened very slightly and could be adjusted according to the results of the first days.

Two or three volunteers from the watsan committees of each community were trained to monitor the wells' FRC levels using a pool tester (Palintest SP610 and DPD1 tablets, Oxfam code FPO/1). FRC was first tested in all the wells just before installing the pot chlorinators. Once the chlorinators were installed, the volunteers were asked to monitor wells FRC 4 times a day, once early in the morning, once before night, and two other times when they could during the day. In addition, each well was visited and checked once a day. This enabled the collection of results from the previous day, adjust the valve, answer questions from the volunteers or the well owners and try to resolve any problem that might have occurred.

3.3.2.2. Local pot chlorinators

As various pot chlorinator designs exist, it was decided to test the most common type first, namely simple pot chlorinators filled with various layers of gravel, sand, sand and chlorine mix. The first design would be based on guidance from the literature and depending on which material are available locally, and could be modified according to

the results of the first field tests and evaluations. The two other common designs (double pot chlorinators and designs involving chlorine tablets) were also to be tested if time and materials were available.

The procedure for the field tests of local pot chlorinators was the same than for the Oxfam floating ones, with four to five daily monitoring of FRC. Instead of adjusting a valve, the idea was to make the number and size of the holes in the containers match wells with different volumes, chlorine demand, and abstraction rate.

3.3.2.3. Chlorination with bleach

In the previously presented methods of chlorination with bleach, two different objectives have been noticed. Some methods involved continuous chlorination to leave some residual chlorine in the wells, while others consisted in periodical chlorination, with doses varying from 0.5 to 50 mg/L, to only reduce the water contamination.

Oxfam decided that considering the Liberian context and the risks of cholera, continuous chlorination with a residual would ensure safe water and reduce the spread of the disease, while only reducing wells contamination without leaving any chlorine residual might not have a big enough impact on potential epidemics.

Tested well chlorination methods therefore consisted in daily injection of commercial bleach in the wells. On the first day, bleach doses were calculated with the well volume and chlorine demand, and with the volume and FRC level on the following days. After each injection, water was mixed in the well with a bucket, and people were asked to wait 30 minutes before drawing, to ensure mixing and contact time. Volunteers checked the wells FRC twice a day, once in the morning and once in the afternoon, and followed guidelines to dose bleach and readjust FRC levels. In addition, each well was visited and checked once a day by the researcher.

3.3.2.4. Household chlorination

As some Liberian aid workers had tried well chlorination with pot chlorinators and bleach and did not find it effective, it was decided to also investigate household chlorination. However, the main subject of the research was well chlorination and little time was available. No field tests could be carried out at the household level. As the other experiments required several measurement of the wells chlorine demand, this data, combined with information about available materials (chlorine, syringe, etc) permitted a quick examination of the feasibility and effectiveness of a household chlorination intervention.

3.3.3. Criteria of the evaluation

After the field tests, the different chlorination systems were evaluated on effectiveness (quantitative criteria) and appropriateness (qualitative criteria). Table 7 lists these criteria (agreed with Oxfam) and how they were assessed.

	Effectiveness (quantitative criteria)	Appropriateness (qualitative criteria)
Criteria for the evaluation	<ul style="list-style-type: none"> • Residual free chlorine is constantly between 0.2 and 1.0 mg/L, everywhere in the well, for a long time • Hardware is rationally adaptable to different types of wells (adjusting the valve, holes or chlorine quantities) • Contact time is more than 30 minutes 	<ul style="list-style-type: none"> • Materials are easily and quickly available • It is robust, easy to make, operate and maintain • It is adapted to and accepted by local people • Low capital and recurrent costs, cost-effective solution • It can be implemented by Oxfam with a quick and easy logistics
How to evaluate ?	<ul style="list-style-type: none"> • Field tests in wells, monitoring FRC • Questions to well owners, observation (contact time, see 2.4. below) 	<ul style="list-style-type: none"> • Study of the markets/shops • Discussions with Oxfam Liberia Public Health and Logistics staff • Discussions with Watsan committees and volunteers • Discussions with well owners

Table 7 : Criteria and methodology for the evaluation of well chlorination systems

Based on these criteria, an evaluation table was created to easily compare the various systems between each others. Each system received a mark out of 5 for each evaluation criteria, resulting in two sub-totals (effectiveness out of 15, appropriateness out of 25) and one total mark out of 40 (see table 8). All marks were given after field tests (effectiveness) and after discussions with the communities and Oxfam Public Health and Logistics teams.

	Criteria	Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time		
	Adaptability		
	Contact time		
	<i>Subtotal</i>	<i>/15</i>	
<i>Appropriateness</i>	Availability		
	Easy O&M		
	Acceptability		
	Costs per unit		
	Logistics		
	<i>Subtotal</i>	<i>/25</i>	
	TOTAL	/40	

Table 8 : Well chlorination system evaluation table

3.4. Assessing the needs for awareness and training

Although hardware aspects were important, it was also necessary to understand what awareness and knowledge communities had about chlorination, and how this could be developed. This was achieved through informal discussions with members of watsan committees and well owners, simply asking if people used chlorine, why, what kind, how. These people were also observed when doing or manipulating chlorine or pot chlorinators, to determine potential needs for training.

Moreover, the volunteers made observations and asked questions to the well users, while monitoring abstraction rates. Each time someone came to the well, they wrote down whether it was a woman, a man or a child, to determine if software interventions have to target specific groups within the population. In addition to that, they asked people when they would use the water, to assess a potential need for contact time awareness.

4. RESULTS & DISCUSSION

4.1. Communities participating in the research

Five peri-urban communities identified by Oxfam GB Liberia as cholera hotspots were visited: Chicken Soup Factory and Struggle Island in Gardnersville, and Police Academy, Duport Road in Paynesville, as well as Soul Clinic next to Red Light.

Oxfam had already built or rehabilitated wells and latrines in these communities and established watsan committees. Visiting the communities highlighted the following:

- The communities have different levels of wealth, education and organisation
- They mostly rely on open shallow hand-dug wells for their drinking water and do not have enough sanitation infrastructure
- People were happy to participate in the research, but showed variable interest in volunteering to help monitor the experiments

After several visits and meetings, it was decided to limit the research to Chicken Soup Factory, Struggle Island and Duport Road communities, because it was difficult to work in too many places. These communities also seemed more motivated to participate. Two to three members of their respective watsan committees volunteered to help in monitoring the wells.

These volunteers sometimes raised the issue of a salary, as they all gave some of their time to monitor the wells and would have liked to be paid. However, it was agreed with Oxfam GB in Liberia that no money should be given for this work. The importance of participation was stressed to the volunteers and watsan committees, and each volunteer was given a watch as a present. They worked willingly, monitoring the wells, giving their opinions and advice, and finding solutions to problems. Considering the distance between each communities and the security situation in Liberia, making it difficult to be in the communities very early in the morning or late in the afternoon, the research would not have been possible without these people.

4.2. Characteristics and baseline data for selected wells

Table 9 (see page 20) summarises the values of the tests and measurements made in the 12 selected wells.

These wells were chosen because of their different volumes (from 1.4 to 8.4 m³) and their range of protections. As volumes are variable (depending on abstraction rates, hydrogeology, drought and rainfall), the table gives average values.

It was found that some wells in Chicken Soup Factory have periodic or continuous turbidity problems, because of iron but also because of possible construction problems (gravel pack, organic matter). Other wells have very low turbidity (< 5 NTU).

Water temperatures are high (25 to 27 °C) and pH is slightly acid (6.5 to 6.8), which rain does not seem to significantly change.

Faecal pollution was measured once in all the wells taking 100 mL water samples, then once more in all unprotected wells, after rain, taking 10 mL sample. Pollution is quite low in protected wells, but very high in unprotected ones. In two of the unprotected wells, the two faecal pollution tests gave significantly different results. This might be due to a mistake during one of the tests, as they were done by two different persons.

Chlorine demands were tested several times throughout the research. However, table 9 only gives the values of the first test, which was done before any chlorination system was tested. The following ones (after having started chlorination field tests) gave significantly reduced chlorine demands.

The forms volunteers were asked to fill in to monitor the wells abstraction rates were maybe a bit too ambitious. Most volunteers could not stay the whole day next to the wells, and volume estimations were very approximate (e.g. a child drawing 40 gal. for drinking now). The forms were filled in hazardly, and therefore difficult to make use of. They showed two water consumption peaks, one in the morning (6-7 am to 10-11 am) and one in the afternoon (3-4 to 6-7 pm). The wells are however used all day long. The forms made it possible to estimate the total number of people coming daily to draw water in each well, and it was considered after observation that people draw an average of about 15 L of water per journey.

Community	Well identification			Well physical characteristics						Water quality						Water consumption			
	Well code	Well location	Owner's name	Protection	Diameter (m)	Total depth (m)	Average static water level (mbgl)	Average water column (m)	Average volume (m ³)	Colour	Odour	Turbidity (NTU)	pH	T° (°C)	Faecal coliforms (#/100ml)		First chlorine demand (mg/L)	People coming to draw water daily	Estimated total drawn volume (15L/pers)
															S1	S2			
Chicken Soup Factory Community	CSF7	Block E	Community	Lining, apron, Consallen hand pump (5,3 mbgl), drain	0,9	5,7	2,4	3,3	2,1	Brown	None	20 (variable, to 30)	6,5	25	3	-	>6	60-70	900-1050
	CSFow1	Block D	James Toe	Covered, unlined, headwall, no apron, rope and bucket	1,0	7,2	1,1	6,1	4,8	Clear	None	<5 (always)	6,8	26	49	>2000	1,0	60-70	900-1050
	CSFow2	Block C	John Wesseh	Uncovered, unlined, no apron, headwall, rope & bucket	1,6	4,8	0,6	4,2	8,4	Clear	None	<5 (variable, to 30)	6,8	26	TNC	>2000	2,9	80-90	1200-1350
	CSFow3	Block D	Nancy Nyorokoro	Covered, unlined, headwall, small apron, rope & bucket	1,0	4,2	0,6	3,6	2,8	Clear	None	<5 (always)	6,8	26	TNC	>2000	1,5	50-60	750-900
Struggle Island Community	SI4	Block A	Community	Lining, apron, Consallen hand pump (5 mbgl), drain	1,2	3,1	1,1	2,0	2,3	Clear	None	<5 (always)	6,8	25	8	-	4,9	80-90	1200-1350
	SIow1	Block B	Albert Wherboe	Covered, unlined, headwall, no apron, rope & bucket	1,2	4,6	0,4	4,2	4,7	Clear	None	<5 (always)	6,8	27	TNC	>2000	1,0	90-100	1350-1500
	SIow2	Block A	Katherine Deso	Uncovered, unlined, no apron, headwall, rope & bucket	1,1	2,5	1,0	1,5	1,4	Clear	None	<5 (always)	6,8	26	TNC	>2000	>6	60-70	900-1050
Duport Road Community	DR1	PCS Highschool	Community	Lining, apron, Afridev hand pump (6,5 mbgl), drain	1,2	6,0	2,7	3,3	3,7	Clear	None	<5 (always)	6,8	25	18	-	0,2	60-70	900-1050
	DRow1	Next to PCS	David Polson	Uncovered, unlined, no apron, headwall, rope & bucket	1,2	3,4	1,8	1,6	1,8	Clear	None	<5 (always)	6,8	27	TNC	>2000	0,4	50-60	750-900
	DRow2	Main road (1st)	James Cooper	Uncovered, unlined, small apron, headwall	1,3	5,0	2,2	2,8	3,7	Clear	None	<5 (always)	6,8	26	TNC	>2000	0,2	50-60	750-900
	DRow3	Main road (2nd)	Sesay Kekula	Covered, unlined, headwall, no apron, rope & bucket	1,3	3,2	1,1	2,1	2,8	Clear	None	<5 (always)	6,8	26	9	>2000	0,5	40-50	600-750
	DRow4	Block B	Andres Horace	Covered, unlined, no apron, headwall, rope & bucket	1,1	4,1	1,3	2,8	2,7	Clear	None	<5 (always)	6,8	27	TNC	>2000	1,0	70-80	1050-1200

Table 9 : Characteristics of the 12 selected wells

4.3. Chlorination systems designed, tested & evaluated

4.3.1. Availability of materials

Waterside, Chicken Soup Factory, and Red Light markets were visited, as well as small shops in the communities. Wholesalers and supermarkets were also visited in the city centre. Table 10 summarizes the availability of materials and their price (L\$ 60 = US\$ 1). It was assumed gravels and sand could be collected for free in the communities.

Materials	Peri-urban Monrovia		Central Monrovia	
	Markets	Small shops	Supermarkets	Shops
HTH granules	L\$ 10 for 20-30 g packets but rare	-		US\$ 350 for a 45kg (65%) drum
Bleaching powder	-	-	-	-
Bleach	Various brands. The most common is Chlora, imported from Côte d'Ivoire, 5% available chlorine, L\$ 60 for 1 L			
Chlorine tablets	-	-	-	Aquatab, 200 × 1g tablets for US\$ 7
Clay pots	Various sizes, around L\$ 120 for a 6 inch diameter pot		-	-
Plastic buckets	Can be found anywhere, US\$ 2 for 5L			
Recycled plastic containers	Chlora or Crown containers, 1 gallon for L\$ 25	-	-	Chlora or Crown containers, 1 gallon for L\$ 25
Plastic bags	Can be found anywhere, L\$ 5 for a strong bag			
Rope	Can be found anywhere, L\$ 200 for 200 yards of 2 mm diameter rope			
Syringe	-	L\$ 5 for 5mL	-	L\$ 10 for 10 mL
Gravel, sand	To be collected in the communities			

Table 10 : Availability and prices of local well chlorination materials

In addition to these commercially available materials, Oxfam provided floating pot chlorinators and 200 g slow dissolving trichloroisocyanuric acid tablets, imported from the United Kingdom.

4.3.2. Oxfam floating pot chlorinators and chlorine tablets

Oxfam floating pot chlorinators have been tested in all 12 wells over a 15 days period. Table 11 presents a summary of the field tests results (see appendix 9 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC and optimum floating pot chlorinator's adjustments
CSF7	Lined, hand pump	2.1	>6.0	High turbidity (iron), high chlorine demand	60-70	FRC is in the 0.2-1.0 mg/L range for more than 15 days, with the valve is slightly open (1-2 mm) for the first week then more open (8-9 mm). Turbidity remains high.
CSFow1	Unlined, covered	4.8	1.0	High faecal contamination, periodical turbidity	60-70	FRC is very high (>1.0 mg/L), even with the valve closed and the chlorine tablet wrapped in 5 layers of rice bag
CSFow2	Unlined, open	8.4	2.9	High faecal contamination	80-90	FRC is in the 0.2-1.0 mg/L range for 10 days, with the valve open 1mm.
CSFow3	Unlined, covered	2.8	1.5	High faecal contamination	50-60	FRC is in the 0.2-1.0 mg/L range for 11 days, with the chlorine tablet wrapped in 3 layers of rice bag, the valve closed at the beginning and open 1 mm after 7 days.
SI4	Lined, hand pump	2.3	4.9	High chlorine demand	80-90	FRC seems in the 0.2-1.0 mg/L range for more than 15 days, with the chlorine tablet wrapped in 3 layers of rice bag and the valve slightly open (2-3 mm)
SIow1	Unlined, covered	4.7	1.0	High faecal contamination	50-60	FRC seems in the 0.2-1.0 mg/L range for more than 15 days, with the chlorine tablet wrapped in 3 layers of rice bag and the valve closed
SIow2	Unlined, open	1.4	>6.0	High faecal contamination, high chlorine demand	60-70	FRC is in the 0.2-1.0 mg/L range or slightly higher for more than 15 days, with the chlorine tablet wrapped in 2 layers of rice bag, valve closed
DR1	Lined, hand pump	3.7	0.2	Medium faecal contamination	60-70	FRC seems in the 0.2-1.0 mg/L range for more than 15 days, with the chlorine tablet wrapped in 2 to 3 layers of rice bag and the valve closed
DRow1	Unlined, open	1.8	0.4	High faecal contamination	50-60	FRC seems in the 0.2-1.0 mg/L range for more than 15 days, with the chlorine tablet wrapped in 4 layers of rice bag and the valve closed
DRow2	Unlined, covered	3.7	0.2	High faecal contamination	50-60	FRC seems in the 0.2-1.0 mg/L range for more than 15 days, with the chlorine tablet wrapped in 4 layers of rice bag and the valve closed
DRow3	Unlined, open	2.8	0.5	High faecal contamination	40-50	FRC seems in the 0.2-1.0 mg/L range or slightly higher for more than 15 days, with the tablet wrapped in 4 layers of rice bag and the valve closed
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC was too high, even with the valve closed and the chlorine tablet wrapped in 4 layers of rice bag

Table 11 : Summarized results of the field tests with Oxfam floating pot chlorinators

The performance of these pot chlorinators can be summarised as follows:

- In wells where volume and/or chlorine demand and/or abstraction are small, FRC levels were usually too high, as Oxfam pot chlorinators are normally designed for bigger volumes. They can however be reduced and adapted to some wells by closing the valve and wrapping the chlorine tablet in three to five 20×20 cm pieces of woven plastic rice bags.
- In wells where volume and/or chlorine demand and/or abstraction are greater, FRC levels can sometimes be too low.
- An adjustment (with the valve and/or pieces of rice bags) can provide adequate FRC levels during a few days but might have to be changed if the water quantity or quality varied significantly (massive rain, massive abstraction, etc.). This chlorinator needs regular monitoring.
- Chlorine tablets seem to last a long time (sometimes more than 15 day).
- The fact that this chlorinator is floating is problematic. It sometimes annoys people who draw water with a bucket, especially in very narrow wells. After repeated shocks, the lid can break and the tablet fall into the well. The handle also often break, which volunteers however repaired by piercing a hole at the side of the plastic air chamber with a piece of hot metal. The fact that the chlorinator is at the surface probably also reduces contact time in open wells, as people draw the water directly surrounding the chlorinator. Moreover, it is easy for curious children to play with it, or for thieves to take it, which happened during the research.
- It seems that there is no simple way of precisely foreseeing the adequate chlorinator adjustments (valve, bags) according to a specific volume, chlorine demand, abstraction or protection.
- Not surprisingly, the chlorinators are less efficient in wells with periodical problems of turbidity as sometimes happens in Chicken Soup Factory Community.

The evaluation table for the Oxfam floating pot chlorinator is shown on the following page.

Criteria		Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	3	FRC usually quite high, at least at the surface. The chlorine tablets last at least 10 days.
	Adaptability	4	Adaptable to different wells with the valve and pieces of rice bags. Difficult to use in very narrow wells.
	Contact time	1	Chlorinators are at the surface, where water is abstracted in open wells. Contact time is better in wells with handpumps
<i>Subtotal</i>		<i>8/15</i>	
<i>Appropriateness</i>	Availability	2	Completely imported by Oxfam
	Easy O&M	3	Needs monitoring. Handles and lids can break easily.
	Acceptability	3	The fact that chlorinators are floating can annoy people and makes it easy for children to play with it or for people to steal it
	Costs per unit	2	Capital: £ 16.0 (US\$ 8.5) Recurrent: £ 0.4 per tablet (US\$ 0.2)
	Logistics	2	Easy logistics because Oxfam is the supplier, but material can take up to two weeks to arrive, as chlorine is classed as hazardous
<i>Subtotal</i>		<i>12/25</i>	
TOTAL		20/40	

Table 12 : Evaluation of Oxfam pot chlorinators

The Oxfam pot chlorinator's effectiveness and appropriateness can be described as fair. The major drawbacks are the probable lack of contact time, the need for regular monitoring, the limited acceptability of the chlorinators as well as the fact that they are completely imported by Oxfam, which takes time and is not sustainable. A more local chlorinator would be preferable.

4.3.3. Local pot chlorinators

All the simple pot chlorinator designs described in 1.3.3.1. use bleaching powder, which could not be found in Monrovia. Solid chlorine was only available as 1 g tablets, which is very expensive, or HTH granules. It was therefore decided to fill the local chlorinators with HTH instead of bleaching powder, adapting the quantities to get approximately the same amount of available chlorine (HTH contains 65% of available chlorine, while bleaching powder contains 35%).

4.3.3.1. *Designs PC1, PC2, PC3 with HTH granules*

In the published literature, simple pot chlorinators designs use 1.5 kg of bleaching powder mixed with an equal or double weight of coarse sand, surrounded by layers of sand, gravel and/or stones, in a 4 to 8 L clay pot or plastic container pierced 6 to 8 times with 5-10 mm diameters holes, or up to 30 times with a needle.

Both clay and plastic pots could be found locally. Recycled plastic containers were preferred because they were cheaper, more easily available, more resistant to damage and could be sealed with a lid. The most suitable containers seemed to be recycled 4L Chloro (bleach) jerrycans, which were already used by MSF France to make pot chlorinators.

HTH granules contain more or less twice as much available chlorine as bleaching powder. Instead of 1.5 kg of bleaching powder, it was therefore decided to use half this weight of HTH, that is to say 750 g or approximately 1 litre (L) in the first design (PC1, see figure 5).

Coarse sand was difficult to find in the communities, but 0.5-1 mm diameter sand was collected and cleaned. For the design PC1, it was decided to mix chlorine with the double volume of sand, e.g. 2 L. To isolate more chlorine from the water, this sand/chlorine mixture was surrounded by 0.25 L of the cleaned sand and 0.25 L of 4-5 mm diameter gravels.

The container was pierced with two 3 mm diameter holes, one at the bottom and one at the top (to let the air go out of the chlorinator once installed in water). The number of holes was to be adapted to each well during the field tests.

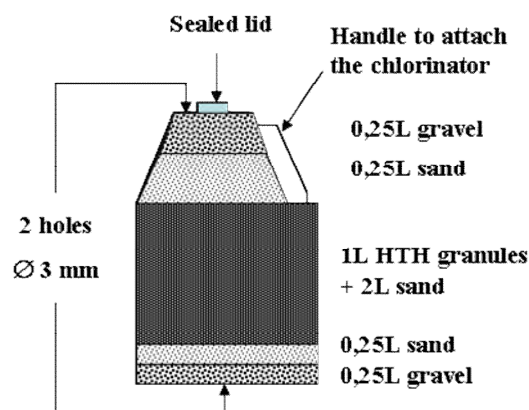


Figure 5 : Local pot chlorinator, design PC1

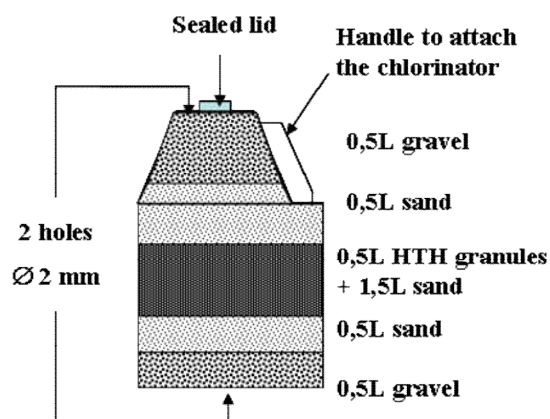


Figure 6 : Local pot chlorinator, design PC2

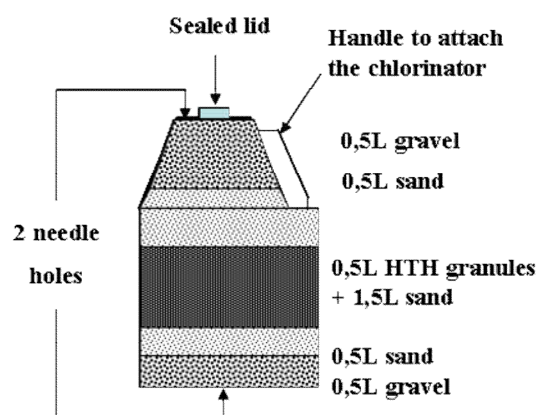


Figure 7 : Local pot chlorinator, design PC3

Design PC1 has been tested in 10 wells for 6 days. Table 12 provides a summary of the results obtained (see appendix 10 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
CSF7	Lined, hand pump	2.1	>6.0	High turbidity (iron), high chlorine demand	60-70	FRC > 3 mg/L
CSFow1	Unlined, covered	4.8	1.0	High faecal contamination, periodical turbidity	60-70	FRC > 10 mg/L
CSFow2	Unlined, open	8.4	2.9	High faecal contamination	80-90	FRC > 3 mg/L
CSFow3	Unlined, covered	2.8	1.5	High faecal contamination	50-60	FRC > 10 mg/L
SI4	Lined, hand pump	2.3	4.9	High chlorine demand	80-90	FRC > 10 mg/L
SIow1	Unlined, covered	4.7	1.0	High faecal contamination	50-60	FRC > 10 mg/L
SIow2	Unlined, open	1.4	>6.0	High faecal contamination, high chlorine demand	60-70	FRC > 10 mg/L
DRow2	Unlined, covered	3.7	0.2	High faecal contamination	50-60	FRC > 3 mg/L
DRow3	Unlined, open	2.8	0.5	High faecal contamination	40-50	FRC > 1.5 mg/L
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC > 3 mg/L

Table 13 : Summarized results of the field tests with design PC1

It is clear that FRC levels are far too high, sometimes above 10 mg/L (when the colour of DPD tablets is bleached during a test with a pool tester). Wrapping the pot chlorinators in a rice bag did not reduce FRC levels. Design PC1 is not suitable, and people do not like it because it makes water bitter or even impossible to drink.

Design PC1 was therefore modified. It was decided to reduce to quantity of HTH granules to 0.5 L, and to isolate the chlorine further from water by using more sand and gravels, as well as by reducing the size of the holes to 2 mm. Figure 6 illustrates the design PC2 (see on page 25).

As FRC levels remained very high for several days in most of the wells after the field tests with design PC1, design PC2 was tested in only 4 wells over 5 days. Table 14 presents a summary of the field tests results (see appendix 11 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
SIow1	Unlined, covered	4.7	1.0	High faecal contamination	50-60	FRC > 1 mg/L
SIow2	Unlined, open	1.4	>6.0	High faecal contamination, high chlorine demand	60-70	FRC > 1 mg/L
DRow1	Unlined, open	1.8	0.4	High faecal contamination	50-60	FRC > 2 mg/L
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC > 3 mg/L

Table 14 : Summarized results of the field tests with design PC2

FRC levels are still too high with PC2. Wrapping the pot chlorinators in a rice bag did not reduce them. This design showed little improvement over design PC1, and it seems that HTH granules still dissolve too quickly. The design needs further modification.

It was therefore decided to test design PC3, which is actually similar to design PC2, except the two holes in the plastic containers were pierced with a needle (see figure 7 on page 25), to try and slow the chlorine dissolution rate down. The number of holes was still to be adapted to each well.

Design PC3 was tested in 6 over 4 days. Table 16 presents a summary of the results (see appendix 12 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
CSF7	Lined, hand pump	2.1	>6.0	High turbidity (iron), high chlorine demand	60-70	FRC > 2 mg/L
CSFow2	Unlined, open	8.4	2.9	High faecal contamination	80-90	FRC < 0.2 mg/L
CSFow3	Unlined, covered	2.8	1.5	High faecal contamination	50-60	FRC > 3 mg/L
SI4	Lined, hand pump	2.3	4.9	High chlorine demand	80-90	FRC > 2 mg/L
SIow1	Unlined, covered	4.7	1.0	High faecal contamination	50-60	FRC < 0.2 mg/L
SIow2	Unlined, open	1.4	>6.0	High faecal contamination, high chlorine demand	60-70	FRC > 2 mg/L

Table 15 : Summarized results of the field tests with local pot chlorinators, design PC3

After two successive modifications of the design, this pot chlorinator is still not effective, as FRC levels are either too high or too low. It seems this kind of design (simple pot chlorinators filled with layers of gravels, sand, chlorine) is not suitable for these wells.

The evaluation table for design PC1, PC2 and PC3 is shown below.

	Criteria	Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	0	FRC levels are generally too high, even if the pot chlorinators are wrapped in rice bags. The chlorine seems to dissolve too quickly.
	Adaptability	0	Not adapted to any well
	Contact time	2	Chlorinators are below the surface, where water is abstracted in open wells, contact time is hence better than with Oxfam pot chlorinators but maybe not long enough
	<i>Subtotal</i>	<i>2/15</i>	
<i>Appropriateness</i>	Availability	4	Only locally easily available materials
	Easy O&M	3	Easy O&M but it takes time to refill the pot chlorinator with layers of gravel, sand, chlorine, etc.
	Acceptability	1	People do not like it because of high FRC
	Costs per unit	1	Capital: L\$ 25 (US\$ 0.5) Recurrent: US\$ 2.9 (0.5 L of HTH) to US\$ 5.8 (1 L) per filling (expensive)
	Logistics	2	All materials are local but containers have to be bought in several informal shops and markets, and it takes time to make the chlorinators
	<i>Subtotal</i>	<i>11/25</i>	
	TOTAL	13/40	

Table 16 : Evaluation of local pot chlorinators, designs PC1, PC2 and PC3

These three successive designs of local pot chlorinator seem neither effective nor appropriate. This chlorination system is not recommended, as the FRC levels are too high or too low. Too high levels of chlorine will discourage people from using chlorinated water and can have counterproductive public health consequences, while too low FRC levels do not ensure safe water. Moreover, design PC1, PC2 and PC3 are quite expensive, due to the quantity of chlorine used. To reduce both FRC levels and the price of the chlorinator, the design should be modified.

4.3.3.2. Design PT with locally pressed HTH tablets

The results given by the previous designs were rather disappointing, because chlorine dissolved too quickly in the wells. It was therefore decided to try a design using locally pressed HTH tablets, in order to try and reduce the chlorine dissolution rate.

A local carpenter was asked to make a tablet mould, cutting a large circular hole (approximately 5 cm diameter) in a thick piece of wood (approximately 3 cm thick). This mould was placed on another piece of wood, and a plastic bag filled with five kitchen spoons of HTH granules (approximately 70 g) was placed inside it (the plastic bag only aimed at isolating the chlorine from the wood). This was covered with a lid, and the tablet was finally pressed, using the carpenter's clamp at different points on the lid to get a more or less uniform compression (see figure 8). It took around 5 minutes to press each tablet.

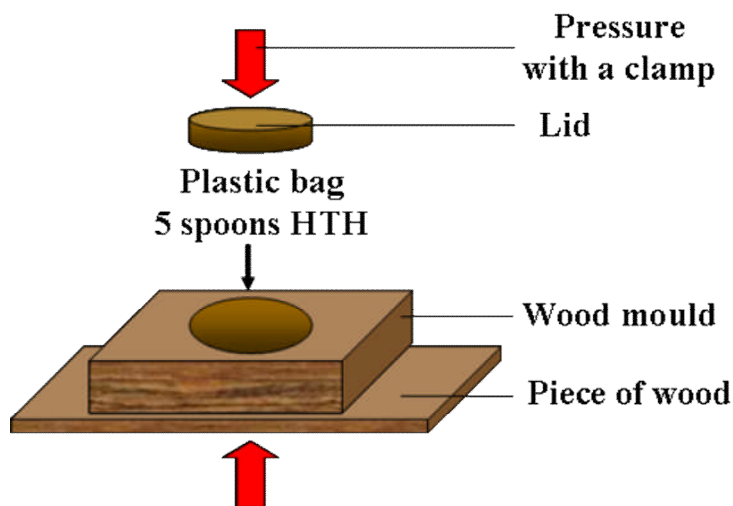


Figure 8 : Locally manufactured press for HTH tablets

These tablets were too big to be inserted in the previously used plastic containers. It was decided to replace them by strong plastic bags. These bags were filled with 2 L of sand, with the chlorine tablet roughly in the middle, and pierced twice with a needle, as shown in figure 9. The bags were then tied with a rope and hung in the wells.

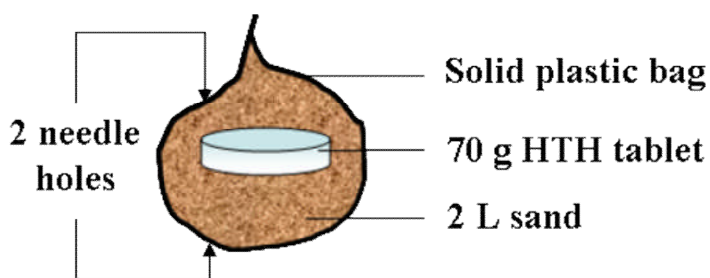


Figure 9 : Local pot chlorinator, design PT

Design 4 has been tested in 5 wells in Duport Road for 6 days. Table 17 summarizes the results for design 4 (see appendix 13 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
DR1	Lined, hand pump	3.7	0.2	Medium faecal contamination	60-70	FRC is between 0.2 and 1.0 mg/L for more than 6 days
DRow1	Unlined, open	1.8	0.4	High faecal contamination	50-60	FRC is between 0.2 and 1.0 mg/L for 4 days
DRow2	Unlined, covered	3.7	0.2	High faecal contamination	50-60	FRC is between 0.2 and 1.0 mg/L for 3 days
DRow3	Unlined, open	2.8	0.5	High faecal contamination	40-50	FRC is between 0.2 and 1.0 mg/L for 3 days
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC is between 0.2 and 1.0 mg/L for 4 days

Table 17 : Summarized results of the field tests with local pot chlorinators, design PT

It is unfortunate chlorination this system could not be tested in more wells, because the preliminary results are very encouraging. FRC levels were found to be within the target range.

The wells in which design PT was tested typically have a low chlorine demand and average volume and abstraction. This design should however be adaptable to bigger, more contaminated or more used wells by using several tablets and adjusting the number of holes in the plastic bag. The chlorine tablet does not last very long (3 to 4 days in unprotected wells, more than 6 days in the protected one), but it is very easy to refill the chlorinators with new tablets, just opening the bag.

Contact time is however still problematic, as it is impossible to monitor. To optimise it, the chlorinators were installed approximately in the middle of the well, between the bottom where new water comes in and the top where people draw. However, it is not sure that a minimum of 30 minutes of contact time was ensured..

The evaluation table for design PT is shown on the following page.

Criteria		Mark (/5)	Remarks
Effectiveness	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	4	FRC levels are adequate for 3 to 7 days
	Adaptability	4	The number and size of tablets can be adapted to other wells
	Contact time	2	Chlorinators are below the surface, contact time is hence better in open wells than with Oxfam pot chlorinators but may be not long enough
<i>Subtotal</i>		<i>10/15</i>	
Appropriateness	Availability	5	Only locally available materials, cheap and easily available at large scale
	Easy O&M	4	Easy O&M, it is very easy to refill the pot chlorinator with tablets, but some tools are needed to make them.
	Acceptability	5	No problem
	Costs per unit	5	Capital: L\$ 5 (US\$ 0.1) Recurrent: US\$ 0.6 per tablet
	Logistics	4	All materials are local and can be purchased anywhere in big quantities, tablets and pot chlorinators are easy and quick to do
<i>Subtotal</i>		<i>23/25</i>	
TOTAL		33/40	

Table 18 : Evaluation of local pot chlorinators, design PT

This design definitely seems the best of all the pot chlorinators tested, and is both effective and appropriate. The cost is less than the 3 previous designs, and all materials can be found quite easily in the peri-urban communities and in Central Monrovia. Tablets are easily made, operation and maintenance is simple and people seemed to accept the chlorinators without any problem.

As with all pot chlorinators, its main weakness is the uncertainty about contact time. It will be necessary to tell people to wait 30 minutes after they draw water and before they use it, which will also disinfect their containers, provided there is enough residual chlorine. More field tests are however needed to determine the exact number of tablets and holes to use in different wells.

4.3.4. Daily chlorination with liquid bleach

4.3.4.1. Design LB1 : FRC = 0.6 mg/L twice a day

Chlorination with Chlora (the most widely available commercial liquid bleach, 5 % available chlorine), dosing wells up to 0.6 mg/L twice a day was tested in 5 wells in Duport Road over 4 days.

On the first day, the dimensions and chlorine demand of each well were measured with the volunteers (see procedure to test chlorine demand in appendix 7). The volunteers received guidelines and explanation of how to calculate the volume of a well and the first dose of Chlora needed to bring its FRC level up to 0.6 mg/L (see guidelines in appendix 14). Bleach volumes were calculated with cheap plastic syringes found in local shops. Volunteers were asked to check the FRC levels in the wells with a pool tester twice a day (once alone, once with the researcher) and readjust them with Chlora as indicated in the guidelines. After each bleach injection, water was mixed in the well with the bucket and well owners were asked to wait 30 minutes before drawing water, to ensure mixing and contact time.

Table 19 provides a summary of the field tests results for design LB1 (see appendix 15 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
DR1	Lined, HP	3.7	0.2	Medium faecal contamination	60-70	FRC sometimes below 0.2 mg/L, sometimes 0
DRow1	Unlined, open	1.8	0.4	High faecal contamination	50-60	FRC sometimes below 0.2 mg/L, sometimes 0
DRow2	Unlined, covered	3.7	0.2	High faecal contamination	50-60	FRC sometimes below 0.2 mg/L, sometimes 0
DRow3	Unlined, open	2.8	0.5	High faecal contamination	40-50	FRC sometimes below 0.2 mg/L, sometimes 0
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC sometimes below 0.2 mg/L, sometimes 0

Table 19 : Summarized results of the field tests with design LB1

This chlorination system is not very satisfactory, as FRC levels are sometimes too low in spite of the daily monitoring. Some people were surprised by the idea of chlorinating with bleach (Chlora is usually used to clean clothes), and some people did not like the fact that they had to wait 30 minutes after chlorination, which represents a minimum contact time. It was also quite difficult for the volunteers to use the guidelines, and training was needed for them to be understood.

The evaluation table for this first chlorination system using liquid bleach is shown below.

	Criteria	Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	2	FRC are adequate but do not last half a day, mixing is ensured after the bleach injection by agitating water with the bucket
	Adaptability	0	Not adapted to any well
	Contact time	4	Contact time is ensured by asking people to wait 30 minutes after chlorination to draw water
	<i>Subtotal</i>	<i>6/15</i>	
<i>Appropriateness</i>	Availability	5	Only locally available and cheap materials
	Easy O&M	2	Daily O&M, chlorination must not be forgotten, needs for training
	Acceptability	3	Some people do not like Chlora in water, people have to wait
	Costs per unit	4	Capital: L\$ 5 (US\$ 0.1) Recurrent: L\$ 60 for 1L of bleach (US\$ 1)
	Logistics	2	All materials are local and can be purchased in small shops, chlorination is straight forward but good training is needed
	<i>Subtotal</i>	<i>16/25</i>	
	TOTAL	22/40	

Table 20 : Evaluation of design LB1

This system cannot be recommended, as its effectiveness is below average. FRC does not last half a day, which does not ensure safe water. As a consequence, bleach doses were increased to bring FRC levels up to 1.0 mg/L in design LB2.

4.3.4.2. Design LB2: FRC = 1.0 mg/L twice a day

Chlorination with Chlora up to 1.0 mg/L twice a day has been tested in the same 5 wells over 6 days, following the same procedure than for the previous experiment. Appendix 16 presents the new guidelines used by the volunteers to calculate the volumes of the wells and the doses of Chlora to inject.

Table 21 presents a summary of the field tests results with design LB2 (see appendix 17 for complete data set).

Well	Protection	Vol. (m ³)	Chlorine demand (mg/L)	Water quality problems	Abstraction (pers./day)	FRC
DR1	Lined, HP	3.7	0.2	Medium faecal contamination	60-70	FRC always between 0.2 and 1.0 mg/L
DRow1	Unlined, open	1.8	0.4	High faecal contamination	50-60	FRC always between 0.2 and 1.0 mg/L
DRow2	Unlined, covered	3.7	0.2	High faecal contamination	50-60	FRC sometimes below 0.2 mg/L
DRow3	Unlined, open	2.8	0.5	High faecal contamination	40-50	FRC sometimes below 0.2 mg/L
DRow4	Unlined, covered	2.7	1.0	High faecal contamination	70-80	FRC sometimes below 0.2 mg/L

Table 21 : Summarized results of the field tests with design LB2

This chlorination system seems relatively effective. Design LB2 was actually tested in 6 other wells in Chicken Soup Factory and Struggle Island Communities. The volunteers from these communities had less education than the volunteers from Duport Road. It seemed very difficult for them to understand and apply the guidelines, and to inject the right amount of bleach in the wells, which is why these results are not presented in appendix. This approach to chlorination really needs good training. The evaluation table for design LB2 is shown below.

Criteria		Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	3	FRC is often adequate for half a day, mixing is ensured after the bleach injection by agitating water with the bucket
	Adaptability	2	Adaptable to some wells
	Contact time	4	Contact time is ensured by asking people to wait 30 minutes after chlorination to draw water
<i>Subtotal</i>		<i>9/15</i>	
<i>Appropriateness</i>	Availability	5	Only locally available and cheap materials
	Easy O&M	1	Daily O&M, chlorination must not be forgotten
	Acceptability	3	Some people do not like Chlorine in water, people have to wait
	Costs per unit	4	Capital: L\$ 5 (US\$ 0.1) Recurrent: L\$ 60 for 1L of bleach (US\$ 1)
	Logistics	2	All materials are local and can be purchased in small shops, chlorination is straight forward but good training is needed
<i>Subtotal</i>		<i>15/25</i>	
TOTAL		24/40	

Table 22 : Evaluation of design LB2

This chlorination system is actually quite effective and appropriate. Its main positive points are mixing and contact time. However, it requires daily monitoring, with the difficulties of not forgetting and dosing bleach correctly. This system can be used but will need trained people chlorinating daily a large number of wells, which can make the chlorination campaign difficult to manage. This system is not so effective or appropriate as the pot chlorinators with locally pressed HTH tablets.

4.3.5. Household chlorination

Household chlorination was studied without any field tests, just using the data previously collected in the communities and throughout discussion with various INGOs watsan staff in Liberia.

Household chlorination could be done using diluted HTH granules, or even more easily using Chlorax. Bleach quantities could be measured using spoons, drops or syringes, with different dosing guidelines for the various containers volumes people generally use (1, 3, 5, 10 gallons for instance).

The main problem is however to calculate these simple household chlorination guidelines, avoiding underdosing (ineffective) or overdosing (dangerous and counterproductive). The first time chlorine demand was measured in the 12 wells, prior to any chlorination, values were ranging from 0.2 to more than 6 mg/L. In this conditions, standard guidelines (e.g. x mL in y gallons) will inevitably be very little effective, even with a 30 minutes contact time. The evaluation table for household chlorination is shown below.

	Criteria	Mark (/5)	Remarks
<i>Effectiveness</i>	FRC is between 0.2 and 1.0 mg/L, everywhere in the well for a long time	1	Chlorine demands are very different and variable
	Adaptability	1	Idem
	Contact time	4	People can wait 30 minutes after chlorination
	<i>Subtotal</i>	<i>6/15</i>	
<i>Appropriateness</i>	Availability	5	Only locally available and cheap materials
	Easy O&M	2	Chlorination must not be forgotten or duplicated
	Acceptability	3	Some people do not like Chlorax (usually used to clean clothes) in water
	Costs per unit	4	Capital: 5 L\$ (0.1 US\$) Recurrent: 60 L\$ for 1L of bleach (1 US\$)
	Logistics	1	All materials are local and can be purchased in small shops but many people must be trained
	<i>Subtotal</i>	<i>15/25</i>	
	TOTAL	21/40	

Table 23 : Evaluation of household chlorination

Household chlorination appears to be relatively appropriate but not very effective, nor easy to implement and control. Its overall mark is only average. This approach to chlorination is therefore not recommended.

In addition to the tests and evaluation of the various previously discussed chlorination systems, the research aimed at investigating what kind of software (awareness, training) would be needed during a well chlorination campaign in these peri-urban communities.

4.4. Awareness and training needs assessment

Informal discussions and observations with members of the watsan committees and well owners highlighted the basic knowledge people from these peri-urban communities have of water quality chlorination:

- People are aware of the benefits of water chlorination, some even periodically chlorinate their wells (every one or two months), using small packets of HTH bought from local markets. Doses are however not determined rationally, people dilute a few bags in a bucket and throw the solution into their well, which they close for one or two days before people drink the water again.
- Few people are aware that chlorine is dangerous (contact, fumes), and that it loses strength over time. People do not usually assimilate Chlorax (bleach) to chlorine, they only use it for washing clothes.
- People do not mind too much if water tastes of chlorine. FRC up to 1.0 or even 1.5 mg/L were usually well accepted during the field tests, which is however not recommended.
- Basic hygiene practices during the abstraction, transport and storage of water could be improved. Some people draw water with their own rope and bucket or leave the common ones on the ground, which can potentially cross contaminate the wells. Few people have clean containers with lids. Hand washing, for example after defecation, is far from being a systematical practice, for the lack of infrastructure but also awareness, according to the watsan committees' health motivators.

Moreover, the questions introduced in the water abstraction forms highlighted the facts that the vast majority of people use the water directly after they draw it (or maybe 10 minutes after, the time to come back home) and that men rarely fetch water (this task is clearly performed by women and children).

All this information made it possible to identify issues to be addressed with appropriate trainings and awareness campaigns during a well chlorination campaign in these cholera hotspots peri-urban communities:

- Chlorination need training, to use and store chlorine safely, to make and install the chlorination system and possibly to monitor it. The best people to be trained are the watsan committees and/or well owners.

- People usually easily accept chlorinated water, but there might be a need to inform them about which wells are chlorinated and to encourage them to use these sources or protected wells.
- Contact time is definitely an issue, as most people use their water directly after drawing it. It might be necessary to incite them to wait 30 minutes.
- Making sure the water is safe might not be enough to fight waterborne diseases outbreak, as contaminations can easily happen at the household level (Oxfam GB, 2004). Chlorination campaigns should also integrate hygiene promotion messages on safe water abstraction, transport and storage, as well as hand washing. These messages could be delivered by the existing health motivators of the watsan committees. Chlorination and hygiene sensitisation campaigns should target women and children, as they are responsible for water, and could take place in markets, women groups, and schools.

5. CONCLUSIONS & RECOMMENDATIONS

5.1. Well chlorination systems

- Oxfam floating pot chlorinators can be adapted to well chlorination, adjusting the FRC levels with the valve and the number of layers of rice bag. They are however not recommended as they are imported, expensive, and neither very effective nor very appropriate.
- Local simple pot chlorinators in plastic containers filled with layers of gravels, sand, and HTH cannot be used, as chlorine seems to almost always dissolve too quickly, making the technology little effective and appropriate.
- Daily well chlorination with liquid bleach, to bring the FRC level up to 1.0 mg/L twice a day seems to be quite effective and appropriate. It is however not recommended because it needs intensive monitoring and is quite complicated to implement quickly at a large scale.
- Household chlorination could be appropriate, but it seems difficult to make it effective because of the very different chlorine demands of the wells. Moreover, chlorination can be forgotten, duplicated or done incorrectly as it is not controlled. Household chlorination can also be difficult to implement quickly at a large scale. It is therefore not recommended.
- The best system tested seems to be the pot chlorinator with a 70 g locally pressed HTH tablet and 2 L of sand in a solid plastic bag, pierced twice with a needle and hung in the well at approximately half or two thirds of its depth. This proved both very effective and appropriate, but was tested in a limited number of wells, all with relatively low chlorine demands (0.2 to 1.0 mg/L) and average volumes and abstraction (1.8 to 3.7 m³, 40 to 70 users per day). It should however be adaptable to wells with bigger volume, chlorine demand and/or abstraction by increasing the size and number of chlorine tablets and holes. This system proved effective during the rainy season, when major water related disease outbreaks are more likely to happen. It might not be adapted to the dry season, when wells volumes are reduced.

5.2. Chlorination awareness and training

- Before a well chlorination intervention, watsan committees and well owners or attendants will have to be trained to use and store chlorine safely, to make and operate the chlorination system and to monitor FRC levels with pool testers. They must know water should contain between 0.2 and 1.0 mg/L of FRC, and be able to adjust the chlorination system to keep within these limits.
- Existing health motivators from the watsan committees should inform people about which wells are chlorinated, and encourage them to use chlorinated or protected wells, with a strong message to wait 30 minutes before using chlorinated water. This could be coupled with hygiene promotion messages on safe water abstraction (use collective and clean rope and bucket, not leave them on the ground), transport and

storage (clean container, lid, cup), as well as hand washing. Songs, drama, and group discussions in markets, women groups, and schools would be a friendly way of passing these messages to women and children, who are responsible for water. Messages and songs on local radios might also be interesting because of their large coverage, but will probably mainly be heard by men.

To summarise, well chlorination using local pot chlorinators and locally pressed HTH tablets can probably be an effective way of preventing or reducing waterborne diseases such as cholera, especially if this is coupled with adequate software including training, awareness and hygiene messages. Further research is recommended to determine rational guidelines indicating how many tablets and holes should be used in different wells. It could also be interesting to test a similar system with thirds or quarters of Oxfam trichloroisocyanuric acid tablets.

As this chlorination system is simple, quick and cheap, it can be used in both short term emergencies (e.g. Oxfam rapid intervention to prevent or reduce a cholera or diarrhoea outbreak) and longer term projects (e.g. sustainable community managed chlorination system). However, it seems important to remind that chlorination must not substitute for the protection of sources in the long term. In such a case, protection seems more effective and more sustainable than chlorination on its own. Well protection and chlorination can also be coupled.

At last, Liberia has a rainfall average greater than 5000 mm over a 6 month rainy season, during which risks of epidemics are especially high. As many houses are covered with corrugated iron sheets or tarpaulins, it is recommended to investigate household rainwater harvesting as an option to get safe water in peri-urban Monrovia during part of the year.

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