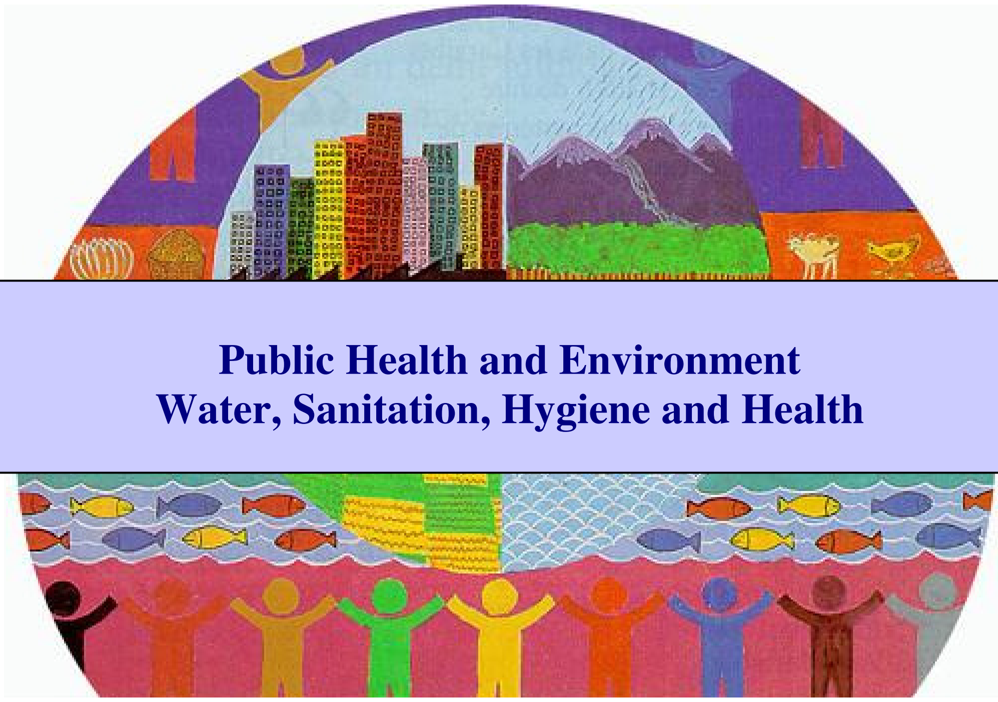
Scaling Up Household Water Treatment Among Low-Income Populations



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Scaling Up Household Water Treatment Among Low-Income Populations

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Contents

LIST OF ACRONYMS

AIDS	acquired immunodeficiency syndrome
BRAC	(formerly) Bangladesh Rural Advancement Committee
CAWST	Centre for Affordable Water and Sanitation Technology
CDC	Centers for Disease Control and Prevention (United States of America)
CFU	colony-forming units
CI	confidence interval
EAWAG	Swiss Federal Institute for Environmental Sciences and Technology
ENPHO	Environment and Public Health Organization
HIV	human immunodeficiency virus
HWTS	household water treatment and safe storage
IDE	International Development Enterprises
JMP	Joint Monitoring Programme for Water Supply and Sanitation (WHO/UNICEF)
KWAHO	Kenya Water for Health Organisation
LRV	log_{10} reduction values
MDG	Millennium Development Goal
NaDCC	sodium dichlorisocyanurate
NGO	nongovernmental organization
OR	odds ratio
PAHO	Pan-American Health Organization
PATH	Program for Appropriate Technology in Health
POUZN	point-of-use water treatment with zinc supplements
PSI	Population Services International
RBM	Roll Back Malaria
RDI	Rural Development International
SANDEC	Department of Water and Sanitation in Developing Countries
SWS	safe water system
UN	United Nations
UNICEF	United Nations Children’s Fund
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

SUMMARY

Providing safe, reliable, piped-in water to every household is an essential goal, yielding optimal health gains while contributing to the Millennium Development Goal (MDG) targets for poverty reduction, nutrition, childhood survival, school attendance, gender equity and environmental sustainability. While strongly committed to this goal and to incremental improvements in water supplies wherever possible, the World Health Organization (WHO) and others have called for targeted, interim approaches that will accelerate the heath gains associated with safe drinking-water for those whose water supplies are unsafe.

Interventions to treat and maintain the microbial quality of water at the household level are among the most promising of these approaches. In many settings, both rural and urban, people have access to sufficient quantities of water, but that water is unsafe. Effective household water treatment and safe storage (HWTS)—if used correctly and consistently—can significantly improve the microbiological integrity of the water at the point of ingestion. Ensuring widespread and equitable access to effective HWTS solutions to those for whom water is a significant pathway for the transmission of enteric infection can deliver some of the health benefits of improved water supplies and thus complement other efforts in water, sanitation and hygiene.

This report examines the evidence to date regarding the scalability of HWTS. It seeks to consolidate existing knowledge and experience and distill the lessons learnt. Its primary aims are to 1) review the development and evolution of leading household water treatment technologies in their efforts to achieve scale, 2) identify the main constraints that they have encountered and 3) recommend ways forward.

The report begins by defining scale in terms of both coverage (supply) and uptake (demand and correct/consistent use) by a vulnerable population. Section 2 examines efforts to scale up other important household-based interventions—sanitation, oral rehydration salts, guinea worm filters and insecticide-treated mosquito nets—for lessons of potential value to scaling up HWTS. Among the important recurring themes from such interventions are the need to 1) focus on the user's attitudes and aspirations; 2) take advantage of simple technologies to minimize the need for intensive behaviour change promotion; 3) promote non-health benefits, such as cost savings, convenience and aesthetic appeal; 4) use schools, clinics and women's groups to gain access to more vulnerable population segments; 5) take advantage of existing manufacturers and supply channels to extend coverage; 6) provide performance-based financial incentives to drive distribution; 7) align international support and cooperation to encourage large-scale donor funding; 8) use free distribution to achieve rapid scale-up and improve equity; 9) use targeted subsidies, where possible, to leverage donor funding; and 10) encourage internationally accepted standards to ensure product quality.

Section 3 presents case-studies of the most common HWTS products and technologies that are being promoted by governments, United Nations (UN) agencies, nongovernmental organizations (NGOs), social marketers and the private sector. Boiling is the most prevalent means of treating water in the home; it is practised by hundreds of millions of people, perhaps because the necessary hardware are already available in most cases. In certain Asian countries, boiling is practised by more than 90% of the population. Boiling is among the most effective methods of improving the microbiological quality of water, even under a variety of conditions that challenge other methods. This combination of scalability and effectiveness renders boiling the benchmark by which other methods must be measured. At the same time, boiling presents potential disadvantages in actual practice that raise questions about whether it should continue to be promoted over other HWTS options. These include relatively high cost compared with certain alternatives, susceptibility of boiled water to recontamination, contribution to poor indoor air quality and adverse environmental impact. Some of these shortcomings can be minimized with cleaner fuels, more efficient stoves, the use of simple indicators to show householders when pasteurization temperatures have been reached, and safe storage. Unless and until alternatives to boiling have demonstrated higher performance at scale, boiling should continue to be encouraged.

The current HWTS movement had its origins in pioneering work by the Centers for Disease Control and Prevention of the United States of America and the Pan-American Health Organization, which introduced the "safe water system", a combination of sodium hypochlorite (liquid bleach), safe storage and a hygiene message as a means by which householders could protect themselves against

cholera. No single approach has been more extensively tested, and, apart from boiling, none has reached the same levels of scale, despite some resistance in uptake due to objections to taste and odour. Along the way, however, the intervention evolved in its delivery. Local production has shifted to national, and the safe storage vessel has been dropped. Programme delivery has shifted almost entirely from governments and NGOs to a single social marketing organization, Population Services International (PSI). In 2007, more than 7.3 million bottles of sodium hypochlorite—enough to treat 7.6 billion[1] litres of drinking-water and supply 10.4 million users—were sold for routine (non-emergency, non-outbreak) use in 18 countries. Nearly 60% of these sales were in just three countries, and Zambia, Nigeria and Kenya arguably represent examples of HWTS having achieved scale in coverage at the national level. On the other hand, there is evidence there and in other countries that uptake is greatest among urban, higher-income and better educated populations, which may not be most vulnerable to waterborne diseases. These same disparities may be even greater for HWTS products other than the sodium hypochlorite, which benefits from its low cost of entry and overall cost of use, high awareness and widespread availability. Targeted delivery through schools, clinics and human immunodeficiency virus/acquired immunodeficiency syndrome programmes may overcome some of the disparities in product uptake.

Like sodium hypochlorite, chlorinated isocyanurates (e.g. sodium dichloroisocyanurate [NaDCC] tablets) produce hypochlorous acid to disinfect drinking-water. At the same time, NaDCC may have certain advantages over sodium hypochlorite owing to its solid form, long shelf life, visual activity, convenience and lower up-front cost (although higher overall cost per litre treated). Microbiological performance has been demonstrated in the laboratory and in the field, and a health impact trial has recently been completed in Ghana. While NaDCC tablets have been used widely in emergency response for more than 30 years, the product has only recently begun to be deployed in routine HWTS applications owing in part to regulatory acceptance. After only a few years, however, NaDCC tablets have come to represent a considerable share of overall HWTS coverage. In 2007, the leading manufacturer sold more than 150 million tablets, enough to treat 2.86 billion litres of water and meet the drinking-water needs of an estimated 2.35 million routine users. To date, however, coverage is confined to eight countries, with a majority of sales in Kenya, where it may be benefiting from PSI marketing. There is also little compelling evidence to date that uptake of the product is any better than that of sodium hypochlorite. While early results appear promising for the potential scalability of NaDCC tablets, promoters must still demonstrate that they can establish local distribution and delivery in multiple countries, overcome objections to the taste and smell of water treated with chlorine, compete at a higher price point than the sodium hypochlorite and succeed in reaching and securing regular use by the most vulnerable populations.

Solar disinfection, which synergistically applies the biocidal action of heat and ultraviolet radiation, has also been shown to be effective, both microbiologically and in reducing diarrhoeal disease and cholera. Although continuous commercial systems are used in some settings, the approach that has gained the largest traction among low-income populations consists simply of filling clear plastic bottles with water and placing them on the roof to expose the water to sunlight for at least 6 h. Like boiling, this method is fundamentally a behaviour change strategy more than a product and thus has little commercial potential. Accordingly, it is promoted exclusively by governments and NGOs. Despite these limitations, solar disinfection reported more than 2.1 million users as of the end of 2007. While the delivery strategy and low cost may overcome some of the disparities in uptake that are more likely to impact market-driven HWTS products, scaling up solar disinfection widely has thus far met challenges in acceptability and longer-term use, partly due to some resistance in gaining credibility among potential users, some inconvenience, its inability to deliver improvements in water aesthetics and its lack of aspirational appeal. These are, however, many of the same challenges that boiling has had to overcome.

Among various filtration options whose microbiological performance has been demonstrated, only ceramic and biosand filters have been promoted actively as HWTS options for lower-income populations. Ceramic filters have been tested widely in the laboratory and in the field and have demonstrated their capacity for reducing diarrhoeal disease, despite little, if any, capacity for removing viruses. While ceramic "candle" filters have a long history in treating water in the home,

[1] In this report, "billion" is defined as a thousand million (10^9).

inconsistent performance owing to poor quality of the medium, especially in Asia, has limited the potential of these devices for making an important contribution to overall scale. Large producers of higher-end ceramic candles in Brazil, Switzerland, the United Kingdom and elsewhere have so far demonstrated only minor interest in lower-income markets, although 100 000–150 000 microbiological-quality units are estimated to be in use. Pot-style filters have shown more promise recently, especially in Cambodia, where factories have produced more than 194 000 filters to date, overcoming quality challenges and creating some demand at full cost-recovery pricing. Collectively, an estimated 423 000 people in 21 countries were using ceramic filters as of the end of 2007, producing 2.6 billion litres of water to meet the needs of an estimated 2.5 million users. Like other HWTS approaches, however, there is comparatively little evidence of the uptake and longer-term use of ceramic filters. While local production has considerable appeal, it also presents challenges in scaling up, as evidenced by failed efforts in certain countries over the past 20 years. Quality control, breakage in transport or cleaning, high up-front cost, slow flow rates, the need for regular cleaning and susceptibility to water recontamination are challenges that may inhibit scaling up this alternative.

Biosand filters provide a means by which the well-established process of continuous slow sand filtration can be carried out intermittently, thus making it suitable for household-based applications. While somewhat less effective in microbiological performance than other HWTS options—possibly due in part to recontamination arising from a lack of safe storage—biosand filters have nevertheless been shown to reduce diarrhoeal disease in efficacy trials. Like solar disinfection and pot-style ceramic filters, biosand filters have been promoted mainly by NGOs. Recipients are expected to assist in the fabrication and transportation of their filter. The Centre for Affordable Water and Sanitation Technology, a Canadian NGO, has provided much of the training and technical assistance to local NGOs for the construction of moulds to fabricate the concrete filter housing. Their latest annual survey suggests that approximately 143 000 concrete-style filters were in operation as of June 2007, serving an estimated 858 500 users in 36 countries. For the year, they produced nearly 1.3 billion litres of drinking-water (at 25 litres/unit per day). Uniquely among HWTS products, however, biosand filters can produce 80 litres/day or more. While the number of filters in operation continues to grow annually, it seems unlikely that biosand filters will achieve a breakthrough in scale, largely due to limitations in manufacture and distribution. A plastic version of the filter more suitable for mass production and intended to be sold for cost has recently been introduced in the hope of overcoming some of these challenges.

Sachets combining a flocculant and disinfectant have been marketed for more than a decade, but only recently has one version been shown to be effective in killing or removing microbial pathogens (and arsenic) and in reducing diarrhoeal disease. Although the product is used extensively in emergency settings, efforts to commercialize it were suspended after they failed to achieve significant levels of repeat purchasers, despite considerable effort to promote and ensure access to the product. While the strategy of selling fast-moving consumer products in small sachet quantities has been successful in increasing coverage of many household and personal care products, the relatively high cost of routinely treating water with flocculant-disinfectant, the need for demonstrations to introduce the product, and the time and effort required to use the product limited its ability to achieve widespread uptake. Distribution in non-emergency settings is now mainly promoted through PSI using social marketing strategies that require some level of support, even if some cost recovery is possible. In 2007, the manufacturer estimated 216 000 regular users of its sachets in non-emergency settings in nine countries.

Combining the current levels of coverage across products and technologies presents certain challenges, owing to the variety of products and technologies, the different ways in which manufacturers and programme implementers report and the various assumptions they employ regarding use. Although efforts are under way to improve metrics, even rough estimates of combined coverage are useful in order to take stock of achievements to date, examine trends, compare progress against the need and assess the potential for HWTS technologies to achieve scale. In 2007, the combined efforts of the above-described HWTS products—exclusive of boiling and emergency applications—produced approximately 15.5 billion litres of treated water. This represents an average annual growth of 25.5% over 2005 and 2006 levels of 9.9 billion and 12.2 billion litres treated, respectively. Manufacturers and programme implementers reported 18.8 million users of these HWTS products as of the end of 2007, compared with 12.0 million in 2005 and 15.5 million in 2005—an average annual growth rate of 25.1%. It is noted that these figures do not include boiling, which is practised by more than 350 million people, a figure that does not include large populations in China, Indonesia and elsewhere, where boiling is also believed to be common. They also do not include emergency use of HWTS products—an important role for point-of-use water treatment, but one that does not contribute to the overall levels of coverage under routine conditions.

These figures are impressive, especially given that most of these HWTS programmes have been under way for less than 10 (and some less than 5) years. However, given 884 million people relying on unimproved water supplies and many more whose water is not consistently safe for drinking, the results to date for HWTS methods other than boiling provide a perspective that is more sobering. At the current pace, these HWTS methods will not cover even 100 million users until 2015. Except for the sodium hypochlorite product in Zambia and, arguably, Madagascar and some promising ceramic filter coverage in Cambodia, no HWTS method other than boiling can be said to have achieved scale in coverage. This is due in part to some of the same challenges facing novel public health interventions among low-income populations—creating awareness, securing acceptance, ensuring access and affordability, establishing political commitment, addressing sustainability, etc. However, there are at least a few special constraints that HWTS must overcome before it can achieve scale. These include 1) the persistent belief that diarrhoea is not a disease; 2) scepticism about the effectiveness of water quality interventions; 3) special challenges associated with uptake, including low aesthetic appeal for consumables, high up-front cost, the need to replace components for durables and the need to continuously use the product, even in the face of disease through other transmission pathways; 4) public health suspicion of the agenda of commercial products and strategies; 5) the orphan status of HWTS at the public sector level, with neither the water sector nor the health sector willing and able to assume ownership of the intervention; 6) minimal public sector participation in the promotion of HWTS; 7) a lack of focused international effort and commitment to advance HWTS; and 8) perceived policy conflict with efforts to promote piped-in water supplies.

It is impossible to escape the conclusion that current efforts to scale up HWTS will fall far short of meeting the actual need. Although it is possible that we are approaching a "tipping point" leading to rapid acceleration of coverage and uptake along the steep incline of the S-curve that typically characterizes diffusion of innovations, there is little evidence that such a transition is imminent. While some cite the rapid expansion of mobile phones as an example of the potential of HWTS products, evidence compiled in a recent World Bank report shows why this may be an exception. Moreover, shortcomings in existing products, delivery strategies and a basic understanding of what householders want continue to hamper efforts to achieve widespread coverage and uptake.

The goal of scaling up HWTS will not be achieved simply by putting more resources into existing programmes or transitioning current pilot projects to scale. The gap between where we are and where we need to be is too great, given the urgency of the need. What is needed is a breakthrough. The largely public health orientation that has brought HWTS to its present point now needs to enlist the help of other experts: consumer researchers, product designers, educators, social entrepreneurs, micro-financiers, business strategists and policy advocates. The private sector is one obvious partner; it possesses not only much of this expertise but also the incentive and resources to develop the products, campaigns and delivery models for creating and meeting demand on a large scale. At the same time, market-driven, cost-recovery models are not likely to reach vast populations at the bottom of the economic pyramid where the disease burden associated with unsafe drinking-water is heaviest. As WHO ultimately concluded in the case of insecticide-treated mosquito nets, mass coverage among the most vulnerable populations may be impossible without free or heavily subsidized distribution. For this population segment, the public sector, UN organizations and NGOs that have special access to these population segments must engage donors to provide the necessary funding and then demonstrate their capacity to achieve both scale and uptake. Governments and international organizations can also help encourage responsible action by the private sector by implementing performance and safety standards and certification for HWTS products; reducing barriers to importation, production and distribution of proven products; and providing incentives for reaching marginalized populations.

It may be possible to accelerate the pace of scaling up HWTS. Below are 10 steps that warrant particular priority. Notably, they seek to engage not only public health officials, but also policy-makers, donors, regulators, private companies, NGOs and householders themselves. They are presented in greater detail in the final section of this report.

1. *Focus on the users.* Focus on those who could most benefit from the intervention. Find out what they really want, need and will use, and deliver it.
2. *Develop and use partners.* Creative collaborations between the private sector, public sector and civil society have particular potential for overcoming the challenges of getting safe, effective and acceptable HWTS products into the homes of the most vulnerable populations.
3. *Improve and expand on boiling*. Despite certain shortcomings, boiling is among the most microbiologically effective of HWTS methods; it is also the only approach that has achieved scale. Technological and behavioural research could help overcome some of the shortcomings and potentially expand coverage. The potential for boiling should not be ignored in favour of more commercial approaches.
4. *Continue to pursue non-commercial strategies.* The vast population that subsists on less than one or two US dollars per day should receive safe, effective and appropriate HWTS products free or at highly subsidized prices as part of a mass distribution campaign. A clear position statement to this effect by the international public health community and standards for eligible products based on field-demonstrated safety, microbiological performance, acceptability and use will advance efforts to scale up the intervention among these populations, as they did for insecticide-treated mosquito nets.
5. *Continue to pursue market-driven strategies*. Market-driven approaches—used by both for-profit, private companies and non-profit, social marketing organizations—are responsible for achieving most of the coverage to date for HWTS methods other than boiling. They also provide opportunities for leveraging public sector and donor resources by achieving coverage at middle levels of the economic pyramid.
6. *Leverage existing local strengths*. Take advantage of existing manufacturing capacity and supply chains in targeted countries that reach even the most remote locations. Provide investment and technical assistance to improve the quality of locally produced products and develop local skills.
7. *Initiate and use relevant, practical research.* While existing HWTS methods are effective in improving water quality and preventing disease, all have certain shortcomings. A breakthrough in HWTS technology, like the long-lasting insecticide-treated bed net for malaria, could contribute significantly to achieving scale of effective HWTS. Research can also make valuable contributions to improving the efficiency of boiling, increasing coverage and uptake of this and other solutions, and building the case for HWTS as an intervention worthy of support by policy-makers and donors.
8. *Overcome public policy barriers to advancing HWTS.* The Joint Monitoring Programme for Water Supply and Sanitation (JMP) of WHO and the United Nations Children’s Fund should clarify the contribution that safe and effective HWTS can make towards advancing health, even though, for policy and methodological reasons, it should not count towards the MDG water target. National governments should embrace the intervention while they work to extend piped-in supplies of treated water.
9. *Engage national and regional governments*. Take steps to inform governmental officials about the benefits of HWTS and show them how the intervention can leverage their own conventional efforts in water and health by reducing outlays for health costs. Activate governmental champions for HWTS wherever they arise, and give them the tools and knowledge to become advocates.
10. *Engage international leadership to support HWTS.* Establish and maintain a higher international profile for diarrhoea and other waterborne diseases. Highlight the progress to date—especially success stories in Zambia, Madagascar, Malawi, Cambodia and Kenya—to demonstrate the potential for achieving scale and the contribution that HWTS can make as part of an integrated water, sanitation and hygiene strategy. Demand funding to promote HWTS that is commensurate with the contribution it can make to reducing a substantial burden of diarrhoeal disease.

1. INTRODUCTION

1.1 Background

More than 35 years ago, a landmark study on domestic water reported that 950 million people—one quarter of the world's then 3.7 million population—lacked access to safe drinking-water supplies (White, Bradley & White, 1972). Since then, substantial efforts have been undertaken to make safe water supplies available, especially to the poor in developing countries. International policy-makers have also drawn attention to the sector, designating the 1980s as the United Nations (UN) "International Drinking Water Supply and Sanitation Decade". The proportion of the population that still relies on unimproved sources of drinking-water has shrunk over this period, as has the absolute number of people without coverage, from 950 million in 1970 to an estimated 884 million in 2006 (WHO/UNICEF, 2008b). Nevertheless, the current definition of "improved supplies" addresses only the type of supply (protected well, borehole, etc.), not the quality of that supply. Thus, millions of those whose supplies meet the definition of "improved" nevertheless rely on water that is unsafe for consumption (WHO/UNICEF, 2005).

As part of its Millennium Development Goals (MDGs), the UN expressed its commitment by 2015 to reduce by half the proportion of people without "sustainable access to safe drinking water" (United Nations, 2000). As discussed more below, there is no metric for such access, and "improved supplies" has become an imperfect proxy. By this measure, progress is being made, with many countries on track to meet the targets. Nevertheless, current trends will leave hundreds of millions unserved by the target date (WHO/UNICEF, 2006). Three quarters of these will live in rural areas where poverty is often most severe and where the cost and challenge of delivering safe water are greatest. In sub-Saharan Africa, where many countries are falling short of MDG targets, current trends will actually result in a 47 million person increase in the number of unserved. Thus, the health benefits of safe drinking-water—especially in preventing diarrhoea, which kills 2.2 million annually, including 17% of children under 5 years of age in developing countries (WHO, 2008a)—will remain elusive for vast populations for years to come.

Filtering and disinfecting water at conventional treatment facilities and delivering it in sufficient quantities to households through an intact distribution system are the ideal solution for minimizing waterborne disease. However, to reach the MDG target for safe water using such approaches would necessitate an investment of tens of billions[1] of US dollars each year to connect households at the rate of 300 000 per day, about a third more than the current pace (Hutton & Bartram, 2008). While careful not to encourage diversion of resources away from connected taps, public health officials have called for other approaches that will provide some of the health benefits of safe drinking-water while progress is being made in improving infrastructure (Mintz, Reiff & Tauze, 1995; Thompson, Sobsey & Bartram, 2003; WHO/UNICEF, 2005).

One such alternative is household water treatment and safe storage (HWTS). In many settings, both rural and urban, populations have access to sufficient quantities of water, but that water is unsafe for consumption as a result of microbial or chemical contamination. This is increasingly true even for piped-in water, since supplies are rarely provided on a 24 h/day, 7 day/week basis, forcing householders to store more water in the home in ways subject to recontamination and leading to microbial infiltration of poorly maintained systems. Effective treatment at the household level—often using the same basic approaches of filtration, disinfection and assisted sedimentation, or a combination thereof, as characterize conventional water treatment—can remove, kill or inactivate most microbial pathogens (Quick et al., 1996; Luby et al., 2001; Rangel et al., 2003; Souter et al., 2003; Caslake et al., 2004; Clasen & Cairncross, 2004). Moreover, by focusing at the point of use rather than the point of delivery, treating water at the household level minimizes the risk of recontamination that even improved water supplies can present (Mintz et al., 2001; Wright, Gundry & Conroy, 2003).

Although HWTS is not new, its potential as a focused public health intervention strategy is just emerging. For centuries, householders have used a variety of methods for improving the appearance and taste of drinking-water, including filtering it through porous rock, sand and other

[1] In this report, "billion" is defined as a thousand million (10^9).

media or using natural coagulants and flocculants to reduce suspended solids. Even before germ theory was well established, successive generations were taught to boil water, expose it to the sun or store it in metal containers, all in an effort to make it safer to drink. In 2000, the World Health Organization (WHO) commissioned a comprehensive study to review these household water treatment and storage practices. The review identified 37 different options for household-based water treatment and assessed the available evidence on their microbiological effectiveness, health impact, acceptability, affordability, sustainability and scalability (Sobsey, 2002). Seeking to create a forum and clearinghouse for advancing HWTS, a variety of organizations met in Geneva in 2003 and launched the WHO-backed International Network to Promote Household Water Treatment and Safe Storage (http://www.who.int/household_water/en/). The HWTS Network now claims more than 100 members from government, UN agencies, international organizations, research institutions, nongovernmental organizations (NGOs) and the private sector; it meets regularly, rotating among continents.

Working through its members, the HWTS Network has accomplished much in terms of advocacy/communication, research and implementation. It has actively promoted HWTS at dozens of national and international conferences, forums and meetings on water strategies. It has published scores of papers, briefings, fact sheets and brochures on options for HWTS in various settings, many of which are available in full on its web site. As discussed more fully below, research has addressed many of the issues concerning the safety, efficacy, field effectiveness and health impact of HWTS options. Although not entirely "mainstream", HWTS is no longer considered "fringe" in the health or water sector. Surveys have shown that projects and programmes employing HWTS have been implemented in 53 countries (Murcott, 2006). There is also evidence that household-based water treatment strategies can play a role in emergency relief (Roberts et al., 2001; Clasen et al., 2005; Doocy & Burnham, 2006). In 2006, the Bill & Melinda Gates Foundation awarded a 5-year, US$ 17 million grant to Seattle-based Partners for Affordable Technologies in Health to identify, evaluate and develop appropriate products and investment strategies to enable sustainable commercial enterprises to produce, distribute and sell HWTS products to low- and middle-income populations.

Despite these achievements, the promise of HWTS—and the mission of the HWTS Network to "achieve a significant reduction of waterborne disease, especially among children and the poor" (WHO, 2007)—cannot be realized unless the interventions can be implemented at scale. That is the focus of this report.

1.2 Definition of scaling up

"Scaling up" is fundamental to most health interventions and is widely discussed in the literature. A list of references from a bibliography on "Scaling Up Health Interventions" runs a remarkable 73 pages (Gillespie et al., 2007). The term "scaling up", however, is rarely defined. One source calls it "the process of reaching larger numbers of a target audience in a broader geographic area" (AYA, 2006). A source on "scaling up communication" cited one of the most far-reaching (if ineloquent) definitions: "Scaling up aims to provide more quality benefits to more people over a wider geographical area more quickly, more equitably and more lastingly" (DFID, 2002). Most of the references, however, are to expanding or increasing *coverage* (Curtis et al., 2003; Johns & Torres, 2005; Pokhrel, 2006).

In epidemiological terms, "coverage" is a measure of the extent to which the services extend to the potential need for those services. It is expressed as a proportion in which the numerator is the number of persons served by an intervention and the denominator is the number of persons in need of the intervention (Last, 2001). The MDG water target, which is expressed in terms of reducing the proportion of the population without sustainable access to safe water, is concerned with increasing coverage. The WHO/United Nations Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation (JMP), which measures the proportion of the population with sustainable access to improved drinking-water and access to improved sanitation, expresses its results in terms of the percentage of coverage (WHO/UNICEF, 2006).

Coverage is an important metric for measuring progress towards scaling up. However, increasing the supply of HWTS products may be a necessary but not sufficient condition to secure the benefits of household water treatment. Like most health interventions, HWTS promoters must actually reach the target population with safe, effective, appropriate and affordable solutions. This can be a daunting challenge, even for an intervention such as a vaccine, especially where it must be protected through a cold chain, is delivered in multiple doses and must reach high levels of coverage even in remote areas in order to be fully successful. However, in order to maximize health gains from environmental interventions such as improved drinking-water, the intervention must target the poor (Gakidou et al., 2007). Also, unlike vaccines and certain other interventions, water treatment in the home requires householders to embrace and routinely use the intervention in order to provide protection (Clasen et al., 2006). Thus, the real potential for household water treatment to scale up depends not only on the extent to which it can be made available to the target population (coverage), but also on the extent to which it is adopted by that population and used correctly and consistently (uptake). In other words, scaling up HWTS must address not only the *supply* (ensuring that the intervention reaches the population) but also the *demand* (promoting use) (Clasen, 2006; Pokhrel, 2006).

This need to secure uptake of, and not just access to, the intervention is certainly not unique to HWTS. Many environmental health interventions, including some that are implemented at the household level, represent a combination of "hardware" as well as some action to deploy or use that hardware, often on a regular basis. Examples include insecticide-treated nets for preventing malaria and other vector-borne diseases, soap for hand washing, latrines for preventing diarrhoea and other faecal–oral diseases, guinea worm filters for preventing dracunculiasis and oral rehydration salts for preventing dehydration associated with diarrhoea. However, insofar as uptake requires some behaviour change, it can be exceedingly difficult to achieve and maintain (Figueroa & Kincaid, in press). Even the tools and indicators used to measure behavioural outcomes associated with HWTS are still in development (Hernandez, 2007).

In examining efforts to scale up HWTS, this report will employ this more expansive definition, focusing on efforts both to reach the target population with effective interventions and to secure their adoption and use of the interventions.

1.3 Does the evidence support scaling up?

A threshold question is whether the evidence to date on the benefits of HWTS is sufficient to support efforts to scale up the intervention. A 2006 Cochrane review described the evidence on water quality interventions to prevent diarrhoeal diseases, making several key points about the deficiencies in the evidence concerning HWTS (Clasen et al., 2006). These include evidence of bias in reported effect and the need for rigorous, blinded, longer-term trials; the presence of substantial heterogeneity among studies; and the need to demonstrate affordability, acceptability, use and sustainability of the intervention (Clasen et al., 2006). Schmidt & Cairncross (2009) cited these and other issues and concluded that promotion of household water treatment among poor populations is premature. Others, including the author of this monograph, have reviewed these issues and challenged their conclusions, arguing that they ignore important aspects of the research (Clasen et al., 2009). Among other things, they note the following:

- The authors of each of the blinded trials of HWTS interventions conducted to date have themselves emphasized shortcomings in their studies and the generalizability of their findings. Accordingly, a superficial comparison of blinded versus open study designs that does not actually examine the underlying studies is misleading.

- Although efforts are under way to conduct rigorous, blinded trials, it is not clear that the intervention can be successfully blinded in low-income settings, for both technical and ethical reasons. However, the absence of placebo-controlled studies has not called into question the benefits of other environmental interventions to prevent diarrhoea, such as improving water supplies, sanitation or hygiene, despite the same risk of bias, and there is no need to raise the evidentiary standard for HWTS given the undisputed evidence of its capacity for improving water quality in vulnerable households on a sustainable basis.

- There is compelling evidence of the health impact of improving microbiological water quality with no accompanying change in water quantity and access (Cutler & Miller, 2005). In fact, much of the improvement in reduced child mortality and morbidity in developed countries over the last century is attributable to improvements in water quality. As improvements in water supplies do not always ensure improved water quality and are not likely to reach remote populations in the near future, interventions such as HWTS that specifically address water quality cannot be dismissed, even though they may not deliver all the gains associated with reliable piped water supplies.

- Wood et al. (2008) concluded that the absence of blinding and objective outcomes collectively inflated the actual effect by about 25%. Adjusting the pooled effect from the HWTS trials by this factor would still yield a protective effect of more than 30%—a very substantial benefit, given the heavy burden of diarrhoeal disease and the comparatively low cost of some HWTS interventions.

- Contrary to the assertion by Schmidt & Cairncross (2009), HWTS trials have included objective health outcomes. Two studies that collected and analysed stool samples in addition to reported diarrhoea found both a lower prevalence of diarrhoeagenic agents among intervention group members and substantial reductions in reported diarrhoea (Mahfouz et al., 1995; Quick et al., 1999). In one of the few blinded trials of HWTS, anthropometrics showed that intervention group members were less likely to suffer from malnutrition than those in the control group (Austin, 1992). Crump et al. (2005) reported fewer deaths among intervention group members using HWTS (relative risk = 0.58, P = 0.036) as well as reductions in reported diarrhoea when compared with a control group.

- The high level of heterogeneity among outcomes in HWTS is in fact consistent with a true, underlying effect that is not exclusively due to bias. Heterogeneity would be expected in view of the clinical and methodological heterogeneity among the studies (Thompson, 2001). The differences include exposure (pathogens, transmission pathways, preventive measures, such as hygiene and sanitation), interventions (filters, disinfectants, hybrids), methods of delivery, levels of compliance and study methodologies (case definitions of diarrhoea, manner of disease surveillance, measures of disease frequency, measures of effect). The major factor influencing the effect in a specific situation is likely to be the extent to which water is the dominant pathway for transmission of diarrhoeagenic agents. Thus, any given trial, blinded or open, is unlikely to yield an estimate of effect that is fully generalizable, as the underlying effect will depend on transmission dynamics that vary according to settings, seasons and other factors. If the protective effect in these studies were due exclusively to bias, one would in fact expect more homogeneity. The fact that the magnitude of an effect varies is not an argument against scaling up an intervention. Rather, it points towards the need to study these influences and learn how to best target the intervention to maximize public health benefit.

Underlying much of the concern with promoting HWTS appears to be the assumption that funding of water, sanitation and hygiene is a zero-sum game: that scaling up the intervention would divert resources away from infrastructural interventions. This perspective illustrates the intrasectoral competition that has sometimes characterized the water, sanitation and hygiene sector and perhaps limits it from sharing in the major surges in funding that have benefited acquired immunodeficiency syndrome (AIDS), malaria and other diseases. However, even Schmidt & Cairncross (2009) acknowledged that there is in fact little evidence of any such diversion and that in any event it may be small. Much of the cost to improve household water supplies, by digging and protecting wells and installing pumps, is borne by the householders themselves. This has also been the case with HWTS, whether by boiling or using commercial methods. Schmidt & Cairncross (2009) also speculated that governments may use HWTS to divert attention from failures in public water supplies. However, increasing householder awareness of deficiencies in water quality at the point of distribution may actually have the opposite effect.

Those involved in HWTS have acknowledged in dozens of previous studies that there is a need to demonstrate that the intervention will be used correctly and consistently by vulnerable populations over the long term. However, there is no serious question about whether HWTS is acceptable at scale and sustainable over the long term. This is evident from the fact that boiling and other HWTS methods have been practised by hundreds of millions of vulnerable householders for decades (A. Rosa & T. Clasen, unpublished data, 2009). Improving the microbiological performance and reducing the cost and environmental impact of these methods will themselves yield gains. However, the potential for HWTS will not be fully realized if the practice continues to be highly concentrated in some countries, such as Viet Nam and Indonesia, and not in other countries, such as most of Africa.

There is a need for more research to identify the actual contribution that the intervention can make in preventing diarrhoea under different conditions, and not to overstate the effect due to bias. This research will also help target the intervention to populations that could benefit the most. It can also help identify the role of boiling and safe storage, two HWTS interventions that offer considerable promise but are not being widely investigated, perhaps because they offer few commercial opportunities. Moreover, advocates of HWTS should always be clear about the limitations of the intervention and its shortcomings compared with lasting improvements in water supplies. Providing safe, reliable, piped-in water to every household yields optimal health gains while contributing to the MDG targets for poverty reduction, nutrition, childhood survival, school attendance, gender equity and environmental sustainability.

Drinking-water that is free from high levels of faecal contamination is not a sufficient condition for human health, but it is a necessary one that is far from the reach of billions of people worldwide. HWTS offers an opportunity to provide the most needy populations with a tool to take charge of improving their own water security while they patiently wait for the pipe to finally reach them.

1.4 Objective and methods

This report seeks to advance efforts to scale up HWTS by consolidating existing knowledge and experience and distilling the lessons learnt. Its primary aims are to 1) review the development and evolution of leading household water treatment technologies in their efforts to achieve scale, 2) identify the main constraints that they have encountered and 3) recommend ways forward. In order to provide some context, the report begins by briefly examining efforts to scale up other health interventions that may be relevant to HWTS.

The information included in this report is derived mainly from published papers, internal reports and other documents. The author solicited relevant information mainly from members of the HWTS Network. Where useful, personal interviews were conducted with representatives from programme implementers, private companies and research institutions and with consultants.

The methodology employed in preparing this report has three important limitations. First, as it is restricted to a few leading technologies, this report does not address significant efforts to scale up dozens of other approaches to HWTS. Some of these efforts have been reviewed elsewhere (Sobsey, 2002). Second, like any research that relies on published sources and reported accounts, there is a potential bias in the sources towards exaggerating successes and understating failures. While efforts were made to verify information from multiple sources, this was not possible in most cases. Finally, information from private enterprises involved in manufacturing, marketing or selling HWTS products was often proprietary in nature and could not be disclosed for competitive reasons. Where possible, this information was summarized to limit its sensitivity or strategic value, and the summaries are included herein. In many other cases, however, this report covers only the information that such companies were willing to make public. In any event, generic names are used instead of trade names to avoid the implication that WHO endorses or recommends a particular manufacturer's product in preference to others.

2. SCALING UP OTHER HOUSEHOLD-BASED HEALTH INTERVENTIONS

As noted above, scaling up is a challenge faced by virtually all interventions. Yet programme implementers often fail to take advantage of important lessons from comparable interventions or delivery strategies. Often this is due to the fact that the intervention is based on an innovation in products or technology, new media or other means of reaching the target population or new findings regarding the mechanisms affecting uptake. In other cases, however, it is because health interventions are delivered vertically or implemented by specialists who view them in isolation from other activities. A lack of historical perspective or institutional memory together with the practice of operating remotely and independently with suboptimal communication channels also contribute to the failure to benefit from previous experience.

This section briefly highlights some of the household-based interventions that may offer useful lessons in attempting to increase coverage and use of HWTS. Each of these initiatives is complex and intricate, and many have been carefully analysed and documented to identify the factors believed to have contributed to or limited their success. This brief summary is not intended and should not be read as a complete or even balanced summary of the lessons learnt from any single initiative. Rather, it is designed to draw attention to the parallels that may exist between HWTS and other household-based interventions and to suggest that programme designers and implementers investigate the lessons that these other initiatives may offer in order to avoid some of the problems and accelerate the process of scaling up HWTS interventions.

2.1 Household sanitation

In 1980, the UN General Assembly declared 1981–1990 as the "International Drinking Water Supply and Sanitation Decade". Whereas the water interventions advanced by the initiative were mainly conventional improvements in water supplies (protected wells and springs, boreholes, gravity systems and community supplies) that were not based at the household level (Glennie, 1983), the sanitation solutions were largely household based. In his review of the 10-year effort to provide poor communities with access to low-cost waste disposal facilities, Cairncross (1992) emphasized the need to understand and address consumer preferences and generate demand:

> The principal lesson is that progress and continuing success depend most on responding to consumer demand. A program's designers and managers must understand that they are selling a product, not providing a service. Where sufficient demand exists, the facilities and services offered must be tailored to that demand; where demand is not strong, it must be stimulated.

In order to assess and promote such demand, governments and agencies were encouraged to employ consumer research and commercial marketing techniques and to promote solutions through consumer education. Design solutions must focus on the needs of a community and offer consumers a choice:

> Equipment choice, installation, financing, maintenance strategies, and cost recovery are important considerations that must be dealt with afresh in each locality. It is important to test several options and approaches in the communities where they will be used. It is also vital to offer consumers a range of choices and allow them to choose the one they prefer and are willing to pay for. [Cairncross, 1992]

More recent research has confirmed the need to understand and respond to consumer preferences in order to scale up household sanitation. In Benin, the adoption of latrines was driven principally by prestige/status, convenience and revulsion to seeing or smelling faeces, rather than genuine concerns about faecal–oral transmission of disease (Jenkins & Curtis, 2005). Adopters associated latrines with the "good life"—modern, urban, comfortable and clean—and sought to increase their well-being by increasing privacy, saving time and minimizing exposure to other environmental risks (scratches, stings, bites, flies, accidents). The research describes the steps taken in deciding whether to build a household latrine (become aware, evaluate options, seek opinions, procure/save funds, contract builders) and confirms that adoption follows the classic S-curve associated with the diffusion of innovations, including the key role played by early adopters and communication channels (Rogers, 2003). It also suggests that demand for household sanitation can be created through targeted marketing messages based on an understanding of consumer attitudes and aspirations rather than traditional health education.

A 2005 report on scaling up rural sanitation in South Asia examined eight programmes in Bangladesh, India and Pakistan, where 900 million people (66% of the population) lack improved excreta disposal (WSP, 2005). Most programmes followed a "total sanitation" approach to blanket an area with the construction of low-cost latrines using behaviour change strategies. The more successful programmes not only provided high access to sanitation (coverage) but also ensured high usage through a combination of participatory processes, hygiene promotion and institutional incentives (financial rewards for achieving universal toilet coverage, community bans on open defecation, fines for open defecation, etc.). Four common constraints to successful scale-up were identified: 1) failure to monitor local outcomes, 2) high hardware subsidies (including the provision of free latrines), 3) ineffective intermediation (especially by governmental bodies) and 4) unsustainable supply chains. Studies of two programmes that had already achieved significant scale suggested that programmes should be based on partnerships that combine governmental resources and monitoring networks with NGOs and self-help groups that have necessary social development skills and community trust. According to the report, successful programmes promoted low-cost sanitation technologies with zero (or low) hardware subsidies, thus freeing up a greater proportion of programme funds for social intermediation and hygiene promotion.

The initial and ongoing cost of household-based sanitation and who pays for it are important issues for scaling up coverage, as they are for other environmental interventions, including HWTS. With an estimated median cost of about US$ 60 per capita for the construction of an improved but unconnected latrine (WHO, 2002), cost would appear to be a major constraint in securing widespread coverage of sanitation. In fact, however, research has suggested that even the poor have expressed a willingness to pay for sanitation, provided credit is available on reasonable terms to smooth out the cash flow implications of the investment (Altaf, 1994; Allan, 2003). While there is a perception that cost is an obstacle to procuring sanitation at the household level, this perception is mainly due to a lack of consumer awareness about the true cost of latrines and especially low-cost options, the high cost of capital to these borrowers and disagreement about who should pay (government, owner, tenant). As improved sanitation—like other environmental interventions—is attended by significant externalities, policy implications are raised about whether the public sector should deliver this "public good" free, support scaling up through subsidies or promote its adoption using commercial methods or its regulatory authority. Arguments have been marshalled against the widespread use of subsidies for sanitation: that they tend to limit overall coverage (to the size of the government or donor budget), encourage the design and installation of unaffordable technologies, benefit the better-off and distort the market (Cairncross, 2003). As will be seen for insecticide-treated nets below, these are continuing questions for other household-based interventions, such as HWTS.

2.2 Oral rehydration salts

While more in the nature of case management than prevention, oral rehydration therapy represented a breakthrough in treating persons suffering from dehydration as a result of diarrhoea, dramatically reducing the case fatality rate. *The Lancet* has called the homemade version of oral rehydration salts the most important medical discovery of the 20th century (Anonymous, 1978). While diarrhoea morbidity has remained largely constant, at an estimated 4 billion cases annually, the diarrhoea mortality rate for children under 5 years of age has fallen from almost 5 million to 1.8 million per year in the 20 years since oral rehydration therapy was first widely used (Fontaine & Newton, 2001).

Developed simultaneously in Dhaka and Calcutta in the 1960s, oral rehydration therapy first demonstrated its potential as a life-saving intervention in response to cholera outbreaks associated with the Bangladesh war of independence in 1971 (Mahalanabis et al., 1973). Following additional projects that established the feasibility, acceptability and efficacy of the intervention, WHO settled on its first standard formulation of oral rehydration salts and launched its Diarrhoeal Diseases Control Programme in 1978 with three goals: 1) development of at least 80 national diarrhoeal disease control programmes, 2) extending coverage to over 30% of all childhood diarrhoea cases and 3) preventing at least 1.5 million childhood deaths due to diarrhoea annually. UNICEF and the private sector also played important roles in scaling up the intervention, especially in ensuring the production and supply of oral rehydration salts.

Bangladesh is one of the countries in which oral rehydration therapy has been scaled up most dramatically, mainly through the efforts of the government, NGOs and the private sector. The government's National Oral Rehydration Programme initially established four oral rehydration salt production units on a cottage industry basis (Chowdhury et al., 1997). Staff and volunteers were trained and oral rehydration salt packets distributed through established health centres at the subdistrict level, with only limited success. BRAC (formerly the Bangladesh Rural Advancement Committee), a Bangladesh NGO, began promoting oral rehydration therapy in 1979. Using female health workers to provide oral rehydration salts and instruction (including demonstrations) on a door-to-door basis, it claims to have reached 12.5 million households during the 1980s. The methods used by BRAC have been fully documented, with lessons learnt that could be relevant to HWTS (Chowdhury & Cash, 1996). Workers were paid on a performance basis, evaluated by an independent group of monitors. In order to gain their confidence, men were motivated by male workers through meetings at bazaars, mosques and schools; schools and village healers were also engaged. The campaign also relied on mass media (radio and television) and print materials.

A number of studies have assessed uptake of oral rehydration salts following the campaigns. Reported use ranged significantly, from 25% to 100%, although the differences may be attributable to the definition of diarrhoea used in the study (Chowdhury et al., 1997). Field assessments in 1993 of 9000 households in 26 villages showed that over 70% of the mothers could prepare a chemically safe and effective oral rehydration salt and that oral rehydration therapy was used in 60% of all diarrhoea cases; pharmacists and village doctors also routinely recommended oral rehydration salts. Although the authors concluded that there was significant intergenerational transfer of knowledge on oral rehydration therapy methods, more recent studies have shown a reduction in the proportion of mothers who are aware of and use oral rehydration salts, especially young mothers, thus suggesting the need for continued efforts (A. Bowen, unpublished data, 2006). Nearly 80% of the householders in the Bangladesh survey reported that when they require oral rehydration salts, they purchase prepackaged packets from a local shop or pharmacy. Of 495 such retail outlets, oral rehydration salts were in stock in 32% of shops and 80% of pharmacies. The price was generally Taka 3 (about US$ 0.075) per packet.

The role of the private sector in manufacturing and distributing oral rehydration salts has also been examined. In India, only 30–35% of patients receive oral rehydration salts from the public sector; the balance go to the private sector, and between 3% and 13% of these receive oral rehydration salts from largely unlicensed private practitioners in rural areas (Rohde, 1997). In Pakistan, free distribution of oral rehydration salts had led to only limited coverage, leading the government to rely more heavily on commercial sales. The volume of packets increased significantly, from 10 million in 1987 to 26 million in 1990 (Slater & Saadé, 1997). Increased distribution and use of oral rehydration salts were also reported in the Plurinational State of Bolivia, Kenya and Indonesia when supplies were distributed through commercial channels (Slater & Saadé, 1997). Others, however, have questioned the extent to which the private sector can supply oral rehydration salts at costs that are affordable to the most vulnerable populations, arguing instead for homemade alternatives. In many countries, the cost of prepackaged solutions is 25–75% of the daily wage (Werner & Sanders, 1997). Population Services International (PSI) and others have used social marketing strategies in an attempt to reach more vulnerable populations with oral rehydration salts.

2.3 Guinea worm filters

When dracunculiasis (guinea worm disease) was first identified as a promising candidate for successful eradication more than 20 years ago, there were an estimated 3.5 million cases (Cairncross, Muller & Zagaria, 2002). Working together under the Guinea Worm Eradication Initiative, a coalition led by The Carter Center succeeded in reducing the annual incidence of the disease to fewer than 26 000 cases in 2006 (http://www.cartercenter.org/health/guinea_worm/index.html). Recently, only the Sudan and Ghana report a significant number of cases. If the eradication effort is successful, it will represent only the second such accomplishment and the first time that eradication has been achieved without drugs or vaccines.

Among the most important components of the eradication initiative is a simple point-of-use water filter. The filter indirectly eliminates the disease-causing nematode (*Dracunculus medinensis*) from drinking-water collected from ponds and open wells by mechanically removing the 1- to 2-mm copepods (cyclops) that serve as its intermediate host. The household-based version of the filter consists of monofilament nylon cloth stretched around a wooden frame or sewn with a clinch string for placement over a vessel opening; a simple cloth can also provide some protection. An alternative device, consisting of a portable pipe-style filter with the medium permanently affixed inside a narrow pipe or straw, was developed and deployed after programmers found transmission of the waterborne parasite to occur when people were working outside the home. The pipe filter has also been particularly important for nomadic populations in the Sudan. A donation of monofilament nylon cloth by the manufacturer was an important contribution to the programme; over time, however, governments purchased the filters (Cairncross, Muller & Zagaria, 2002). A private commercial company that supplies insecticide-treated bed nets, sheeting and other products reports having sold approximately 9 million pipe-style guinea worm filters to The Carter Center and others as part of the initiative (T. Vestergaard-Frandsen, personal communication, 2006).

Whereas providing millions of poor, mainly illiterate people in thousands of remote, often inaccessible villages with these hardware solutions (coverage) was daunting enough, changing their behaviour to ensure correct and consistent use of the filters (uptake) was perhaps even a bigger challenge. Promoters relied chiefly on health education, mainly following an approach described by Brieger (1996) as “the behavioristic mode utilizing simplistic, professionally determined messages”. One factor favouring health education was that the ministries of health could in fact mobilize such campaigns without support from other ministries (such as water) or significant financial resources. Notably, the filtering of water was not completely new to the target population; many householders were already using cloth or sieves to remove suspended solids from water or to filter other liquids.

Early programmes distributed cotton cloth as a filter medium, but this was often diverted to other uses or quickly became clogged and unusable. Thanks to a corporate donation, programme implementers were able to replace the cotton cloth with monofilament nylon, which was less susceptible to clogging. Cheaper polyester fabric was later found to be equally effective. The filters became so popular that householders in non-endemic villages bought and used them to improve the appearance and taste of their water. Although a study in Pakistan found the filters to be in satisfactory condition after 12–15 months of use (Imtiaz et al., 1990), filters rarely lasted more than 1 year, thus necessitating a system to ensure regular replacement. The supply chain was remarkably successful, with filters available even in remote rural villages. Uptake was more limited, however, in areas in which programme administrators chose to charge a nominal fee for the filters to help defray costs. National programmes all distribute the filters free of charge now, even though the cloth medium is no longer donated.

According to The Carter Center and persons involved in the initiative, the success of the overall initiative was attributable, among other things, to widespread political support, international cooperation, donor funding, strategic advocacy, careful planning and tenacious execution (Cairncross, Muller & Zagaria, 2002). A committed national government, careful and extensive disease surveillance and case-finding, and rigorous and regular monitoring and assessment (based on data collected no less frequently than monthly) were also deemed critical to the success of the initiative (E. Ruiz-Tiben, personal communication, 2006).

2.4 Insecticide-treated nets

The Roll Back Malaria (RBM) global partnership was founded in 1998 by WHO, UNICEF, the World Bank and the United Nations Development Programme, with the objective of halving the malaria burden worldwide by the year 2010. At an RBM summit in Abuja, Nigeria, in April 2000, leaders of 44 African countries agreed to the goal of providing protective measures, including insecticide-treated nets, to 60% of the at-risk population (especially children under 5 years of age and pregnant women) by 2005. RBM later revised this objective to reach 80% coverage by 2010 (RBM, 2005), even though coverage reached the 60% target in only 1 (Eritrea) among 34 malaria-endemic

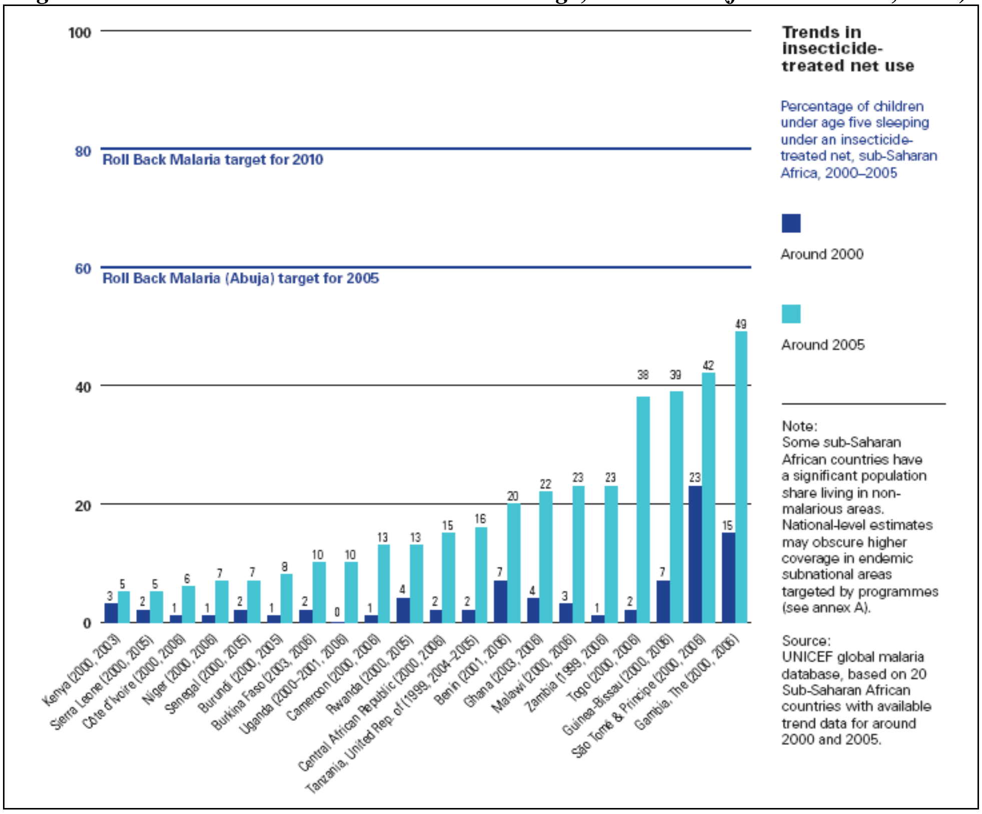
African countries for which data are available (RBM, 2005). This specific (although non-exclusive) emphasis on insecticide-treated nets among the various interventions for preventing malaria has been credited in part for a substantial increase in donor support, particularly from the Global Fund to Fight AIDS, Tuberculosis and Malaria, the Bill & Melinda Gates Foundation, the World Bank's Malaria Booster Programme and the Presidential Malaria Initiative of the United States of America. The importance of achieving scale was shown in a recent four-country analysis by the WHO Global Malaria Programme, which found that the main factor contributing to success was the sufficient quantities of insecticide-treated nets delivered in mass distributions (WHO, 2008b).

RBM's approach for increasing coverage of insecticide-treated nets is outlined in *Global Strategic Plan: Roll Back Malaria 2005–2015* (RBM, 2005). It consists of both short-term and longer-term strategies. The short-term strategy relies heavily on donor-funded delivery of free or subsidized insecticide-treated nets to vulnerable populations using existing public sector programmes. Nets are distributed free of charge during measles and other health campaigns, sold at subsidized prices to qualifying beneficiaries by government health clinics and community-based groups, or supplied through commercial retailers in exchange for vouchers delivered to the qualified beneficiaries by the health-care system. For longer-term sustainability, the strategic plan calls for subsidized programmes to be complemented by commercial sales through social marketing and the private sector. It is believed that such commercial sales will be enhanced by reductions in taxes and import tariffs on insecticide-treated nets, donor support for increased production and distribution, and increased consumer demand responding to lower prices, higher quality and greater availability and accessibility. The strategic plan stresses the need for demand creation through traditional instruction, education, communication, health education channels and mass media. It also maintains that the free and subsidized distribution of insecticide-treated nets will prime the market by showing householders the benefits of net use, thereby creating future demand and willingness to pay, the prerequisites of market development. This argument is also asserted by private sector suppliers (Vestergaard-Frandsen, Sorensen & McGuire, 2004).

There was considerable controversy over whether coverage of insecticide-treated nets could best be achieved by reliance on the commercial market or the public sector and who should pay for the nets. Curtis et al. (2003) argued that while the private sector was increasingly meeting a demand for insecticide-treated nets to protect against nuisance mosquitoes, sustained subsidies were needed to achieve high coverage for the rural poor at greatest risk of malaria. They urged policy-makers to treat insecticide-treated nets as a "public good"—like childhood vaccines—and use the public sector to secure coverage through free or highly subsidized distribution in vulnerable African rural populations that bear much of the world's burden of malaria. They also cited evidence that public sector distribution was most cost-effective. Lines et al. (2003) argued that the RBM strategy already included sustained subsidies for targeted populations, but emphasized the contribution that commercial net markets could make to achieving coverage. They cited China and Viet Nam as countries in which most people bought their own nets while relying on the government to re-treat them with insecticides. They noted that if a policy of free distribution were to be pursued, the contribution that these local commercial markets make towards achieving coverage—and the important potential for whole or partial cost recovery that would free up scarce public resources for other health priorities—would be destroyed. They further argued that commercial sector involvement has increased the quality and reduced the cost of insecticide-treated nets.

While questions about the long-term impact and sustainability of RBM's strategy of mass distribution are yet to be resolved, it seems clear that the initiative has been effective in scaling up coverage. As illustrated in Figure 1, coverage of insecticide-treated nets in many sub-Saharan countries grew by more than 10-fold between about 2000 and 2005 (UNICEF, 2007). Worldwide production of insecticide-treated nets more than doubled in just 2 years, from 30 million in 2004 to 63 million in 2006. UNICEF alone increased its procurement from 1 million nets in 2000 to more than 25 million nets in 2006. Although no sub-Saharan country met the 60% RBM target for 2005, most are making dramatic progress in achieving scale (UNICEF, 2007).

Figure 1: Trends in insecticide-treated net coverage, 2000–2005 (from UNICEF, 2007)



Apart from the issues around increasing coverage, there is also an important question as to which distribution strategies are most effective in reaching the poor. Webster et al. (2005) reviewed national surveys from 26 African countries to compare the equity of coverage of insecticide-treated nets, untreated nets and the Expanded Programme on Immunisation using the concentration index. While most insecticide-treated nets are provided through public programmes, most untreated nets are supplied through commercial channels. Data showed that coverage of untreated nets was highly equitable across socioeconomic classes and was comparable to that of the Expanded Programme on Immunisation. Insecticide-treated nets, on the other hand, were strongly concentrated in the least poor households in almost all countries, with coverage significantly more inequitable than that of untreated nets or the Expanded Programme on Immunisation. The authors concluded that the public health contribution of the commercial net markets has been greatly undervalued and that nets distributed through these markets have contributed more to the equitable and sustainable coverage than insecticide-treated nets delivered through public sector systems and projects.

On the other hand, in a series of cross-sectional studies among 3700 children in four districts in Kenya, Noor et al. (2007) found that coverage reached only 7.1% in 2004 when the predominant source was the commercial retail sector. By the end of 2005, following the expansion of a heavily subsidized clinic distribution system, insecticide-treated net coverage rose to 23.5%. In 2006, after a large-scale mass distribution of insecticide-treated nets was mounted, providing nets free of charge to children, coverage increased to 67.3%. Moreover, with each subsequent survey, socioeconomic inequity in net coverage decreased sequentially. From 2004, with 2.9% coverage among "most poor" versus 15.6% among "least poor" (concentration index 0.281), coverage reached equality in 2006, with 66.3% coverage among most poor versus 66.3% among least poor (concentration index 0.000). The authors concluded that the free mass distribution method achieved the highest coverage among the poorest children, the highly subsidized clinic nets programme was marginally in favour of the least poor, and social marketing favoured the least poor.

In 2007, WHO announced an unambiguous position in favour of free distribution of insecticide-treated nets on a large scale:

> The best opportunity for rapidly scaling-up malaria prevention is the free or highly subsidized distribution of [long-lasting insecticide-treated nets] through existing public health services (both routine and campaigns). [Long-lasting insecticide-treated nets] should be considered a public good for populations living in malaria-endemic areas. [WHO, 2007]

It also supported targeted distribution through antenatal clinics, either by delivering the net directly or by providing vouchers to allow for free or subsidized access from local merchants. While the position paper acknowledges the contribution that commercial distribution can make for ensuring access and sustainability, it concludes that such channels are unlikely to make major contributions to rural and remote locations where populations are at great risk.

WHO, UNICEF and the Rockefeller Foundation sponsored a comprehensive market study and business plan designed to stimulate the development, manufacturing and widespread distribution of insecticide-treated nets (WHO, 2004a). Among other things, the study noted the important role that WHO can play in developing international safety and performance standards for insecticide-treated nets, the need for improved quality control in the manufacture of products and the need to reduce taxes and tariffs on imported products in order to increase access and reduce costs to consumers. Of particular importance was the WHO-sponsored effort to standardize insecticide-treated net testing procedures and performance standards through the WHO Pesticides Evaluation Scheme. The report provides perhaps the best example of the type of information that stakeholders can use to determine the need and current capacity. Its approach would seem to be directly transferable to HWTS.

2.5 Summary

Table 1 summarizes some of the salient lessons learnt from these other experiences in attempting to scale up other household-based health interventions. Many of these are common among the various interventions, suggesting perhaps some universal principles. Others, however, such as pricing/cost-recovery strategies, are directly opposing, showing the need for individual tailoring.

Table 1: Summary of lessons learnt from efforts to scale up other household-based health interventions

Intervention	Lessons learnt
Household sanitation	• Focus on the user's attitudes and aspirations • Offer a range of choices • Promote non-health benefits • Use governmental/health resources to promote demand • Take advantage of existing private sector manufacturing capacity and supply chains • Overcome up-front cost and willingness-to-pay barriers by providing consumers more information • Avoid (excessive) subsidies • Offer credit/financing schemes • Engage efficient government cooperation • Encourage partnerships between commercial and non-profit sectors
Oral rehydration salts	• Align international support and cooperation to encourage large-scale donor funding • Take advantage of potential promoters, such as women's groups • Use existing supply channels, such as shops and kiosks • Provide performance-based financial incentives to promoters • Use school settings to increase awareness • Use governmental/health resources to promote demand • Price appropriately to ensure affordability and sustainability • Use large-scale international suppliers that can ensure quality and reduce cost • Implement a rigorous monitoring and evaluation system
Guinea worm filters	• Align international support and cooperation to encourage large-scale donor funding • Develop and use effective behaviour change communication strategies

Intervention	Lessons learnt
Insecticide-treated nets	• Focus on a few solutions that have been shown to be effective, acceptable and scalable • Do not rely on cost recovery to get to scale; distribute free • Take advantage of simple technologies to minimize the need for behaviour change • Emphasize improvements in water aesthetics, not necessarily health benefits • Build effective national-level organizations • Develop governmental support and cooperation • Use large-scale international suppliers that can ensure quality and reduce cost • Implement a rigorous monitoring and evaluation system • Encourage consensus of leaders of target countries • Align international support and cooperation to encourage large-scale donor funding • Focus on a few solutions that have been shown to be effective, acceptable and scalable • Pursue commercial and non-commercial strategies to optimize coverage • Use free or heavily subsidized distribution to reach large-scale distribution rapidly • Use targeted subsidies to the most vulnerable populations, and leverage donor funding • Adopt standards and performance specifications to improve product quality and encourage large-scale production • Use large-scale international suppliers that can ensure quality and reduce cost • Take advantage of simple technologies to minimize the need for intensive behaviour change promotion • Encourage internationally accepted standards to ensure product quality

Observers may debate the extent to which the foregoing household-based health interventions were actually successful in achieving scale. They may also debate the purported lessons from attempts to scale up these interventions and the relevance of such lessons to HWTS. Nevertheless, at least some of these lessons reflect themes that have already arisen in the context of HWTS interventions, as will become clear in the case-studies described in the next section.

3. CASE-STUDIES IN SCALING UP HWTS METHODS

Household-based water treatment technologies may be introduced to a population by four categories of implementers: 1) the public sector, 2) NGOs, 3) an NGO/private sector hybrid (social marketers or social entrepreneurs) or 4) the private sector. These actors, in turn, may pursue one of three basic approaches to the dissemination of the intervention: 1) providing it free of charge (or for nominal consideration) as a public good, 2) providing it at a subsidized price with partial cost recovery and 3) selling it on a commercial basis at a price designed to cover its full manufacturing and sales cost, together with a profit. Table 2 shows examples of some of these combinations of implementers and basic strategies.

Table 2: Examples of household water treatment implementers and implementation strategies

Implementer	Government- or donor-supported, with no charge or nominal charge to beneficiary	Subsidized distribution with partial cost recovery	Commercial sales with full cost recovery and profit
Public sector	Emergency and outbreak response by UNICEF, UN Office for the Coordination of Humanitarian Affairs and national governments	X	X
NGO	Promotion of solar water disinfection by Swiss Federal Institute for Environmental Sciences and Technology (EAWAG)/Department of Water and Sanitation in Developing Countries (SANDEC); distribution of sodium hypochlorite and flocculant-disinfectant sachets in emergency response by Samaritan's Purse, CARE, International Committee of the Red Cross, American Red Cross and others; distribution of ceramic filters by Oxfam	Promotion of ceramic filters by International Development Enterprises (IDE), Rural Development International (RDI) and Environment and Public Health Organization (ENPHO); promotion of biosand filters by Centre for Affordable Water and Sanitation Technology (CAWST) and BushProof	Promotion of ceramic filters in Kenya by Network for Water and Sanitation; sales of ceramic water filters in the Plurinational State of Bolivia by Sumaj Huasi; some sales of filters in Cambodia by IDE and RDI
Private sector	X	Promotion of flocculant-disinfectant sachets by manufacturer (corporate social responsibility strategy and cooperative donor funded)	Sales of sodium hypochlorite solution by Aman Tirta; sales of sodium dichloroisocyanurate (NaDCC) tablets by manufacturer; sales of ceramic water filters by manufacturer
Social marketer	Government purchase and distribution of sodium hypochlorite solution and flocculant-disinfectant sachets through PSI as part of acute watery diarrhoea response in Ethiopia	Promotion of sodium hypochlorite, flocculant-disinfectant sachets and NaDCC tablets by PSI; promotion of filters and disinfection products by Academy for Educational Development	Sales of sodium hypochlorite and NaDCC tablets in certain markets by PSI and Academy for Educational Development

X, unlikely/no example known

Using different implementers and implementation strategies to scale up the delivery of household water treatment is an acknowledgement of important differences in the target population (buying power, priorities, geographical location) and in the products and technologies used to treat water in the home (cost, portability, length of life). Solar disinfection in plastic bottles, for example, involves a relatively minor hardware component and considerably more programmatic support. Accordingly, its profit potential for a private sector provider may be limited, even though a creative entrepreneur could potentially sell communities the service of introducing the intervention or sell consumers solar-disinfected bottled water. Filters carry higher costs, especially at the front end. These may limit the market in some countries. At the same time, they may offer the best opportunity for product differentiation and the highest unit profit, thus making them more attractive to private sector purveyors. Disinfection products and combined flocculation/disinfection products are produced by the private sector, but are distributed by all four types of actors (government, NGOs, private sector and social marketers), suggesting their potential at least for scaling up following multiple strategies.

This section presents case-studies of selected household water treatment approaches and efforts to scale them up. Most of the cases discussed here were chosen because they represent interventions that have achieved a comparatively high level of coverage within the lower-income populations most vulnerable to waterborne disease. Other cases are designed to illustrate alternative dissemination strategies or novel technologies, even if they have not yet achieved significant coverage. Each case begins with a discussion of the background of the intervention, including product origins, development and testing. Efforts to scale up the intervention are then summarized, including the evidence to date on the uptake of the intervention by the target populations. Wherever possible, these case-studies are based on independent research. In other cases, they are based on internal reports and analyses prepared by, or interviews with, programme implementers, product manufacturers or other stakeholders.

3.1 Boiling

Boiling or heating with fuel is perhaps the oldest means of disinfecting water at the household level (Sobsey, 2002). If practised correctly, boiling is also one of the most effective, killing or inactivating all classes of waterborne pathogens, including bacterial spores and protozoan cysts that have shown resistance to chemical disinfection and viruses that are too small to be mechanically removed by microfiltration (Block, 2001). Heating water to even 55 °C has been shown to kill or inactivate most pathogenic bacteria, viruses, helminths and protozoa that are commonly waterborne (Feachem et al., 1983). Moreover, while chemical disinfectants and filters are challenged by turbidity and certain dissolved constituents, boiling can be used effectively across a wide range of physical and chemical characteristics. In rural Kenya, pasteurization of water using a simple wax indicator to show householders when water reached 70 °C increased the number of households whose drinking-water was free of coliforms from 10.7% to 43.1% and significantly reduced the incidence of severe diarrhoea compared with a control group (odds ratio [OR] = 0.55, $P = 0.0016$) (Lijima et al., 2001).

Governments, NGOs and others have promoted boiling, both in developing countries where water is routinely of uncertain microbial quality (Gilman & Skillicorn, 1985) and in developed countries when conventional water treatment fails or water supplies are interrupted as a result of disasters or other emergencies. Sources vary in the time recommended for bringing water to a boil for necessary disinfection, from 1 min (CDC, 2005) to 10 min (Davis & Lambert, 2002) and even to 25 min (Nnochiri, 1975). These longer times may have been generalized from recommendations for sterilizing medical devices rather than the water itself. The WHO Guidelines for Drinking-water Quality simply recommend bringing water to a rolling boil as an indication that a disinfection temperature has been achieved (WHO, 2004b).

Despite its long history, boiling water presents certain disadvantages that may limit its further expansion as a means of routinely treating drinking-water. First, the unavailability or high cost of fuel may render boiling impossible or impractical to many householders. A recent cost analysis from India, based on both laboratory data and field observations, estimated the annual cost of treating water by boiling to be US$ 2.11 per person for households using liquefied petroleum gas and US$ 1.66 for households using wood (Clasen et al., 2008a). A similar study in Viet Nam reported an annual cost of fuel per person of US$ 0.65 for wood collectors and US$ 4.03 for wood purchasers (Clasen et al., 2008b). While these costs represented a comparatively small portion of the study household's income, these estimates are equal to or more than the annual per capita cost of other household-based interventions, such as solar disinfection (US$ 0.63) and sodium hypochlorite (US$ 0.66) (Clasen et al., 2007a). Gilman & Skillicorn (1985) investigated the affordability of boiling in a village in

Bangladesh. Families in the lowest-income quartile would have had to spend 22% of their yearly income on fuel; even those in the highest income bracket would have spent 10%. For a typical family in the lowest income quartiles, boiling of drinking-water would require an 11% increase in household budget. The investigators concluded that governments should discontinue steps to advocate boiling as the method of choice to provide safe household drinking-water to villages in developing countries until its financial feasibility could be demonstrated.

Second, more than half of the world's population relies chiefly on wood, charcoal and other biomass for their energy supplies (Rehfuess, Mehta & Prüss-Üstün, 2006). In sub-Saharan Africa, South-east Asia and the Western Pacific regions, the figures are 77%, 74% and 74%, respectively. The procurement of these fuels represents a substantial commitment of time and energy, primarily for women and girls, and may detract from other productive and potentially health-promoting activities (Biran, Abbot & Mace, 2004). It is estimated that 1 kg of wood is needed to boil 1 litre of water (Davis & Lambert, 2002). An alternative means of treating water that does not require the use of such fuel may reduce the time spent collecting the same.

Third, boiling may contribute to other health hazards. Because many of those who must treat their own water rely on wood, charcoal or other high-emission fuels and frequently cook indoors on low-efficiency stoves in poorly ventilated rooms, boiling can aggravate what is often already poor indoor air quality (Rehfuess, Mehta & Prüss-Üstün, 2006). The use of these fuels is also environmentally unsustainable in many countries. Boiling water at home has also been associated with higher levels of burn accidents, especially among young children (Houangbevi, 1981).

Despite these shortcomings, boiling is believed to be the most common means of treating water currently practised at the household level, and the only HWTS method that has unquestionably reached scale in certain countries. Results from recent JMP surveys of 58 low- and middle-income countries suggest that boiling is regularly practised by more than 350 million people worldwide (A. Rosa & T. Clasen, unpublished data, 2008). This figure does not include large populations in China, Indonesia and elsewhere, where boiling is also believed to be common. In certain countries, especially in Asia, boiling is the norm. These include Uzbekistan, where 98.6% of households report boiling their water before drinking it, Mongolia (95.3%), Viet Nam (90.1%), Cambodia (59.7%) and Belarus (53.3%). In a survey of 293 households in Karachi, Pakistan, 58% of households reported treating their water by boiling, compared with 11% for filtering, the next most popular method (Luby et al., 1999). Household surveys in Peru found 51% of householders claiming to boil their water before use (Nawaz et al., 2001).

However, the practice of boiling is still largely regional and probably does not correspond with risk. Rural populations, for example, are much less likely to have piped-in water supplies or other improved water sources; in 2006, rural dwellers represented 84% of the population worldwide using unimproved sources of drinking-water (WHO/UNICEF, 2008b). However, in all geographical regions, rural populations are less likely to be boiling their water. With only 58% of its population having access to improved water sources, sub-Saharan Africa is one of the regions most likely to rely on unsafe water supplies. Nevertheless, only 4.9% of the population in 17 countries in Africa report boiling their water before drinking it. This compares with 20.4% in Latin America and the Caribbean, 21.2% in South-east Asia, 34.8% in central Europe and 68.3% in the Western Pacific region (A. Rosa & T. Clasen, unpublished data, 2008).

Despite its success in reaching scale in certain regions, little is known about how such coverage was achieved. In some countries, national and district/state governments performed a leading role, recommending boiling as part of their overall health or hygiene campaigns and training health workers or community mobilizers to promote the practice at the village and community level (Wellin, 1955). Some of these programmes seem to have been remarkably effective. In Indonesia, a sustained campaign by the Ministry of Health since the 1950s has contributed to a near-universal practice of household boiling. In the Indian state of Kerala, whose government has actively campaigned for health initiatives over many years, 61% report treating their water, with 77% of those practising boiling as their principal treatment method, 3 times the rate in the country overall, despite having half the level of piped-in water coverage. In other countries, such as Nicaragua, NGOs played a major role in promoting boiling as a means of making water safe for drinking. The current policy statement on water and sanitation adopted by the National Red Cross Societies in the Southern Africa Region encourages members to promote boiling water for 10 min as a means of purifying small amounts of water for personal use (AFRC, 2000). UNICEF promotes boiling through health and hygiene programmes in schools and has shown corresponding uptake at the household level (Lozinski, 2006). It also trains community hygiene promoters who go from house to house educating mothers about the importance of clean water and the need to boil it (UNICEF, 2004).

In many cases, boiling water was already commonly practised to make tea, coffee or other beverages or in preparing foods. In 1917, the Rockefeller Foundation observed that the widespread practice of boiling water to make tea helped reduce the risk of hookworm infection from consuming water collected from drains (Rockefeller Foundation, 1917). Significantly, householders typically possessed not only the apparatus they needed to immediately adopt the practice of boiling drinking-water, but also a long-developed habit of heating beverages before consuming them. This combination of hardware and software undoubtedly facilitated the uptake of boiling as a means of treating drinking-water. It may also explain findings, such as those from Peru, that 20% of householders boiled their drinking-water even without knowing that it was eliminating waterborne pathogens (Nawaz et al., 2001).

As the JMP only recently began collecting data on boiling and other HWTS practices, there are no longitudinal data from which to explore trends in boiling. It is possible, for example, that the practice is not growing and may actually be shrinking as more people move into urban environments where they are forced to purchase rather than collect fuel. In regions where boiling is not well established, scaling up the intervention has been challenging. Wellin (1955) described the diligent efforts of community-based health promoters in rural Peru to convince their neighbours to boil their drinking-water as part of a national initiative to reduce waterborne disease. After an intensive 2-year campaign directed at 200 families in the community, only 11 (5.5%) actually adopted the practice. The case is still ubiquitously cited in consumer research and is believed to offer important lessons in promoting a wide variety of new products and services—especially the need to understand and leverage existing communication networks, to focus early on opinion leaders to help achieve a critical mass, to recruit and use influential insiders as change agents, and in general to be “client oriented” rather than “innovation oriented”. Unfortunately, the study is rarely mentioned by those promoting HWTS, where its lessons are most directly applicable.

There is also relatively little evidence on the extent to which householders who claim to boil their drinking-water actually follow the practice consistently and correctly (uptake). In a survey of householders randomly selected from 24 villages in rural Kenya, 90% of respondents reported boiling as their primary water treatment method (Makutsa et al., 2001). In focus group discussions, however, most participants acknowledged that they rarely treated their water, despite believing that contaminated drinking-water was the main cause of diarrhoea in their village. Studies have shown resistance to boiling on the part of householders due to 1) inconvenience (including the time required to heat the water and wait for it to cool before drinking), 2) the adverse effect that boiling has on the taste of the water and 3) lack of understanding of the risk presented by faecally contaminated water (Wellin, 1955; McLennan, 2000).

Finally, there is an increasing body of evidence suggesting that as actually practised in the home, boiling and storing water often do not yield microbiologically safe drinking-water. Once the water begins to cool, it is immediately vulnerable to recontamination from hands and utensils, since it contains no residual disinfectant and is often stored in open vessels without a tap (Wright, Gundry & Conroy, 2003; Brick et al., 2004). Among 137 households in Pakistan who reported boiling as their only method for treating water, only 24 (17.5%) samples from stored water were free of faecal coliforms (Luby et al., 1999). In the 2004 Indian Ocean tsunami response, boiling was the most common approach to treating water at the household level, particularly in Aceh, where UNICEF and the Ministry of Health have promoted boiling for years. However, in one study, 47.5% of water samples from 400 households (78% of which reported boiling, the others not treating their water at all) were positive for *Escherichia coli*, and a significant majority found it often (25.7%) or sometimes (42.6%) difficult to practise boiling, mainly due to the unavailability (65.5%) or cost (62.8%) of fuel or lack of a stove (20.8%) (Handzel, 2005). Outside the emergency context, boiling has been shown to be more effective, reducing the geometric mean thermotolerant coliform count among boilers in Viet Nam by 97% and in India by 99% (Clasen et al., 2008a, 2008b). Nevertheless, a quarter of water samples in these studies still contained medium or high levels of faecal contamination.

Notwithstanding these challenges, boiling is the one HWTS method that has clearly achieved scale, at least in some countries. It is among the most effective methods of improving the microbiological quality of water, even under a wide range of water conditions that challenge other methods. This combination of scalability and effectiveness renders boiling the benchmark by which other methods must be measured. The method should therefore continue to be encouraged. At the same time, research should be undertaken to overcome some of the current shortcomings of boiling. These include the use of cleaner fuels, more efficient stoves, simple indicators to show householders when pasteurization temperatures have been reached, and effective safe storage solutions.

3.2 Safe water system (SWS)

3.2.1 Product origins, development and testing

Although the practice of treating water in the home dates back several millennia (Sobsey, 2002), the origin of the current movement arguably began in 1991 in Peru. While investigating an epidemic of cholera in several Andean countries, the United States Centers for Disease Control and Prevention (CDC) and the Pan-American Health Organization (PAHO) found that treating water at home with citrus fruit juice and storing water in narrow-mouthed vessels were protective against the disease (Mujica et al., 1994). These 1991 findings concerning the benefits of improved vessels are consistent with more recent studies that show that improved water-handling practices in the home, including the use of vessels with taps and narrow openings to prevent the introduction of hands, could substantially improve the microbial content of stored drinking-water by preventing its contamination in the home (Wright, Gundry & Conroy, 2003).

Eager to help prevent future outbreaks and to reduce the staggering burden of endemic diarrhoea in the developing world, the CDC sponsored a competition to design an improved water storage vessel that would be suitable for remote, low-income populations in developing countries. The winning design was a 20-litre robust, plastic, rectangular-shaped vessel with a handle (and head-shaped indentation) for transport, a small cap for filling and a tap for accessing the water. In lieu of citric acid, they chose to use chlorine, the most common water disinfectant worldwide and an agent whose safety and range of biocidal activity are well documented. They also agreed that the intervention should include some basic instruction on how to use the hardware (Mintz, Reiff & Tauze, 1995). An initial trial among householders showed that only the combination of the vessel and the disinfectant improved the microbiological quality of the stored household water (Quick et al., 1996). A subsequent trial found that the complete intervention—vessel, disinfectant and instructions—reduced the risk of diarrhoea by 44% (Quick et al., 1999).

Although the CDC and PAHO believed that this simple intervention, known as the “safe water system” or SWS, had potential for wide-scale application, they continued to refine it. Their first priority was to ensure a sustainable supply of affordable disinfectant. Although sodium hypochlorite—a suitable source for the hypochlorous acid produced by any chlorine donor during water disinfection—is widely available in diluted form as household bleach, researchers found that remote communities did not always have access to bleach. More problematic was the fact that the concentration of sodium hypochlorite in bleach sold in developing countries varies widely even among different batches of the same brand, thus making it impossible to ensure proper dosing of the disinfectant. Building on work by the University of San Simone in Cochabamba, communities were encouraged to produce their own sodium hypochlorite by processing brine with imported electrolytic cells—a practice that was thought to create an entrepreneurial opportunity as well as meeting local demand. In practice, however, even simple electrolytic cells proved impractical. The up-front cost of US$ 1500 to US$ 2000 usually required outside funding. While the electrolytic cells had more than sufficient capacity to serve a group of villages, coordinating sales across sometimes distant communities proved logistically difficult, as did procuring a consistent supply of suitable-quality 500-ml bottles in which the product was initially sold. It also proved difficult for locally trained producers to achieve a consistent concentration of the active agent or to routinely test the product to ensure its quality. While the electrolytic cells were also explored in the national-scale programmes in Madagascar and Zambia, it was found to be more effective to buy the disinfectant from local, national suppliers with demonstrated capacity to consistently produce a high-quality product and to meet demand during epidemics (D. Lantagne, personal communication, 2006). Today, only a few programmes manufacture the disinfectant on site with the generators, including national-scale programmes in complex emergencies such as Afghanistan and Myanmar and all community-based SWS programmes.

The CDC and PAHO endeavoured to expand the use of the intervention in the Plurinational State of Bolivia and eight other Latin American countries, working mainly with local NGOs to establish demonstration projects (Reiff et al., 1996). Lacking strong governmental or other support, however, and with little funding, the programmes largely floundered, especially as the risk of cholera in the region subsided. None of these programmes evolved beyond the demonstration phase, and none survive today.

Believing that the intervention was suited for implementation by NGOs engaged in other community projects, the CDC and PAHO developed and distributed a step-by-step guide for programme implementation (CDC, 2000). In 1999, the CDC and CARE, an international NGO, added a SWS component to an ongoing water, sanitation and hygiene programme serving 72 rural communities in Nyanza province in western Kenya. The sodium hypochlorite product was procured from a company in Nairobi, promoted by CARE and its local partners, together with modified clay pots for safe storage, and distributed and sold at subsidized prices through existing community-based organizations. The project achieved 33.5% coverage (compared with a reported 5–15% in other countries) (Makutsa et al., 2001). However, intensive community education activities in the area were expensive and suspended when programme funding ended. Subsequently, a national social marketing initiative was implemented by PSI. Programme organizers documented the challenges they encountered, including costly transportation and distribution of the product into remote areas and difficulties in increasing sales volumes under this implementation model (Makutsa et al., 2001). A cost analysis showed the high start-up and indirect costs of this approach, the challenge of amortizing these and other fixed costs over relatively low sales, and the minor contribution that cost recovery could make to sustain such a programme on this scale. The area today remains a research laboratory for household water treatment programme evaluation and is served by a socially marketed product.

The specially designed vessels also proved to be an obstacle in implementing the intervention. Initially, the vessels were procured in the United States (at prices ranging from US$ 4.00 to US$ 6.00) and shipped to the intervention site (with an additional cost of US$ 0.50–1.00 per unit). This was quickly found to be uneconomical, and the mould was sold to a local manufacturer in the Plurinational State of Bolivia for local production. In other countries, suitable vessels were procured and in some cases modified to render them appropriate for the intervention (Reiff et al., 1996). When PSI began promoting the SWS through local distribution channels using the social marketing model, they found the vessel component of the intervention impractical and uneconomic. The rigid, non-nesting vessels presented transportation challenges even when produced in-country, and their high cost and low turnover made them costly for local shops and kiosks to stock. Requiring householders to purchase a special vessel when an existing one would do was also found to present an obstacle to the uptake of the intervention. Although implementers of the SWS have developed nestable, bucket-style vessels with tight-fitting lids and taps to reduce distribution obstacles, these are now promoted as part of the intervention only in emergency and other settings when the local population has no suitable safe storage vessel of their own that can be used for treating and storing water safely, such as the widely used “jerry can”.

Another change made for the PSI national-scale programmes is in the size of the bottle. In order to reduce the cost of the bottle to facilitate programme sustainability, a smaller, regional cap was designed. More than half of the cost of the product consists of the cost of the bottle and cap. Transportation and delivery costs also comprise a significant portion of the final cost of the product. Initially, the disinfectant was offered in 500-ml bottles (designed to treat 2000 litres of water or to cover a household for about 3 months), because 500-ml bottles with a 10-ml dosing cap were widely available in the country already. Over time, however, research and experience showed that a smaller bottle with a higher-concentration solution was easier to transport, less expensive for the user on a per litre treated basis and less expensive on a per purchase basis. Based on consistent water quality research and design engineering, a standard 150-ml bottle with a 3-ml dosing cap was developed, the implementation of which has improved quality control and logistics (Lantagne, 2006). This bottle will treat 1000 litres of clear water using one 3-ml cap per 20-litre volume of water and lasts a family of

5–6 persons approximately 50 days. In Africa, the 150-ml bottles are blow-moulded in most SWS countries by a single, local plastics manufacturer using moulds produced in Kenya under PSI specifications. Caps, which use more expensive and precision injection moulding processes and are cheaper to transport in bulk, are currently made by a single manufacturer in Kenya and shipped to each participating country. Lastly, the 150-ml standard regional bottle can support a greater portion of the actual production cost, thus leading to higher cost recovery.

No HWTS method has undergone more testing and field assessments than the SWS. Apart from chlorine-resistant cysts and other microbes of lesser health significance in connection with drinking-water, the microbiological efficacy of the SWS has been demonstrated (Quick et al., 1996; Rangel et al., 2003). The effectiveness of the intervention in reducing diarrhoeal disease has also been demonstrated in a variety of settings (Semenza et al., 1998; Quick et al., 1999, 2002; Reller et al., 2003; Luby et al., 2004; Chiller et al., 2006). Unlike most HWTS methods, however, the SWS has also been carefully scrutinized for its uptake. The results from these uptake studies, which are discussed in section 3.2.5 below, are relevant to perhaps all HWTS methods.

3.2.2 Scaling up—PSI and social marketing

Despite the setbacks in programme implementation, the CDC and other research institutions were continuing to demonstrate the effectiveness of point-of-use water treatment with chlorine in the field (Macy & Quick, 1998; Semenza et al., 1998). Based in part on this growing body of evidence, the Ministry of Health of Zambia invited the CDC to undertake a field trial to assess the impact of the SWS on water quality and diarrhoea. The study, which took place in two communities in 1998, found that the intervention significantly reduced the level of faecal bacteria in the stored water of intervention households, while decreasing the risk of diarrhoea by 48% (Quick et al., 2002). Based in part on these results, a national programme for the implementation of the SWS was initiated in Zambia following a cholera outbreak. The Society for Family Health, the local affiliate of PSI, led the implementation in conjunction with the Ministry of Health and the Central Board of Health using a social marketing approach. PSI's other initial large-scale roll-out of the SWS followed in Madagascar in 1999, coincidentally occurring immediately prior to a nationwide cholera epidemic and three successive cyclone emergencies (Dunston et al., 2001).

Social marketing employs commercial marketing techniques to promote products, services and practices that benefit the consumer or society as a whole (Kotler, Roberto & Lee, 2002). A recent systematic review has shown the effectiveness of social marketing to effect healthful behaviour change (Stead et al., 2006). With offices in over 60 countries, PSI is perhaps the largest social marketing organization in the world. Founded in 1970 to demonstrate the social marketing of contraceptives, PSI's current primary foci are malaria, oral rehydration salts, nutrition/micronutrients, family planning and human immunodeficiency virus (HIV)/AIDS. In most cases, products such as insecticide-treated nets and condoms are manufactured by commercial contractors, marketed under PSI brands, and distributed and sold through existing commercial wholesale and retail supply networks. Employing a variety of promotional techniques, including national media campaigns, group training sessions and one-on-one appeals, PSI seeks to create demand, which it then meets through national or regional manufacturing, usually on a contract basis. Sales channels include local women's groups (Haiti and India), restaurants in urban neighbourhoods (Madagascar), community-based agents on bicycles and on foot who carry the product to local markets (Kenya) and co-marketing with commercial soap companies (United Republic of Tanzania). PSI recovers some or all of the production cost, while attempting to ensure that products reach the consumer at an affordable price after sales costs and margins. Donor funding is usually required to pay for mass media, point-of-sale materials, street theatre, and person-to-person and other communications designed to generate demand for the products. More than half of PSI's funding is from governmental sources, largely from the United States Agency for International Development (USAID) and the United Kingdom Department for International Development.

While PSI's first involvement in HWTS actually came in the Plurinational State of Bolivia, where it fielded the commercial SWS application in cooperation with the CDC and PAHO, outbreak and emergency responses in Zambia and Madagascar led to the first significant sales of the product and ultimately to sustained programmes and other country initiatives. Relying initially on its own funds to launch in new countries, its strategy was to demonstrate the potential for the intervention and then seek outside donor support to expand and sustain the programme. This strategy has not always been successful; programmes in Uzbekistan and Burkina Faso were terminated owing to insufficient funding for a strong marketing campaign to establish consumer demand for the product. Experience has now led it to develop and impose disciplined criteria for country implementation. Among the key factors that have been identified for PSI's success are 1) involvement of key stakeholders from inception; 2) due diligence on developing and maintaining a quality product; 3) responding to the unique marketing, communications and distribution challenges and opportunities that SWS presents; 4) extensive work with governmental, private and community partners to reach rural and target populations with product and communications; and 5) consistent donor support (POUZN Project, 2007).

PSI's strategy and changes from the initial SWS programmes have led to significant growth (Table 3). [1] In December 2007, it was supplying SWS product in 18 country-level programmes, with a total of nearly 75 000 distribution points (retail outlets, partner sites, etc.). With annual sales in non-emergency settings of more than 7.3 million units in 2007, PSI estimates that its SWS products provided approximately 7.6 billion litres of safe drinking-water for the year. Based on its assumption of 730 litres/person per year (i.e. 2 litres/person per day), this was sufficient to meet the needs of nearly 10.4 million users in 2007. In 2007, PSI distributed an additional 3.2 million bottles of sodium hypochlorite in emergency and outbreak response; this would be capable of treating an additional 3.3 billion litres of water.

Table 3: PSI non-emergency distribution of SWS product, 2005–2007 (data from PSI)

	2005	2006	2007
No. of countries with programmes	13	17	18
No. of distribution outlets	40 869	62 439	71 143
No. of bottles sold[a]	5 350 551	6 381 986	7 342 664
No. of litres treated[b]	5 920 636 325	6 867 384 179	7 584 686 244
No. of users at year end[c]	8 110 461	9 407 376	10 389 981

[a] Bottles vary in size and disinfectant strength.
[b] Calculated based on CDC dosing recommendations.
[c] Assumes consistent use of 730 litres/person per year (2 litres/person per day).

Apart from boiling, PSI's SWS programme has been the most successful in scaling up HWTS to date. In some countries, at least, PSI has arguably achieved scale in respect of coverage. A closer review of the data shows unit sales to be highly concentrated. In 2007, for example, three African countries represented approximately 60% of non-emergency unit sales: Zambia (31.2%), Nigeria (15.9%) and Kenya (12.7%); Malawi and Madagascar represent an additional 8.9% and 6.2%, respectively. Previous years' sales were similarly concentrated. Zambia may, however, represent a country in which PSI could be said to have achieved scale. It reported 3.34 million users in 2007, representing approximately 31% of the entire population of 10.8 million. If used exclusively by the estimated 4.54 million Zambians without access to improved water supplies, this would represent a coverage level of 73.6%. Cholera outbreaks also reportedly drove coverage in Madagascar, where an estimated 18% of households use the SWS product (WHO/UNICEF, 2005). In 2007, PSI's estimated 1.1 million users of SWS product in Madagascar represent approximately 7% of the total population and 12% of those without access to improved water supplies. The corresponding figures are 5% and 19% coverage in Malawi.

In 2006, PSI and Abt Associates, a consulting group, won a major USAID contract to support HWTS initiatives that combine point-of-use water treatment with zinc supplements (POUZN). Currently, many of the PSI country programmes are continuing to grow, and more SWS programmes are being planned. There is significant research on linking the socially marketed product to local programming and supplementary implementation approaches to increase uptake. These include

[1] Because the focus of this report is on scaling up HWTS interventions for routine use, the volume of HWTS distributed in emergency or outbreak settings is segregated from that distributed outside such emergencies and outbreaks wherever it was possible to obtain a breakdown in numbers.

motivational interviewing (Thevos et al., 2000) and the use of schools (O'Reilly et al., 2008) and clinics (Parker et al., 2006). In a recent report sponsored by USAID, Abt Associates summarizes PSI's experience with SWS programmes, including its assessment of lessons learnt, best practices, successes and challenges (POUZN Project, 2007). It also recommends ways in which these lessons can be used to plan, implement and expand SWS programmes worldwide. These lessons, divided by subject area, are reproduced in Box 1. As the report represents the most comprehensive assessment of a strategy to scale up HWTS, the full report warrants careful study.

Box 1: Lessons learnt from implementing SWS in 20 countries (from POUZN Project, 2007)

1: Project design

- 1.1: The target group must meet the dual criteria of health needs and private sector viability
- 1.2: A long-term funding strategy should be developed
- 1.3: A range of technical expertise is needed

2: Production of SWS components

- 2.1: Arranging local production is not easy, but it is ultimately critical to sustainability and cost-effectiveness
- 2.2: Ongoing quality monitoring is essential
- 2.3: Product shelf life is important to market acceptance
- 2.4: Correct chlorine dosage is key to product viability
- 2.5: Standardization of the plastic containers simplifies programme implementation and reduces programme costs
- 2.6: Packaging must be appropriate for rural transportation and distribution

3: The regulatory environment

- 3.1: Involve all relevant government agencies early in the process
- 3.2: Respond immediately to government concerns
- 3.3: Prepare programme staff to respond to technical questions about the product

4: Marketing and communications

- 4.1: Shifting the focus of the product launch to rural communities with unsafe water and sanitation has been very effective in enhancing product prestige
- 4.2: Communications must address specific safe water programme behavioural constructs
- 4.3: The branded marketing campaign should be positive and aspirational
- 4.4: Safe water campaign messages need to be complementary to related campaigns
- 4.5: Timing of a safe water project launch affects success
- 4.6: Choosing the most appropriate communication channels is highly context specific
- 4.7: Targeted technical information can address concerns about chlorine use
- 4.8: Behaviour change for safe water is a long process, requiring sustained funding
- 4.9: Marketing templates (such as labels) can be developed and adapted to local requirements

5: Sales and distribution

- 5.1: While the commercial sector will distribute the safe water product, programme success requires a complementary "push" from the project
- 5.2: Capitalizing on NGO networks can significantly improve rural penetration
- 5.3: Entry of a socially marketed safe water product can encourage commercial sector participation

6: Creating partnerships

- 6.1: Partnerships are vital to the successful adoption of the safe water product at all levels
- 6.2: Donor advocacy and support can make a considerable contribution to the success of safe water programmes
- 6.3: With appropriate coordination and training, NGO programmes can offer a wealth of opportunities for reaching rural and high-risk populations
- 6.4: Trusted spokespersons and product champions are fundamental to product adoption

7: Product costs, pricing and cost recovery

- 7.1: Product cost may be recovered through sales
- 7.2: In most countries, product subsidies are not required

8: Integrating safe water into HIV/AIDS programming

- 8.1: Partnering with local NGOs that provide care for persons living with HIV/AIDS has been a successful model for reaching people living with HIV/AIDS
- 8.2: Interest in reaching people living with HIV/AIDS can provide the stimulus for a national safe water campaign

3.2.3 For-profit sodium hypochlorite products

While socially marketed SWS represents the most successful effort by non-profit organizations to promote bottles of dilute sodium hypochlorite to treat water at the household level, comparable commercial products have been available in many countries for decades (Sobsey, 2002). In Kenya, at least four commercial enterprises have emerged offering knockoffs to the original commercial sodium hypochlorite product, often even trying to take advantage of the market leader's brand with products with similar-sounding names (D. Lantagne, personal communication, 2007). In Indonesia, Aman Tirta, a public–private partnership supported by USAID, is following a commercially driven strategy to promote a privately produced sodium hypochlorite product (http://www.jhuccp.org/asia/indonesia/aman_tirta.shtml). Launched in 2006, Aman Tirta reported sales of approximately 158 000 bottles of sodium hypochlorite in 2007, providing 104 million litres of safe drinking-water to an estimated 142 500 routine users. It also sold 102 000 bottles for emergency applications. Sales in 2006 were higher, although this may represent "sell-in" to retailers and not "sell-through" to customers. There is also for-profit production in the Philippines, Mexico and certain other countries. Although simple household bleach is not recommended for the treatment of water owing to the presence of fragrances and other compounds and, for some products at least, inconsistent levels of available free chlorine, it is clear that some of these products are also used for treating water, especially when householders perceive the risk to be high.

Except for private marketing reports for a few countries (e.g. Baytell Associates) and JMP surveys reporting households that chlorinate their water at home, there is little information on the current sales volumes and growth of such commercial products. Moreover, no studies have been identified that assess the extent to which such products are consistently and correctly used by vulnerable populations to treat their water. Thus, it is difficult to estimate their coverage or contribution to HWTS. In East Africa, where PSI has been most successful in promoting its SWS products, there is evidence of increasing availability of (and competition from) private, for-profit products (Heijnen, 2006; POUZN Project, 2007). The CDC, however, has observed problems with the quality and consistency of certain commercial products available in these countries (D. Lantagne, personal communication, 2007). There is also a danger that the commercial producers will "cream" the market by selling only to higher-income populations in higher-density locations, thus not only failing to reach the poor in rural and other remote settings, but also depriving social marketers from needed volume over which to spread their fixed costs. Research is necessary to determine the impact that these commercial initiatives will have on HWTS coverage and uptake.

3.2.4 Community-based programmes

Concurrent with efforts to launch national-scale programmes with PSI and other social marketing NGOs, the CDC has also been pursuing community-based programme implementations leveraging the resources of local NGOs, faith-based organizations, Rotary groups and other decentralized funders that wish to start smaller, local projects. Some of these programmes are in countries (Bangladesh, Sri Lanka) or regions of countries (rural areas of Haiti) that do not have access to a socially marketed product and so manufacture the solution themselves by working with a private company or using an electrolytic generator. Other community-based projects use the existing socially marketed product in their programming (Uganda).

The most successful of these programmes, the Jolivert Safe Water for Families project in rural Haiti, offers lessons for scaling up locally. Technicians based in a health clinic in rural northern Haiti manufacture the solution, train families to use the solution and store it safely, conduct follow-up visits at the household level to provide continuing education and chlorine residual monitoring, and maintain records on when each family purchased the solution and the results of testing. Evaluations have been conducted 3 times over the history of the programme. A 2007 assessment found that the project had grown from 200 registered households in 2003 to 2141 households in 2006, that 22 591 bottles of solution had been sold in that time frame, that the average household purchased 6.24 bottles per year and that 76.66% of approximately 3000 stored water samples assessed between October 2002 and April 2007 were positive for free chlorine residual. Additional details appear in Table 4. The project has been replicated in Gros Morne, Haiti, and plans for further expansion in four other communities are under way in conjunction with the NGO Deep Springs International.

Table 4: Jolivert Safe Water for Families (Haiti), 2004–2007 (M. Ritter, unpublished data, 2008)

	2004	2005	2006	2007 (estimate)
No. of distribution outlets	7	11	20	24
No. of bottles sold[a]	2 593	7 240	9 401	8 734
No. of litres treated[b]	2 355 481	6 576 362	8 539 414	7 934 047
No. of users[c]	3 227	9 009	11 698	10 869

[a] Each bottle designed to treat 908 litres of water.
[b] Calculated based on CDC dosing recommendations.
[c] Assumes consistent use of 730 litres/person per year (2 litres/person per day).

3.2.5 Uptake of SWS

Compared with the numerous laboratory- and field-based studies of the SWS and other accounts of pilot and demonstration projects, there are relatively few assessments of uptake of the intervention in a programmatic (non-research) context over a period of time. The most comprehensive assessments to date were conducted by Olembo et al. (2004) in Zambia and by Rheingans & Dreibelbis (2007) in Madagascar. Both studies revealed a number of sobering findings that should give pause to those who may believe that the promising results in scaling up coverage can readily be translated into uptake. While these studies are limited to SWS products, there is little compelling evidence to date that other HWTS products would be more effective in achieving uptake within the population that could benefit most from such products.

Olembo et al. (2004) at Johns Hopkins University evaluated the PSI programme in Zambia from 1998 to 2003. While they found 41% of the 1319 households surveyed reported use of dilute bleach solution, they sampled only from geographical areas with comparatively high sales of the product; nationally, the 2001–2002 Demographic and Health Survey placed the figure at 13.5% following 5 years of country-wide media campaigns (radio, television, newspapers, posters, etc.) and active promotion at the community and household levels by pharmacists, staff and volunteers. Regular users were more likely to be from urban and periurban settings, better educated, with better houses and generally of higher socioeconomic class—hardly the most vulnerable to diarrhoea. An estimated 22% from the sample reported that they had tried the product but discontinued use, mainly because of cost, poor taste and the belief that their water was already safe. Of the 546 households that reported using the dilute bleach solution, residual chlorine was found in the stored water of 36.1% of those reporting use for more than 1 year, 27.3% for users for 6–12 months and 20.0% for users for less than 6 months. While these cross-sectional follow-up data are substantially lower than the 72–90% compliance reported in the field trial in Zambia (Quick et al., 2002), they may still demonstrate an effective intervention.

Rheingans & Dreibelbis (2007) used data from a 2006 national survey by PSI of 2484 households in Madagascar to assess disparities in the awareness and use of SWS product. Overall, 68% of respondents reported having heard of the SWS product, 27% reported having used it and 10% reported having used it in the previous month. They found significantly lower levels of product awareness, however, among less advantaged groups, including those with lower levels of education, minority ethnic status, residence in rural areas, longer distances to health clinics and aged less than 23 years. Population characteristics associated with less use of the product included low socioeconomic status, low level of education, minority ethnic status and residence in rural areas. The authors also used secondary information on the health burden to estimate the health impact of using the SWS product in Madagascar. They concluded that because of the disparities in use, "the vast majority of the deaths and [disability-adjusted life years] averted come from the richest socio-economic groups." If the current uptake (use) levels within the richest population strata could be achieved across the entire population, they estimated that the number of deaths and disability-adjusted life years averted would increase 3-fold.

Parker et al. (2006) reported greater success in the adoption of the SWS as a result of promotion by nurses in Kenya. Eleven nurses underwent a 4-h training session on how to incorporate the SWS and hand-washing instructions into their regular clinical practice. They were also given instructional material and pocket guides to leave with their clients. The nurses then trained their assigned clients in 5-min one-on-one encounters or 30-min group sessions (varying from 8 to 50 individuals), covering all 220 persons who typically visited the maternal and child health clinic each day. Water sampling from follow-up visits to clients who had visited the clinic 2 weeks previously showed that 68% had detectable free chlorine residuals in their stored water; after 1 year, the figure was 71%.

As with other household-based water treatment interventions, promoters of the SWS have recently begun to target their efforts on linking a quality socially marketed chlorine solution product to populations that are particularly vulnerable (e.g. young children and the immunocompromised) and at entry points in which their strategies may be more effective in securing uptake. One such focus has been in schools. Migele et al. (2007) reported on a pilot project in Kenya in which the SWS was introduced into a rural primary school, providing the hardware and using teachers to promote point-of-use water treatment as part of the school's curriculum. Retrospective, ecological data suggested lower rates of diarrhoea among schoolchildren after implementation, and this had the potential for net savings (after the cost of the intervention) to the private school from reduced medical expenditures. After 3 years, the intervention is still in place. A larger school-based water and hygiene intervention in 45 public primary schools in Kenya was associated with an increase in home-based water treatment (O'Reilly et al., 2008). Fourteen per cent of the parents of children attending the schools reported treating their water at home 1 year after the intervention, compared with 6% at baseline ($P < 0.01$). The intervention was also associated with a decrease in absenteeism. The study also documents the increase in awareness of issues around safe drinking-water among both children and their parents.

3.3 Sodium dichloroisocyanurate (NaDCC) tablets

3.3.1 Product origins and development and testing

One alternative to sodium hypochlorite is sodium dichloroisocyanurate (NaDCC), also known as sodium dichloro-s-triazinetrione or sodium troclosene. Widely used for decades in household and commercial laundry bleaches, scouring powders and industrial and recreational water disinfection, NaDCC has recently found applications ranging from the sanitizing of medical instruments to the cleaning of baby bottles and contact lenses. For more than 30 years, the effervescent tablet version of NaDCC has been used for the emergency treatment of water; tens of millions of NaDCC tablets were distributed in connection with the response to the 2004 Indian Ocean tsunami (Clasen et al., 2005). Its widespread use in non-emergency household water treatment applications began after review of the chlorinated isocyanurates by the United States Environmental Protection Agency (USEPA), WHO and the Food and Agriculture Organization of the United Nations for the routine treatment of drinking-water. NaDCC may also offer certain other advantages over sodium hypochlorite in terms of safety, shelf life, up-front cost and convenience, although these have not yet been shown to impact coverage or uptake (Clasen & Edmondson, 2006). A blinded field trial has shown the product to be effective in treating drinking-water (Clasen et al., 2007b), and a blinded health impact trial has recently been completed in Ghana (R. Quick, personal communication, 2008).

3.3.2 Scaling up NaDCC tablets

An Irish company is believed to be the largest producer of NaDCC tablets for treating drinking-water. In 2007, it manufactured and sold tablets sufficient to treat more than 2 billion litres of water, over half of which were used in household water treatment programmes, with the majority of the balance being used for emergency applications. The company produces foil-wrapped strip packs of tablets specifically sized to treat 1, 2, 5, 10 or 20 litres of water, according to the vessel size and other requirements of customers. The product is marketed and sold mainly under its own brand name. In most cases, the product must be registered with health, sanitary or pharmaceutical regulators prior to importation and sale. According to company representatives, the company's single plant, located in Wexford, Ireland, has the capacity to produce substantially greater volumes of product by adding additional mixing, tablet-forming and packaging equipment. As one of the largest worldwide users of high-quality dichloroisocyanurates, the company enjoys favourable pricing, which has allowed it to secure long-term contracts with UNICEF and others that procure large quantities of the product, mainly for emergency response.

The company's principal strategy for scaling up use of the NaDCC tablets among householders has been through private sector distributors that import the product in bulk strips and then repackage and retail the tablets for local sale. While securing suitable country-level distributors has not always been easy, the company currently has commercial sales intermediaries in Algeria, Ghana, Haiti, Indonesia, Kenya, the Philippines and the Bolivarian Republic of Venezuela. It also currently works with PSI in the United Republic of Tanzania, Uganda, the southern Sudan and Swaziland.

Another company in the Bolivarian Republic of Venezuela has been distributing NaDCC tablets since 1996, marketing three sizes of tablets (for treating 1, 5 and 20 litres) and achieving aggregate sales during the ensuing decade sufficient to treat approximately 400 million litres (approximately 60 million litres in 2006). While this company works with the Bolivarian Republic of Venezuela Ministry of Health, UNICEF and NGOs, sales are mainly targeted to higher socioeconomic classes, which pay the full cost of the product (US$ 1.22, US$ 1.27 and US$ 1.59 per pack for 30 tablets for the three sizes, respectively). The initial product launch included mass media (television, radio, newspaper, magazines, billboards) and distribution of samples and literature at stores, toll booths, government agencies and local NGOs. Currently, advertising continues in catalogues, point-of-use displays and leaflets distributed in subways. While the company continues to collaborate with the government and NGOs, mainly in disaster response, sales are chiefly to the middle class and in urban settings.

In Haiti, the most impoverished country in the hemisphere, the local distributor has had greater success reaching lower-income populations. The product was launched in 2000 after the local distributor secured local registration. The local distributor uses a number of strategies to promote sales, including advertising on radio, television, newspapers, wall murals and signage; promotion at carnivals and other public events; presentations at schools and health clinics; and visits to medical doctors, pharmacies and governmental agencies to provide product samples and literature. Only one size of tablet is sold in Haiti: the 17-mg NaDCC tablet suitable for treating 4–5 litres of water is compatible with the 1 United States gallon (approximately 3.8 litres) "boutique" container used by most urban householders. In the 6 years through 2006, approximately 16 million tablets had been shipped to Haiti, enough to treat approximately 68 million litres. The consumer cost is between US$ 1.20 and US$ 1.50 per carton of 50 tablets; in smaller "cabin" shops, householders can also buy single tablets for US$ 0.12–0.15. An unpublished report by the Global Safe Drinking Water Alliance (P. Edmondson, personal communication, 2007) provides some evidence that the product is highly acceptable to consumers and preferred by some over sodium hypochlorite in the form of commercial bleach because of ease of use, better taste and prestige.

A private label programme under which the Irish manufacturer supplied strip packs of NaDCC tablets to a worldwide leader in household cleaning and disinfection products was suspended after the initial roll-out in Pakistan was deemed unsuccessful. Marketed under a different brand name, the product did not achieve a sufficient volume of initial or repeat sales. Much of the resistance was believed to be affordability; the special four-tablet strip pack specified by the company had a cost that was considerably higher than that of the standard packaging. The dosage used was also twice that normally used for clear drinking-water, giving rise to adverse customer feedback on the taste of the water. The programme was terminated within the first year.

In 2006, the Irish manufacturer began selling NaDCC tablets in the United Republic of Tanzania through the social marketer, PSI. While PSI had a history of selling its own brand of sodium hypochlorite solution in the country, focus group discussions suggested that householders preferred NaDCC tablets owing to their lower front-end cost (despite their higher cost per litre treated), ease of use, and ease of transport and storage. Following field testing of the product by the Ministry of Water and Livestock to demonstrate its antimicrobial effectiveness, PSI began importing bulk strip packs of a single-sized 20-litre tablet that are packed locally by PSI in boxes of 36 10-tablet strips. Electing to build on its existing brand rather than establish a new product identity, PSI added the tablets to its marketing campaign (radio, newspaper advertisements, posters, point-of-use displays, culture shows), promoting both the liquid (SWS) and tablet products for use in households as part of hygiene, safe water and diarrhoea reduction programmes. A detailed description of the product launch and surveys with consumers and retail outlets provide useful insights on the challenges faced in establishing a new point-of-use water treatment product using social marketing strategies (Heijnen, 2006). Commission sales agents, most of whom handle all of PSI's products in the United Republic of Tanzania, are used to secure retail outlets. Despite securing shelf space at numerous pharmacies, shops and other retail outlets, sell-through was disappointing until PSI secured funding to support the marketing programme. Dedicated commission sales agents who have their own transportation were demonstrably more effective in securing sales. There is some evidence that the new product will cannibalize existing sales of the SWS product while at the same time increasing overall market share. A 5-week cross-sectional survey of 165 households that purchased NaDCC tablets showed that drinking-water stored in the home was significantly more likely to be free of faecal coliforms (78%) than source water used by the same households (20%) ($P < 0.001$) (Tomasi, 2006).

Finally, in Kenya, the Irish manufacturer is pursuing a commercial distribution strategy with a private distributor of pharmaceuticals, laboratory equipment and veterinary supplies. Strip packs of 10 20-litre tablets are promoted through conventional advertising (FM and Citizens' Band radio, newspaper ads and inserts) and sold at retail (kiosks, pharmacies, chemists) for 20 Kenya shillings (equivalent to US$ 0.26), resulting in a cost of 2 Kenya shillings (US$ 0.026) for each tablet and 0.1 Kenya shillings (US$ 0.0013) per litre treated. The distributor also supplies Kenyan NGOs and the public sector for distribution in emergencies. Introduced in October 2006, sales for the first 12 months were 50.5 million tablets (sufficient for treating more than 766 million litres of water), of which 30.1 million tablets (602 million litres) were specifically for household water treatment (P. Edmondson, personal communication, 2007). It is not yet fully clear, however, whether "sell through" can be achieved to sustain or increase sales.

Overall, the Irish company's sales of NaDCC tablets have increased dramatically in recent years (Table 5). Significantly, sales to the household (non-emergency and non-defence) sector represent the most substantial growth, exceeding 150 million tablets in 2007, enough to treat more than 2.86 billion litres of water. Although the manufacturer did not break sales down by country, much of the growth is understood to have been in Kenya. It is not yet clear whether this success can be duplicated elsewhere, the extent to which it benefited from PSI promotion of SWS in Kenya or whether sales may be cannibalizing SWS sales in the market. In 2007, the Irish company also sold more than 325 million NaDCC tablets (enough for treating more than 1.65 billion litres of water) to 37 UN agencies, governments and NGOs for emergency applications.

Table 5: Routine (non-emergency) sales of NaDCC tablets, 2005–2007 (data from the manufacturer)

	2005	2006	2007
No. of countries with programmes	5	10	8
No. of distribution outlets		Not available	
No. of tablets sold[a]	53 626 000	80 433 200	150 278 000
No. of litres treated	981 070 000	1 470 592 000	2 862 860 000
No. of users at year end[b]	806 359	1 208 706	2 353 035

[a] Includes tablets suitable for treating 1, 5, 10 and 20 litres of drinking-water.

[b] Based on 20 litres per day for a household of five persons (i.e. 3.3 litres/person per day), which corresponds to the manufacturer's experience.

3.3.3 Uptake of NaDCC tablets

Once again, there is little evidence of uptake of NaDCC tablets to date. There were high levels of compliance observed in two Bangladesh field studies (Afroz Molla, 2005; Clasen et al., 2007a), although these were efficacy trials and not follow-up assessments of ongoing programmes, like those evaluated for SWS programmes. The only other research investigated consumer preferences, not actual use. For example, in a 2005 pilot study in Bangladesh, 78% of mothers expressed satisfaction with the tablets because they found them easy and safe to use, they dissolved quickly and they left no objectionable smell or taste (Afroz Molla, 2005). In 1997, an independent consumer research study sponsored by a distributor of NaDCC tablets surveyed 100 households in a suburb of São Paulo, Brazil, which were then treating their water with sodium hypochlorite (Data Kirsten Research, 1997). After using one brand of NaDCC tablets for 3 weeks, 69.6% of householders expressed a preference for the NaDCC tablets, citing convenience of use, safety in handling and better odour and taste. In the United Republic of Tanzania, PSI has been marketing a 0.75% solution of sodium hypochlorite since 2002. Recently, it conducted focus groups to compare household preferences between the sodium hypochlorite and NaDCC tablets (N. Gade, personal communication, 2006). Once again, 70% of participants preferred the tablets (scoring 42 of 60 first-place votes) to liquid bleach. In other countries, however, informal evaluations by PSI found that some users preferred liquid sodium hypochlorite (SWS), whereas others preferred NaDCC tablets (D. Lantagne, personal communication, 2007).

3.4 Solar disinfection

3.4.1 Product origins, development and testing

Research on solar water disinfection was first conducted by Professor Aftim Acra at the American University of Beirut in the early 1980s (Acra, Raffoul & Karahagopian, 1984). While the antimicrobial activities of both infrared and ultraviolet radiation were known, the synergistic effect of the two sources of energy was demonstrated in work by EAWAG/SANDEC. Laboratory tests showed that at a water temperature of 50 °C, only a quarter of the ultraviolet light required at 30 °C is necessary to kill the same level of faecal coliforms (Wegelin et al., 1994). SANDEC then undertook field testing to evaluate a variety of configurations and materials for exposing water to the sun, emphasizing locally available materials such as glass, plastic bottles and plastic bags. It also evaluated these approaches in terms of cost, acceptability and sustainability, as well as the manner in which the intervention would be introduced and supported programmatically. In the end, it settled on a system in which householders fill 1- to 2-litre clear, plastic polyethylene terephthalate bottles with water, place them on their roofs for at least 6 h during the daytime and store the water in the bottles until it is actually consumed. Under cloudy conditions, the length of exposure must be increased; for simplicity, solar disinfection users are told to keep bottles on the roof for 1 sunny day or 2 days if cloudy. As suspended solids may block the ultraviolet radiation, water with high levels of turbidity (>100 nephelometric turbidity units) must undergo some process (filtration, flocculation or simple sedimentation) to reduce particulate prior to use.

Solar disinfection has been subject to rigorous testing, both in the laboratory and under field conditions, and evaluated for effectiveness and cost-effectiveness in preventing diarrhoeal disease. While such testing has included permanently mounted panels and other configurations (Kang, Roy & Balraj, 2006), the solar disinfection bottle system has been particularly well documented. Testing in both the laboratory and the field has shown the approach to be effective against a variety of faecal pathogens (Wegelin et al., 1994; Heaselgrave et al., 2006) and in reducing diarrhoeal disease (Conroy et al., 1996, 1999, 2001; Lijima et al., 2001; Rose et al., 2006). *Giardia* and *Cryptosporidium* have both shown susceptibility to sunlight (McGuigan et al., 2006). A cost-effectiveness analysis reported that the mean cost of implementing the intervention in 13 countries, including hardware (new bottles) and programme costs, was US$ 0.63 per person per year, just below the US$ 0.66 cost attributed to the SWS and far less than the US$ 3.03 for ceramic filters and US$ 4.95 for flocculant-disinfectant sachets (Clasen et al., 2007a).

3.4.2 Scaling up solar disinfection

Other than boiling, solar disinfection is the most non-commercial of HWTS options in its implementation. Although users often must purchase the bottles (an analysis of 13 country programmes showed the average price to range from US$ 0.03 to US$ 0.15), there are no instances to date in which the solar disinfection system has been rolled out by private entrepreneurs on a for-profit basis. While solar disinfection generally could be compatible with a commercial model, as it is for solar water heaters, by using other proprietary products for exposing water to the sun, the use of bottles as promoted by the solar disinfection system probably is not. There are efforts under way to link solar disinfection to commercial product marketing channels with the development of accessories for the application of solar disinfection, such as metal panels for exposing the bottles, bottles coated with titanium dioxide or reusable ultraviolet indicators. Thus far, however, implementation of solar disinfection more closely resembles hygiene promotion, which has little or no potential for cost recovery. Like hand washing with soap, barriers to scale principally involve creating awareness and changing behaviour rather than cost and availability of products or technology.

Implementation of solar disinfection programmes has been through partnerships, mainly with NGOs working in health or education. In some cases, such as Pakistan, programmes are implemented through the ministry of health using existing medical facilities, health workers and volunteers. Programmes typically are launched on a district or provincial level, although there are cases of nationwide roll-out. SANDEC's role is mainly to provide technical assistance, on-site training and, in some cases involving NGO partners, financial support. In order to qualify, interested parties complete formal applications, and additional information is collected from other sources. Where financial support is provided, amounts usually do not exceed US$ 20 000 per year. SANDEC also helps secure acceptance from the ministry of health and other governmental authorities, although this often requires repeating testing locally to demonstrate the method's biocidal activity to sceptical officials. Partners develop training materials in local languages, taking into consideration local conditions, and select and train community mobilizers, who do the actual householder training and follow-up. As the partners are already working in the community and have community workers (sometimes volunteers) on staff, implementation of solar disinfection often represents only a minimal additional burden for many partners. The budget of solar disinfection projects covers staff salaries of project manager and trainers as well as community workers, cost for the development and printing of training and education material, transport costs as well as cost for media campaigns, as the training at the grassroots level is complemented with awareness-building campaigns on television and radio, street theatre, health fairs, wall painting and posters, and training in schools.

Local partners pursue different strategies to encourage awareness and uptake of the intervention. In Nepal and certain other countries, national campaigns were undertaken that included radio and television advertisements. SANDEC has learnt, however, that communication through mass media alone rarely inspires adoption, except among those who may have been previously trained. Personal appeals through door-to-door solicitation by community workers are generally necessary to procure attendance at training sessions, and follow-up is essential to ensure continued use. A key role in this process is played by the solar disinfection promoters: "Their ability to address families' initial reluctance and doubts and later specific technical and social problems that arise in the household and community context was central for the success of the [solar disinfection] method" (Hobbins, 2004). According to SANDEC, a major constraint in scaling up is identifying strong partners with capacity and resources to undertake programme implementation. As project continuation and growth beyond the 2-year start-up require the partners to develop their own sources of funding (usually from governments, local foundations, etc.), there is also considerable attrition among partners that cannot secure such resources. Kenya Water for Health Organisation (KWAHO), a Kenyan NGO working in the Kibera slum in Nairobi, for example, has succeeded in securing funding from Rotary International, allowing coverage to increase to an estimated 100 000 users.

KWAHO's impressive numbers illustrate one important factor in achieving coverage: with the same financial effort, more households can be reached in a densely populated area, as community workers can reach out to several families in 1 day. In Indonesia, for example, Yayasan Dian Desa has trained 180 000 users in just 12 months. In more remote, rural or mountainous regions, where large distances have to be covered, far fewer households can be trained with the same budget, even though their vulnerability may be greater (M. Saladin, personal communication, 2007). While this paradox in scaling up HWTS is true to some extent for all methods of household water treatment, it is particularly so with solar disinfection, which has minimal equipment costs.

However, the need for suitable equipment—clear plastic bottles—should not be minimized. Although beverages are sold in 2-litre polyethylene terephthalate bottles in all but the most remote regions, the lack of bottles continues to be a major constraint in scaling up solar disinfection. Used bottles are acceptable, but as they are valuable containers (not waste) in many low-income settings, householders who wish to practise solar disinfection must still purchase them in most instances. The

Coca-Cola Company and its bottlers have donated bottles in some cases; in Indonesia, the donation was used to establish an initial inventory that the programme implementer could sell and replace to ensure an adequate supply of bottles to programme participants.

SANDEC has learnt that at the grassroots level, participatory awareness building, training involving participatory hygiene and sanitation transformation methods, and the presentation of other water treatment strategies are generally most effective and sustainable. In some countries, however, a top-down approach was used in promoting and implementing solar disinfection. In Uzbekistan, the system was implemented through provincial public health units using nurses and other medical personnel who, in turn, provided training at the district level. District personnel then trained health post nurses and volunteer health promoters who actually trained the householders. SANDEC has found that where governments take greater ownership of the programme, scaling up is more assured, since it removes the common problem of an NGO's inability to secure ongoing funding. It also takes advantage of existing resources, capacity, credibility and authority. Governmental support, including participation by the Ministry of Education, has also been a major factor in the roll-out of solar disinfection in Nepal, where it is part of the school curriculum in primary and secondary schools, and teachers are trained to include the method in science and health classes.

In Latin America, a special grant led to the creation of Fundación Sodis, an NGO based in the Plurinational State of Bolivia that promotes solar disinfection in seven South and Central American countries. Its goal is to extend coverage of solar disinfection to 300 000 people in 5 years (2001–2006) and an additional 2 million people by 2011. Concluding that householders needed alternatives to solar disinfection in certain regions with high turbidity or inadequate sunshine, Fundación Sodis has also begun promoting ceramic filtration, boiling and home-based chlorination. While Fundación Sodis also works with NGO and governmental partners, it takes a more direct role in programme implementation than does SANDEC. It engages directly, for example, in advocacy, materials development, testing, research and development, and reporting on results in its target countries, and it takes a much more active role in recruiting implementation partners to ensure country-wide coverage. Thus far, this has not necessarily resulted in higher numbers of users; rather, a larger number of partners are each addressing smaller populations (e.g. 1000 households) in smaller communities. It uses 1- to 2-day workshops to generate interest among potential partners and to introduce the interventions to governmental officials. In 2005, Fundación Sodis also initiated the "Alianza Agua Segura", an alliance of NGOs, governments, universities and international agencies engaged in household-based water treatment interventions in selected Latin American countries to better coordinate efforts to implement large-scale programmes with the cooperation of donors and national governments.

SANDEC asks implementing partners to report semiannually on the number of persons trained, number of regular users (20–25 days/month), number of occasional users (when they have time) and non-users (attending training but did not practise). Table 6 shows the total number of users (regular and occasional) reported as of the end of 2007, by country programme. The total number of reported users increased 49.9% from 2005 to 2006 and an additional 35.8% from 2006 to 2007. Assuming the same 2 litres/day used in calculating the number of users of SWS products, this translates into 970 million litres treated by solar disinfection users in 2007. This is up from 764 million litres in 2006 and 387 million litres in 2005.

Table 6: Solar disinfection users in 2007 (data from SANDEC)

Country	NGO	No. of users[a]	Total no. of users
Latin America	Fundación Sodis		**360 000**
Asia			**1 420 293**
North-east India	AU	158 085	
South India	LEAD India	236 025	
Sri Lanka	Community Self-Improvement	10 740	
Pakistan	Consolidated Appeals Process	483 140	
Nepal	ENPHO	139 530	
Uzbekistan	Joint Development Associates	94 395	
Cambodia	Adventist Development and Relief Agency	4 550	

Country	NGO	No. of users[a]	Total no. of users
Indonesia	Yayasan Dian Desa	180 000	
Viet Nam	Helvetas	73 835	
Philippines	Helvetas	29 605	
Bhutan	Helvetas	10 388	
Africa			**344 565**
Kenya	KWAHO	168 750	
Kenya	Country Cooperation Strategy	28 810	
South Africa	Mattcomm	10 810	
United Republic of Tanzania	Water and Development in Dodoma (MAMADO)	2 155	
Uganda	Comp. Canada	15 000	
Benin	Regional Centre for Water and Sanitation	100	
Guinea	Regional Centre for Water and Sanitation	3 200	
Cameroon		15 000	
Democratic Republic of the Congo		8 890	
Zimbabwe		83 125	
Senegal	District Rotary Foundation Subcommittee Chairs	8 725	
Total number of solar disinfection users			**2 124 858**

[a] Assumption: five persons per household.

3.4.3 Uptake of solar disinfection

A number of assessments have been conducted of solar disinfection projects to determine the acceptability of the intervention and the factors that are associated with uptake. In Bangladesh, investigators found that the successful introduction of solar disinfection was mainly dependent on environmental factors, water sources in use, occupation of household and season, as well as strong intrafamilial and gender-related factors (Hobbins, Maeusezahl & Tanner, 2000). In the Plurinational State of Bolivia, use of solar disinfection (defined as having solar disinfection–treated water in the home at the time of the investigator's visit) was strongly associated with a householder's attendance at a community workshop designed to introduce solar disinfection, monthly follow-up visits and children who attended school-based programmes; it was also positively associated with family size (Hobbins, Maeusezahl & Tanner, 2002; Hobbins, 2004). Families reported using solar disinfection mainly because it would improve their (including their children's) health (77.3%), it was easy to apply (9.4%) or for economic reasons (4.2%), all consistent with promotional messages. However, only 17% of individuals reported water as one of the perceived causes of diarrhoea, despite clear messages on the risk of contaminated water.

A 2005 study of eight regions in which solar disinfection had been promoted showed a significant range in the portion of households that had solar-treated water available at the time of the interview (0–70%, with a mean of 35%) (Moser, Heri & Mosler, 2005). Assessments of the promotional strategies found television advertising, health fairs and events to be more effective than radio advertising or working through women's groups. Actual use of solar disinfection–treated water was associated with perceptions of a health benefit (less diarrhoea), but also with regularly seeing neighbours and others in the community follow the practice. The study recommended a greater understanding of drinking-water habits, as it found that users frequently boiled water in the morning and used solar disinfection–treated water when the boiled water was exhausted. It observed that long-term adoption of the method required overcoming ingrained habits and recommended extensive follow-up with novice users and specific efforts to address major reasons for not adopting or discontinuing solar disinfection: lack of time (24%), cold or rainy weather periods (14%) and lack of sufficient bottles (13%). In Nepal, regular users cited the method's cost-effectiveness, simplicity, health impact and environmental friendliness; non-users noted lack of bottles, limited time, lack of awareness and difficulty cleaning bottles. Among persons who never tried solar disinfection, the main reasons were doubts about the effectiveness of such a simple and low-cost technology and about the risk of diarrhoea, lack of bottles or roof space in which to expose them to the sun, and preference for another method.

Surveys by ENPHO, a SANDEC partner in Nepal, found 66.83% regular users, 14.67% irregular users and 18.50% non-users among more than 13 000 householders it trained in the method. However, in another study using a more limited training regime, only 9% of households routinely adopted the intervention (Rainey & Harding, 2005). These compare with estimates of 25% usage reported in an independent evaluation of solar disinfection adoption 6 months after implementation in the Plurinational State of Bolivia (Hobbins, 2004). There is even less certainty about longer-term use. One study reported a 31% reduction of users in the second year when follow-up visits were suspended (Hobbins, Maeusezahl & Tanner, 2002). In Nepal, study participants mentioned the benefit of treating water to reduce stomach ailments, but this did not outweigh the perceived barriers of heavy domestic and agricultural workloads, other cultural barriers, uncertainty about the necessity of treating the water and lack of knowledge that untreated drinking-water causes diarrhoea (Rainey & Harding, 2005). Evaluations of past and ongoing programmes are under way in order to assess the extent to which householders continue to practise solar disinfection after the initial introduction.

3.5 Ceramic filters

3.5.1 Product origins, development and testing

Ceramic water filters were first introduced in 1827 by John Doulton, a British merchant working out of a pottery shop in Vauxhall Walk, Lambeth, not far from the River Thames. Initially, only the vessels were ceramic; the actual filter element consisted of powdered carbon. By 1835, when Queen Victoria (whose husband, Prince Albert, died of typhoid) commissioned the company to produce water purifiers for the Royal household, they were fitted with clay filter elements and probably capable of some level of bacterial removal. The British Army began constructing gravity filters with ceramic elements in the 1850s (Warwick, 2002). The hollow cylindrical "candles" of the type introduced by Doulton and other commercial filters first appeared in 1904. Silver, first recognized for its antimicrobial activity in 1869 (and, following Carl Credé's recommendations in 1881, widely used until recently to prevent blinding by gonorrhoea in newborns), was introduced as a bacteriostatic agent in ceramic water filters by a Swiss-based company (Russell & Hugo, 1994). An estimated 10–15 million ceramic candles are produced and sold annually, mainly to middle-income consumers, by the dozens of producers in Brazil, Mexico, the United States, the United Kingdom, Switzerland and numerous Asian countries. Many are still used in gravity-type systems; others are installed in plastic housings with pipe fittings, where they are plumbed into pressure water systems at the point of use. Some are also fitted into portable pump-style units used mainly by outdoor enthusiasts. It is not clear what portion of these are of microbiological quality and are being promoted for use by vulnerable populations for effective water treatment in the home. For purposes of this report, we used a conservative estimate of 1%.

While the candle-style filter has been driven mainly by commercial companies, alternative designs have begun to emerge in low-income settings, mainly with governmental and NGO support. The most widely used alternative is an open, pot-style design, in which the upper ceramic vessel itself serves as the filter element. This first evolved from a comparative study by the InterAmerican Development Bank in 1981, which emphasized the appropriateness of the technology to developing countries (Lantagne, 2001). USAID financed the development of a factory in Ecuador to produce the filters. The enterprise was abandoned in 1985, reportedly because of its inability to develop sufficient demand for the product. With assistance from Potters for Peace, a United States–based non-profit organization, and the Massachusetts Institute of Technology, the design and method of fabrication of the pot-style filter have been refined. Most recently, Practica Foundation, IDE, RDI, Rotary clubs and Red Cross organizations have established factories for local production of the Potters for Peace design and distribute them to householders either completely free or through social marketing with partial cost recovery. A disc-shaped filter element that is cemented into the bottom of a vessel has also been developed (Cheeseman, 2003; Dies, 2003). While this design has a lower cost and fragility, disc-shaped elements have not been implemented, mainly because of challenges in sealing the element into the floor of the raw water holding chamber.

The microbiological effectiveness of ceramic filters tends to vary based on their quality and cost. The highest-quality commercially fabricated candle elements produced in Europe and North America by several companies have been shown to reduce bacteria by more than 6 logs (99.9999%) and cysts by more than 3 logs (99.9%), but they achieved no more than 1 log (90%) reduction of viruses (Ongerth et al., 1987; Schlosser et al., 2001; Horman et al., 2004). In one of the most comprehensive laboratory evaluations of pot-style filters to date, Van Halem (2006) reported $\log_{10}$ reduction values (LRV) between 4 and 7 for spikes with *E. coli*, successful removal of sulfite-reducing *Clostridium* spores (10^3–10^5 spores/100 ml) and partial removal of MS2 bacteriophages (LRV 0.5–3.0).

The capacity of household-based ceramic filters to reduce diarrhoeal disease has only recently been evaluated. Studies have shown both candle filters (Clasen & Cairncross, 2004; Clasen et al., 2005) and Potters for Peace–style filters (URL, 1995; Brown, Sobsey & Proum, 2007) to be effective in reducing diarrhoeal diseases. The filters have also been shown to be highly cost-effective (Clasen et al., 2007a).

3.5.2 Scaling up ceramic filters

The global market for ceramic filters consists mainly of candle-style elements used in gravity or pressure (in-line) systems used at the household level by upper- and middle-income consumers concerned about the quality or appearance of their drinking-water. A 1999 study by Anderson Consulting focusing on microbiological-quality ceramic water filters (various brands) showed that sales of 2 million ceramic candle filters were predominantly to developed countries in North America (26% of world sales), the Middle East (20%), the Far East (20%) and the Russian Federation (16%); India represented less than 5% of the market, and sub-Saharan Africa less than 1% (Anderson, 1999). It also noted that the overall market for ceramic filters is growing at a rate of 5–10% per year, less than the overall market for household water treatment products. High-quality ceramic filters can cost US$ 100 or more. High-quality candles can also be purchased for US$ 6–8 and fitted into locally fabricated filters made from plastic buckets and taps, resulting in equivalent performance for about US$ 25–35 (Clasen & Cairncross, 2004).

India, Brazil and Mexico have represented leading developing country markets for commercial candle filters. According to the Anderson (1999) report, however, sales in India peaked around 1996, when ceramic filters were used by an estimated 15–25% of Indian households, mainly in the principal metropolitan regions of Delhi, Kolkata, Mumbai and Chennai. Production of lower-quality elements, largely from China but also from India, Viet Nam and other Asian countries, flooded the market. However, sales began to decline when consumers began to learn, perhaps from suppliers of competing ultraviolet, iodine and other water treatment systems, that "candles are only filters, not purifiers". In Brazil, two of the largest producers of middle-market filters produce and sell a variety of ceramic candle and complete systems, mainly to the domestic market, but also for export throughout Latin America. While pricing is a fraction of the Swiss and English candles (about US$ 2.50 to the distributor), the units are still sold primarily to upper- and middle-market consumers and are largely unavailable in remote locations. In Mexico, the market for ceramic filters started about 30 years ago with door-to-door sales and consisted mainly of generic product without labels, trademarks, etc. Penetration never achieved more than an estimated 5% of households, partly because consumers found the low flow rate and the need to brush (clean) them unacceptable. According to producers, consumer resistance has also resulted from the Mexican governmental position that only boiling is effective for purifying water. Two companies dominate the Mexican home water treatment market. One of them once had 600 people selling door-to-door, and it may have been selling about 4000 filters per month in its best years.

The foregoing suggests that while candle-style filters have reached some coverage, they are largely beyond the reach of lower-income populations that are most vulnerable to waterborne disease. For pot-style filters, the situation is precisely the reverse: little coverage (except in Cambodia), but with a clear focus on the poor.

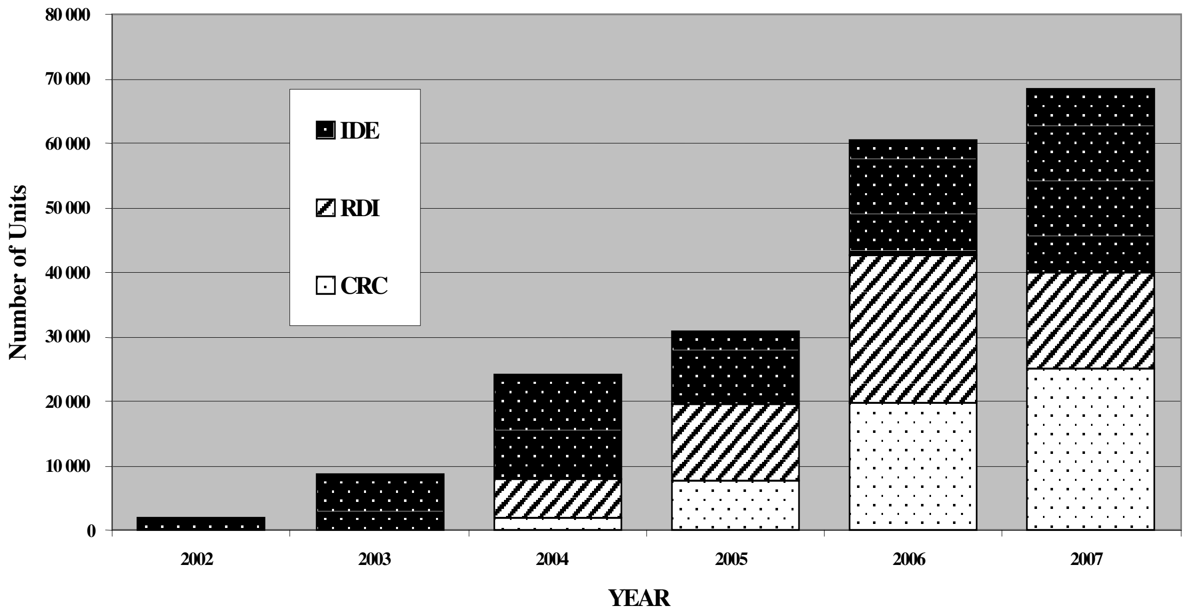
A recent report for Potters for Peace, which still provides most of the technical assistance for NGOs seeking to implement local production of pot-style filters, provides information on 17 country-level projects (R. Rivera, personal communication, 2007). However, filters are currently being produced in only seven of these countries. Table 7 shows existing, planned and failed programmes. The most successful projects are in Cambodia, Guatemala and Nicaragua. In Cambodia, IDE and RDI have each established local factories producing 5500 filters per month (with a capacity of 7000 per month) (Brown, Sobsey & Proum, 2007); the Cambodian Red Cross has developed a factory under a World Bank Development Marketplace award. Filters are sold at production cost (US$ 7.50), although targeted recipients receive a US$ 5.00 subsidy. The filters were subject to breakage (about 2% per month) during the 4-year follow-up period (Brown, Sobsey & Proum, 2007). The study also concludes that filters were used longer and more effectively by households when other water, sanitation and hygiene interventions are bundled with the filter, that access to replacement parts is key to longer-term use and that use is increased when householders pay for the filters. In Guatemala, the American Family Association, a local NGO, started a factory in 1995 to produce pot-style filters under a licence from Potters for Peace after the Instituto Centroamericano de Investigación y Tecnología, the inventor of the filter, sold a reported 20 000 units locally. A randomized controlled trial of the American Family Association filters in 1996 reported high acceptability and a 53% reduction in diarrhoea among users of the filters (URL, 1995). However, while the filters are of good quality, production is limited to 40 units per day after a reported 70% failure rate (Lantagne, 2006).

Table 7: Existing, planned and discontinued pot-style filter projects as of November 2006 (adapted from Lantagne, 2006)

Status	Country programmes
Fully equipped facility with some level producing filters full time	Nicaragua, El Salvador, Guatemala, Ghana, Cambodia (2), Myanmar, Mexico
Partially equipped facility not believed to be producing filters	Indonesia (Bali), Cuba, Sri Lanka, Ecuador, Thailand
Countries where filter production is in planning	Yemen, Indonesia, United Republic of Tanzania (3), Mozambique, Nigeria, Benin, Kenya, India, Colombia, Cameroon, Morocco, Honduras (El Progresso), Mexico (2), Guatemala (2)
Discontinued projects	Iraq, Haiti, the Sudan, Bangladesh

Despite more than 25 years of history, results to date show that pot-style filters have only recently begun to show promise of achieving some success in coverage and uptake, and then only in Cambodia. Much of the failure is attributed to poor planning, lack of technical expertise and support, inadequate funding or special circumstances that led to early suspension. IDE, RDI and the Cambodian Red Cross have overcome some of these obstacles in Cambodia, demonstrating the potential for larger-scale production and distribution. The reasons for their success have been comprehensively documented (Brown, Sobsey & Proum, 2007), and IDE and RDI are eager to transfer their strategy to other NGOs. Collectively, IDE, RDI and the Cambodian Red Cross produced an estimated 194 000 ceramic water purifiers between 2002 and 2007 (Figure 2). Even assuming 2% breakage per month (as reported by Brown, Sobsey & Proum, 2007), they estimate that more than 760 000 users (based on 5.2 persons per household) are currently using the filters, mainly in Cambodia. As of the end of 2007, the filters were available through more than 200 retailers and NGOs.

__Figure 2: Growth of ceramic water purifier sales by IDE, RDI and CRC in Cambodia, 2002–2007 (data from IDE and RDA)__



There are continued efforts in product development, testing, quality control, production and sales. Graduate students in engineering at the Massachusetts Institute of Technology in the United States have conducted laboratory and field studies designed to evaluate and improve filter performance and explore business strategies for commercially marketing the device (http://web.mit.edu/watsan/). Practica Foundation, a Dutch NGO with a demonstrated track record for promoting appropriate water and other technologies, has added the Potters for Peace filter to its product line and is providing technical and other support to NGO implementers. It and others recently sponsored a comprehensive study of various technical aspects of the units (Van Halem, 2006). One company has worked on alternative designs and improved methods for local production of colloidal silver, the bacteriostatic agent used to impregnate or coat the ceramic element. Feasibility studies and planning are under way in at least 15 countries. Another business recently began producing pot-style filters in Ghana.

3.5.3 Uptake of ceramic filters

The acceptance and continued use by vulnerable populations of both candle- and pot-style ceramic filters have been documented in a number of studies by researchers independent of the programme sponsors. These studies are summarized in Table 8. With the exception of one programme in Sri Lanka, in which recipients received filters in an emergency response with little programmatic support, the follow-up studies showed reasonably consistent use of the filters (usually defined as operating units in the home filled with water at the time of the visit).

Table 8: Summary of results of independent follow-up studies of ceramic filters

Location	No. of study households	Follow-up point	Observed use	Reference
Plurinational State of Bolivia (Charinco)	50	16 months following pilot commencement	76% of filters still in active use in the home	Jamison (2004)
Sri Lanka	75	3–6 months following post-tsunami distribution	Galle: <10% Trincomalee: 90% Weligama: 96%	Palmer (2005)
Haiti	110	6 months following post-flood distribution	64% (one third discontinued use due to 6-month expiration of candles)	Caen (2005)
Dominican Republic	431	16 months after post-flood distribution	88.7% in the home; 59.1% still being used in the home; 48.7% "still working"	Clasen & Boisson (2006)
Plurinational State of Bolivia (Chiniri)	60	9 months following end of pilot programme	67% "regular use", 13% "intermittent use"	Clasen, Brown & Collin (2006)
Cambodia	506	24–48 months after filter distribution	Average filter breakage of 2% per month after delivery; 31% continued use in 24–48 month group	Brown, Sobsey & Proum (2007)

In a Cochrane review of water quality interventions, Clasen et al. (2006) speculated that the higher reduction in diarrhoea associated with filters could be attributed to higher compliance. In the first field trial of candle-style ceramic filters, the authors found a high level of acceptability and a favourable perception among users (Clasen et al., 2004). All of the 24 intervention households interviewed reported that they liked the filter, and 96% of respondents would recommend it to others; 92% reported that they did not find using the filter inconvenient, 71% said that using the filter did not add significantly to their household duties, and 92% reported that since using the filter, they felt better. At the same time, in only 72% of the cases were the filters clearly in use at the time water was sampled, and the same percentage acknowledged that they at least occasionally drank unfiltered water while away (40%), while working (27%) or when the filter was empty or slow (27%). Almost half (46%) reported that the filter was occasionally too slow to provide water for the family at all times.

Several of the follow-up studies of ceramic filters examined use of units distributed in an emergency response (Caen, 2005; Palmer, 2005; Clasen & Boisson, 2006). Oxfam, for example, distributed candle-style filters in response to flooding in the Dominican Republic in 2003 in seven affected communities. In a follow-up study 16 months following distribution, visits to about a quarter (115/431) of the households that received the filters revealed that 88.7% of the households still had the filters in their possession, and 48.7% were still working (i.e. no broken or missing parts, correctly assembled and still in use by the householder). In total, 23 (41%) households had changed the first set of candles within 6 months of distribution (in accordance with Oxfam's instructions), 11 (21%) changed them between 6 months and 1 year, and 20 (38%) were still using the same filter elements after 16 months. Of the 13 families that no longer had the filters, most had given them to relatives, and 2 had sold them. In total, 34 (33%) of the filters were not being used to filter water, mainly because the householders no longer had working candle filters owing to breakage (22), clogging (6) or leaking of granular activated carbon into the product water (4). Householders reported that the ceramic candle breakage occurred when systems accidentally fell from a table or other surface or during cleaning or replacement. For those filters no longer in use, the average period of operation reported by householders was 9 months. Most filters that were no longer operational were nevertheless being used, mainly for storing drinking-water in the home or for rainwater collection.

Brown, Sobsey & Proum (2007) assessed use of and attitudes towards pot-style filters acquired by Cambodian householders 24–48 months prior to the study. Of 506 households in the study, 156 (31%) were using the filter regularly at the time of follow-up, although the proportion in use was strongly associated with the length of time elapsed between filter installation in the household and follow-up, with a discontinuation rate of about 2% per month. Average use was about 2 years. Householders who purchased their filters were 3 times more likely to be continuing to use them than those who received donated filters. Sixty-five per cent of householders who no longer used their filters attributed such non-use to breakage of the ceramic filter element, the spigot or the container; others considered the filters to be too slow (5%), stopped using them because they had exceeded their recommended use period (5%) or had given the filters to friends or relatives (3%). Continued filter use was also associated with water source (deep well users were more likely to discontinue use, possibly because of clogging due to dissolved iron in their water or to a perception that their water was of higher quality than water from surface sources and shallow wells) and knowledge of prescribed water, sanitation and hygiene practices (suggesting higher health-seeking behaviour). Users reported filling the filter an average of 1.8 times per day and cleaning it 2.3 times per week. One hundred and thirty-three (86%) households reported using the filter for drinking-water only. Of 281 households with disused filters responding, 120 (43%) households reported a willingness to purchase an additional filter.

3.6 Biosand filters

3.6.1 Product origins, development and testing

Slow sand filters have been used in community water treatment systems for more than a century, and their effectiveness has been documented (Hijnen et al., 2004). Unlike rapid sand filtration, which is used mainly to remove particulate matter as part of a multistage system, slow sand filters operate as the treatment step in which the medium exists to provide a combination of biological and physical removal mechanisms, including predation, natural death, inactivation, adsorption and surface straining/screening. Gravity-driven raw water is passed at a constant rate of 0.1–0.2 m^3/h through a 0.6–1.0 m^2 bed of sand supported by coarse sand and gravel. The constant flow provides oxygen and nutrients to a biological layer (*schmutzdecke*) that grows over 2–3 weeks and eventually occupies the top 0–5 cm of the filter. In large, municipal systems, slow sand filters can treat 28–56 million litres of water per hectare, but the same process is employed in barrels and basins to supply water for villages and compounds. Like most other filters, the top portion of the medium must be cleaned or replaced at regular intervals, requiring the removal of the top layer of sand and time to re-establish the *schmutzdecke* to achieve optimal performance.

The so-called "biosand" filter, first developed in 1991 by Dr David Manz at the University of Calgary in Canada, allows a slow sand filter to be operated intermittently, thus making it more suitable for household applications (Buzanis, 1995). This is achieved in the design by making the highest point of the outflow tubing 5 cm above the sand, thus ensuring that water covers the sand at all times. A diffuser plate placed above the level of the water protects the sand below from damage when water is poured into the system. A "clean in place" technique minimizes the need for sand bed removal, simplifying maintenance and increasing continuity of performance (Baker & Duke, 2006). Initial field testing in Nicaragua in 1995 demonstrated the feasibility of the system in low-income settings and led to certain design improvements.

The most common version of the system used in development settings is fabricated of concrete using steel moulds, which cost from US$ 250 to US$ 900 each (depending on where they are made) and produce 1–2 filters per day. Because of the weight (approximately 150 kg), the biosand filters are typically fabricated close to sites in which they are intended to be used. Material and production cost is estimated at US$ 12–40. A more recent concrete design with thinner walls reduces the weight of the container to about 77 kg, thus improving transportability while reducing material cost. A plastic version of the filter, also developed by Dr Manz and used in both commercial and development applications, substantially reduces the weight of the unit and allows for centralized production at scale. An arsenic biosand filter incorporates media designed to remove arsenic from product water (Ngai et al., 2005). One advantage of the biosand filter over other HWTS options is that it produces sufficient volume of treated water for other potentially health-related purposes, including personal and domestic hygiene and food preparation, at no additional cost.

While slow sand filters have been shown in the laboratory to reduce faecal bacteria by 2–3 logs, viruses by 1.5–2 logs and *Cryptosporidium* oocysts by more than 5 logs (Hijnen et al., 2004), tests of the biosand filter both in the laboratory and in the field achieved a mean reduction of *E. coli* of less than 2 logs (Stauber et al., 2006). Although these tests raise questions about whether biosand filters can match the bacteriological performance of slow sand filters, a randomized controlled trial to assess the health impact of biosand filters in the Dominican Republic reported reductions in diarrhoea of 30–40%, depending on age strata, similar to the results for other HWTS methods (Stauber, 2007). Tests have shown biosand filters to consistently remove turbidity, a sometimes-essential pretreatment step for effective chlorination or solar disinfection. Such supplemental disinfection is encouraged where possible to minimize recontamination, a more significant risk with biosand filters.

Meanwhile, follow-up assessments of biosand filter programmes provide useful information concerning the microbiological performance of the filters in the field over time. A 2001 evaluation conducted by Samaritan's Purse of 100 household-based biosand filters in six countries in which it had implemented programmes showed mean reductions of faecal coliforms of 93% (Kaiser et al., 2002). In Kenya, a cross-sectional study of 51 household-based biosand filters produced and sold commercially 4 years earlier by local technicians found 70.6% of the filters producing water with <10 colony-forming units (CFU) of faecal coliforms per 100 ml of sample water, compared with a mean ambient level of 462 CFU of faecal coliforms per 100 ml; another 23.5% of the filters improved the raw water quality but produced water with >10 CFU of faecal coliforms per 100 ml (Fewster, Mol & Wiesent-Brandsma, 2004). These results were essentially identical to the performance of the filters when tested 3–4 weeks after initial installation. In Haiti, where 2000 filters had been installed between 1999 and 2004, investigators visited 110 recipient households and found 107 with working filters (Duke et al., 2006). Water sampling of these filters found a mean reduction in *E. coli* of 98.5% compared with source water; 80% of the filters produced water meeting the WHO standard of 0 CFU/100 ml, and only 3% of samples had >10 CFU/100 ml. However, there was substantial post-filtration contamination during storage, as there often is in the absence of safe storage or residual chemical protection. In Ethiopia, sampling from 37 filters that had been in service for at least 5 years showed a mean reduction in *E. coli* of 87.9%; 54.1% of filters produced water with 0 CFU/100 ml, and 21.6% from 1 to 10 CFU/100 ml (Earwaker, 2006). The filters in each of these projects significantly reduced water turbidity, an important visual indicator that has been shown to reinforce use by householders.

3.6.2 Scaling up biosand filters

Enthusiasm for the biosand filter led the University of Calgary in Canada to secure a patent on the technology with a view towards commercializing it. It then licensed the technology to Davnor Water Treatment Technologies Ltd, a company formed by Dr Manz. While pursuing a for-profit strategy to market and sell plastic systems for use in remote locations in higher-income countries, Davnor also began providing NGOs in developing countries with the technology and technical assistance to fabricate concrete systems. One of its initial NGO partners, Samaritan's Purse, has also been one of the largest promoters of biosand filters, producing more than 14 000 units by 2001 in 24 countries (Kaiser et al., 2002). In 2001, Davnor formally split off its humanitarian activities into CAWST, a non-profit entity. Davnor failed commercially and ceased operations in 2005, but it subsequently licensed its plastic biosand filter technology to International Aid.

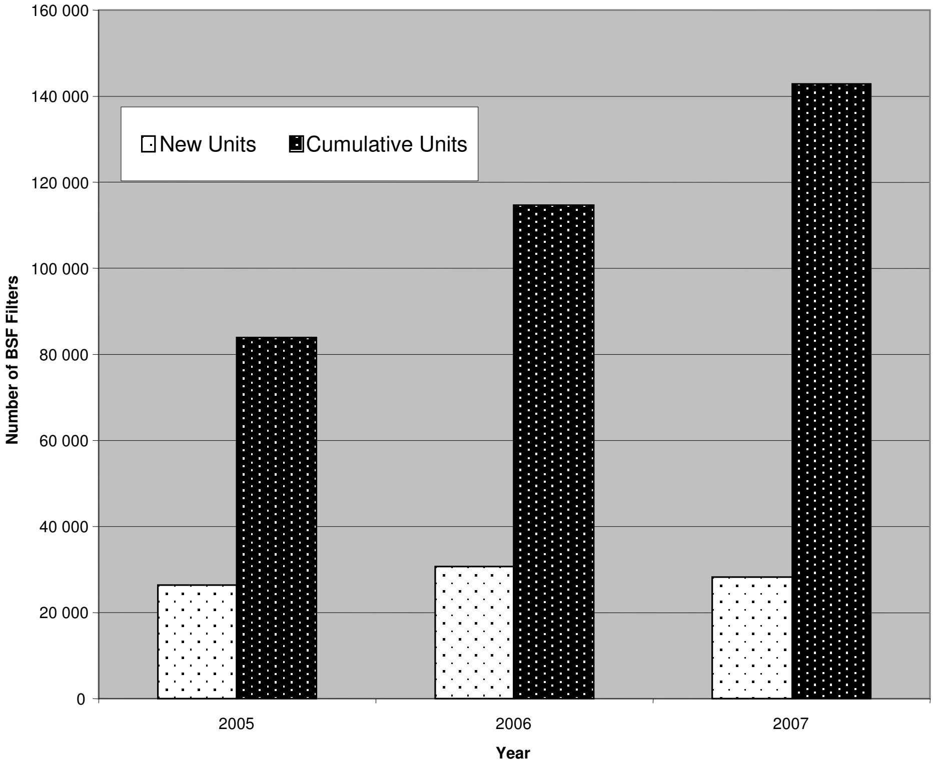
CAWST (http://www.cawst.org) continues to be the leading source for development and promotion of biosand filters (although it supports other HWTS technologies as well). BushProof also promotes the device and maintains a web site on the technology. Unlike the other HWTS products discussed in this report, however, CAWST's strategy for promoting coverage and uptake of the filter is not to manufacture or sell the device directly. Rather, following an approach developed by its co-founder (Dow Baker, 2000), CAWST works with NGOs and provides them with the technology, technical assistance and consulting services necessary to initiate and build programmes for the production and dissemination of the biosand filter. While providing its NGO partners with the drawings and specifications for the filters and moulds, CAWST emphasizes building capacity within the NGOs, not only to fabricate and distribute the biosand filters, but also in planning for HWTS projects, securing funding, generating demand and transferring expertise to other NGOs ("training the trainer"). BushProof also provides training in biosand filter production and distribution as well as prefabricated moulds.

Samaritan's Purse Canada, an early recipient of training, provides perhaps the best example of how this process can succeed. With support from the Canadian International Development Agency, Samaritan's Purse worked through local partner NGOs to build and distribute 14 000 biosand filters in 24 countries by 2001. By June 2006, it reported producing 65 000 biosand filters, a significant portion of which were fabricated by its own NGO partners in Brazil, El Salvador and Cambodia. Hagar, its Cambodian partner, has produced over 35 000 filters since 2004, following a "moving workshops" model. In Ethiopia, it has distributed 8000 filters since 1999 in two phases, through the Ethiopia Kale Heywet Church Water and Sanitation Programme. These projects have been unusually well documented in follow-up assessments. A comprehensive evaluation completed in 2002 of its biosand filter programmes in six countries concluded that the units were effective, appropriate, acceptable and sustainable (Kaiser et al., 2002). Among other things, it recommended 1) providing recipients with properly labelled buckets for raw and treated water to reduce recontamination of treated water, 2) producing appropriate materials on biosand filter usage, maintenance and water hygiene and 3) enhancing capacity of local technicians and ensuring that each village has a trained person to attend to filter problems. In some cases, the report recommends that filter production be centralized, possibly through moving workshops, to improve quality and consistency.

This NGO model of dissemination typically requires filter recipients to participate in training sessions and assist in the manufacture, transport and installation of the biosand filter at the household. Such "sweat equity" reduces or completely satisfies a cash contribution by the beneficiary, thus potentially allowing the filters to reach the most poor. With little or no cost recovery, however, programme implementers must rely on donor funding to initiate and grow the projects, a challenge that CAWST reports to be a major constraint to expansion of biosand filter coverage (S. Curry, personal communication, 2007). Even a successful programme, such as the Samaritan's Purse/Ethiopia Kale Heywet Church Water and Sanitation Programme project in Ethiopia, risks complete suspension of filter production and distribution when its funding expires in 2007, idling trained technicians and equipment, despite some evidence of the commercial viability of the project (Earlwaker, 2006). At least one programme in Kenya has followed a full cost-recovery model. After MedAir discontinued a 1-year biosand filter project in 2000, the technicians trained by the NGO continued to produce the filters, establishing a small commercial business that sold more than 2000 filters in its first 4 years (Fewster, Mol & Wiesent-Brandsma, 2004). Using an improved, round mould, local technicians in Kenya can produce 4–5 filters from one bag of cement and some polyvinyl chloride pipe, reducing the material cost to less than US$ 10 and yielding a significant profit on the filters when sold for about US$ 22.

According to an annual survey of NGOs undertaken by CAWST (2007), Samaritan's Purse represents a large portion of the aggregate number of biosand filters implemented to date. Figure 3 shows new units put into service and cumulative number of systems in operation during the 3 years ending June 2007. Assuming, as CAWST does, that six persons on average are using the filters deployed at the household level, the total number of persons benefiting from biosand filters to date is 858 500. This is obviously the maximum, as it assumes no breakage or discontinued use. CAWST reports that each filter treats up to 80 litres/day (29 200 litres/year). The number of additional units sold during each of these years was essentially flat, but, because of the durable nature of the filters, the number of cumulative users grew by 46%, 36% and 25% during these 3 years. While making an important contribution to HWTS efforts, biosand filters face significant barriers to reaching substantial levels of coverage, even assuming continued annual growth at these levels. The current model for concrete biosand filters is not suitable for mass production and distribution. And although the "train the trainer" model adopted by CAWST is capable of exponential growth through an expanding network of NGOs and community-based organizations, this has not yet yielded significant increases in coverage.

Figure 3: Cumulative concrete biosand filters in service as of the years ending June 2005, 2006 and 2007 (data from CAWST)



International Aid, a United States–based NGO working with Rotary clubs, is seeking to overcome some of the barriers of the concrete filter and its distribution model by manufacturing and selling a plastic version of the biosand filter. It manufactured a mould in 2007 in the United States and is producing the plastic filters in the United States for export. The cost of each is US$ 32, and large-scale expansion plans with Rotary support are planned for the Dominican Republic, Ghana and elsewhere. Through 2007, the project claims that 9000 filters have been sold, mainly to Rotary groups seeking to implement safe water programmes (J. Bodenner, personal communication, 2008). Pure Water for the World, a Rotary-supported NGO, has established biosand filter projects in 14 communities in Central America and one in Haiti and is currently planning major expansion in Haiti using a plastic filter made locally using inexpensive rotational moulds.

3.6.3 Uptake of biosand filters

While coverage of biosand filters is still limited, follow-up studies of implementation programmes provide evidence that the uptake of the filters may be significant and sustained, with continued use well beyond the rates reported by certain other HWTS interventions. The six-country Samaritan's Purse evaluation of 600 household-based biosand filters distributed at least 3 months previously concluded that 98.4% of all recipients used their filters on a regular basis and that 88.5% of households used such filters every day (Kaiser et al., 2002). In Kenya, 97% of householders who had purchased their filters 4 years before reported that they were "generally satisfied" with the filters; only one family had permanently stopped using the filter, and all 51 householders agreed that the biosand filter had been a "worthwhile" purchase (Fewster, Mol & Wiesent-Brandsma, 2004). In Haiti, 97% of the filters were functioning after an average 2.5 years, 92% were considered well maintained, and all users reported liking the units, citing mainly better water quality (49%) and improved health (22%) (Duke et al., 2006). In Ethiopia, a survey of 57 randomly selected households that received biosand filters in a Samaritan's Purse programme at least 5 years previously showed 66.7% still in "constant use" (Earwaker, 2006).

3.7 Middle-market commercial filters

Retail outlets in the major cities of China, India, South Africa, Mexico, Brazil and many other countries offer dozens of commercial water filtration products for household use. A search of the Internet reveals many more. Often these products are hybrids, combining different filtration media with other microbial barriers, such as ultraviolet radiation, adsorption and chemical disinfection. There are a number of proprietary market reports that purport to provide the size and scope of this market (e.g. Baytell & Associates). While these products are not typically marketed to lower-income populations, the conclusions from these market reports suggest the potential for significant uptake that may ultimately include the base of the economic pyramid. For example, the summary of a Frost & Sullivan (2005) report on the Global Competitive Environment for Residential Water Treatment Equipment Markets makes the following points:

1. Increasing consumer awareness has boosted the market for residential water treatment equipment. Growing health consciousness among people has brought awareness about the quality of drinking-water and is spurring the development of water treatment products. Apart from bacterial and viral contamination, myriad chemicals, fertilizers, pesticides and heavy metals, which cannot be removed by boiling, also pollute water.

2. Manufacturers of residential water treatment equipment are educating consumers about the efficacy of their products in resolving these problems. As a result, residential consumers are beginning to prioritize water treatment, pushing up the sales of water treatment devices.

3. Certification of quality is likely to determine the growth of the market. The presence of a variety of water treatment technologies on the market, many of which claim to provide similar options and capabilities, confuses consumers seeking to choose a system for their specific need. As NSF International (the main certifying organization) does not certify microbial performance except for protozoan cysts, there is a need for new standards for certification of point-of-use water treatment devices.

4. Aggressive competition and price pressures are key challenges. Investing in user education as well as advertising to increase awareness about the water treatment devices' price, aesthetics and technology has stepped up competition among existing market participants. Although this has boosted the sales of equipment, the lack of radical improvements in technology has made price the main differentiator in the water purification equipment market.

5. Larger manufacturers offering products that have been manufactured in Asian countries at lower costs further intensify pricing pressures. These companies are able to capitalize on the low cost of manufacturing and distribution, making it difficult for smaller participants to compete. As the end users are price sensitive, cost becomes an important factor in the decision to purchase water purification equipment. This constraint is expected to have a high impact on the revenue growth of the global residential water treatment equipment market.

In general, however, little is known about the microbiological performance of these middle-market products or their suitability as health interventions for low-income populations. When some products have actually been tested for microbiological performance and safety, they have been found wanting (Clasen & Menom, 2007). They are primarily sold through commercial distribution channels in urban and periurban settings and are less commonly available in rural and other remote locations. Thus, while the proliferation of these products may suggest that they could contribute to the scaling up of household water treatment, there is little evidence to date that clearly demonstrates their potential role. In fact, much of the evidence raises questions about the suitability of these products for protecting vulnerable populations from waterborne disease. First, many of these filtration products are designed only to improve water aesthetics and not to eliminate microbial or chemical contaminants. Unfortunately, consumers are not always aware of this distinction, not only in low-income countries, but in developed countries as well. Second, in many countries, there are no standards for microbiological performance or safety. The USEPA Guide Standard and Protocol for Testing Microbiological Water Purifiers (USEPA, 1987), and its American National Standards Institute/NSF International equivalent in Protocol P231, has not been widely accepted outside the United States; outside of military applications,[1] efforts to update the standard to cover additional technologies that do not require power or piped-in water have not yet been successful. A WHO initiative on environmental technology verification is intended to help remedy this problem by developing guidelines for developing such standards. Third, many manufacturers do not actually undertake independent, rigorous testing of their products in order to demonstrate their performance and safety because of cost or the lack of compulsory standards. This lack of standards may contribute to failure of quality products to emerge at scale in these markets. Finally, few of these products are actually directed to low-income populations. Their pricing and lack of availability in remote locations place them beyond the reach of those most affected by waterborne disease.

These limitations notwithstanding, there are lessons to be learnt from the experience of these middle-market commercial products and cases in which they may ultimately play a role in delivering safe water to vulnerable households. One example is a fully integrated, gravity-fed microbiological water treatment system designed for use at the household level with water of unknown microbiological quality. In order to meet the particular challenges of India and other developing countries, the unit was specifically designed to operate without electricity or other power and without a piped-in water supply. It was also intended to produce a sufficient volume of water to meet the average household demand for drinking-water and to do so below a US$ 0.01/litre target cost to consumers. The system incorporates four discrete consumable components: 1) a cleanable mesh prefilter, 2) a carbon block filter to remove disinfectant-resistant cysts and certain chemical contaminants, 3) a chlorine-based disinfection unit and 4) a granular activated carbon scavenger to remove residual chlorine. The unit was also designed to address the physical and bacterial challenges presented by Indian source water as established by a survey of 14 major Indian cities, which found frequent and substantial faecal contamination. A bench trial showed the device to meet the USEPA protocol's 6-4-3 LRV for bacteria, viruses and cysts (Clasen, Nadakatti & Menon, 2006).

Unlike the manufacturer's core consumer products, which consist mainly of food, personal care and household cleaning products, this water treatment unit is a durable appliance with a relatively high up-front cost. As a result, the company's traditional distribution channels were not suitable for the device. Moreover, because the product lacks proprietary technology, the company has sought to control the supply chain and protect against knockoffs by pursuing a direct sales strategy. When the product was initially launched in Chennai, prospective customers who met a targeted profile were invited to one of the "Safe Water Zones" opened throughout the city—retail sites where they learnt about the risks of contaminated water and received a demonstration of the product, all part of a carefully orchestrated sales strategy. As the product was expanded into other cities and states, however, these retail outlets were abandoned. Mass media, including television ads, encourage potential customers to call the company for a free at-home demonstration. More recently, the company has sought to expand its sales coverage downmarket. It has partnered with UNICEF to pilot a programme for deployment of the units in schools, much like those in Kenya (O'Reilly et al., 2008). It also partnered with CARE's micro-finance affiliate in India and has begun selling to micro-finance institutions that market the device—with a specially designed loan package—to members of women's self-help groups. Evaluations of these programmes are under way. Although the Indian-based affiliate that developed the system has declined to release any sales figures for this report, it has now commenced a national roll-out of the device in India.

The affiliate's strategy for this product also differs from those for most other HWTS products described in this report in two other important respects. First, the device is not sold on the basis of health. In fact, the health benefits from using the device are not even featured in the company's marketing campaigns. This strategy comports with much of the research that has found health to rarely be a motivation for behaviour change (Figueroa & Kincaid, in press). Instead, the campaign is built around the slogan "as good as boiling" and mainly emphasizes the convenience and cost savings

[1] A recent protocol for testing microbiological water purifiers for military applications draws mainly on the USEPA protocol but contains important differences in microbiological agents and test procedures (see NSF International, 2006).

of using the device as an alternative to boiling. This perhaps reflects the fact that the target market for the device is not the lower socioeconomic classes to which other HWTS devices are targeted, but households that perhaps already treat their water, mainly through boiling, which, as noted above, is very common in India. A second but related distinction is that the Indian company seeks to make the device "aspirational"—something that consumers want and are proud to own. In Indian homes, the device is often displayed proudly in reception rooms; only rarely is it back in the kitchen. Notwithstanding this positioning of the product, however, the company has demonstrated that the product is within the reach of some of the lower socioeconomic classes that are likely more vulnerable to waterborne disease. It offers the product on an instalment sales basis, allowing customers to pay the relatively high up-front cost in multiple payments.

3.8 Flocculation/disinfection products

3.8.1 Product origins, development and testing

Sachets combining flocculation and disinfection agents were developed in South Africa more than two decades ago. The original products, still sold under two different brand names, employ alum to reduce turbidity and chlorine-resistant protozoan cysts and dichloroisocyanurate to inactivate bacteria and viruses. The process has been described as replicating, in 10-, 15- or 20-litre batches, the operation of a typical municipal water treatment facility. While used widely by some NGOs in emergency relief, these products have seen relatively minor application in development settings.

In the late 1990s, a United States–based consumer products giant began to explore household-based water treatment products. Although the company is a major supplier of household bleach in certain markets, its commercially driven strategy favoured a proprietary (non-commodity) water treatment product. It also saw an important value-added opportunity over bleach in settings where turbidity was present, interfering with halogen disinfection and leaving water aesthetically objectionable. In 1996, it entered into a Cooperative Research and Development Agreement with the CDC to explore potential products and technologies. In 1999, it acquired a company that was a leader in activated carbon and glass fibre faucet-mounted and pitcher/gravity filters used in developed countries to remove cysts and improve aesthetics, as well as a line of iodinated resin–based microbial purifiers used mainly by outdoor enthusiasts (later sold to a Swiss-based company). The company first tested filters in Guatemala in 1999, but abandoned the technology when it was found to be too susceptible to clogging.

In 2002, the United States–based company began field testing its own flocculant-disinfectant sachets. The product uses ferric sulfate as the flocculant and calcium hypochlorite as the disinfectant and was designed to address other perceived deficiencies in other combination products. Users open the sachet, pour the contents into 10 litres of water, stir the water repeatedly for several minutes until the floc settles out in the bottom of the vessel, pour the supernatant through a clean cloth into another vessel, then allow it to stand for 30 min. Produced at a cost of US$ 0.035 and intended to be sold to consumers at US$ 0.10 after commercial markups in the supply chain, each sachet treats 10 litres of water, resulting in a cost of US$ 0.01 per litre, high compared with the cost of most other household water treatment options (Clasen et al., 2007a). Based on its experience with soap, shampoos and other consumer products that it markets and sells in small volumes, however, the company's focus was on minimizing the up-front cost of point-of-use water treatment. Apart from NaDCC tablets, which can also be purchased in one-batch sizes but are not suitable for highly turbid water and are not effective against chlorine-resistant protozoan cysts, the flocculant-disinfectant sachets present consumers with the lowest-cost barrier to enter the HWTS practice, assuming householders already have at least two buckets or other 10-litre vessels, a clean cloth and a stirring utensil.

Few HWTS technologies have been tested as extensively as these flocculant-disinfectant sachets, in both the laboratory and the field. Laboratory tests demonstrated that the product is highly efficacious, not only against bacteria (>99.99999% reduction), viruses (>99.99%) and cysts (>99.95%), but also in reducing levels of arsenic, a significant chemical health hazard in many South Asian water supplies (Souter et al., 2003). Aside from boiling and the Indian filter described in section 3.7, these sachets are the only household water treatment option designed for use in low-income settings that would appear to satisfy the requirements of a microbiological water purifier established under the USEPA protocol and the American National Standards Institute/NSF International Protocol P-231 (USEPA, 1987). Early fieldwork also demonstrated, however, that the target residual chlorine level of 3.5 mg/l was objectionable to some consumers. The company found that it was able to reduce the volume of calcium hypochlorite in the sachets in order to yield a residual disinfectant level of 2.0 mg/l without compromising its antimicrobial performance. A series of rigorous health outcome trials ensued. These trials showed the intervention to reduce levels of diarrhoea in adults and children by between 17% and 92% (Reller et al., 2003; Crump et al., 2005; Chiller et al., 2006; Doocy & Burnham, 2006; Luby et al., 2006). Crump et al. (2005) also reported that the use of either these sachets or sodium hypochlorite solution was associated with a reduction in mortality when compared with the use of traditional water management practices, the only study to date that has obtained such a finding from a HWTS field trial.

3.8.2 Scaling up of flocculation/disinfection products

Initially, the United States–based company's marketing and distribution strategy for its flocculant-disinfectant sachets was mainly commercial. Management saw the potential of the product to make a significant impact on the burden of waterborne disease and eagerly promoted it as part of the company's commitment to health (Allgood & Keswick, 2003; Carpenter, 2003). At the same time, it sought to establish its sachets as another successful consumer product that contributed to the company's profit by generating sufficient sales revenue to more than cover its direct and indirect costs. Initial test marketing in Guatemala proved promising, leading to larger-scale tests there and in the Philippines, Pakistan and Morocco (Hanson & Powell, 2006). These typically involved demonstrations at local markets, schools and health clinics or within the home, using women's groups, student groups, teachers, health providers and church groups. Much of the emphasis of these campaigns was on the health risks of drinking contaminated water, a message that can be contrasted with that of its competitor in India.

By 2003, it was becoming clear within the company that flocculant-disinfectant sachets for low-income populations were failing as a commercial venture. In Pakistan, where it had achieved the greatest penetration in large-scale tests, the company made a final effort to demonstrate the product's commercial potential. A campaign aimed at the country's 15 million urban population included high-level participation by its government and medical community. An education campaign included television, radio and billboard advertisements; doctors and other opinion leaders were also targeted. USAID funds supported a non-branded campaign to promote the link between safe drinking-water and the prevention of waterborne disease, including the use of options such as sodium hypochlorite and flocculant-disinfectant sachets. The company, with assistance from Johns Hopkins University's Center for Communication Programs, ran parallel campaigns promoting the sachets but using similar visuals designed to reinforce the basic educational message about safe drinking-water and introducing the sachets. A number of logistical problems led to suboptimal coordination of the campaigns (Hanson & Powell, 2006). After 3 months, repeat purchases of flocculant-disinfectant sachets reached about 5%. The attempt to scale up coverage following a commercial strategy was pronounced a failure (Ellison & Bellman, 2005). This was not, however, the end of the product.

While the company had always drawn on NGOs and other non-commercial organizations as part of its dissemination strategy, these partners now became a central focus. A Global Development Alliance Grant from USAID created the Safe Water Alliance, a partnership led by the company, CARE, the Center for Communication Programs and PSI. The grant, together with continued corporate investment from the company, created opportunities to promote flocculant-disinfectant sachets in development and emergency settings. The Center for Communication Programs supported the programme by conducting research in Guatemala and Pakistan on the knowledge and behavioural factors associated with safe drinking-water and the uptake of HWTS products such as these sachets (Figueroa & Kincaid, in press).

PSI added flocculant-disinfectant sachets to its point-of-use water line, starting in Uganda and Haiti in 2004 and adding Pakistan in 2005 and the Dominican Republic, Kenya, Malawi, the Congo and Ethiopia in 2006. While PSI endeavours to achieve full cost recovery for the product, many of its marketing and promotional campaigns have been supported by USAID and other PSI funds. Moreover, as the company has shifted away from a commercial strategy, it has found increasing support for its sachets as part of its corporate social responsibility effort. The company's corporate philanthropic fund has designated the product as its leading focus, providing funds to purchase sachets for distribution in development and emergency settings.

PSI is pursuing a targeted strategy for flocculant-disinfectant sachets (PSI, 2006). The focus areas, together with PSI's own characterization of the opportunity, appear in Box 2. The plan is said to be based on what PSI has found most effective in positioning the product and what it believes will maximize its health impact. The plan, which may appear unusually strategic to conventional NGOs and public health officials, illustrates how commercial strategies are being used by a social marketing organization to scale up HWTS interventions. Results from PSI's implementation of the plan are not yet available.

Box 2: Focus areas for promotion of flocculant-disinfectant sachets by PSI (PSI, 2006)

1. *Using schoolchildren as change agents*
Although still relatively new, school sampling programmes conducted with flocculant-disinfectant sachets appear to be resulting in significant sustained habit change at the household level. The successful school programmes include an integrated effort with effective outreach to the parents through the schoolchildren, PSI sales force engagement of the local trade and a radio campaign. This effort can reach significant scale for an investment of about US$ 1 per child (US$ 100 000 per 100 000 children) and is likely an efficient way to achieve up to 300 000 demonstrations a year (each child receives three sachets for household demonstrations). The Ugandan school sampling outline may be used as a model.

2. *Outreach through clinics and nurses, particularly focused on children 6–24 months of age*
Demonstrations at clinic immunization days have been found to be effective. Importantly, clinic outreach directly reaches the children that experience the highest percentage of sickness and death from diarrhoea. Mothers at clinics are thinking about their families' health and are looking for solutions. In Kenya, it was determined that recommendations from nurses to clients resulted in long-term habit change. Specifically, a year after receiving a recommendation from a nurse at a health clinic for use of PSI's safe water solution, 71% of homes had chlorine residuals in their drinking-water.

3. *Provision of safe water to people living with HIV/AIDS*
People living with HIV/AIDS are more susceptible to diarrhoeal disease and the most likely to be weakened by such diseases. For example, while diarrhoea bouts caused by parasites such as *Giardia* and *Cryptosporidium* are normally self-limiting in healthy adults, they can be fatal in people living with HIV/AIDS. Flocculant-disinfectant sachets are particularly effective in removing these chlorine-resistant parasites. Programmes such as the one conducted by the Safe Drinking Water and HIV/AIDS Program in Kenya have resulted in long-term sustained use of flocculant-disinfectant sachets over 2 years. These sachets have also been included in monthly healthy living kits in Haiti. Importantly, water purified by flocculant-disinfectant sachets can make infant formula safe for the children of seropositive mothers by ensuring that the water used to make it is free of pathogens.

4. *Emergency relief*
Flocculant-disinfectant sachets are highly effective in emergency situations, and more than 40 million sachets have been used by UNICEF, AmeriCares, Samaritan's Purse, PSI and other groups for disaster relief. It has also been found that emergency relief sales can be a significant portion of total sales for PSI country programmes and can enhance programme sustainability. UNICEF is a critical partner, as it recently assumed responsibility not only for UN but also NGO disaster water and sanitation coordination globally. PSI programmes are advised to work with UNICEF and their disaster relief contacts to pretrain emergency personnel on the proper use of flocculant-disinfectant sachets prior to the implementation of disaster response programmes.

5. *Include The Aquaya Institute's standard operating procedure for the deployment of flocculant-disinfectant sachets in emergency situations*
This document (http://www.aquaya.org/files/Aquaya_PUR_SOP.pdf) addresses most questions about flocculant-disinfectant sachets. If programme implementation personnel read and understand this standard operating procedure, then they will be able to answer most questions about these sachets.

6. *Outreach through faith-based groups*
Faith-based organizations are collaborating with PSI to broaden outreach efforts in Kenya, Haiti, Uganda and

elsewhere. These groups provide the sustained and credible communication efforts necessary to enable long-term consumer habit change among otherwise difficult-to-reach populations and provide synergies for other PSI interventions.

7. *Inclusion of flocculant-disinfectant sachets in nutrition feeding programmes*
The inclusion of flocculant-disinfectant sachets in feeding programmes can increase health impact. In Ethiopia, CARE's inclusion of these sachets in such feeding programmes has met with a high degree of acceptance, reduced incidences of diarrhoea and vomiting and accelerated rates of weight gain.

8. *Outreach to community-based organizations*
Community-based organizations can be a key channel for both communications and product distribution. Select organizations should be encouraged to incorporate flocculant-disinfectant sachets into existing health and education programmes and to provide sustained communication. Successful examples include the Peace Corps in the Dominican Republic and the Safe Drinking Water and HIV/AIDS Program in Kenya.

PSI's strategy is based on a candid assessment of the manufacturer's prior experience with its flocculant-disinfectant sachets. Its conclusions (PSI, 2006) are expressed in a series of lessons learnt and recommendations. Among the most salient of its findings are the following:

- Traditional social marketing methods have not yet generated sustainable sales volumes of flocculant-disinfectant sachets at any programme site. Flocculant-disinfectant sachets are a visual product that needs to be demonstrated in small group sessions. Despite many attempts, television copy has not been effective in replacing small product demonstrations. Radio, mobile video units and billboards help to promote and sustain brand awareness, but mass media should be a smaller part of the budget and used as part of an integrated campaign with school and clinic programmes.

- Demonstrations at celebration events/large markets have been shown to be very ineffective, since mothers are not concentrating on health during these events and generally do not pay attention or retain information from such demonstrations.

- Although rural areas tend to be the most impoverished, they typically do have adequate commercial infrastructure in place to fulfil market demand for water treatment products generated by promotional efforts. Rural vendors sell low-cost everyday items: batteries, biscuits, soap, etc. This product is sold in a single-use sachet, which is an effective way of overcoming cash flow issues commonly faced by poor rural consumers.

- Because the primary target populations for flocculant-disinfectant sachets tend to be poor rural people, pricing is a key issue. In especially poor countries (Malawi, Ethiopia), the price may need to be set initially to cover the cost of goods sold, while external subsidy covers promotion, educational campaigns and administrative costs. As demand rises over time, prices may be adjusted to cover a greater share of the support costs. In wealthier countries (Botswana, Dominican Republic), the introductory price can be set to cover all programme costs. PSI/Dominican Republic is demonstrating that cross-subsidy between wealthier and poorer populations is possible. In all cases, consumer price sensitivity should be monitored closely.

- School programmes seem to be one of the most effective ways to reach children and their families. PSI recommends that the PSI sales forces select and gain necessary permissions, while also taking steps to make the school community aware that flocculant-disinfectant sachets are available. This provides incentives for retailers to make sure that the product is in stock. Trained nurses—not the sachet sales force—conduct the classroom sessions about the product. The sales force should provide prizes such as T-shirts for each class.

- Free distribution of flocculant-disinfectant sachets is sometimes necessary to facilitate the launch of a country programme initially or in emergency situations. However, such efforts should be limited in scope and monitored closely, as they may do little to foster perceived product value, demand or behaviour change.

- Flocculant-disinfectant sachets can be an excellent product for people living with HIV/AIDS. However, it is advisable for such targeted programmes to be introduced after a general population programme has already been rolled out, so as to avoid stigmatizing the product or conveying the impression that it should be free.

- Experience in Haiti and elsewhere has shown that significant investments of time and money are required to generate and sustain satisfactory sales volumes through social marketing. Institutional sales via memoranda of understanding with NGOs and community-based organizations are key to programme success. Such partnerships tend to strengthen brand awareness, access and self-efficacy. Risk perception can also increase, if a proper training component is included.

Throughout the plan, PSI emphasizes the suitability of flocculant-disinfectant sachets for treating highly turbid waters where its sodium hypochlorite product may be inadequate, partly because it does not improve water aesthetics. At the same time, it notes the opportunity to launch flocculant-disinfectant sachets as a brand extension of its sodium hypochlorite product, as it has done with NaDCC tablets, leveraging existing consumer awareness of its sodium hypochlorite brand and other PSI brands for water treatment. It also recommends working with national governments to reduce or eliminate tariffs on the importation of flocculant-disinfectant sachets.

Distribution of flocculant-disinfectant sachets has been significant, mainly in emergency settings (i.e. in response to natural disasters, conflicts, outbreaks, etc.). Table 9 provides selected data provided by the manufacturer for both non-emergency and emergency applications. Most non-emergency distribution has been through PSI. Emergency distribution is through UN agencies, governments and NGOs.

Table 9: Routine and emergency distribution of flocculant-disinfectant sachets, 2005–2007 (data from the manufacturer)

	Routine/non-emergency			Emergency response[a]		
	2005	2006	2007	2005	2006	2007
No. of countries	3	9	9	4+	4+	3+
No. of distribution points	2 000	16 000	20 000	Not applicable		
No. of sachets distributed	4.7 million	6.7 million	15.8 million	24 million	15 million	17.1 million
No. of litres treated[b]	47 million	67 million	158 million	240 million	150 million	171 million
No. of users[c]	64 400	91 700	216 400	1 331 500	821 900	937 000

[a] Programmes in which flocculant-disinfectant sachets were used for at least 3 months.
[b] Each sachet treats 10 litres of water.
[c] Assumes 2 litres/person per day (730 litres/year). For routine use, assumes continuous use throughout the year. For emergencies, assumes users discontinue use after 3 months.

3.8.3 Uptake of flocculation/disinfection products

Like most of the other household-based water treatment products described in this report, relatively little research has been done on the uptake of combined flocculant-disinfectant products or on their correct, consistent and sustained use by the target population. DuBois et al. (2003) followed up on 117 purchasers of flocculant-disinfectant sachets in Kenya, administering a questionnaire to help identify factors that motivated the decision to buy and use the product. They administered the same questionnaire to 193 matched non-users in the same area. Logistic regression revealed that users were more likely than non-users to obtain their drinking-water from a highly turbid source (OR = 16.2, 95% confidence interval [CI] = 2.1–126). Users also had higher economic status (using housing characteristics as a proxy) (OR = 1.7, 95% CI = 1.3–2.3). Curiously, users were less likely to believe that diarrhoea was a serious problem in their community (OR = 0.46, 95% CI = 0.27–0.76).

When it was endeavouring to establish a commercial business with its flocculant-disinfectant sachets, the manufacturer used extensive media and other strategies to increase awareness and ensure product access, even in remote locations. Nevertheless, penetration did not meet the company's expectations, reaching about 15% in the Philippines and only 5% in Guatemala (Hanson & Powell, 2006). Even among participants in the study community in which Chiller et al. (2006) had achieved a 39% reduction in diarrhoea, an aggressive 6-month marketing campaign did not increase adoption beyond such 5%, leading investigators to conclude that demonstrated effectiveness of the intervention was not enough to increase uptake (Luby et al., 2008). More village-level tests ensued, in an effort to identify the main constraints to market acceptance. After a year, penetration (measured by the portion of consumers repeatedly purchasing the product) reached 50% in some villages in Pakistan. In Morocco, where the same campaign was employed, penetration was about half of the Pakistan level until the Ministry of Education allowed promotion in schools.

According to the manufacturer, the major obstacle to increasing uptake was a lack of knowledge on the part of the target population about the need for water treatment and its impact on health. It became clear that acceptance of the product would require effective and sustained communication about the health risks of unsafe drinking-water to complement effective commercial distribution and encourage people to use the flocculant-disinfectant sachets (Allgood & Keswick, 2003; Macgregor-Skinner et al., 2004). Moreover, although most public health officials and the company's own consumer research suggested that users found the sachets affordable, some observers objected to the cost on a per litre treated basis, asserting that it represented another example of the poor paying more than middle- and upper-income populations for a basic necessity.

4. COMBINED SCALE OF HWTS

4.1 The challenge of measuring coverage

Providing a more complete view of the efforts to scale up HWTS in low-income settings requires an aggregation of the coverage data from the various products and technologies described in section 3.[1] However, this presents certain challenges.[2] First, some estimates do not separate emergency applications from product used in routine development settings. As this report focuses mainly on non-emergency use, the figures below exclude the emergency supplies whenever possible. Second, only rarely are there independent assessments of coverage figures, and these typically do not extend beyond communities or districts. Accordingly, coverage estimates are based almost exclusively on data from manufacturers, suppliers, sellers or implementers and are not independently audited. Third, the assumptions that are used to assess coverage vary among projects and programmes. In calculating number of users, for example, informants used 5, 5.2 and 6 persons per household, representing a range of 20%. Fourth, implementers of durable products, such as filters, make different assumptions about the longevity of their products. For example, IDE and RDI assume a 2% monthly reduction in cumulative filters in place, consistent with an independent assessment of breakage, but no reduction due to discontinued use. Estimates for biosand filters assume no breakage or discontinuation of use.

Moreover, the metrics used for assessing coverage are not equally suitable across the full range of point-of-use water treatment products and technologies. This is particularly apparent in terms of unit sales for consumable products (e.g. bottles of sodium hypochlorite, NaDCC tablets, flocculant-disinfectant sachets) versus the durable products (e.g. solar disinfection bottles, ceramic filters, biosand filters). Even within these two broad categories, however, there are significant differences. Some consumable products treat as few as 1 or 10 litres of water, whereas others treat almost 1000 litres; a single solar disinfection bottle produces 1.5–2.0 litres of water daily, whereas a biosand filter produces 80 litres or more. As a result, cross-product comparisons of units sold or placed into service by year are not particularly useful.

Three other metrics are potentially more valuable in assessing coverage of HWTS across products: 1) number of days with safe water, 2) number of litres treated and 3) number of users. The number of days with safe water has not been used extensively by promoters of HWTS to date, and little information is available. It also requires some assumptions about the volume of water per person, a metric that itself presents certain issues (Howard & Bartram, 2003). Number of litres treated is perhaps a more fundamental metric on which to compare coverage of HWTS approaches. Once again, however, important assumptions must be made in deriving these figures. While filters are rated to deliver a prescribed volume per day based on certain (usually optimal) conditions, their production varies considerably in the field, based on turbidity in the source water and level of maintenance. Similarly, chlorine-based disinfectants have prescribed dosing levels, but these must be increased in the presence of elevated levels of chlorine demand.

The most valuable metric for assessing scale—the aim of this report—is number of users. This provides a numerator from which to calculate coverage. Unfortunately, few implementers of HWTS directly track and report the number of users of their interventions. Most derive estimates based on the number of units sold or placed in service. For durable products, such as filters, this usually means assumptions that each unit is used by everyone in the household and a calculation based on average household size. For consumables, the number of users is usually based on assumptions about amounts of water treated per day and the overall capacity of the bottle, tablet or

[1] There have been independent efforts by the HWTS Network to collect and collate information on HWTS implementation (Murcott, 2006). Although these are not yet complete, they are useful in mapping the geographical distribution of household-based interventions.

[2] The HWTS Network has taken steps to develop and use alternative metrics that can be used to assess the impact of HWTS products and technologies (Murcott, 2005). Part of the aim is to establish a common denominator for measuring coverage and uptake. At the same time, however, the metrics seek to go further in order to assess actual outcomes. These efforts are still under way.

sachet at a given level of dosing. Users of solar disinfection are computed based on a portion of the number of persons trained, and both regular and "occasional" users are included in the figures. Under these circumstances, any effort to combine data across HWTS products and interventions is systematically flawed.

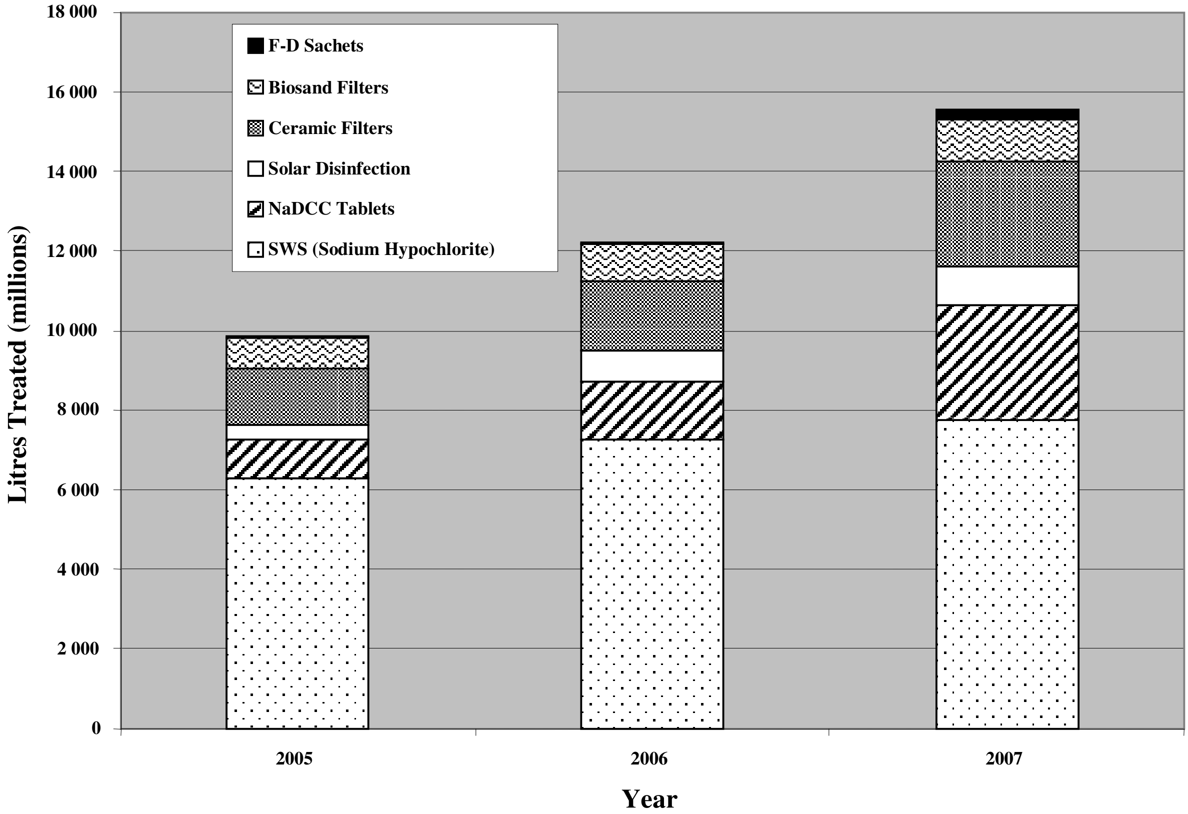
Nevertheless, some combined data are helpful in assessing, at least in broad terms, trends, progress and potential for HWTS. Accordingly, we solicited information from the major implementers of HWTS programmes described in section 3 that have been engaged in providing effective point-of-use water treatment to low-income populations for at least 3 years. The products actually included in the estimates are identified in the notes to the figures. The estimates exclude boiling—undoubtedly the largest segment of users—as well as chlorination and filtration data that are currently being compiled from the JMP surveys. They also exclude emergency treatment for those products (sodium hypochlorite, NaDCC tablets and flocculant-disinfectant sachets) that account for such applications separately. The estimates also exclude other private, commercial products, some of which are described in section 3, that are widely available in some countries but are marketed and sold primarily to middle- and upper-income segments of the populations, which are less vulnerable to waterborne disease and often have access to "improved water supplies".

This report presents the data as actually supplied by the manufacturer or programme implementer. To minimize misinterpretation, the assumptions underlying the data are included whenever provided. This should make it possible for others to recalculate coverage estimates using other metrics and based on other assumptions. Finally, readers are cautioned that insofar as implementing organizations are generally inclined to ensure that their efforts are fully credited, any bias in these figures is probably towards overestimating, rather than underestimating, their coverage.

4.2 Combined estimates of coverage and growth

The combined estimates of ***number of litres treated*** for the HWTS products described in section 3 of this report for which data were provided were 9.9 billion in 2005, 12.2 billion in 2006 and 15.5 billion in 2007 (Figure 4). Sodium hypochlorite solution makes the greatest overall contribution to HWTS coverage to date, representing 50.0% of the total number of litres treated in 2007. NaDCC tablets contributed another 18.4%. Together with flocculant-disinfectant sachets, these chemical disinfectants collectively represented 69.8% of the total number of litres treated in 2007. Ceramic and biosand filters contributed 17.0% and 6.9%, respectively, whereas solar disinfection represented 6.2% of the total number of litres treated in 2007. Between 2005 and 2007, the number of litres treated by these programmes grew at an average annual rate of 25.5%. Average growth during this period was 11.38% for the sodium hypochlorite solution, 18.5% for biosand filters, 37.0% for ceramic filters, 62.2% for solar disinfection, 72.2% for NaDCC tablets and 132.5% for flocculant-disinfectant sachets.

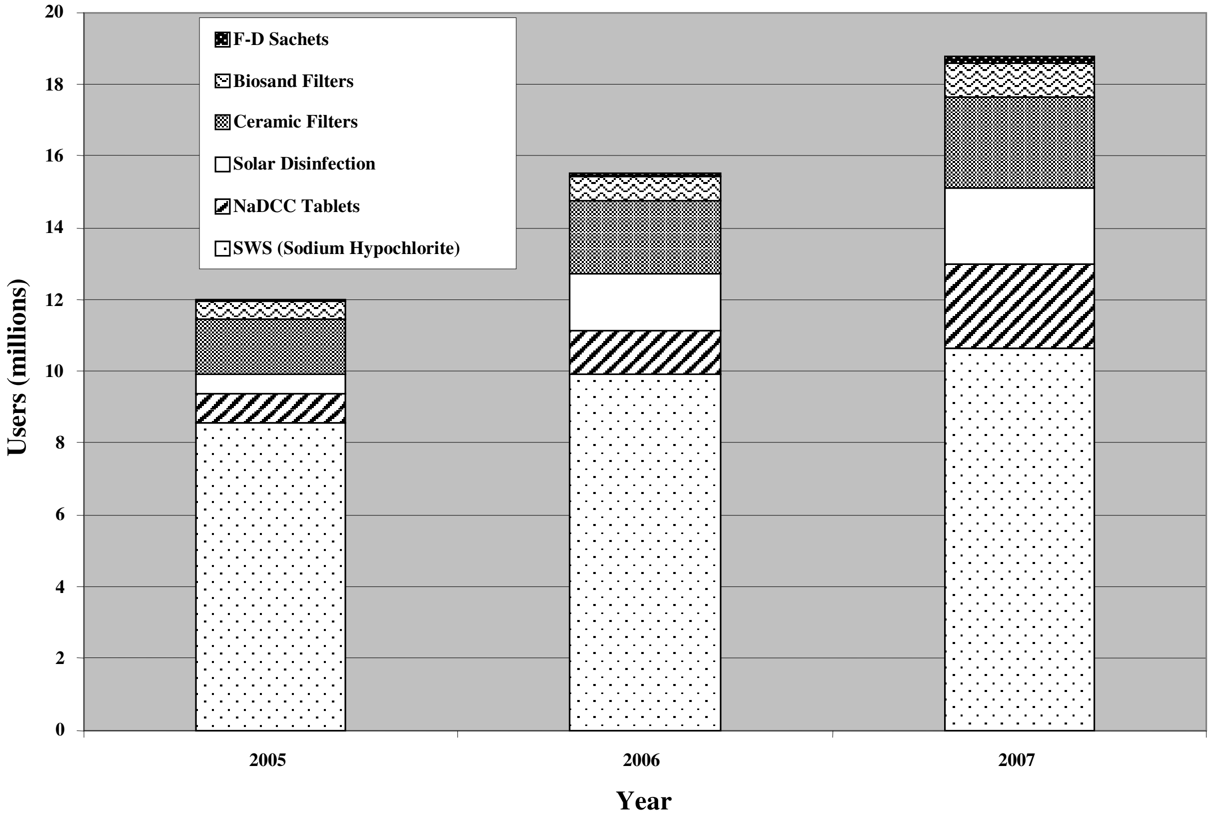
Figure 4: Combined estimate of number of litres treated for selected HWTS products, 2005–2007



Notes:
1. Estimates for the SWS (sodium hypochlorite) include data from PSI, Aman Tirta (Indonesia), Jolivert (Haiti) and Constella Futures (Afghanistan). NaDCC results are from the manufacturer. Estimates for solar disinfection are from SANDEC/EAWAG and Fundación Sodis in Latin America. Estimates for ceramic filters include IDE Cambodia, RDI Cambodia, Cambodian Red Cross, Potters for Peace programmes and an estimate for candle filters deployed by UN agencies and NGOs (100 000, 125 000 and 150 000 units for 2005, 2006 and 2007, respectively). Estimates for biosand filters are from the CAWST annual survey and International Aid; estimates for flocculant-disinfectant (F-D) sachets are from the manufacturer. All data were reported directly by such sources, except that IDE provided information on Cambodian Red Cross. Except as described in notes 3–4 below in which estimates were calculated based on other information, estimates of number of litres treated are as reported by the data source.
2. For consumable products (sodium hypochlorite, NaDCC tablets, flocculant-disinfectant sachets), estimates of number of litres treated assume maximum utilization of the product sold in the year. For durable products (solar disinfection, ceramic filters and biosand filters), number of litres treated is computed based on half of the increase in the number of units in service at the end of the year to reflect the average number of products actually producing water in the year.
3. For solar disinfection, number of litres treated is calculated at the rate of 2 litres/person per day for the number of users reported by SANDEC/EAWAG.
4. For ceramic filters and biosand filters, number of litres treated is calculated based on 25 litres/filter per day for the cumulative number of filters reported to be in use, even though biosand filters are capable of producing 2 or 3 times that rate. RDI, RDE and Cambodian Red Cross figures are discounted by 2% per month since filter delivery to take account of actual breakage experience; other figures assume continued use of all filters indefinitely after delivery.
5. Excludes emergency use reported by PSI and the manufacturers of NaDCC tablets and flocculant-disinfectant sachets.

The estimated ***number of users*** of the same HWTS products was 12.0 million in 2005, 15.5 million in 2006 and 18.8 million in 2007 (Figure 5). While these numbers correspond roughly with the number of litres treated, manufacturers and implementers of HWTS products use different assumptions about the number of litres treated for each user. Filters, for example, tend to produce more litres for each user. Thus, they represent a smaller percentage of users than the percentage of litres treated. Once again, the largest number of users employ sodium hypochlorite solution (56.6% in 2007), followed by ceramic filters (13.5%), NaDCC tablets (12.5%%), solar disinfection (11.3%), biosand filters (4.9%) and flocculant-disinfectant sachets (1.2%). The average annual increase in users was 25.1% over the period 2005–2007. It was 11.4% for SWS programmes, 29.5% for ceramic filters, 34.5% for biosand filters, 72.3% for NaDCC tablets, 89.2% for flocculant-disinfectant sachets and 115.5% for solar disinfection.

Figure 5: Combined estimate of number of users of selected HWTS products, 2005–2007



Notes:
1. Estimates for the SWS (sodium hypochlorite) include data from PSI, Aman Tirta (Indonesia), Jolivert (Haiti) and Constella Futures (Afghanistan). NaDCC results are from the manufacturer. Estimates for solar disinfection are from SANDEC/EAWAG and Fundación Sodis in Latin America. Estimates for ceramic filters include IDE Cambodia, RDI Cambodia, Cambodian Red Cross, Potters for Peace programmes and an estimate for candle filters deployed by UN agencies and NGOs (100 000, 125 000 and 150 000 units for 2005, 2006 and 2007, respectively). Estimates for biosand filters are from the CAWST annual survey and International Aid; estimates for flocculant-disinfectant sachets are from the manufacturer. All data were reported directly by such sources, except that IDE provided information on Cambodian Red Cross. Except as described in note 2 below, in which estimates were calculated based on other information provided, estimates of number of users are as reported by the data source.
2. Implementers of SWS and flocculant-disinfectant sachets calculate the number of users based on actual product distributed and assuming 2 litres/person per day (730 litres/person per year). For NaDCC tablets, the manufacturer assumes double dosing of a portion of its product as recommended for high-turbidity conditions; without such double dosing, the product would yield 3.3 litres/person per day. For ceramic filters and biosand filters, the number of users was calculated based on cumulative number of units distributed multiplied by six users per unit. RDI, RDE and Cambodian Red Cross figures are discounted by 2% per month since filter delivery to take account of actual breakage experience; other figures assume continued use of all filters after delivery.
3. Excludes emergency use reported by PSI and the manufacturers of NaDCC tablets and flocculant-disinfectant sachets.

The combined estimates of number of litres treated and number of users are impressive, especially given that most of these HWTS programmes have been under way for less than 10 (and some less than 5) years. When compared with the need, however, the results are more sobering. The estimated 18.8 million users of HWTS products in 2007 represent only 2.1% of the 884 million people who lack access to improved water supplies. If the denominator includes those who have improved supplies but whose water is nevertheless microbiologically unsafe, the percentage is even less. Moreover, although the 25.1% annual growth rate is impressive, continued linear growth at that rate would result in 113 million users by 2015, or approximately 13% of the current 884 million without access.

It is also important to note that these numbers represent coverage, not uptake. As noted consistently in the case-studies presented in section 3, the evidence on long-term use, such as it is, suggests that many of the householders whom these interventions succeed in reaching do not actually embrace and use them in a manner that provides optimal protection. Large numbers of householders try the products but do not continue to use them (Hanson & Powell, 2006; Stockman et al., 2007; Luby et al., 2008). Others use them only sporadically when they perceive the risk to be greatest. Some discontinue use even though they regard the product to be affordable and have observed its health benefits. As the effectiveness of these interventions is contingent on use (Clasen, 2006), it is possible that the health gains reported in the research-driven randomized controlled trials may not actually be sustained among these populations when uptake erodes, a conclusion that researchers have already suggested in reviewing the SWS trials (Arnold & Colford, 2007).

Finally, it should not be assumed that the populations represented by these coverage estimates are the most vulnerable to waterborne disease. Once again, there is a disquieting paucity of evidence on the risk profile of the householders who purchase or otherwise acquire HWTS products. The evidence that does exist suggests that at least some of the products and marketing/distribution strategies—especially those employing commercial or quasi-commercial methods—may be more heavily targeted to urban or periurban settings where promotional campaigns are more efficient and supply channels more established (DuBois et al., 2003; Olembo et al., 2004; Rheingans & Dreibelbis, 2007; Stockman et al., 2007). There is also evidence that uptake is higher among better educated and higher-income householders (Olembo et al., 2004; Rheingans & Dreibelbis, 2007). If so, then these coverage figures are probably biased away from the populations who are most at risk of mortality and the other serious sequelae associated with waterborne disease.

5. SPECIAL CONSTRAINTS TO SCALING UP HWTS

The sobering conclusions about the current coverage and uptake of HWTS make clear that the intervention is still far from demonstrating its potential contribution to health. This is due, at least in part, to some of the same challenges facing any novel public health interventions among low-income populations—creating awareness, securing acceptance, ensuring access and affordability, establishing political commitment, addressing sustainability, etc. However, there are some special constraints that face HWTS and that advocates of the intervention may need to overcome before it can achieve scale.

5.1 Belief that diarrhoea is not a disease

One of the threshold constraints to the uptake of HWTS is the belief that diarrhoea is not a disease. Figueroa & Kincaid (in press) cite numerous studies from various countries in which participants reported diarrhoea to be a natural and even desirable condition, especially in young children, not worthy of special preventive measures. While there is evidence that the acquisition and use of household water treatment products are higher among those who consider their water unsafe or their families at risk of diarrhoea, longer-term adoption was no more likely even among populations that had actually experienced less diarrhoea. Although health benefits often lack significant motivational impetus for driving preventive measures, the fact that diarrhoea is not even considered a disease by many of the most vulnerable populations further limits this strategy. Among policy-makers and health officials faced with a variety of life-threatening diseases, diarrhoea may not receive the commitment of resources that its status as one of the two leading causes of burden of disease in the world would suggest it deserves (WHO, 2008a).

5.2 Scepticism about the effectiveness of water quality interventions

Although the CDC and PAHO demonstrated the microbiological effectiveness and health impact of household water treatment as early as 1996, it was not immediately embraced by governments, NGOs or other potential implementers. In fact, they characterized the initial reaction as "open hostility" (R. Quick, personal communication, 2007). Within the water sector, which often focuses mainly on conventional improvements in water supplies, HWTS was dismissed as outside of its mission. Even within the health sector, where the CDC and PAHO had credibility and access, household water treatment was received sceptically. This scepticism about the contribution that improvements in water quality can make to health continues today.

One important obstacle is the widespread perception, based largely on literature reviews by Esrey and colleagues (Esrey, Feachem & Hughes, 1985; Esrey et al., 1991), that interventions to improve the microbiological quality of drinking-water are less effective in preventing diarrhoea and certain enteric infections than those to improve water supplies, sanitation or hygiene. The dominant paradigm prevailing among governments, donors and experts in water and sanitation interventions has been that to achieve broad health impact, greater attention should be given to safe excreta disposal and proper use of water for personal and domestic hygiene rather than to drinking-water quality (Clasen & Cairncross, 2004). The corollary had become equally established: that interventions aimed solely at improving drinking-water quality have relatively little impact in reducing diarrhoeal disease. Despite recent work noting that the reviews by Esrey and colleagues (Esrey, Feachem & Hughes, 1985; Esrey et al., 1991) did not include any studies on household-based interventions and increasing evidence showing that household-based interventions are about twice as effective as traditional source-based interventions in preventing diarrhoea (Fewtrell et al., 2005; Clasen, 2006), this view continues to persist widely among policy-makers and implementers, many of whom are unfamiliar with the more recent evidence.

5.3 Special challenges associated with uptake

As noted in section 1, scaling up HWTS requires not only reaching the target population with effective water treatment solutions, but also securing their uptake. Interventions that require some level of behaviour change present special challenges, as experience with sanitation and hygiene has demonstrated. The widespread adoption of boiling—at least in some regions—suggests that this is at least possible in the case of household water treatment. Nevertheless, the evidence to date in procuring the adoption of most other HWTS options—and even boiling among many vulnerable populations—suggests even greater obstacles.

First, the more affordable solutions for treating water have little "aspirational" appeal. Few householders are proud of using methods as mundane as boiling, bleach or empty plastic bottles to treat their water, and many completely reject the practices, since they do not improve the aesthetics of water but make it warmer or taste and smell worse. Second, filters or flocculants-disinfectants that can make water look, taste and smell better are often unaffordable owing to their high up-front or long-term cost, and credit is often unavailable to these consumers. Third, all existing HWTS methods require some effort on the part of consumers to acquire, use, maintain and (except, perhaps, biosand filters) replace exhausted supplies. Such efforts increase the daily burden on the person in the household who already carries most of the load. Fourth, the decision to adopt the intervention is not a one-off like vaccines, but one that must be made every day and indefinitely. Faced with limited time and money, competing priorities and an uncertain risk of the consequences of non-compliance, householders easily backslide, secure in the knowledge that they themselves probably grew up on untreated water. Finally, even if householders embrace the intervention and treat their water correctly and consistently, most will still suffer from diarrhoea caused by agents transmitted through other pathways. Thus, the health benefits may not be convincing. These are only some of the reasons why uptake of HWTS has been so challenging.

5.4 Public health suspicion of commercial agenda and lack of standards governing HWTS products

HWTS is a health intervention. However, unlike vaccines and pharmaceuticals, the intervention is practised using what appear to be consumer products. To a considerable extent, government and public health officials are still suspicious of commercial companies and the contribution they can make towards achieving important societal gains. This is true despite MDG goal 8, which seeks "in cooperation with the private sector, to make available the benefits of new technologies". It is also true despite an increasing number of successful public–private partnerships organized especially to combine complementary strengths to fight poverty and disease, improve education and enhance economic development. This continued mistrust is a constraint in scaling up HWTS.

Recently, researchers and programme implementers have demonstrated the value of cooperation between those who promote health and those who sell consumer products (Bustreo, Harding & Azelsson, 2003; Curtis, Garbrah-Aiddo & Scott, 2007). Representatives of the private sector clearly believe that they have a role to play in advancing health outcomes by promoting commercial products in low-income settings (Clasen, 2002; Carpenter, 2003; Duncan, 2004; Vestergaard-Frandsen, Sorensen & McGuire, 2004). Some efforts have also been undertaken to establish guidelines for private sector participation in the water sector (Rothenberger, Frei & Brugger, 2005). The public sector and civil society should continue to focus on their mission of promoting effective health interventions to at-risk populations. They must also target their efforts to those who are unable to procure the interventions themselves. At the same time, they can advance these priorities by working with the private sector in ways that do not compromise their independence. They may, for example, undertake generic (non-branded) public health campaigns around waterborne diseases that encourage householders to consider and choose from a variety of effective HWTS products. They can also reduce tariff and non-tariff barriers that limit or increase the cost of effective HWTS products, particularly where there is little prospect for local competition. The HWTS Network itself is an example of how partnerships among the public and private sectors and civil society can advance research, implementation, advocacy and communication around HWTS.

Finally, suspicions about the private sector agenda in HWTS are aggravated by the lack of widely recognized standards or certification procedures with respect to HWTS products. Because the point-of-use water treatment industry is highly fragmented, with no clear market leader, and because consumers are unable to assess the safety and microbiological efficacy of the products, market forces will not drive product quality or integrity. Governments will contribute to public confidence in HWTS by adopting internationally harmonized, evidence-based standards, with practical and affordable testing and certification procedures, that govern the safety and performance of HWTS products. These should be accompanied by simple and understandable product labels and a communication campaign that helps consumers understand the issues and choose among HWTS products.

5.5 Orphan status of HWTS at public sector level

Coordinated public sector advocacy, funding and support have been shown to be important factors in the successful scaling up of most health interventions. They were clearly important contributors in the expansion of oral rehydration salts, guinea worm filters and insecticide-treated nets described in section 2 above. With the possible exception of boiling, however, where governmental support in certain countries may have once played an important role in scaling up the intervention, public sector promotion of HWTS programmes has not been extensive in most cases over the last several decades.

Two special factors conspire against public sector support and funding for HWTS, leaving it without a champion or even a parent. The first is the engineering orientation of water ministries and their emphasis on improvements in water supplies. Nearly all populations that do not enjoy piped-in water on a 24 h/day, 7 days/week basis express priority for increasing the quantity and access to water over improving its quality. Governments respond accordingly, aware of not only the political value from these popular projects (and the particularly photogenic value of water emerging from new pumps and valves), but also the health and development gains that are available from reducing the time people spend collecting and transporting water to their homes and from the productive use of water in agricultural activities. Multilateral and bilateral funding also tends to focus on such infrastructural projects, despite compelling evidence that HWTS is cost-beneficial and highly cost-effective (WHO, 2002; Hutton & Haller, 2004; Clasen et al., 2007a).

A second factor is the frequent lack of coordination between or among government ministries in the area of drinking-water quality, especially at the household level. A number of ministries as well as regional, district and municipal authorities are usually involved in drinking-water. HWTS, with its emphasis on water quality, has no obvious home within any of these ministries or authorities. Moreover, drinking-water standards and responsibility for ensuring water quality frequently end at the point of delivery, despite widespread evidence of recontamination prior to the point of consumption.

5.6 Minimal public sector participation

Where HWTS has made progress to date, it is largely without significant public sector participation. Although PSI credits government participation for its success with the SWS programme, it is mainly to ensure that necessary approvals are secured and concerns quickly assuaged (POUZN Project, 2007). Except possibly for boiling, where the contribution of government is unclear, most of the coverage of HWTS to date has been generated by NGOs and the private sector. In North America, where point-of-use water treatment has reached 20% market penetration, the public sector has had little role other than to help set standards and police claims over performance. This may lead some to believe that governments do not have a vital role in scaling up HWTS and that its orphan status is not actually a constraint.

Some of these same organizations argue forcibly against public subsidies or government participation. However, past successes in scaling up oral rehydration salts, insecticide-treated nets, guinea worm filters and boiling have all been attributed at least in part to governmental support. As well, most advocates of HWTS, even those in the private sector, believe that governments play an essential role in promoting the intervention. Regardless of the debate about the centrality of the role of the public sector, it seems clear that governments can make a variety of contributions to facilitate coverage and uptake of HWTS. These include:

- conducting public health campaigns that recognize the health gains from HWTS and help create awareness and product demand;
- supporting settings-based initiatives to introduce HWTS in schools, clinics, HIV/AIDS programmes and emergencies;

- reducing customs tariffs and taxes and facilitating the importation of HWTS products that can be produced centrally at lower cost and higher quality;
- implementing standards and regulatory monitoring to help encourage public health and consumer confidence in the safety and performance of HWTS products;
- collaborating with other governments to make HWTS products an international priority and generate donor support.

5.7 Lack of focused international effort and commitment

This point—how governments can come together to focus international commitment and support on a particular initiative—was perhaps best demonstrated in Abuja when the African heads of state agreed to align and focus their malaria prevention strategies, leading directly to a dramatic effort to scale up insecticide-treated nets (section 2.4). By emphasizing a focused approach, establishing an agreed performance specification and ensuring donor funding for the production and programmatic distribution of nets, the initiative overcame many of the barriers that were limiting expansion. The result was a quintupling of production in less than 5 years.

However, the success of the insecticide-treated net programme was also attributable in part to international collaboration and commitment. RBM and the Global Fund to Fight AIDS, Tuberculosis and Malaria are just two of the examples of high-profile, well-financed, international campaigns against important infectious diseases. Although diarrhoea accounts for more mortality and morbidity than tuberculosis or malaria, there is no global fund or presidential initiative to address it. This is even more scandalous when health authorities agree that we currently have all the tools to prevent 94% of the burden of diarrhoeal disease through environmental measures (Prüss-Üstün & Corvalán, 2007).

While water generally attracts significant attention, much of the focus lies outside of waterborne diseases, attaching instead to water resource management, water scarcity, environmental contamination, water rights, fishing and agricultural uses of water. UN Water (http://www.unwater.org), for example, was established as the official UN mechanism for follow-up on MDG water-related targets. However, according to its web site, its work encompasses "all aspects of freshwater, including surface and groundwater resources and the interface between fresh and sea water. It includes freshwater resources, both in terms of their quality and quantity, their development, assessment, management, monitoring and use (including, for example, domestic uses, agriculture and ecosystems requirements)." WHO's Water, Sanitation, Hygiene & Health Programme (http://www.who.int/water_sanitation_health/en/index.html), the World Bank's Water and Sanitation Program (http://www.wsp.org/) and UNICEF's Water, Environment and Sanitation programme (http://www.unicef.org/wes/), among others, provide important international leadership and coordination in health-related water interventions, but comparatively little funding, given the magnitude of the disease burden and the MDG challenges in water. Public–private collaborative efforts, such as the HWTS Network (http://www.who.int/household_water/en/) and the Latin America–based Alianza de Agua Segura y Hábitos Saludables (http://www.aguasegura.org), are making important contributions and show the potential for focused international efforts. To date, however, they have not succeeded in establishing a global champion or in placing HWTS firmly on the mainstream public health agenda in most countries.

5.8 Perceived policy conflict with efforts to promote piped-in water supplies

Finally, there is a perceived conflict between efforts to promote HWTS, on the one hand, and piped-in water, on the other. This arises from the fact that point-of-use water treatment addresses only water quality, offering potential health gains but few other benefits that are associated with piped-in water supplies. Some regard the option as an interim measure that diverts resources away from the first-class reticulated systems enjoyed in developing countries.

These are serious and legitimate issues that policy-makers must resolve in order to support HWTS. Even the private sector, which might hope to finesse these issues by avoiding the debate and going directly to consumers, will see its efforts hindered unless these questions are resolved.

WHO and the HWTS Network recognized this potential conflict from the outset. The HWTS Network's strategic plan for 2003–2008 summarizes its position:

> Efforts to deliver the safe and reliable water services necessary to create a healthy living environment and other benefits for people in developing countries are an essential long-term goal. At the same time, steps can be taken immediately to accelerate the health gains associated with improved water and therefore poverty alleviation and development. One of the most important immediately achievable steps is the treatment and safe storage of water at the point of use. [International Network to Promote Household Water Treatment and Safe Storage, 2004]

Similar language is contained in its recent advocacy document: "Providing safe and reliable water services to the 1.1 billion people [884 million people as of 2006] who currently lack access to improved water sources is an essential long-term goal that will yield great health and economic benefits. Less well known is the large potential contribution that household-level water quality interventions can make to immediately improve the health of the most vulnerable" (WHO, 2007). Many of the papers and other publications on HWTS interventions contain the same caveat (Reiff et al., 1996; Quick et al., 1999; Clasen & Cairncross, 2004). Even these statements, however, suggest that HWTS is at best a temporary, short-term measure. As such, they do little to assuage the concerns over diversion of resources. Moreover, they directly acknowledge that important non-health benefits associated with piped-in water are not advanced by treating water in the home.

One clear point of contention is whether practising HWTS falls within the scope of "improved water supplies" under the JMP or "access to safe drinking water" prescribed by the MDG targets. These are not academic issues, as funding and other resources are largely directed at increasing coverage under the JMP and meeting the MDGs, despite widespread criticism of the distinction (UNDP, 2007). A recent report by the UN Millennium Task Force on Water and Sanitation suggests that HWTS advances the MDGs, but the report falls short of recommending that the practice count towards the MDG water target (UN Millennium Project, 2005). More recently, a background paper prepared for the JMP on the role of HWTS in the context of the MDG water target concludes that it is premature to count HWTS towards the MDG water target as a result of incomplete evidence and certain policy and methodological issues (Clasen et al., 2008b). There is a need to translate the promising results from efficacy trials into larger, programmatic success and to demonstrate the correct, consistent and sustained use of the intervention—including boiling.

Nevertheless, effective HWTS should be actively encouraged among any population that cannot safely rely on the microbiological integrity of its water supplies, whether they be "improved" or "unimproved". In order to encourage adoption of such practices—and to help ensure that they are targeted optimally to settings in which water is the dominant transmission route—the JMP should measure and report on them as it began doing in 2008 (WHO/UNICEF, 2008b). Positioning the intervention among policy priorities, however, requires a more nuanced assessment of water coverage than the dichotomous "improved" versus "unimproved" approach currently used by the JMP. A ladder approach, which recognizes and encourages incremental improvements in water supplies, was recently adopted in reporting sanitation coverage in Africa (WHO/UNICEF, 2008a) and partially implemented in the 2008 JMP report (WHO/UNICEF, 2008b; Bartram, 2008). However, HWTS has no place yet on the rungs of the ladder. Until this ambiguity about the role of HWTS is resolved, national governments, eager to demonstrate that they are using international funding to make progress towards the MDGs, are unlikely to commit substantial resources to the intervention, despite the potential for leveraging their efforts from civil society and the private sector to achieve measurable health gains.

6. CONCLUSION AND RECOMMENDATIONS

Despite promising results in a few countries, it is difficult to escape the conclusion that the current efforts to scale up effective HWTS are insufficient. Notwithstanding the real progress that has been achieved to date, the overall result is modest when compared with the actual need.

One possibility is that we have not yet reached the "tipping point"—that magical moment described in Malcolm Gladwell's popular book of the same name when an idea, product or social behaviour crosses a threshold and spreads like an epidemic (Gladwell, 2000). He cites dozens of examples of products that rapidly became widely accepted: fax machines, cell phones and more. And Gladwell argues that by understanding the role of three common factors that characterize the evolution of trends (the role of a few key champions whose behaviour is "contagious", that relatively small changes in the message can cause the innovation to "stick" and that change happens not gradually but at one dramatic moment), it is possible in some cases to manipulate them and actually create scale.

Perhaps HWTS is on the edge of the tipping point. Perhaps it is still progressing along the slow but steady S-curve that Rogers (2003) and other subscribers to "diffusion theory" regard as an inevitable process among early adopters, leading to rapid uptake and long-term adoption. It is the same process that marketing professionals see as part of a consumer product's natural life cycle. If so, then given the enormous need, HWTS may have a bright future. But this is not inevitable; most new products are commercial failures. Harris (2005) documented the overall failure of certain efforts to commercialize HWTS products, although curiously expressing optimism about their potential. While some observers invariably cite mobile phones as an example of how dramatically diffusion can occur, a recent World Bank report demonstrates that this and other success stories are in fact the exception rather than the rule, especially in lower-income settings (World Bank, 2008). Achieving scale in household water treatment is by no means inevitable.

Table 10 identifies three areas that may contribute to the failure of HWTS to realize its promising potential: 1) poor product choices, 2) consumers that find the value and benefits of the product unconvincing and 3) poor delivery systems to ensure that high-risk populations in particular have access to effective HWTS options. The shortcomings in each of these areas may need to be addressed before dramatic progress can be made.

Table 10: Certain reasons for failure of HWTS to realize its potential scale

Category	Problems
Product	• Designed primarily for microbiological performance and not to address users' preferences (convenient, affordable, makes water look and taste better, reliable, low maintenance, attractive, safe, robust, appealing)
	• Except for boiling and other costly alternatives, are not effective against the full range of pathogens and do not operate equally under various water conditions brought by seasonal changes
	• Rely on imported, foreign parts, even for replacement components, which are seldom accessible or affordable
	• Implementers provide only a single choice rather than a suite of options from which users can select
Consumer understanding	• Uncertainty as to the need to treat water at all, given long traditions of consuming untreated water
	• Uncertainty about what products are suitable and effective for the particular conditions
	• Diarrhoea is considered natural for infants and only an annoyance for adults
	• Boiling is most widely used despite cost, inconvenience and environmental impact
	• Consumers have no clear and convincing evidence of the health and economic benefits of treating their water
	• Lack of understanding about what, if anything, users are willing and able to pay, resulting in low-cost options that remind the poor of their status and are not aspirational to other socioeconomic groups that may nevertheless be at risk

Category	Problems
Delivery models	• Heavy reliance on social marketing model • Driven by sales volume and thus focus on urban areas where disease burden may not be heaviest • Poor follow-up to provide replacement parts and consumables • Multilayered distribution channels are excessively costly • Do not take advantage of existing infrastructure or distribution systems • Little on-the-ground collaboration between public sector, NGOs and private sector

The goal of scaling up HWTS will not be achieved, however, simply by putting more resources into existing programmes or transitioning current pilot projects to scale. The gap between where we are and where we need to be is too great, given the urgency of the need. ***What is needed is a breakthrough.*** The largely public health orientation that has brought HWTS to its present point—the engineers, microbiologists, epidemiologists, social scientists and health economists who have answered important questions about the safety, operation, effectiveness, health impact, acceptability and cost-effectiveness of the array of HWTS products and technologies so far—may not have the skills to take the intervention to scale. Having been present at its conception and delivery, these midwives must now enlist the help of other experts: consumer researchers, product designers, educators, social entrepreneurs, micro-financiers, business strategists, policy advocates and representatives from donors and government.

The private sector is one obvious partner; it possesses not only much of this expertise, but also the incentive and resources to develop the products, campaigns and delivery models necessary for creating and meeting demand on a large scale. At the same time, the private sector, acting alone, is not likely to reach the most vulnerable populations at the bottom of the pyramid where the disease burden associated with unsafe drinking-water is heaviest. Thus, it must work with the public sector and NGOs that have a special capacity and dedication to reach these population segments. Governments and international organizations can also help encourage responsible action by the private sector through product standards and certification, by reducing barriers to importation, local production and distribution of proven products, and by providing incentives for reaching marginalized populations.

Sections 2 and 3 of this report identify many areas that can be addressed in order to advance the coverage and uptake of HWTS. Section 5 describes special constraints that should be confronted and overcome. Based on the overall findings of this report, however, the following 10 recommendations are believed to warrant particular priority in order to enhance the goal of scaling up of HWTS:

1. *Focus on the users*—First, find the users who can most benefit from the intervention—those in settings where water is the dominant transmission route; scaling up among others will bring no more benefit than bottled water has provided in developed countries. Then find out what they really want, and deliver it. Don't prejudge what it is, and don't assume it is health. Ask them. Show them the range of options, and let them participate early and often in designing solutions to meet their needs. To generate uptake, find out who influences them, whom they trust and believe, and engage them—neighbours, teachers, ministers, health-care professionals, footballers and movie stars—in promoting effective HWTS options. Use high-quality consumer research to inform decisions about methods, media and content of communication campaigns. Give users choices, and make the options not only functional, but also attractive and appealing. Enable users by providing solutions that are convenient, accessible and affordable—using financing where necessary. Meet their reasonable expectations, and they will drive demand, brand loyalty, volume and margin for the supplier, and ultimately coverage and uptake at scale for HWTS.

2. *Develop and use partners*—Experience with oral rehydration salts, guinea worm filters, insecticide-treated nets and the most successful HWTS operations to date demonstrates the importance of alliances, joint ventures, creative collaborations and other partnerships. The

value of international cooperation and governmental collaboration has been emphasized throughout this report. So has the need for foreign and local suppliers to leverage national and local supply and distribution channels. However, reaching geographically and economically remote populations with HWTS solutions may require even more creative collaborations. International NGOs and multinational corporations are increasingly combining their complementary strengths to reach low-income populations with effective, affordable and appropriate products and services (Prahalad, 2005; Brugmann & Prahalad, 2007). Commercial companies have developed direct marketing sales forces through partnerships with schools, micro-finance institutions and individual entrepreneurs, much in the way BRAC, UNICEF and others did in the distribution of oral rehydration salts. Micro-entrepreneurs and micro-financiers are being engaged to assist in overcoming the barriers to acquiring HWTS products.

3. *Improve and expand on boiling*—Perhaps because it did not require the establishment of supply chains and built on cultural preferences in certain regions, boiling has been the most successful among HWTS methods at achieving scale. Combined with its microbiological effectiveness regardless of water conditions, it is the benchmark against which all alternative HWTS initiatives should be measured, in terms of performance, cost and scalability. While potential disadvantages of boiling over other alternatives raise questions about the extent to which the intervention should be encouraged over other alternatives, some of these can be minimized with technology and behaviour change.

4. *Continue to pursue non-commercial strategies*—The widespread adoption in certain regions shows the potential for non-commercial strategies at scaling up HWTS. Moreover, while commercial approaches may ultimately deliver impressive gains in scale, they will not reach the absolute base of the pyramid—those who can afford to make little or no cash contribution towards HWTS solutions. Remote, displaced, disenfranchised and other special population segments will also be off the commercial radar screen. They should receive safe, effective and appropriate HWTS products free or at highly subsidized prices as part of a mass distribution campaign. At the same time, programme implementers must explore new delivery strategies rather than simply continue to rely on old, tired models. These may include targeted approaches through schools and clinics; synergistic approaches with other household-based interventions; water partnerships with maternal/childhood, HIV/AIDS and other health initiatives; collaboration with NGOs promoting micro-finance and micro-entrepreneurial activities; and leveraging emergency applications of HWTS for long-term applications. It is also critical that the efforts of these implementing bodies be independently monitored, assessed and reported in order to ensure the same level of accountability to which the private sector is subject by virtue of putting investment at risk.

5. *Continue to pursue market-driven strategies*—Commercial strategies—used by both for-profit, private companies and non-profit, social marketing organizations—have made impressive gains in improving coverage of HWTS. They also provide opportunities for leveraging public sector and donor resources by achieving coverage at middle levels of the economic pyramid. Implementation surveys also suggest that these approaches are the most widespread (Murcott, 2006). The Program for Appropriate Technology in Health (PATH), the largest single initiative to investigate the potential for scaling up HWTS, is specifically focused on enabling sustainable commercial enterprises to produce, distribute and sell HWTS products to vulnerable populations. Commercial strategies are not a panacea; they are not likely to reach some of the most vulnerable populations that have little purchasing power to devote to HWTS products. As well, commercial approaches have not always been successful, either in direct efforts to promote HWTS (e.g. flocculant-disinfectant sachets) or as public–private partnerships to promote hand washing with soap. Nevertheless, the success of some commercial approaches to date in HWTS and widespread success in other sectors suggest that this strategy offers the best hope for attaining scale. It should be pursued vigorously.

6. *Leverage existing local strengths*—In Brazil, India, China and certain other countries, upper- and middle-market HWTS products enjoy substantial sales. In these and virtually every other country, commercial companies have established supply chains that reach even the most remote locations with household goods, processed foods and beverages, health and beauty products and medicines, generating massive sales. Nevertheless, these local resources currently contribute relatively little to the coverage of HWTS among the most vulnerable populations. Some existing products made and sold in these countries may well be effective and could be readily moved downmarket using brand differentiation and other common approaches to avoid derationalizing existing markets. Local fabricators are capable of manufacturing acceptable-quality filters, disinfectants and hybrid products; with partners that could provide capital, technology and technical assistance, their quality and consistency would improve. Local production is often critical to sustainability and cost-effectiveness (POUZN Project, 2007). Effective local distribution is simply essential to achieving scale in HWTS.

7. *Initiate and use relevant, practical research*—HWTS can be regarded as both a health intervention and a consumer product, and much has been learnt already about the effectiveness of strategies to scale up both. Take full advantage of the lessons learnt. Creative research, such as that of Ashraf, Berry & Shapiro (2006), which showed how higher prices of SWS-type bottles of sodium hypochlorite can actually increase unit volume and product use, can readily be used by HWTS implementers. Walley et al. (2007) argued that research can be more effectively translated into practice if investigators begin by working with practitioners ("getting practice into research"). Students in engineering, public health, business and economics find compelling and meaningful research issues in HWTS, enjoy the opportunity to conduct fieldwork and are a low-cost means of answering important questions. While researchers continue to make incremental improvements in existing methods, a technological breakthrough—a low-cost, long-lasting, attractive, sustainable, portable solution that is easy to use and maintain, is effective against all classes of microbial pathogens, improves water aesthetics and is not impaired by adverse physical or chemical characteristics of the water—could dramatically change the pace of scaling up as it did for long-lasting insecticide-treated bed nets. In the meantime, research can make valuable contributions not only to increasing coverage and uptake of existing solutions, but also to the international acceptance of HWTS as an intervention worthy of support by policy-makers and donors. This research needs to be user focused and implementation based, with scaling-up in mind during the research process. Finally, additional funding must be made available to support such research.

8. *Overcome public policy barriers to advancing HWTS*—Uncertainty about the role of HWTS in the context of the MDGs and other health and development objectives impedes progress in scaling up the intervention. While there are sound reasons not to count HWTS towards the MDG water target, national governments should embrace the intervention even while they work to extend piped-in supplies of treated water. Several factors warrant positioning HWTS as a policy priority: 1) its documented cost-effectiveness and cost-beneficiality, 2) the fact that many beneficiaries have been shown to be willing and able to cover all or part of the cost of the intervention, 3) the suitability of the intervention for populations who have sufficient quantity and access to water, but whose water is unsafe for drinking, and 4) the fact that HWTS can be deployed quickly and with relatively low capital cost.

9. *Engage national and regional governments*—Take steps to inform governmental officials about the benefits of HWTS, and show them how the intervention can leverage their own conventional efforts in water and health. Recent WHO-backed workshops in Kenya, Ethiopia, Viet Nam, Cambodia, Ghana, Indonesia, Lao People's Democratic Republic and the Philippines are examples of potentially effective vehicles in which to establish a platform of support. Encourage cross-ministerial collaboration, but do not wait for it. Activate governmental champions for HWTS wherever they arise, and give them the tools and knowledge to become advocates. As governments are often the gatekeepers, respect and

promptly address their legitimate concerns about new products and technologies and about the impact on local manufacturers. As they are increasingly empowered to make their own decisions about deploying international donor funds, compete vigorously among governmental officials to give HWTS the priority it deserves.

10. *Engage international leadership to support HWTS*—HWTS has been shown to be an effective health intervention that is highly cost-effective and cost-beneficial. By reducing poverty and child mortality, it also contributes directly to other MDGs (UNDP, 2007). As many of the beneficiaries of the intervention can cover much or all of its cost, it allows governments to leverage their funding and other resources. The HWTS Network should work with WHO, UNICEF and others to 1) establish and maintain a higher international profile for diarrhoea and other waterborne diseases, 2) demonstrate the contribution that HWTS can make as part of an integrated water, sanitation and hygiene strategy and 3) demand research and implementation funding that is commensurate with the burden of diarrhoeal disease. This does not necessarily mean that HWTS should seek to establish another vertically oriented, disease-specific body—such as the Global Fund to Fight AIDS, Tuberculosis and Malaria or the President's Emergency Plan for AIDS Relief—for waterborne disease. What is recommended, however, is that advocates of HWTS join with other promoters of effective interventions against diarrhoeal and other water-related diseases and take steps (such as an international donors forum) to ensure that adequate funding be devoted to scale up solutions to these demonstrably preventable diseases.

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