

Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices

By Daniele S. Lantagne, Robert Quick, and Eric D. Mintz¹
U.S. Centers for Disease Control and Prevention

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Introduction: Water and Sanitation Goals

The United Nations' International Drinking Water Supply and Sanitation Decade (1981-1990) failed to achieve its goal of universal access to safe drinking water and sanitation by 1990 (World Health Organization [WHO], 2003). Even though service levels rose by more than 10 percent during the decade, 1.1 billion people still lacked access to improved water supplies, and 2.4 billion people were without adequate sanitation, in 1990 (WHO/UNICEF, 2000). Reasons cited for the decade's failure include population growth, funding limitations, inadequate operation and maintenance, and continuation of a "business as usual approach, drawing on traditional resources, policies, and technologies" (WHO/UNICEF, 1992).

The world is on schedule to meet the Millennium Development Goal (MDG), adopted by the UN General Assembly in 2000 and revised after the World Summit on Sustainable Development in Johannesburg, to "halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation" (World Bank Group, 2004; WHO/UNICEF, 2004). However, success still leaves more than 600 million people without access to safe water in 2015 (WHO/UNICEF, 2000). In addition, although the MDG target specifically states the provision of "safe" drinking water, the metric used to assess the MDG target is the provision of water from "improved" sources, such as boreholes or household connections, as it is difficult to assess whether water is safe at the household level (WHO/UNICEF, 2004). Thus, many more people than estimated may drink unsafe water from improved sources.

Household Water Treatment and Safe Storage

To overcome the difficulties in providing safe water and sanitation to those that lack it, we need more research into novel interventions and effective implementation strategies that can increase the adoption of technologies and improve prospects for sustainability. Despite general support for water supply and sanitation, the most appropriate and effective interventions in developing countries are subject to significant debate. The weak links between the water, health, and

¹ Daniele S. Lantagne, Robert Quick, and Eric D. Mintz work for the Foodborne and Diarrheal Diseases Branch of the U.S. Centers for Disease Control and Prevention. Quick and Mintz also work at the Center for Global Safe Water at Emory University.

financial sectors could be improved by communication programs emphasizing health²—as well as micro- and macroeconomic—benefits that could be gained by achieving the safe water goals.

The new focus on novel interventions has led researchers to re-evaluate the dominant paradigm that has guided water and sanitation activities since the 1980s. A literature review of 144 studies by Esrey et al. (1991) best summarized the old paradigm, concluding that sanitation and hygiene education yielded greater reductions in diarrheal disease (36 percent and 33 percent, respectively) than water supply or water quality interventions.³ However, a more recent meta-analysis commissioned by the World Bank contradicted these findings, showing that hygiene education and water quality improvements were more effective at reducing the incidence of diarrheal disease (42 percent and 39 percent, respectively) than sanitation provision and water supply (24 percent and 23 percent, respectively) (Fewtrell & Colford, 2004).

The discrepancy between these findings can be attributed in part to a difference in intervention methodology. Esrey et al. (1991) reviewed studies that largely measured the impact of water quality improvements at the source (i.e., the wellhead or community tap). Since 1996, a large body of published work has examined the health impact of interventions that improve water quality at the point of use through household water treatment and safe storage (HWTS; Fewtrell & Colford, 2004). These recent studies—many of them randomized controlled intervention trials—have highlighted the role of contamination of drinking water during collection, transport, and storage (Clasen & Bastable, 2003), and the health value of effective HWTS (Clasen et al., 2004; Quick et al., 1999, 2002; Conroy et al., 1999, 2001; Reller et al., 2003).

In 2003, as the evidence base for the health benefits of HWTS methods grew, institutions from academia, government, NGOs, and the private sector formed the International Network to Promote Household Water Treatment and Safe Storage, housed at the World Health Organization in Geneva, Switzerland. Its stated goal is “to contribute to a significant reduction in waterborne disease, especially among vulnerable populations, by promoting household water treatment and safe storage as a key component of water, sanitation, and hygiene programmes” (WHO, 2005).

HWTS Options

This paper summarizes five of the most common HWTS options—chlorination, filtration (biosand and ceramic), solar disinfection, combined filtration/chlorination, and combined flocculation/chlorination—and describes implementation strategies for each option.⁴ We identify

² The health consequences of inadequate water and sanitation services include an estimated 4 billion cases of diarrhea and 2.2 million deaths each year, mostly among young children in developing countries (WHO/UNICEF, 2000). In addition, waterborne diarrheal diseases lead to decreased food intake and nutrient absorption, malnutrition, reduced resistance to infection (Baqui et al., 1993), and impaired physical growth and cognitive development (Guerrant et al., 1999).

³ This study reinforced previous work (Esrey, 1985) that had influenced the water and sanitation sector to de-emphasize improving water quality as a way to reduce diarrheal disease incidence.

⁴ Space precludes exhaustive consideration of all HWTS options, and thus we have chosen those that are most widely used. For a thorough technical review of all HWTS options, the reader is referred to *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply* (Sobsey, 2002). For reviews of safe storage options, the reader is referred to Mintz et al. (1995, 2001).

implementing organizations and the successes, challenges, and obstacles they have encountered in their projects. We consider sources of funding and the potential to distribute and sustain each option on a large scale, and propose goals for future research and implementation.

This paper focuses on point-of-use drinking water treatment and safe storage options, which can accelerate the health gains associated with improved water until the longer-term goal of universal access to piped, treated water is achieved. By preventing disease, household water treatment and storage practices can contribute to poverty alleviation and development. Their widespread use, in conjunction with hygiene education and latrine provision, has the potential to save millions of lives until the infrastructure to reliably deliver safe water to the entire world population has been created.

Evaluation Criteria for HWTS Options

We use a consistent evaluation scheme for each of the HWTS options discussed (see Table 1):

- 1) Does the HWTS option remove or inactivate viral, bacterial, and parasitic pathogens in water in a laboratory setting?;
- 2) In the field, is the HWTS option acceptable, can it be used correctly, and does it reduce disease among users?; and
- 3) Is the HWTS option feasible at a large scale?

Option 1: Chlorination

Chlorination was first used to disinfect public water supplies in the early 1900s, and helped drastically reduce waterborne disease in cities in Europe and the United States (Gordon et al., 1987). Although there had been small trials of point-of-use chlorination (Mintz et al., 1995), larger-scale trials began in the 1990s as part of the Pan American Health Organization (PAHO) and the U.S. Centers for Disease Control and Prevention (CDC) response to epidemic cholera in Latin America (Tauxe, 1995). The Safe Water System (SWS) strategy devised by CDC and PAHO includes three elements:

- Treating water with dilute sodium hypochlorite⁵ at the point-of-use;
- Storing water in a safe container; and
- Educating users to improve hygiene and water and food-handling practices.

The sodium hypochlorite solution is packaged in a bottle with directions instructing users to add one full bottle cap of the solution to clear water (or two caps to turbid water) in a standard-sized storage container; agitate; and wait 30 minutes before drinking. In four randomized controlled trials, the SWS reduced the risk of diarrheal disease ranging from 44-84 percent (Luby et al., 2004; Quick et al., 1999, 2002; Semenza et al., 1998). At concentrations used in HWTS programs, chlorine effectively inactivates bacteria and some viruses (American Water Works Association, 1999); however, it is not effective at inactivating some protozoa, such as cryptosporidium.⁶ Initial research shows water treated with the SWS does not exceed WHO

⁵ Sodium hypochlorite (NaOCl) is a slight yellow, transparent liquid. As a chlorine donor, it serves as a strong oxidizer, bleaching agent, and sterilizer.

⁶ Microscopic parasites of the genus *Cryptosporidium* cause a diarrheal disease called cryptosporidiosis. Once an animal or person is infected, the parasite lives in the intestine and passes in the stool. The parasite is protected by an

guidelines for disinfection by-products, which are potential cancer-causing agents (CDC, unpublished data).

Chlorination: Implementation Strategies

SWS implementation has varied according to local partnerships and underlying social and economic conditions. The disinfectant solution has been disseminated at national and subnational levels in 13 countries through social marketing campaigns, in partnership with the NGO [Population Services International](#) (PSI). In Indonesia, the solution is disseminated primarily through the private sector, led by a local manufacturing company. In several countries—including Ecuador, Laos, Haiti, and Nepal—the ministries of health or local NGOs run the SWS programs at the community level. In Kabul, Afghanistan, the SWS is provided at no charge to pregnant women receiving antenatal care. The SWS has also been made available free of charge in a number of disaster areas, including Indonesia, India, and Myanmar following the 2004 tsunami, and also in Kenya, Bolivia, Haiti, Indonesia, and Madagascar after other natural disasters. When SWS programs are in place, the product's ready availability greatly facilitates emergency response. The CDC has developed an implementation manual and provides technical assistance to organizations implementing SWS projects (CDC, 2001).

PSI's Social Marketing of the SWS in Zambia

PSI is the largest social marketing NGO in the world, with offices in more than 70 countries. PSI designs a brand name and logo for health products; sells them at a low price; distributes them through wholesale and retail commercial networks; and generates demand for the products through behavior change communications, such as radio and TV spots, mobile video units, point-of-sale materials, theater, and person-to-person communications.

In October 1998, PSI launched its Zambian SWS product, a bottle of sodium hypochlorite solution branded as “Clorin”—one of the oldest PSI/CDC collaborations. Sales steadily increased from 732 bottles per month in October 1998 to 132,000 bottles per month in November 2003. A cholera epidemic in 1999 increased demand for Clorin; sustained social marketing and promotion in health centers and door-to-door stimulated further sales (Olembo et al., 2004). A population-based, cross-sectional study conducted by an independent agency showed that 42 percent of households reported using Clorin currently, and 22 percent reported past use (Olembo et al., 2004). However, only 13 percent of households had residual chlorine in their water at the time of the unannounced visit, indicating a discrepancy between reported and actual use. A lower rate of reported diarrhea was not found among users of Clorin as compared to non-users; however, further studies are needed, as large cross-sectional surveys are not reliable for measuring health outcomes as randomized, controlled cohort studies.⁷

The Clorin product is subsidized by USAID; the full cost of the 250 ml bottle—including production, marketing, distribution, and overhead—is US\$0.34, and the retail price is set at

outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine-based disinfectants.

⁷ Large cross-sectional studies, which visit a large number of families once, do not measure diarrheal disease reduction as accurately as randomized, controlled intervention studies, where families with and without the intervention are visited over a period of months to determine disease reduction over time in a population cohort.

US\$0.12. The total program cost per person-month of protection from diarrhea is US\$0.045 (CDC, unpublished data). Increasing the price to achieve full cost recovery could have a negative impact on demand, particularly in a country like Zambia, which ranks 164th out of 177 on the Human Development Index (UN Development Programme, 2004). The program needs studies of the price elasticity of demand for this product, and is currently implementing options to significantly lower costs.

PSI's Zambia project is an example of a successful social marketing intervention that creates demand for a product and makes it widely available through the commercial sector. Interested NGOs can readily incorporate Clorin into their own programming. The two major challenges this program faces are achieving financial self-sufficiency while maintaining access to the product, and increasing demand among the highest-risk populations. With its wide Clorin use and distribution, Zambia is an ideal location for future research on interventions to reduce economic and behavioral barriers to utilization; program effectiveness in disease prevention; and cost-effectiveness.

Community-Based NGO Program in Northern Haiti

In contrast to PSI's national-scale approach, the [Jolivert Safe Water for Families Project](#) (JSWF) produces its own disinfectant, "Dlo Pwòp," at the Missions of Love Clinic in Jolivert, Haiti, for distribution in nearby communities. The JSWF Project installed a hypochlorite generator—a simple device that passes electric current through water and salt to generate hypochlorite—and trained two Haitian technicians to produce the disinfectant, sell it to families, provide educational support, and test for residual chlorine in users' household water. Small-scale local production and distribution has ensured a continuous supply of disinfectant to families in spite of natural disasters and political upheavals.

JSWF spends about US\$7 to provide a bucket with a lid and spigot for safe storage, as well as educational materials, for a family in the program. After that initial investment, disinfectant sales almost meet operating expenses. One month's supply of the disinfectant sells for US\$0.09, which is within the budget of most Haitian families. The project uses refillable bottles to reduce the cost of the disinfectant. JSWF began in September 2002 with 200 families; an independent evaluation four months later documented a reduction in diarrheal disease incidence of 55 percent (Brin, 2003); however, the data were from a cross-sectional survey, which is not as reliable for determining diarrheal disease outcomes as randomized, controlled, cohort studies. JSWF has expanded to more remote areas by transporting bulk disinfectant and distributing it through satellite refilling stations. Currently, the program distributes about 1,000 bottles of solution per month to approximately 1,200 participating families (7,200 people).

This type of program reaches rural populations in ways that are culturally appropriate and more cost-effective than many other programs. In addition, this program has created demand in surrounding communities via word-of-mouth advertising. The main drawbacks are the dependence on the hypochlorite generator and on outside programmatic support to enroll new families.

Chlorination: Benefits and Drawbacks of the SWS

The benefits of point-of-use chlorination include:

- Proven reduction of bacteria and most viruses;
- Residual protection against contamination;
- Easy to use and thus acceptable to users;
- Proven health impact,
- Scalability; and
- Low cost.

The drawbacks include:

- Relatively low protection against some viruses and parasites;
- Lower effectiveness in water contaminated with organic and certain inorganic compounds;
- Potential objections by users to taste and odor; and
- Concern about potential long-term carcinogenic effects of chlorination by-products.

Option 2: Filtration

Porous stones and a variety of other natural materials have been used to filter visible contaminants from water for hundreds of years. These mechanical filters are an attractive option for household treatment because:

- There are many locally available and inexpensive options for filtering water;
- They are simple and ease of use; and
- Such filter media are potentially long-lived.

However, filtration is the least studied HWTS intervention, and pathogen removal, filter maintenance, and the lack of residual protection pose challenges in implementation.

A recent health impact study in Bolivia documented a 64 percent reduction in diarrhea in users of 0.2 micron ceramic candle-shaped filters manufactured in Switzerland (Clasen et al., 2004).⁸ Users prevented recontamination by using a tight-fitting lid over the receptacle, a tight seal to prevent leaking around the filters into the receptacle, and a spigot to access the water; in addition, users could clean the filters without removing them and thus exposing the water in the receptacle to potential contaminants.

Option 2A: BioSand Filtration

The BioSand Filter (BSF) is a slow-sand filter adapted for use in the home. The most widely used version of the BSF is a concrete container approximately 0.9 meters tall and 0.3 meters square, filled with sand. The water level is maintained at 5-6 centimeters above the sand layer by setting the height of the outlet pipe. This shallow water layer allows a bioactive layer to grow on top of the sand, which helps reduce disease-causing organisms. A plate with holes in it is placed on the top of the sand to prevent disruption of the bioactive layer when water is added to the system. To use the system, users simply pour water into the BSF, and collect finished water from

⁸ Most currently used filtration options are locally manufactured.

the outlet pipe in a bucket. In laboratory and field testing, the BSF consistently reduces bacteria, on average, by 81-100 percent (Kaiser et al., 2002) and protozoa by 99.98-100 percent (Palmateer et al., 1999). Initial research has shown that the BSF removes less than 90 percent of indicator viruses (Mark Sobsey, personal communication, March 20, 2005).

BioSand Filtration: Implementation Strategies

The BSF has been implemented through two main strategies. In the NGO model, employed in Cambodia and other countries, the cost of the filters is subsidized, and an NGO promotes the use of the BSF in the community and provides the filters. In the micro-entrepreneur model, used in Kenya and the Dominican Republic, local entrepreneurs construct the BSF, receive training and start-up materials, and then develop micro-enterprises to sell filters within their communities.

Regional-Scale NGO Project in Cambodia

[Samaritan's Purse](#), an international faith-based NGO, is one of the principal implementers of the BSF, responsible for the installation of approximately 30,000 of the 100,000 BSF filters in use worldwide. Samaritan's Purse has developed an implementation manual and employs a staff water expert to provide technical support to BSF projects across the world.

Samaritan's Purse has installed 15,000 filters in Cambodia, where they work with local partners to hold informational meetings for potential BSF users. Attendees interested in receiving a BSF are invited to a second training meeting to sign up to receive a BSF. This self-selected group is then asked to contribute a small amount of the cost of the BSF (about US\$3), attend focus group trainings on hygiene and use of the BSF, and send one family member to assist with the construction and transportation of the BSF. The full cost of installing a BSF in a home in Cambodia is US\$67; funding for this project primarily comes from the Canadian International Development Agency.

The success of this project is directly related to the strength of the cooperating staff in Cambodia (Kaida Liang, personal communication, December 24, 2004). Implementation challenges include the weight of the BSF (350 pounds), which makes transportation difficult and complicates installation in homes on stilts, and human errors. Currently, 75,000 families are waiting to receive a filter, and lack of funding has limited expansion. As the project has grown, economies of scale and lessons learned have made installation more efficient and less costly.

BioSand Filtration: Benefits and Drawbacks

The benefits of the BSF include:

- Proven removal of protozoa and a percentage of bacteria;
- High user acceptability, because it is easy to use and the look and taste of water improves;
- Produced from locally available materials;
- One-time installation with few maintenance requirements; and
- Long life.

The drawbacks of the BSF include:

- Low rate of virus inactivation;
- Lack of residual protection and removal of 100% of the bacteria, which leads to recontamination;
- The current lack of studies proving health impact; and
- Difficulty in transport and high initial cost, which make scalability more challenging.

Option 2B: Ceramic Filtration

Ceramic filters have traditionally been used for water treatment throughout the world. Currently, the most widely distributed ceramic filter is the [Potters for Peace](#) (PFP) filter, which is shaped like a flowerpot, holds 8.2 liters of water, impregnated with colloidal silver,⁹ and sits inside a 20-30 liter plastic or ceramic receptacle with a spigot. Laboratory testing has shown that although the majority of the bacteria are removed mechanically through the filter's small (0.6-3.0 microns) pores, colloidal silver is necessary to inactivate 100 percent of the bacteria (Lantagne, 2001a). The filter removes 99.99 percent of protozoa by mechanical processes (Lantagne, 2001a); however, the effectiveness of the filter in inactivating or removing viruses is unknown.

Ceramic Filtration: Implementation Strategies

Production of the PFP Filter in Managua, Nicaragua

PFP is a U.S.-based NGO whose mission is to build an international network of potters concerned with peace and justice issues. PFP helps potters learn appropriate technologies and marketing skills that improve their livelihoods and sustain their environment and cultural traditions. After staff members were introduced to the ceramic filter design, PFP established a filter-making factory in Managua, Nicaragua. Funding for the project initially came from private donations. The filter factory is now a self-financed micro-enterprise in Nicaragua. NGOs pay US\$10 per filter, and transport the filters themselves to project locations. From 1999-2004, PFP made and sold a total of 23,000 filters in Nicaragua. PFP has also established filter-making factories in 12 other countries, contracted by organizations that provide funding for technical assistance and factory construction.

In the current model, the factory sells filters to NGOs, who then implement a water program. This model is attractive to NGOs because they do not have to produce the filters, but it suffers from a lack of consistent training and education for both the NGO implementers and the users. Recontamination of finished water due to poor cleaning and maintenance of the filter is common (Lantagne, 2001b). To address this issue, PFP is working with cooperating NGOs to develop, implement, and evaluate an educational program that includes safe storage, proper procedures for cleaning the filter, and follow-up visits to ensure continued proper usage and replacement of broken filters. This educational component is critical if the real-world performance of the filter is to match its intrinsic effectiveness in the laboratory, and to test whether filters made with locally produced materials will prevent diarrhea.

⁹ Colloidal silver—tiny silver particles suspended in liquid—is a disinfectant, preventing bacterial growth in the ceramic filter and assisting in inactivating the bacteria in the filter. The use of colloidal silver in the PFP filter does not leave a residual in the drinking water.

Ceramic Filtration: Benefits and Drawbacks

The benefits of the PFP ceramic filter include:

- Proven reduction of bacteria and protozoa in the laboratory;
- Ease of use;
- Long life, if the filter remains unbroken; and
- Relatively low cost, because the filter is locally produced.

The drawbacks include:

- Unknown effectiveness against viruses;
- Lack of residual protection, leading to recontamination;
- Lack of health impact studies of this particular filter design;
- The need to educate the user to keep the filter and receptacle clean; and
- A low flow rate of 1-2 liters per hour.

Option 3: Solar Disinfection

Solar disinfection (SODIS) was developed to inexpensively disinfect water used for oral rehydration solutions (Acra et al., 1984). In 1991, the Swiss Federal Institute for Environmental Science and Technology began to investigate and implement solar disinfection as a HWTS option. Users of SODIS fill 0.3-2.0 liter plastic soda bottles with low-turbidity water, shake them to oxygenate the water, and place the bottles on a roof or rack for six hours (if sunny) or two days (if cloudy). SODIS has been proven to inactivate bacteria and viruses (Wegelin et al., 1994; Sommer et al., 1997). Recent research has shown the protozoa cryptosporidium and giardia are sensitive to solar irradiation as well (Méndez-Hermida et al., 2005; Martin Wegelin & Regula Meierhofe, personal communication, March 8, 2005). SODIS has also been shown to reduce diarrheal disease incidence in randomized controlled studies by 9-86 percent (Conroy et al., 1996, 1999, 2001; Hobbins, 2003).

Solar Disinfection: Implementation Strategies

As a virtually zero-cost technology, SODIS faces marketing constraints. Since 2001, local NGOs in seven countries in Latin America—as well as in Uzbekistan, Pakistan, India, Nepal, Sri Lanka, Indonesia, and Kenya—are disseminating SODIS by training trainers, educating users at the grassroots level, providing technical assistance to partner organizations, lobbying key players, and establishing information networks. The program has been funded by the AVINA and Solaqua Foundations, private and corporate sponsors, and official development assistance. The program has shown that SODIS is best promoted and disseminated by local institutions with experience in community health education. A long-term training approach and repeated contact with the community is required to create awareness of the importance of treating drinking water and to establish corresponding changes in behavior. The Swiss Federal Institute for Environmental Science and Technology has developed an implementation manual, and provides technical assistance to NGOs implementing SODIS. The method, which has been disseminated in more than 20 developing countries, is regularly applied by more than one million users.

An NGO Project in East Lombok, Indonesia

After a successful pilot project, two local NGOs worked closely with the district health department in East Lombok, Indonesia, to promote SODIS use (Meierhofer, 2005). This large-scale dissemination project worked through community health centers to train a group of trainers—including health officials, sanitarians, teachers, and community representatives—on improved hygiene practices and use of SODIS. These trainers, in turn, trained 144 villages and 70 elementary schools in the use of SODIS, reaching 130,000 people in the 14 months of the project.

A key component for the project's success was ensuring sustainability by working closely with government partners. Integrating hygiene education and SODIS into the community health center structure allows for long-term continuity of the project. The project significantly reduced bacterial contamination of household drinking water [97 percent]—from an average of 174 to 4 CFU/100 ml. Attaining enough plastic bottles for each family was a challenge, so the project established a mechanism to transport and sell bottles. Georg Fisher AG, a German corporation, provided funding at a cost of US\$0.80 per capita.

Solar Disinfection: Benefits and Drawbacks

The benefits of SODIS include:

- Proven reduction of bacteria, viruses, and protozoa;
- Proven health impact;
- Acceptability to users because of the minimal cost to treat water, ease of use, and minimal change in taste of the water; and
- Unlikely recontamination, because water is consumed directly from the small, narrow-necked bottles (with caps) in which it is treated.

The drawbacks include:

- Need to pretreat water that appears slightly dirty (with turbidities higher than 30 NTU);
- Low user acceptability, because of the limited volume of water that can be treated at once and the length of time required to treat water; and
- Requires a large supply of intact, clean, suitable plastic bottles.

Option 4: Filtration and Chlorination

Several systems incorporate both a physical filtration step for particle removal and a chlorination step (or steps) for disinfection. This dual approach produces high-quality finished water. The [Gift of Water, Inc.](#) (GWI) purifier is a two-bucket system, with a polypropylene string-wound filter in the top bucket and a granulated activated-carbon filter in the bottom bucket. Users collect water in the top bucket, add chlorine that is purchased locally each month, wait 30 minutes, and then place the top bucket on the bottom bucket, which activates a check-valve allowing water to flow through the two filters into the bottom bucket. Water is removed from the system via a tap in the bottom bucket, and a small amount of chlorine is added manually to the bottom bucket as residual protection. This system has been proven to reduce bacteria sufficiently

to meet WHO guidelines (Varghese, 2002). Studies of protozoal removal have been inconclusive (Borucke, 2002); viral removal has not yet been studied.

Filtration and Chlorination: Implementation Strategies

Faith-Based Village-Scale Programming in Haiti

GWI is a faith-based organization headquartered in Florida that assembles, distributes, and implements village-based programs with the GWI purifier. Church groups in the United States sponsor communities in Haiti, many through the Catholic Parish Twinning Program of the Americas.

Once a village is sponsored, Haitian GWI staff work with the community to establish a water committee and install purifiers in 200-400 homes. In addition, two local Community Health Technicians (CHT) are trained by Master Technicians to visit the users' homes weekly, and perform maintenance and residual chlorine spot checks. The purifier has garnered high levels of community acceptance, and an independent cross-sectional study found a 56 percent reduction in diarrheal disease incidence in users, with a 35 percent reduction when controlled for socio-economic status and hygiene practice (Varghese, 2002), although as noted earlier, cross-sectional studies are not a reliable method for evaluating diarrheal disease. There are currently 70 sponsorships, covering 120 villages, and more than 16,000 purifiers, with 200 paid Haitian staff in the GWI program. The program is expanding at a rate of 8,000-10,000 new families per year.

The program's strength is that it offers a successful product (water treatment for a village) to consumers (churches) who have resources and good intentions, but lack the technical capacity to implement a water intervention in a needy community. In July 2004, a church in Atlanta, Georgia, provided GWI with US\$5,600 to install 400 purifiers, train the community and the CHTs, and pay salaries for two CHTs for the year (Molly Brady, personal communication, December 29, 2004). By September 2004, the program had conducted the training and installed 200 filters; the church was very pleased with the program's progress, but was concerned about its ability to provide the CHTs' salaries indefinitely. The drawbacks thus include the uncertainty of consistent CHT technical support.

Filtration and Chlorination: Benefits and Drawbacks

The benefits of the GWI purifier are:

- High removal rates of bacteria, even in turbid waters;
- Residual protection;
- High acceptability among users due to the ease of use and visual improvement of the water; and
- Health impact, as measured by a cross-sectional study.

Internal GWI studies attribute their success to the CHT piece of the program (Phil Warwick, personal communication, March 8, 2005).

The drawbacks of the GWI purifier are:

- Unknown viral and protozoa removal; and

- The need for regular filter replacement, ongoing technical support, and continuing education, with their concurrent ongoing costs.

Option 5: Flocculation and Chlorination

Several systems incorporate both a chemical coagulation step for particle removal (flocculation) and a chlorination step (or steps) for disinfection. This dual approach produces high-quality finished water. The [Procter & Gamble Company](#) (P&G) has developed a HWTS option for sale at no profit to users and NGOs, called PūR Purifier of Water. This small sachet contains powdered ferrous sulfate (a flocculant) and calcium hypochlorite (a disinfectant). To use PūR, users open the sachet, add the contents to an open bucket containing 10 liters of water, stir for five minutes, let the solids settle to the bottom of the bucket, strain the water through a cotton cloth into a second container, and wait 20 minutes for the hypochlorite to inactivate the microorganisms.

PūR incorporates both the removal of particles and disinfection. Because of this dual process treatment, PūR has high removal rates of bacteria, viruses, and protozoa, even in highly turbid waters (Souter et al., 2003; Le et al., 2003). PūR has been documented to reduce diarrheal disease incidence by 16 percent to more than 90 percent in five randomized controlled health intervention studies (Reller et al., 2003; Chiller et al., 2003; Crump et al., 2004; Agboatwalla 2004; Doocey, 2005). It also can remove heavy metals, such as arsenic. PūR is provided to global emergency relief groups for US\$0.035 per sachet, plus shipping.

Flocculation and Chlorination: Implementation Strategies

P&G has recently moved from research and development of the PūR product to research into effective implementation strategies. P&G is investigating social marketing—in partnership with PSI—in Haiti, Pakistan, and Uganda, and distribution during emergency responses.

Emergency Response using PūR

Three hundred thousand PūR sachets were distributed in response to the flooding after Hurricane Jeanne struck Gonaives, Haiti, in September 2004. PSI and CARE staff were trained in the use of the product and, within weeks of the flooding, distributed PūR and educational materials to affected communities. The experience in Haiti highlighted several critical needs for successful dissemination and uptake of PūR in an emergency. Because correct use of PūR requires several steps, the program's success in Haiti was due to well-trained staff who understood the product “trained the trainers” (local community members) and provided them with the skills, knowledge, and materials to teach others through community demonstrations (Bowen et al., 2005). Adequate supplies of instructional and promotional materials in the local language were also very useful.

The lessons learned in Haiti helped inform emergency response procedures elsewhere. In refugee camps in Liberia, John Hopkins University researchers provided the two buckets necessary to use the product, focus group trainings, and demonstrations, and documented a 93.6 percent reduction in diarrheal disease incidence among PūR users compared to a control group of safe storage users (Doocey, 2005). Before the South Asian tsunami in December 2004, five million

sachets of PūR had been procured for emergency response (Greg Allgood, personal communication, February 3, 2005). Since December 2004, more than 16 million sachets have been purchased and transported to tsunami-affected areas in Indonesia, Sri Lanka, and the Maldives by Samaritan's Purse, AmeriCares, and PSI. Samaritan's Purse, UNICEF, World Vision, International Rescue Committee, and the International Federation of the Red Cross have all completed community mobilization and training around PūR, following an initial model established by Samaritan's Purse that provides affected people a cloth, a spoon, soap, an instruction card, and 72 sachets of PūR packaged in two buckets.

Flocculation and Chlorination: Benefits and Drawbacks

The benefits of PūR are:

- Removes or inactivates viruses, bacteria, parasites, heavy metals, and pesticides, even in highly turbid waters;
- Provides residual protection;
- Proven health impact;
- User acceptability, because of the visual improvement in the water; and
- Easily brought to scale or used in an emergency response situation, because the sachets are centrally produced and are easily transported due to their small size, long shelf life, and classification as non-hazardous material for air shipment.

The drawbacks of PūR are:

- Multiple steps are necessary to use the product, thus requiring demonstrations for new users and a time commitment for water treatment from the users;
- Requires two buckets, a cloth, and a stirring device; and
- High relative cost per liter of water treated.

Discussion

Many researchers, private companies, faith-based organizations, international and local NGOs, donors, ministries of health, and end-users are interested in HWTS options and in mechanisms for their implementation. The evidence base for these interventions is well-established and growing, and an active program of further technical and operations research is being pursued on multiple fronts.

HWTS implementation has enjoyed numerous successes. First and foremost, field-based programs have documented reductions of diarrheal diseases in end-users. Factors that contributed to successful programs include:

- The ability to obtain quality HWTS option components (and any replacement parts) locally;
- Behavior change communications including person-to-person communications and/or social marketing; and
- Availability of implementation materials and technical assistance to support on-the-ground implementers.

HWTS implementation projects have also encountered significant challenges, including:

- Questions regarding the health impact of these interventions in large-scale “real-world” situations;
- Long-term sustainability of the projects; and
- Scaling up to efficiently reach the people without access to improved water sources.

Larger studies will demonstrate the health impact of HWTs in real-world settings, and more time will tell us whether these programs are sustainable. Expanding efficiently to global scale will require a creative combination of market, micro-enterprise, and small-scale community-based approaches.

An additional challenge for implementers is choosing the best HWTs option for a program in a given area. Important criteria to consider when selecting an HWTs option include:

- *Community specific needs and preferences:* For example, if the turbidity of the source water is high, pre-treat water with filtration or coagulation before disinfection and safe storage—or, if users prefer a current practice, such as storing water in ceramic pots, incorporate that practice into the project;
- *The mechanism to prevent recontamination of the treated water:* A number of HWTs options incorporate some form of residual protection (SWS, SODIS, GWI, PūR). Safe storage or other mechanisms to prevent post-treatment contamination should be a part of every HWTs project; and
- *The mechanisms (financial and otherwise) to provide sustained availability:* To ensure long-term access to the HWTs option.

Unfortunately, these criteria may not be systematically considered when HWTs interventions are implemented. The authors studied a BioSand Filter installation in a peri-urban slum with access to piped, processed, municipal water—likely not the most cost-appropriate or effective intervention for this setting. An investigation of source water quality before implementation would have discovered this, and potentially a more appropriate intervention—such as improvement of the local water supply, education about safe water storage to prevent recontamination, or chlorination alone—could have been implemented.

In some situations, no HWTs option may be appropriate. While accompanying a U.S. school group on a trip to Mexico to plan a joint Mexico-U.S. student-run SWS project, an investigation showed the existing piped, treated water in the project communities was of good quality, though with sub-optimal residual chlorine (Lantagne, 2004). Although the SWS project was well-intentioned, it was not an appropriate intervention for these communities. Instead, improvements to the existing water treatment and distribution infrastructure were recommended.

A critical piece of every development program is cost; Table 2 summarizes information on the costs of each HWTs option considered here. Costs are highly program-specific; they vary with location, implementation strategy, and desired end-point, and are not fully generalizable. For example, in comparing the GWI and JSWF projects, both of which operate in rural Haiti, we find that the JSWF project requires a smaller subsidy and thus appears the better option. However, the GWI project incorporates a filtration step that the JSWF project does not, and thus treats turbid water more effectively. One must evaluate both the costs and the treatment needs in a community to determine the most cost-effective and appropriate intervention.

When reviewing cost data, it is important to consider them in comparison to the costs of other water and sanitation improvements. A recent cost-benefit evaluation found that all water and sanitation improvements analyzed were cost-beneficial in all regions of the world, with returns of US\$1.92-\$15.02 on each US\$1 invested, depending on region and type of improvement (Hutton & Haller, 2004). However, disinfection at the point of use (the only HWTS option considered in the analysis) had the lowest cost per person when compared to all non-HWTS interventions to provide improved water supply or sanitation. This initial work indicates that HWTS options are cost-effective mechanisms for providing improved water to households.

Future Work

Although much research has been completed on HWTS options, more remains to be done (WHO, 2004; Mark Sobsey, personal communication, March 20, 2005). Further basic field research needed includes:

- Health impact studies:
 - Of the HWTS options that are widely distributed but have not yet been proven effective at reducing disease;
 - Of a large-scale real-world project, such as one of the national or sub-national PSI SWS projects; and,
 - With longer-term endpoints in children, including growth, cognitive development, and mortality.
- Development of real-term, practical parameters and performance measures to predict safety of drinking water in developing countries;
- Investigations of the economic considerations needed to move to large-scale projects, including cost analysis, economic demand assessment, and sustainability; and
- Determination of the relative and absolute impact of HWTS options and other water, sanitation, and hygiene (WASH) interventions, and research investigating optimal combinations of HWTS and WASH interventions.

In addition, important operational research questions remain, including:

- What motivates users to purchase and use a HWTS option?;
- What are current purchase (use) and re-purchase (sustained use) rates in different demographic, socio-economic, and cultural groups, and how do these correlate with waterborne disease prevalence rates?;
- What is the health impact of routine versus sporadic use of HWTS options in the home?;
- What are optimal behavior change strategies for hygiene and sanitation practices and how do we best incorporate these into different HWTS implementation strategies?; and
- What are the most sustainable and cost-effective ways to reach rural and remote areas?

To address these research questions, the HWTS community should continue to work with academic institutions that provide technical knowledge and student labor. The University of North Carolina, Emory University, MIT, Johns Hopkins University, and the London School of Hygiene and Tropical Medicine, among others, have existing programs in public health or engineering departments that research HWTS options. There have been numerous successes, such as the development of a computer model to ascertain SODIS appropriateness for any area of the world using NASA data (Oates et al., 2002).

One question to ponder: whether students are being trained for job opportunities that do not yet exist. The interest in HWTS options is very high at the student level. The HWTS community should seek to identify and coordinate future human resources needs of HWTS research with the growing number of graduates with relevant field experience.

Lastly, HWTS options simply need to be implemented at scale, in conjunction with other water and sanitation programming, in order to help reduce disease burden and alleviate poverty. A diverse array of creative partners, with adequate capital and technical support, will be needed to complete this work.

Conclusion

HWTS systems are proven, low-cost interventions that have the potential to provide safe water to those who will not have access to safe water sources in the near term, and thus significantly reduce morbidity due to waterborne diseases and improve the quality of life. HWTS implementations have developed from small pilot projects to national-scale programs, and now face questions on how to reach the more than 1.1 billion in need of safe drinking water, and how to effectively work with other water, sanitation, and hygiene programs to achieve the greatest health impact. The active, diverse, and expanding community of researchers, private companies, faith-based organizations, international and local NGOs, and donors interested in answering these questions can play a major role in helping the world achieve the Millennium Development Goal to halve, by 2015, the proportion of people without access to safe water (World Bank Group, 2004). To achieve this goal, and to surpass it, will require continued collaboration, research and development, and investment, but it is our best hope for rapidly reducing the burden of waterborne disease and death in developing countries.

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APPENDIX A: Tables

Table 1: Summary of HWTS Option Performance Criteria

Criterion HWTS Option	1: Lab Studies				2: Field Studies		3: Can intervention be brought to scale?
	Virus	Bacteria	Protozoa	Residual Protection?	Acceptable to users?	Health impact?	
Chlorination	Medium	High	Low	Chlorine	Yes	Yes 4 studies	Yes – operates at village and national scale
BioSand Filtration	Unknown	Medium-High	High	No	Yes	Unknown	Unknown - operates at village and regional level
Ceramic Filtration	Unknown	Medium-High	High	No	Yes	Yes 1 study (imported filters)	Unknown – operates at village and regional scale
Solar Disinfection	High	High	High	Safe Storage	Yes	Yes 4 studies	Unknown - operates at village and regional scale
Filtration and Chlorination	Medium	High	Unknown	Chlorine	Yes	Yes 1 unpublished cross-sectional study	Unknown - operates at village and regional scale
Flocculation and Chlorination	High	High	High	Chlorine	Yes	Yes 5 studies	Yes – operates at village and national scale

Table 2: Cost of HWTS Options

HWTS Option	Project Location and Implementer	Cost of Product to User	Full Cost of Product ¹	
			Initial equipment	Ongoing Cost
Chlorination	Zambia, PSI	1 bottle of chlorine solution at 0.12 USD per family per month	Accounted for in cost of bottle.	0.37 USD per bottle of chlorine solution (0.25 USD per bottle subsidized by donor)
Chlorination	Haiti, JSWF	1 bottle of chlorine solution at 0.09 USD per family per month	7 USD start-up fee per family paid by NGO	0.09 USD per family per month for chlorine solution (no subsidy)
BioSand Filtration	Cambodia, Samaritan's Purse	One-time cost of 3 USD to family for BSF	67 USD per BSF paid by NGO covers all expenses	None
Ceramic Filtration	Nicaragua, Potters for Peace	None	10 USD for filter paid by NGO covers all factory expenses	Unknown
Solar Disinfection	Indonesia, local NGOs	None	None	0.80 USD paid by NGO per capita reached in 14-month project
Filtration and Chlorination	Haiti, GWI	1.71 USD per family for filter 0.12-0.34 USD per family per month for chlorine	12-15 USD paid by NGO per family for filter	4 USD paid by NGO per family per year for education / replacement filters
Flocculation and Chlorination	South Asia Tsunami, Emergency Response	None	Unknown	0.07 USD per day per family for sachets

¹Including delivery, installation, distribution, education, marketing, overhead, and other costs.

APPENDIX B: Photos



The PSI/Zambia Clorin Product
Photo Credit: SFH/Zambia



The Jolivet bucket and product
Photo credit: Genevieve Brin



The PFP Filter
Photo credit: Daniele Lantagne

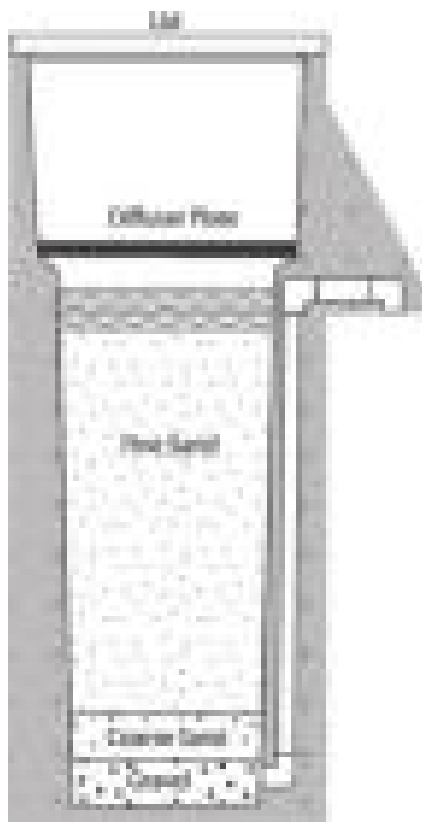


The PFP filter in use in rural home
Photo credit: Daniele Lantagne



SODIS

Photo credit: SODIS Website



Biosand Filter

Photo credit:



The GWI Filter in Haitian Home
Photo Credit: Daniele Lantagne



A GWI Technician with Filter
Photo Credit: Daniele Lantagne



PUR Purifier of Water
Photo Credit: Procter and Gamble