Engineering Inputs to Increase Impact of the CDC Safe Water System Program

D. S. Lantagne, PE[1]

1 Foodborne and Diarrheal Diseases Branch, U.S. Centers for Disease Control and Prevention

Corresponding Author:

Daniele Lantagne, PE

Foodborne and Diarrheal Disease Branch, M/S A-38

Centers for Disease Control and Prevention

1600 Clifton Road NE

Atlanta, GA, 30333

404.639.0231 (phone)

404.639.2205 (fax)

dul4@cdc.gov

Introduction

In September 2000, the United Nations General Assembly adopted the Millennium Development Goals (MDGs) to promote "human development as the key to sustaining social and economic progress" (World Bank Group, 2004). One MDG target is to "halve, by 2015, the proportion of people without sustainable access to safe drinking water (1.1 billion) and basic sanitation (2 billion)" (World Bank Group, 2004). The world is on schedule to meet this water supply target (WHO/UNICEF, 2004); however, even if the goal is met, over 600 million people will still lack access to safe water in 2015 (WHO/UNICEF, 2000). Also, although the MDG target specifically states the provision of "safe" drinking water, the metric to assess the target is provision of water from "improved" sources, such as boreholes or household connections, as assessing whether water is safe at the household level is difficult (WHO/UNICEF, 2004). Thus, many people who drink unsafe water from improved sources will not be impacted by the MDG.

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, 1993), and impaired physical growth and cognitive development (Guerrant, 1999).

The Safe Water System

Chlorination was first used for disinfection of public water supplies in the early 1900's; and is a factor that contributed to drastic reductions in waterborne disease in cities in the developed world (Cutler, 2005). Although small trials of point-of-use chlorination had been implemented in the past (Mintz, 1995), larger scale trials began in the 1990's, 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: 1) water treatment with dilute sodium hypochlorite at the point-of-use; 2) storage of water in a safe container; and, 3) education to improve hygiene and water practices. In four randomized controlled trials, use of the SWS has resulted in diarrheal disease risk reduction from 44-84% (Luby, 2004; Quick, 2002; Quick, 1999; Semenza, 1998).

SWS implementation has varied according to local partnerships and social and economic conditions. The disinfectant solution has been disseminated in 13 countries at national and subnational levels through social marketing in partnership with the NGO Population Services International (PSI). In Ecuador, Laos, Haiti, and Nepal, the Ministry of Health or a local NGO have implemented the SWS program at a community level. The SWS has also been made available free of charge in a number of disaster settings, including Indonesia, India, and Myanmar following the 2004 tsunami, and in Kenya, Bolivia, Haiti, Indonesia, and Madagascar after other natural disasters.

Engineering Input: Standardized Methodology, Dose Factor, and Regionalization

The SWS sodium hypochlorite solution (‘product’) is packaged in a bottle instructing users to add one full 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. From 1993-2003, CDC assisted PSI in eight countries, and NGOs or government ministries in six additional countries, to establish SWS projects. In each location, the best packaging option for the solution was selected from available existing plastic bottles and caps, or by contracting in-country for new bottle and cap designs. A dosing strategy and sodium hypochlorite concentration were selected after some chlorine dosage testing. This strategy led to widely varying products, often with 22-mm diameter standard caps with a volume of 8-10 mL (Figure 1). These large volume caps necessitated a low sodium hypochlorite concentration to ensure correct dosing.

Figure 1. Initial SWS Products (Bolivia, Peru, Zambia, Uganda, Kenya, India, Madagascar)

One drawback of widely varying products is difficulty in comparing dosing strategies. In order to compare dosing strategies across packaging options, a loading factor was developed. This factor, termed the "dose factor", is simply the hypochlorite concentration in percent multiplied by the amount of hypochlorite solution in mL added to 20 Liters of clear water for treatment. The units of this factor are %-mL, which are convenient for use (Equation 1), but more scientifically, the dose factor is the concentration of sodium hypochlorite added to 20 Liters of water (Equation 2).

$$\text{Dose Factor } (\%\text{-mL}) = \text{Hypochlorite Concentration } (\%) \times \text{Amount added to 20 liters (mL)} \qquad \textbf{(1)}$$

$$\text{Dose } (\text{mg/L}_{\text{w}}) = \frac{\text{Hypochlorite Concentration } (\text{mg/L}_{\text{Cl}}) \times \text{Amount added } (\text{mL}_{\text{Cl}}) \times {}^{1\text{ L}}\!/_{1000\text{ mL}}}{20\ (\text{L}_{\text{w}})} \qquad \textbf{(2)}$$

Large variation was seen in the dose factor of the initial SWS products (1.6-8.0, median 4). In order to determine the cause of this variation, a consistent methodology to complete dosage testing for SWS implementation was developed and has since been completed in 15 countries. This methodology is: 1) collecting three 20-Liter containers of water from six representative sources; 2) testing source water for turbidity, pH, conductivity, and chlorine residual; 3) adding a dose factor of 1.875, 3.75, and 7.5 of sodium hypochlorite to one container from each source; and 4) testing of free and total chlorine residual at 1, 2, 4, 8, and 24 hours after chlorine addition to determine the dose factor that leads to a free chlorine residual value that is less than 2.0 mg/L at 1 hour after addition, and greater than 0.2 mg/L at 24 hours after addition. This free chlorine residual range was selected because of user acceptability concerns above 2.0 mg/L free chlorine, and because less than 0.2 mg/L chlorine may not adequately protect water from recontamination. This range meets the World Health Organization guidelines for free chlorine in drinking water (WHO, 2005).

In 73 (84%) of 87 unchlorinated water samples from 13 countries, a dose factor of 3.75 for 'clear-appearing' water, and 7.5 for 'dirty-appearing water', was appropriate. The remaining 14 (16%) of samples had excessive turbidity (57%), metals leading to chlorine demand (21%), or were best treated with a dose factor of 1.875, or between 3.75 and 7.5 (21%). In Angola, 11 of 12 waters tested fell into this 3.75 / 7.5 dose factor regime (Figure 2). The Luanda water at the treatment plant (the tanker truck filling station) was already chlorinated and thus contained over 2.0 mg/L free chlorine at all times, and the river water had higher chlorine demand, necessitating a dose factor of 7.5.

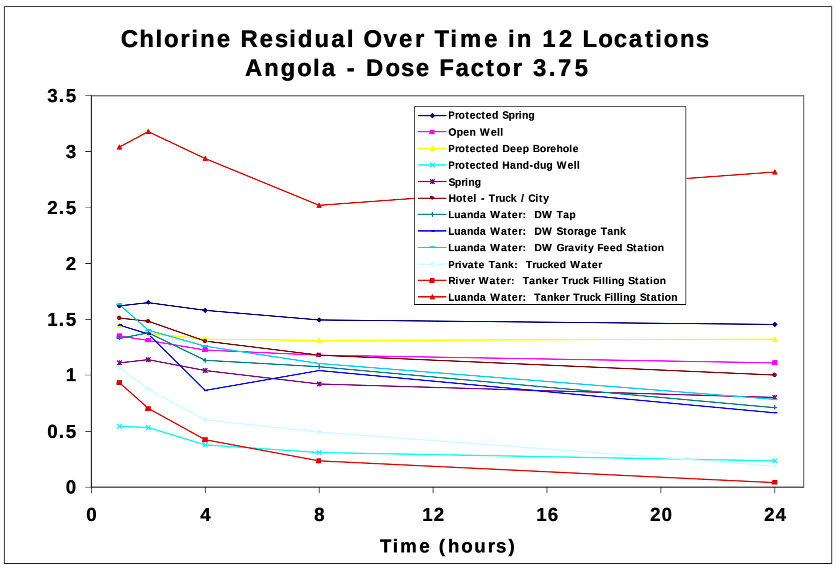

Figure 2. Dosage Testing Results in Angola

These consistent results are in contrast to the wide dosage range seen in the initial products. The wide initial range can be attributed to compromises on dosing to fit available bottles, inconsistent testing methodology, and testing of unrepresentative water sources in pilot project areas.

This consistency has enabled the design of a standard product. By analyzing design variables, dosing requirements, and constraints such as transport considerations and label size available; a 150 mL bottle with a 3 mL cap and 1.25% hypochlorite solution was chosen. This bottle will treat 1,000 Liters of clear water using a one-cap per 20 Liters dosing regime (dose factor 3.75), and lasts a family of 5-6 persons approximately one month.

The social marketing NGO PSI is adopting this ideal product regionally. PSI operates in 70 countries, designing a brand name for health products, selling them at low cost, distributing them through wholesale and retail commercial networks, and generating demand through behavior change communications, such as radio and TV spots, mobile video units, point-of-sale materials, theater, and person-to-person communication. Currently, PSI has SWS programs in 13 countries, with eight additional countries anticipated to launch by mid-2006. PSI has sold over 12 million bottles of SWS solution through 2004, and has adopted or will adopt the regional product in 13 countries, including Kenya (Figure 3).

Figure 3. PSI Kenya Regional Product

PSI implements the regional product by importing a bottle mold (2,200 USD) for installation in a local plastics company. A 12,000 USD investment in the design and manufacture of a 3-mL volume cap mold (AMM Engineering, Nairobi, Kenya), and production of the caps by BlowPlast Industries (Nairobi, Kenya) for the inexpensive cost of 0.011 USD each, allows programs in other countries to access the difficult to produce, but easily transportable, caps. The regional product has significantly reduced product cost (55% cost reduction in Madagascar), simplified project initiation, and greatly facilitated the importation of product from neighboring countries in emergencies. These benefits have moved the SWS program operated by PSI from country-level impact towards at-scale impact across regions of Africa and Asia.

Conclusion

The Safe Water System is a proven, low-cost intervention that has the potential to provide safe drinking water to those who will not have access to treated infrastructure water in the near term, and to significantly reduce morbidity due to waterborne diseases and improve the quality of life. As the SWS has moved from pilot projects to at-scale implementation, engineering inputs were critical to ensure effective, high quality products, designed considering the end-points of ease-of-use and cost-effectiveness. To achieve the Millenium Development Goal, and to surpass it, will require continued collaboration between engineers, public health professionals, and in-country implementers of this intervention. This, and similar point-of-use treatment programs, are our best hope for rapidly reducing the burden of waterborne disease and death in developing countries.

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