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August 2007

Field Note

Improving Household Drinking Water Quality

Use of Ceramic Water Filters in Cambodia

Ceramic filter pilot projects (2002-2006) in Cambodia have yielded promising results that suggest these interventions can be effective in improving drinking water quality and can contribute to substantial health gains in populations using them.

Contents

A glossary of terms used in this note related to water quality, surveys and statistical analysis can be found in the back of this field note, on pages 38 - 40.

The exchange rate used in this note is 1$ = 4000 Riel

Filters ready for firing at the RDI factory in Kandal

Executive Summary

Household-scale ceramic filtration technology is considered among the most promising options for treating drinking water at the household level in developing countries (Lantagne 2001; Sobsey 2002; Roberts 2004). Its use is Cambodia is widespread and growing, with the involvement of local and international NGOs and government efforts that have been supported by UNICEF, WSP-Cambodia, and others. Although several different kinds of ceramic filters are used for household-scale water treatment worldwide, among the most widespread is that promoted by Potters for Peace, a US and Nicaragua-based NGO; the Cambodian version is known as the Ceramic Water Purifier (CWP). It has been used in Cambodia since its introduction in 2001.

Based on early successes in Cambodia (Roberts 2004), further investment in the technology is planned by NGOs and the Cambodian government. Stakeholders identified evaluation of the CWP experience to date in the country as vital to inform the scale up process and to identify lessons learned in the first 4 years of production and implementation. Part of this evaluation was an independent study commissioned by UNICEF and WSP-Cambodia to critically examine two major implementation efforts to date in Cambodia undertaken by the two main producers, IDE and RDI. The goals of the study were to characterize the microbiological effectiveness and health impacts of the CWP in target populations, and to identify successes and potential challenges facing the scale-up and implementation of the technology. The results of the study and program recommendations are presented here.

In order to examine continued use of the filters in households and identify predictors of long term use, we randomly selected and visited approximately 25% of the 2000 households that originally received the filters in 13 villages and in three provinces as long as 4 years ago. These households comprised a sample spanning variability in geography and demographics, time since implementation (0 to 44 months before the study), water sources, implementation method, and filter producer. Households still using the filter (and matched control households, never using the filter) were followed for 3 additional visits that included collection of water samples and health data to determine the impacts of the filters on water quality in the home and associated levels of diarrheal disease.

Impregnating the filters with silver nitrate improves bacterial removal

Households using the filter reported nearly half the cases of diarrhea as matched control households without a filter.

Results from the study suggest that the filters can significantly improve household water quality (up to 99.99% less E. coli in treated versus untreated water), although the filters were susceptible to breakage in household use (about 2% per month, post-implementation) and contamination through improper handling practices. Households using the filter reported nearly half the cases of diarrhea as matched control households without a filter. Results suggest that filters may be used longer and more effectively by households when other water, sanitation, and hygiene (WSH) interventions are bundled with the CWP; that access to replacement filters and spare parts is key to ensuring long-term success of CWP programs; and that cost recovery is positively associated with continued use. Other key findings and programmatic implications are outlined to inform current and future CWP efforts in Cambodia and in the region.

Study Background

The NGOs International Development Enterprises Cambodia (IDE) and Resource Development International (RDI) have been manufacturing and distributing Ceramic Water Purifiers (CWPs) in Cambodia since 2001 and 2003, respectively. IDE established a production facility in Kampong Chhnang and supported construction of a factory in Prey Veng, which is owned and

Box 1: Household water treatment in Cambodia

For the estimated 66% of Cambodians without access to improved drinking water sources (NIS 2004) and the potentially much greater percentage without consistent access to microbiologically safe water at the point of use, household-based water treatment can play a critical role in protecting users from waterborne disease. Surface water in Cambodia is plentiful but often of very poor quality, due in part to inadequate or nonexistent sanitation in rural areas. Only 16% of Cambodians have access to adequate sanitation facilities (ibid.). Some groundwater sources in the country are also known to contain high levels of naturally occurring arsenic and other chemical contaminants (Feldman et al. 2007; Polya et al. 2005). Arsenic in the groundwater is an especially urgent problem in parts of the lower Mekong delta region where there is a high population density. The first cases of arsenicosis in Cambodia were reported in August 2006, in Kandal province (Saray 2006). Surface water and shallow groundwater (often of poor microbiological and aesthetic quality) and rainwater catchment (susceptible to contamination during storage) are the principal alternatives to arsenic-contaminated deep wells.

Due to the poor quality of available drinking water sources and the lack of centralized systems for delivering safe water to households, Cambodia has become a major locus for household water treatment research and implementation. The reality for most Cambodians today is that they must collect water, store it for use in the household, and treat and protect it themselves if they are to have safe water. An estimated 200,000 people (1.5%) already use some form of filtration (sand or ceramic) or chemical treatment at the household level. In addition, many more treat some or all household drinking water using coagulants, traditional cloth filters, or boiling.

Waterborne diseases, in part due to degraded drinking water sources, are a major public health issue in Cambodia. Cholera, for example, is endemic in Cambodia, with more than 1000 cases reported per year throughout the country and major localized outbreaks reported in 1998 and 1999 (WHO 2006). Diarrheal diseases are the number one cause of death and disease in children, with prevalence consistently around 20% for a two-week recall period (NIS 2000). Household-based water treatment and safe storage can provide users with protection against waterborne pathogens where safe water sources and other treatment options are scarce. Recent systematic reviews of field trials established that household-scale water quality interventions can be effective in reducing the burden of diarrheal disease, with mean reductions of 39% - 44% in users versus non-users (Clasen et al. 2006b; Fewtrell et al. 2005).


A demonstration of the CWP at village level. In this case, interested households can buy a filter on the spot

Interventions

There are now three factories in Cambodia producing a total of approximately 5500 CWPs per month (with current capacity up to 7000 per month), which are directly marketed to consumers via individual NGO-supported and independent retailers, distributed at subsidized and market prices in NGO interventions, and sold to other NGOs and the Cambodian government for use in projects around Cambodia (via several implementation models). The first 4 years of experience in establishing and scaling up production and implementation of ceramic filter technology has resulted in substantial

operated by the Cambodian Red Cross. RDI manages a factory in the Kien Svay district of Kandal Province. Both NGOs have performed internal studies to evaluate the ability of CWPs to provide microbiologically safe water to households, including laboratory and field assessments early in their respective programs. Results from these studies were promising, showing improved water quality and substantial decreases in diarrheal disease among users (Roberts 2004). The current study was intended to independently evaluate the microbiological effectiveness and health impacts of the CWP programs and to highlight successes and potential challenges to current and future implementation efforts. Key questions identified by stakeholders were:

- Do the filters substantially improve the quality of water users drink?
- Do the filters contribute to measurable health gains in users versus non-users?
- How do these factors change over the useful life of the filter?
- How long are filters being used by households?
- What factors contribute to successful long-term use in the target population?


Typical filter set-up at home

> Locally produced ceramic pot-style filters have the advantages of being lightweight, portable, relatively inexpensive, chemical free, low-maintenance, effective, and easy to use.

Box 2: Local ceramic water filter technology

Ceramic filtration is the use of porous ceramic (fired clay) to filter microbes or other contaminants from drinking water. Pore size can be made small enough to remove virtually all bacteria and protozoa by size exclusion, down to 0.2µm, in the range referred to as microfiltration. Small-scale ceramic filtration has a long history, having been used in various forms since antiquity (Sobsey 2002). Locally produced ceramic pot-style filters have the advantages of being lightweight, portable, relatively inexpensive, chemical free, low-maintenance, effective, and easy to use. The filters provide for removal of microorganisms from water by gravity filtration through porous ceramics, with typical flow rates of 1-3 liters per hour. They cool the treated water through evapotranspiration and, used with a proper storage receptacle, safely store water for use. There are no significant taste issues, as have been the case with chlorine-based disinfection (Roberts 2003; Clasen et al. 2004). They have functional stability in the sense that they have only one moving part (the tap) and require no external energy source (such as UV lamps) or consumables (such as chlorine packets, or media that must be regenerated or replaced). They have a potentially long useful life of 5+ years (Lantagne 2001b; Campbell 2005) with proper care and maintenance (although implementers often recommend regular replacement of the filter element every 1-2 years). The ceramic filter surface is regenerated through regular scrubbing to reduce surface deposits which slow filtration rates; so the useful life of a ceramic filter depends on the frequency of cleaning, and thus the quality of water being treated, and the thickness, since repeated cleaning will eventually wear away the filter surface. Costs of filters vary, but most retail in the US$5 – US$25 range. Since filters can be made locally by the private sector, they can also provide a source of income in poor communities, although most production of the pot-style ceramic filters worldwide to date is NGO-based.

Inspection and smoothing of newly pressed filter pots

improvement of the technology and more successful strategies for putting them to use in the field.

Approximately 1000 household filters were introduced by Resources Development International (RDI) in Kandal Province from December 2003 and 1000+ filters by International Development Enterprises (IDE) in Kampong Chhnang and Pursat provinces from July 2002. These interventions were the subject of this study, as the two largest CWP implementation efforts to date in Cambodia. In 2003, IDE completed an internal field study of the CWPs after one year in use (Roberts 2004). In 2005, RDI completed a similar internal field study for filter distributions in Kandal province (unreleased). The present study follows up on these previous assessments and represents an independent appraisal of the performance of these two major CWP efforts undertaken in 2002-2006.

Study Design and Methods

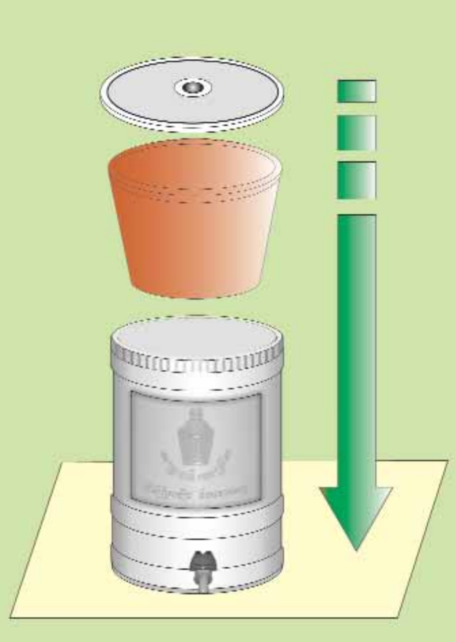
The study was carried out in three parts:

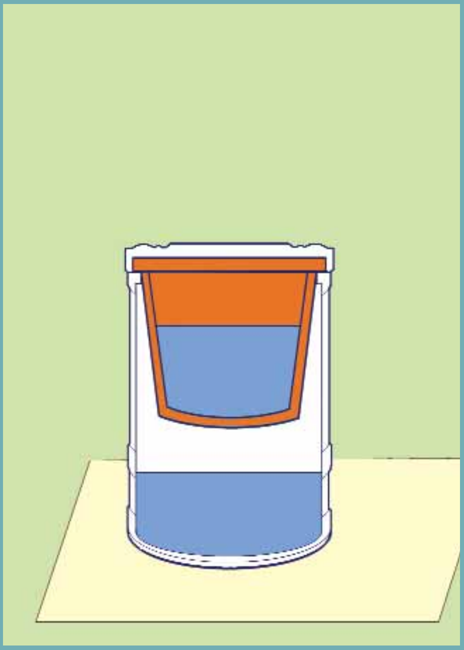
(1) a cross-sectional study of households that originally received filters to determine uptake and use rates, as well as factors associated with continued use of the technology;

(2) a water quality assessment in 80 households successfully using the filters (from part 1) to determine the microbiological effectiveness of the filters in treating household water, focusing on both treated and untreated water; and

(3) a longitudinal health study comparing diarrheal disease prevalence in 80 households using the filters successfully to 80 control households (without filters). Control households were matched by water source, socio-economic criteria, demographic data, and physical proximity. Water quality data were collected for control households as well, including stored, boiled water samples, if available.

Neither floods, nor rain nor heat stopped the field surveyors from the swift completion of their appointed household interviews





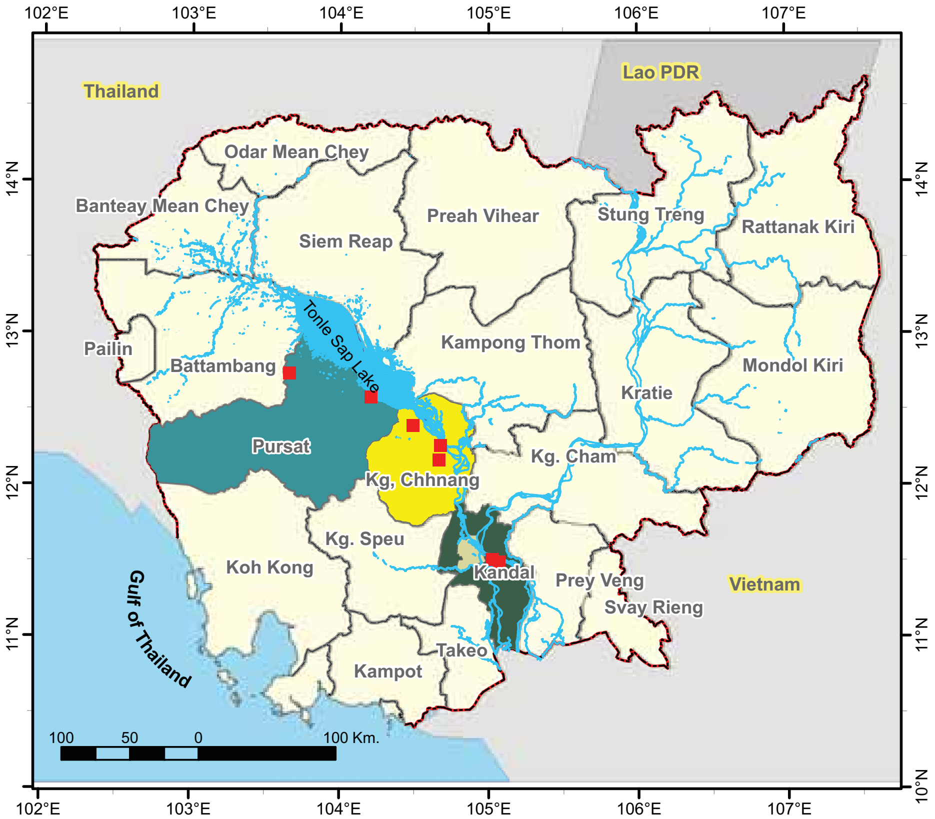
The ceramic water purifier (CWP) is a flower pot shaped (ie, "pot-style") ceramic filter. Porosity in the ceramic (< $1\mu m$ and larger) is created by mixing burnout material into the unfired clay, which is typically very fine sawdust, ground rice husks, or some other combustible material that disintegrates during the firing process to leave behind pore space. Water passes through the porous ceramic filter element (capacity approximately 10 liters) at 1-3 liters/hr into the receiving container (10-20 liters), where it is dispensed via a tap to prevent post-filtration contamination of the product water through dipping or other contact with soiled hands or vessels. Filters are often treated with a silver compound or other agent to inhibit microbial growth in the filter and possibly to enhance microbiological effectiveness. Porous ceramic filters vary widely in design, effectiveness, and cost. The model for the CWP is the ICAITI filter developed in Latin America in the early 1980s (AFA Guatemala 1995), promoted widely by the NGO Potters for Peace.

> In order to evaluate the successful adoption of the filters, 600 households were randomly selected from the original 2000 households that received filters in three provinces.

Cross Sectional Study of Filter Uptake and Use

In order to evaluate the successful adoption of the filters, 600 households were randomly selected from the original 2000 households that received filters in three provinces. Of these, 506 could be located and consented to participate, and so were included in the cross-sectional assessment. After obtaining informed consent from the head of household (and primary caregiver for the children, if a different person), the data collection team first determined whether the filter was in current use. Criteria for 'current use' were that the filter (i), was in good working order (filter element, tap, and receptacle intact and apparently functional) and (ii), that it contained water or was damp from recent use. Since filters typically take 3 or more days to dry completely, filters that were dry were not considered in current use. Each household was scored on filter use and a questionnaire was administered to the adult primary caregiver for the household, usually an adult female. Data on basic household demographics and socio-economic status, household water handling and use, sanitation, health and hygiene behaviors, and other factors thought to be related to CWP adoption were collected. Observational data related to these variables were also noted by the field data collection team. All survey instruments were prepared in both English and Khmer before use in the study; they were pre-structured and pre-tested by back-translation from Khmer to English and used in pilot interviews to determine suitability of content and structure, reliability, and consistency. Surveys used simple, straightforward language with predominantly closed (multiple choice) questions. Individual survey questions were prepared in some cases based on input from previous questionnaires used by RDI and IDE in their own internal assessments of the CWP interventions for comparability purposes. The data collection field team was composed of four interviewers who were native Khmer speakers and had related experience in community health data collection. The team underwent rigorous training in interviewing methods before the start of the study.

The main outcome variable in the cross sectional survey was filter use at the time of follow up. A logistic regression model was employed using filter use at time of follow up as a binary outcome variable. Measured covariates were tested for independent associations with the filter use at time of follow up, controlling for time since implementation coded as a categorical variable with time in 6-month blocks.



This map indicates the general areas where the study was carried out. Each marker may encompass multiple villages.

[This map is for illustrative purposes and does not imply the expression of any opinion on the part of the authors or publishers of this report concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries]

Home owner (on right) showing off a newly purchased filter

Longitudinal Study of Filter Effectiveness and Health Impact

Households identified in the cross-sectional study that were successfully using the filters were asked to participate in a further study of filter effectiveness and family health. Since diarrheal disease in children was a main outcome of interest to the study, only households with one or more children under 5 years of age were eligible. Additional criteria for eligibility were that households stored water in the home, relied on an untreated water source for the majority of household drinking water, and have an eligible control household identifiable by the study team. For each household with a CWP enrolled in the study, a neighborhood matched control household was recruited. Households recruited to be controls shared the same water source as the corresponding intervention household, were in a similar socio-economic stratum as determined by questionnaire data (reported household income estimate, reported monthly electricity payment, household inventory of possessions) and observational data (e.g., house construction), be within one kilometer of the intervention household, also have at least one child under 5 years of age, store water in the home, and rely on an untreated source for drinking water. Control households were intended to be as similar as possible to those households using the filter successfully, with the exception that control households did not use (and never used) a CWP. Some households in both groups treated their drinking water by boiling or other means; use of other methods of drinking water treatment were not considered in determining eligibility for inclusion in the study. All households participating in the water quality and health study were offered a new water filter (gratis) for their cooperation. Details of the cohort are presented in table 8. Participating households were randomly selected from all eligible consenting households within the three provinces, from thirteen rural villages.

The 160 households in the water quality and health study (80 in each group) were visited three times each. At each visit, the field team collected 250ml samples of water from untreated stored household water and additional 250ml samples of treated water (either from the filter, stored boiled water, or both). All samples were stored cold until analysis as soon as possible in the laboratory for E. coli and total coliform, pH, and turbidity using standard methods (Clesceri et al. 1998). Samples in Kandal province were analyzed the same day; samples collected in Kampong

Filters are easy to use and always within reach… A satisfied user

During the study period, 48% of households reported using surface water as their primary drinking water source.

Chhnang and Pursat provinces were stored up to 36 hours before analysis.

The household primary caregiver was interviewed to determine diarrheal disease episodes for each family member within the previous 7 days. Additional data on water handling and use, sanitation, health and hygiene, filter care, use, and user satisfaction were also collected at household visits, using survey instruments and direct observation. All instruments and methods were approved by the Biomedical Institutional Review Board on Research Involving Human Subjects, Office of Human Research Ethics, The University of North Carolina at Chapel Hill, USA, and the Ministry of Rural Development, Kingdom of Cambodia.

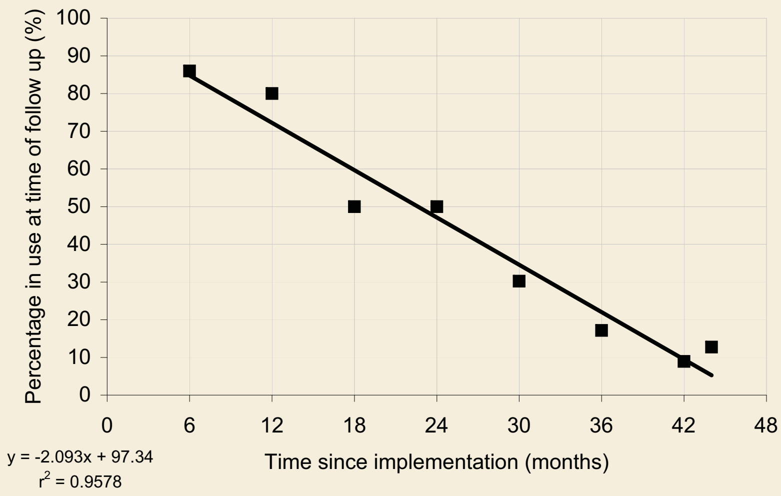
Water quality and interview data were initially analyzed using stratified analyses to identify trends (microbial concentrations in water as well as physical-chemical water quality and diarrheal disease prevalence measures). Longitudinal data were analyzed for differences between the two household groups, those with CWPs (intervention) and those without (control). To control for clustering of diarrheal disease within households and within individuals over time, a Poisson extension of generalized estimating equations (GEE) was employed in log-risk regression analysis (Zeger and Liang 1986; Liang and Zeger 1986), a standard tool used in the analysis of longitudinal health data. Potentially confounding variables in the analytical model were (i) those that affect the exposure in the study population (e.g., factors associated with continued use of the filter); and (ii) those that are risk factors for the outcome of diarrheal disease in the control group. Confounders were identified based on an a priori change-in-estimate criterion of 10%. Measured factors related to socio-economic status (SES); demographics; and other water, sanitation, and hygiene-related variables were examined for potential confounding of the estimate of effect on diarrheal disease due to CWP use.

Health effect measures reported are the prevalence proportion of diarrheal disease in both study groups and the risk ratio (RR) computed as the risk of diarrheal disease among the cohort using the filter intervention divided by the risk of diarrheal disease experienced by the control group, adjusted for clustering within individuals over time and within households. Longitudinal prevalence of diarrheal disease in children has been shown to be a powerful predictor of mortality in children in developing countries (Morris et al. 1996).

Results

A total of 506 households with an average of 5.9 people per household were included in the cross sectional component of the study (total number of persons = 2965, 52% female). A number of households (64, 11%) could not be found as GPS or other locating information was not included with the original implementation records for some households. Other households (29, 5%) had moved during the intervening years. One household (<1%) declined to participate in the study. Table 1 presents data for all households with estimated odds ratios as indicators of association

Figure 1: Percentage of filters remaining in household use as a function of time, with time as a categorical variable (6 month increments).



Using a filter is kid's play; the only moving part is the tap

between measured quantities and the binary outcome of filter use at the time of household visit. Odds ratios were calculated based on all households using filters versus those not currently using filters adjusted for time in use. Odds ratio estimates greater than one suggest a positive association between the factor and filter use; odds ratios less than one indicate a possible negative association (Table 1).

Water, Sanitation, and Hygiene (WSH)

As households were recruited from across three provinces and several villages, a wide variety of water use and handling practices were observed, all of which varied greatly by province. During the study period of February – April (dry season), 243 households (48%) reported using surface water (lake, pond, river, stream, or canal) as a primary drinking water source; 79 (16%) reported use of a deep well (defined here as ≥10m in depth); 152 (30%) used a shallow well; 39 (8%) used stored rainwater from the previous rainy season; and 9 households (2%) reported using bottled drinking water. The distribution of prevalent drinking water sources varied with the region. Respondents were asked to estimate the distance to the primary drinking water source: 340 (67%) of sources were within 100m, 128 (25%) were between 100-500m, and 38 (8%) were >500m away.

All households encountered in the study used one or more water storage containers to store water inside or (more commonly) outside the home; 164 (32%) used one or more uncovered containers (unsafe storage). Containers were most commonly ceramic or concrete vessels of traditional design. Respondents were asked to demonstrate the usual method of collecting water from the container for drinking. A total of 220 (43%) of the respondents dipped hands or a cup directly into the container, while 286 (57%) used a tap or a dipper which was then poured out into a cup for drinking.

Of the 506 households included in the study, 194 (38%) had access to sanitation (either the household's own or a shared latrine). None of the households were connected to a conventional sewerage system. Sanitation access varied greatly by location; in Kandal, 71% of households had access to a latrine, versus 14% in Kampong Chhnang and 26% in Pursat. The difference here is due to the fact that study sites in Kandal were relatively wealthier and also because increasing access to sanitation had been one of RDI's efforts linked to CWP implementation in some communities. Therefore, households that had received filters were more likely to have received sanitation access as well.

Respondents were asked whether and how often they and members of their family washed their hands, for example after defecating and before preparing food. 175 (35%) of household caregivers indicated that s/he washed hands "always" with soap and water at critical points such as after defecating or before preparing food. Respondents were also asked to demonstrate that there was soap in the household at the time of the visit; 339 households (67%) were able to produce it. Additionally, 114 respondents (23%) reported receiving health education relevant to water, sanitation, and hygiene. Of these, 18 (16%) reported receiving information from family and friends, 87 (76%) from a health worker or NGO, 78 (68%) from radio, 103 (90%) from television, and 1 (1%) from school.

Table 1: Data summary & estimated odds ratios for selected factors. Odds ratios are adjusted for time elapsed since implementation.

	Using filter[a] at time of follow up (156 households)	Not using filter at time of follow up (350 households)	OR (95% CI) Adjusted[b]
Caregiver reported receiving health education[c]			
Yes	31 (20%)	83 (24%)	0.74 (0.42-1.3)
No	125 (80%)	267 (76%)	
Soap observed in household[d]			
Yes	119 (76%)	220 (63%)	1.7 (1.0-3.0)
No	37 (24%)	130 (37%)	
Purchased filter[e]			
Yes	112 (72%)	99 (28%)	2.1 (1.2-3.7)
No	44 (28%)	251 (72%)	
Living on less than 1 USD per day per person in household[f]			
Yes	49 (31%)	186 (53%)	0.68 (0.42-1.2)
No	107 (69%)	164 (47%)	
Access to sanitation[g]			
Yes	102 (65%)	92 (26%)	2.4 (1.5-4.0)
No	54 (35%)	258 (74%)	
Safe storage practices observed[h]			
Yes	118 (76%)	224 (64%)	1.6 (0.94-2.7)
No	38 (24%)	126 (36%)	
Caregiver reports washing hands "always"[i]			
Yes	76 (49%)	100 (29%)	1.6 (1.0-2.6)
No	80 (51%)	250 (71%)	
Main drinking water sources during study (dry season)[j]			
Surface water	98 (63%)	145 (41%)	1.7 (1.1-2.7)
Groundwater	41 (26%)	190 (54%)	0.56 (0.34-0.94)
Deep well (≥10m)	14 (9%)	65 (19%)	0.38 (0.18-0.79)
Shallow well	27 (17%)	125 (36%)	0.91 (0.50-1.7)
Rainwater	23 (15%)	16 (5%)	1.4 (0.64-3.0)
Bottled water	2 (1%)	7 (2%)	0.53 (0.08-3.4)
Observed method of collecting household stored water[k]			
Use hands	70 (45%)	150 (43%)	0.90 (0.56-1.4)
Pour, tap, or designated dipper	86 (55%)	200 (57%)	
Months since implementation[l]			
0-5	49 (31%)	8 (2%)	0.56 (0.50-0.63) (per 6 month increase)*
6-11	12 (8%)	3 (1%)	
12-17	16 (10%)	16 (5%)	
18-23	32 (21%)	31 (9%)	
24-29	14 (9%)	30 (9%)	
30-35	6 (4%)	29 (8%)	
36-41	11 (7%)	112 (32%)	
42-48	14 (9%)	96 (27%)	

a. Regular (daily) use, as determined by interview and by visual inspection. Percentages within strata may not add to 100% due to rounding.
b. Odds ratio estimates adjusted for time since implementation, coded as a categorical variable in 6 month blocks, except *.
c. Water, health, hygiene, or sanitation education from any source (school, NGO, media, etc).
d. Respondents were asked to demonstrate that soap was present in the household.
e. Any price. Prices paid for filters ranged from 1000 – 10,000 riel (US$0.25 – $2.50). Actual cost is US$4-$8.
f. Based on self-reported monthly income and number of members in household.
g. Shared or own latrine.
h. Safe storage was defined as using a covered or narrow mouth water storage container and a designated water dipper to collect water.
i. Caregiver responds that s/he washes hands “always” with soap at critical points such as after defecating and before preparing food.
j. Multiple answers possible.
k. Respondents were asked to demonstrate their usual method of gathering water from the storage container.
l. Based on NGO records from the original installation, the manufacturing date stamped onto the filter, or users’ estimates.

After firing the pots, making sure that the flow rate is within the acceptable range is an essential quality control step

Ninety-two percent (92%) of study respondents indicated that diarrhea is a serious illness for children. Eighty-one percent (81%) of respondents reported that water is an important route of disease transmission. These basic health messages, along with instructions on proper use and regular maintenance of the filters, accompanied most implementations of the filters in the study areas.

Filter Use

Of 506 households in the cross-sectional 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 (Table 1; Figure 1). If the filter was in regular (daily) use by the household, users were asked several questions about filter use such as times filling it per day and water uses. Users reported filling the filter an average of 1.8 times per day and cleaning it 2.3 times per week. 133 (86%) of households reported using the filter for drinking water only.

Respondents were also asked where they obtained the filter, whether the filter in the household at the time of the visit is a replacement filter, how much the filter cost, where they would go to buy a new filter if desired, and what an appropriate ("fair") price would be for new filters. A small number of households reported purchasing additional filters after a breakage: 11 (6%) in Kandal, 4 (3%) in Kampong Chhnang, and 6 (3%) in Pursat. Of 281 households with disused filters responding, 120 (43%) households reported a willingness to purchase an additional filter: 24 (73%) in Kandal, 20 (19%) in Kampong Chhnang, and 76 (53%) in Pursat. Respondents were asked to name an appropriate price for the CWP; the mean non-zero response (n=106) was US$2.38: US$1.48 in Kandal, US$1.68 in Kampong Chhnang, and US$2.95 in Pursat. Households that were successfully using the filter on a daily basis were asked about purchasing additional or replacement ceramic filter inserts; 72% of respondents were willing to pay US$2.50, 29% were willing to pay US$4, and 26% were willing to pay US$5. The cost of replacement ceramic filter elements in Cambodia is currently in the US$2.50-$4 range.

Among respondents who previously used but are not currently using filters, factors

Filters ready for testing

With a cost of US$7.50-$9.50 per system, CWPs may be accessible to all but the very poorest with full cost recovery and an acceptable profit for distributors.


The RDI CWP factory in Kien Svay, Kandal province (the pots stacked outside are discarded filters)

associated with a willingness to purchase an additional filter were using a covered household water storage container and having purchased a filter (versus having been given one) before. When respondents were asked whether household members knew where to purchase additional filters and parts, only 26% did, although distribution points are available in all three provinces within 20km from the intervention locations. Whether these distribution points were readily accessible to respondents was not clear, however.

Box 3: Cost recovery and transition to scale-up

Based on early experiences of implementing organizations, CWP production in Cambodia is evolving from a subsidized, NGO-based endeavor to market-based, cost recovery schemes that are intended to boost sustainability and coverage. With a cost of US$7.50-$9.50 per system (and US$2.50 - $4.00 for replacement filter elements), CWPs may be accessible to all but the very poorest with full cost recovery and an acceptable profit for distributors. Assuming a $10 system and 25 liters per day capacity with an average life-span of one year before ceramic element replacement (at US$2.50), the cost of safe drinking water per family is US$0.0011 per liter for the first year, and US$0.00027 per liter thereafter. This makes the technology an attractive low-cost option for providing sustained access to safe water at the household level in Cambodia.

IDE currently has 4 regional distributors covering 131 retailers in 19 provinces, operating on a full cost recovery basis; subsidized distribution ended in 2005. Plans to scale up distribution and support market-based efforts are underway. Total sales per year of filters are currently 22,000+ units (approximately half to NGO partners and half via retail sales) at full cost (US$7.50 – US$9.50) for total sales of approximately US$192,000 per annum.

RDI has factory-based sales direct to users in Kandal province and to NGOs and government agencies in Cambodia. In addition, 26 retailers and one distributor are operating in Kandal and Siem Reap provinces on a full cost recovery plus profit basis, accounting for approximately one-third of total sales. Other sales are direct to communities via mobile marketing and education teams. Total sales per year of filters are approximately 23,000 units at full cost (US$8.00), for total sales of US$184,000. A comparatively small number of filters are also distributed at subsidized cost to villages in NGO-led community health intervention programs in Kandal province. Subsidized filters are targeted to the poorest households, as determined by a means assessment, and costs vary from US$1 - $7.

Other NGOs and government agencies purchasing filters from IDE and RDI may distribute the filters in a variety of ways, including free distributions that could negatively impact the market. When possible, external distributors should be involved in the program so that their activities are not counterproductive to national scale up efforts. See program recommendations.

Rate of Disuse

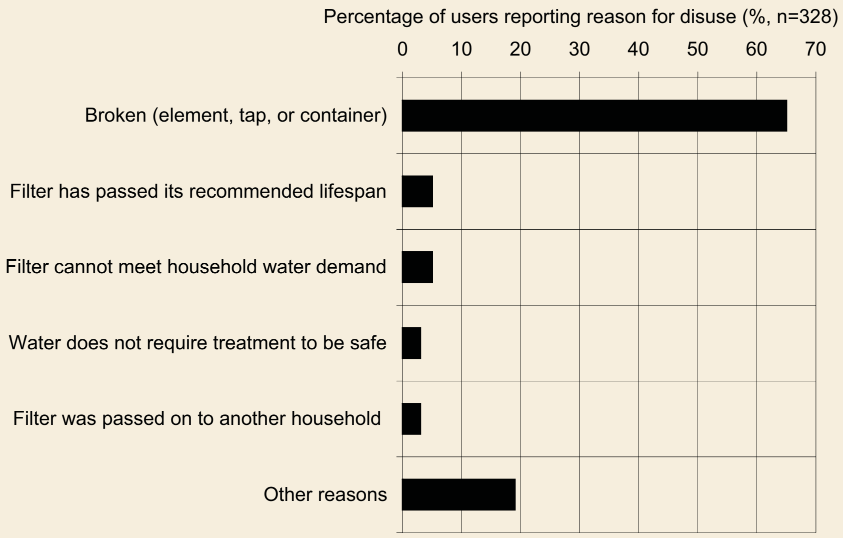
Time since implementation was calculated from the original implementation questionnaire (delivery) date where possible, followed by estimation based on the date stamped on the filter rim (manufacture date), followed by users' best estimates from interviews. Of the 477 filters for which estimates were possible, 253 (53%) were reliably dated using questionnaire or filter data and the remaining were dated by user estimation, which was probably less accurate. Broken filters were often no longer available to inspect. The manufacturing date could not be discerned on many of the oldest filters due to surface wear. Twenty-nine (29) filters, 6% of the total, could not be dated confidently by any means.

At a glance: Details of ceramic filter programs in Cambodia

	RDI	IDE
Filter program established	2003	2001
Implementation strategy	Unsubsidized direct sales to users, distribution through local contract vendors, community-based subsidized intervention projects, sales to NGOs and government agencies	Unsubsidized distribution through national network of vendors (131 retailers in 19 provinces), sales to other NGOs and government agencies
Focus	Community-based, small-scale implementation in concert with other water, sanitation, and hygiene interventions and education	Market-based, national scale, stand-alone technology with limited ongoing support to users; use of popular media (radio, television, billboards) to promote filters and filter use in target areas
Manufacturing model	CWPs are manufactured by local skilled staff who are employees of RDI; workers are paid on an hourly basis	CWPs are manufactured locally at a factory managed by IDE and operated by a women's pottery cooperative who are paid per filter produced
Quality control measures	Flow rate testing (1 – 2 liters/hour), visual inspection	Flow rate testing (2 – 3 liters/hour), visual inspection
2006 production (monthly)	1900+	1880
Unit production cost	US$7.00	US$5.30
Retail cost to users	US$8.00	US$7.50 - US$9.50
Cost to user for filter element replacement	US$2.50	US$4.50 - $5.00

> The most important predictor of the proportion of filters remaining in household use is time since implementation.

Figure 2: Reasons given by respondents for filter disuse at the time of follow up



Of the 350 filters no longer in use, 328 households provided responses when asked why their filter was out of use. A total of 214 (65%) were due to filter unit breakage, either of the ceramic filter element, the spigot, or the container (Figure 2). The other one third of respondents gave the following reasons for disuse: the filter was too slow or otherwise unable to meet the household drinking water demand (5%); the filter had passed its recommended useful life as indicated by the NGO manufacturer, and so users assumed it was no longer effective (5%); gave or sold the filter to a friend or relative (3%); or a number of other reasons. A number of users reported having repaired the containers or taps on their own using locally-available replacement parts (buckets and taps). Filters were in use in households about 2 years, on average (Figure 3).

Factors Associated with Continued Filter Use

Figure 4 graphically displays observed associations between filter uptake and measured factors, together with 95% confidence intervals; odds ratios of less than one (whose confidence intervals exclude the 1.0 null value) are considered strong predictors of decreased use over time. Odds ratios greater than one (whose confidence intervals exclude the 1.0 null value) are considered strong predictors of increased use over time.

The most important predictor of the proportion of filters remaining in household use is time since implementation. The results of logistic regression indicate a declining odds of 44% every 6 months of finding a filter still in use. Figure 1 indicates an average falloff in use rate of approximately 2% per month after implementation.

Other important predictors of continued filter use over time, controlling for time since implementation, were determined to be water source, investment in the technology, access to sanitation, and the practice of other water and hygiene-conscious behaviors in the household. Adjusted odds ratios

Filters are shaped like large flower pots

A household interview in progress. A total of 506 households were interviewed

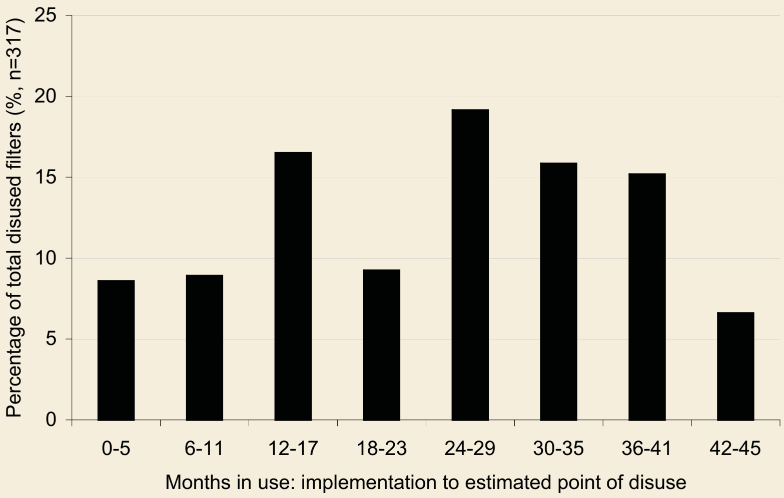
Other potentially important demographic and socio-economic predictors of filter use were also examined as a part of the cross sectional study. Sex of household head and reported household income were not associated with the outcome of continued filter use after controlling for time since implementation.

Cash investment, at any level, by the household in the filter was associated with continued filter use versus receiving the filter gratis. Cash payments for the filters ranged from US$0.25 – $2.50. No clear trend was observed between filter use and the level of cash investment. Respondents who reported other safe water, sanitation, and hygiene practices were more likely to

for selected measured parameters' associations with continued filter use are presented in Table 1 and Figure 4.

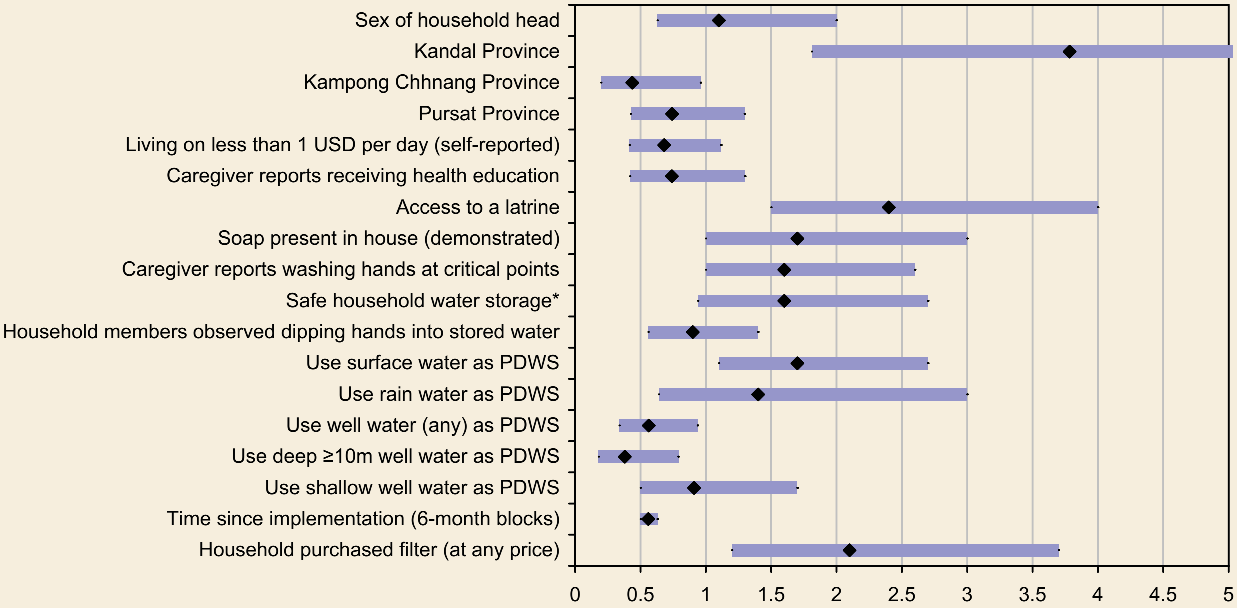
With respect to water source, households that reported groundwater use from deep wells (defined here as ≥10m) were less likely to use the filter after controlling for time since implementation. Conversely, a positive association was observed between surface water use and continued filter use. Similar associations were not observed between continued filter use and the use of covered versus uncovered wells, method of withdrawing water from wells, estimated distance to main drinking water source, method of withdrawing water from the household water storage container, or use of stored rainwater or bottled water during the study period (the dry season).

Figure 3: Histogram showing the distribution of user-approximated time in use of filters not in use at the time of this follow up study (n=317).



Cash investment, at any level, by the household in the filter was associated with continued filter use versus receiving the filter gratis.

Figure 4: Odds ratios (OR) for associations with continued use, controlling for time since implementation; bars are 95% Confidence Intervals



Odds ratio (OR) point estimates (and 95% confidence intervals) for factors associated with continued use of the CWP in 506 households in Kandal, Kampong Chhnang, and Pursat Provinces, adjusted for time since implementation. Odds ratios less than one are negatively associated with continued use and odds ratios greater than one are positively associated with continued use.
PDWS = Primary drinking water source (non-exclusive)
* Covered household water storage container

be using the filter at the time of follow up. For example, access to a household's own or shared latrine, the household caregiver reporting that s/he always washed hands with soap and water at critical points such as after defecating or before preparing food, and the presence of soap in the household were all observed to be positively associated with filter use after controlling for time since implementation. The practice of covering the household water storage container (safe storage) may also be positively associated with continued filter use. No clear association was observed between filter use and caregivers reporting water-related health and hygiene education). Observed associations do, however, suggest a relationship between filter use and knowledge of positive household health and hygiene practices.

Surface water sources like these are preferred by almost half the respondents

Water Quality Data

Household drinking water quality data for all households are presented in Tables 2 and 3. Sixty-six percent (66%) of CWP-treated water samples were under 10 E. coli/100ml, with 40% of samples having <1 E. coli/100ml. Sixty-two percent (62%) of household drinking water samples from control households contained relatively high levels of E. coli (>=101 cfu/100ml) versus 14% of samples from intervention households (table 2). A summary of means of total coliform, E. coli, and turbidity counts in intervention house-

Table 2: Observed levels of E. coli (cfu/100ml) in household drinking water by study group

Number (percentage[a]) of all samples by E. coli concentration of household drinking water[b]

	<1 (cfu/100ml)	1-10 (cfu/100ml)	11-100 (cfu/100ml)	101-1000 (cfu/100ml)	1,001+ (cfu/100ml)	Total samples[c]
Control households	40 (18%)	2 (1%)	42 (19%)	80 (35%)	62 (27%)	226
Kandal	15 (13%)	2 (2%)	24 (21%)	46 (39%)	30 (26%)	117
Kg Chhnang	13 (24%)	0	7 (13%)	15 (28%)	19 (35%)	54
Pursat	12 (22%)	0	11 (20%)	19 (35%)	13 (24%)	55
Intervention households	89 (40%)	54 (26%)	38 (18%)	23 (11%)	7 (3%)	211
Kandal	53 (47%)	32 (29%)	17 (15%)	9 (8%)	1 (1%)	112
Kg Chhnang	18 (42%)	12 (28%)	6 (14%)	4 (9%)	3 (7%)	43
Pursat	18 (32%)	10 (18%)	15 (27%)	10 (18%)	3 (5%)	56

a. Percentages within strata may not add up to 100% due to rounding.
b. Samples were filter effluent in intervention households, stored household drinking water for control households. Households were asked to provide a sample of the water that the family was drinking at the time of visit.
c. Incomplete data for 14 (6%) control households and 29 (12%) intervention household samples.

Respondents who reported other safe water, sanitation, and hygiene practices were more likely to be using the filter at the time of follow up.

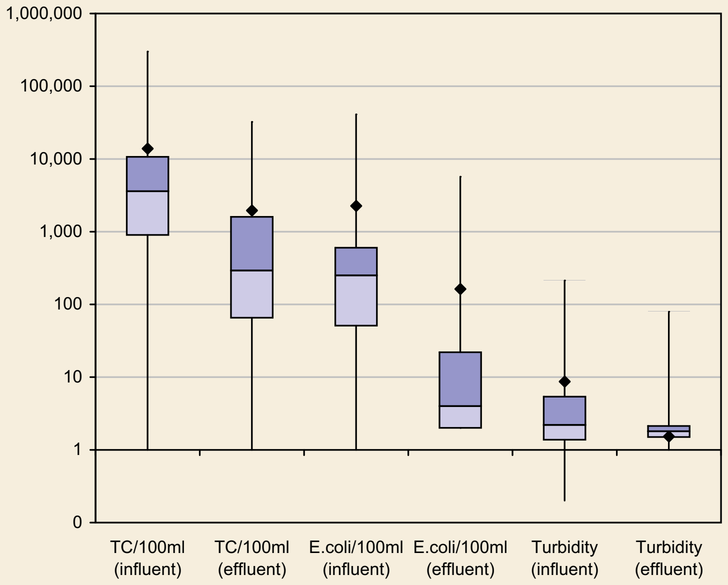
Table 3: Mean total coliform and E. coli counts (cfu/100ml) and turbidity averages for samples taken in intervention households (untreated and treated water).

	Water quality data[a], geometric means (untreated water)			Water quality data[a], geometric means (treated water)		
	TC/100ml	E.coli/100ml	Turbidity (NTU)	TC/100ml	E.coli/100ml	Turbidity (NTU)
All provinces	3,345	474	2.9	308	14	0.77
Kandal	2971	336	2.8	241	8	0.59
Kg Chhnang	5,270	939	2.9	363	18	0.77
Pursat	2,999	536	8.4	458	25	1.3

a. Data from intervention households, raw (untreated) water and filtered (treated water) samples from 3 sampling rounds, February-April 2006 (n=203).

Figures 5, 6, and 7 show distributions of these data over all water samples taken from CWPs.

Figure 5: Box-and-whisker plot showing data for total coliform, E. coli, and turbidity (measured in NTU) in all filter influent and effluent samples.



Upper and lower points represent maxima and minima, boxes indicate 25th and 75th percentile boundaries, the color break within each box represents the median value, and the points are arithmetic means (note log scale).

hold samples (both treated and untreated water) is presented in table 3. The geometric mean E. coli concentration in filter-treated water was 15 cfu/100ml compared to 565 cfu/100ml in control households.

Log$_{10}$ Reduction Values (LRVs)

The log$_{10}$ reduction values of E. coli in treated versus untreated water were computed as standard measures of technology performance. Based on 203 total samples over three sampling rounds, the geometric mean log$_{10}$ reduction of E. coli using the CWP was 1.7 (n=203), or 98%. The geometric mean log$_{10}$ reduction of total coliforms using the CWP was 1.2 (n=203) or 94%. The geometric mean reduction in turbidity was 70% (n=203); Figures 5 and 6 show these data graphically for all samples with the arithmetic means as point estimates.

RDI and IDE produce a combined 3800 filters each month

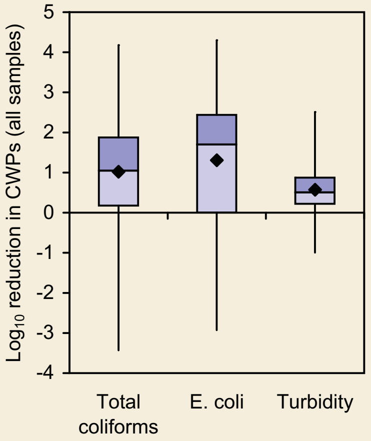
Treated water concentrations greater than untreated water concentrations for the indicator under study (E. coli, cfu/100ml) result in negative $\log_{10}$ reduction values (LRVs). Out of 79 filters in the intervention group, 46 were observed to have negative LRVs at one or more visits: 20 (50%) filters in Kandal, 10 (56%) in Kampong Chhnang, and 10 (48%) in Pursat (Table 4). Nine filters (11%) produced water of worse apparent quality than untreated water at multiple time points.

Stored Boiled Water Samples: A Comparison of Methods for HWT

Many households reported using boiled water for some or all of the household drinking water (55% of control households, 33% of intervention households), although in practice this water is often reserved for adults only. In order to compare stored, treated water quality of the CWP households and stored, boiled water of the controls, a total of 84 boiled water samples were taken and processed for E. coli, total coliforms, turbidity, and pH along with other water samples. The $\log_{10}$ reduction value distribution for the two treatment methods are similar, including the percentage of samples having worse quality than the untreated (raw) water stored in the home as determined by E. coli counts (13% of all boiled water samples compared to 17% of CWP samples).

The geometric mean $\log_{10}$ reduction of E. coli using the CWP was 1.7, or 98%, versus 2.0 for boiling (n=84) or 99%.

Figure 6: Box-and-whisker plot showing $\log_{10}$ reductions for total coliform, E. coli, and turbidity in the CWP.



Upper and lower points represent maxima and minima, boxes indicate 25th and 5th percentile boundaries, the color break within each box represents the median value, and the points are arithmetic means

> A clear negative association in diarrheal disease prevalence was observed in filter households compared to control households, indicating a strong protective effect of the intervention.

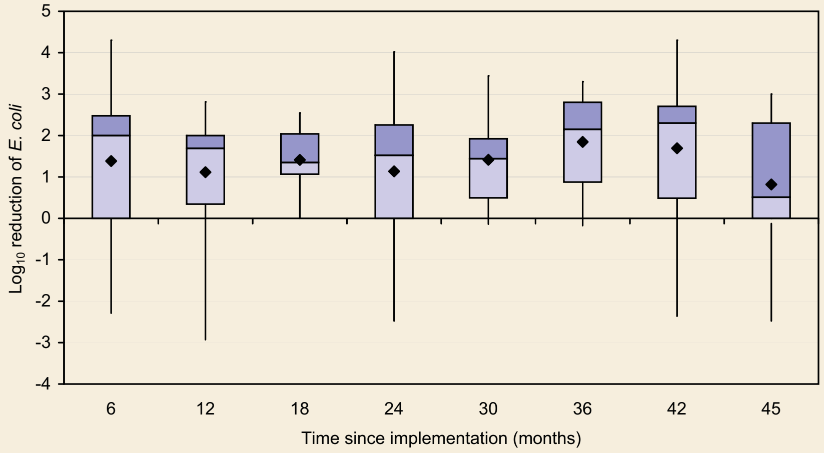
Table 4: Summary of $\log_{10}$ reduction values of E. coli by CWPs, by province

Percentage[a] of all filter samples by E. coli, $\log_{10}$ reduction values[b] (LRV) (n=203[c])

	<0[d]	0[e]	.01-0.99	1-1.99	2-2.99	3-3.99	4.0+
All provinces	17%	10%	12%	16%	36%	7%	2%
Kandal	16%	12%	7%	20%	43%	5%	3%
Kg Chhnang	19%	10%	12%	7%	40%	10%	2%
Pursat	19%	6%	23%	17%	17%	25%	11%

a. Percentages may not add to 100% due to rounding.
b. Log_{10} reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.9% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In forty percent of samples (n=89), filters reduced product water to <1 E. coli per 100ml, so reported LRVs are potential underestimates.
c. 203 (85%) sampling events (out of 240 total: 80 filters sampled three times each) yielded complete data to use in the LRV calculation.
d. Negative LRV values indicate that the effluent water contains more E. coli than the influent water.
e. In 100% of these samples the influent water contained 0 E. coli/100ml.

Figure 7: Box-and-whisker plot for $\log_{10}$ reduction of E. coli in all treated versus untreated water samples by time since implementation, coded in 6-mont blocks.



Upper and lower points represent maxima and minima, boxes indicate 25th and 75th percentile boundaries, the color break within each box represents the median value, and the points are arithmetic means.

Filter Effectiveness and Time

There did not appear to be a strong correlation between filter effectiveness in improving water quality and time in use (Figure 7). Microbiological effectiveness as indicated by E. coli LRVs or by E. coli quantification of filter effluent revealed no trend over time for samples taken from filters representing a broad range of time in use (0 to 44 months).

Diarrheal Disease

Details of the cohort included in the health impact assessment are presented in Table 5. A clear negative association in diarrheal disease prevalence was observed in filter (intervention) households compared to con-

Fetching water from a rain-fed pond (notice the color and turbidity of the water)

trol (non-filter) households, in all age groups, both sexes, and in each province (Table 6), indicating a strong protective effect of the intervention. The adjusted risk ratio (RR) effect estimate for all ages was 0.54, corresponding to a reduction in diarrheal disease of 46%. The estimates for diarrheal disease impact of the CWP were adjusted for no covariates as none produced a ≥10% change-in-estimate of effect (a greater than or equal to 10% change in the overall estimate when adding variables to the model), including socio-economic status as indicated by household income and other measured parameters; household demographics; access to sanitation; measured hygiene practices and observations; and other variables. A greater estimate of effect was observed where the background (control) prevalence proportion of individuals reporting diarrhea was higher. The CWP impact on diarrheal disease was comparable to the reduction in diarrhea reported by those households in the study who reported boiling their drinking water "always" (Figures 10 and 11).

Other Factors Related to Diarrheal Disease

Independent associations between diarrheal disease and other measured cofactors were analyzed, displayed graphically in Figures 8 and 9. These estimates and confidence intervals were adjusted for clustering but more analysis may be needed to identify all potential associations and confounders. Adjusting for clustering within households and within individuals over time, positive associations with diarrheal disease were observed with the following factors: living in the poorest, most rural province, Pursat; being under 5 years of age (0-48 months) at the start of the study; the adult caregiver reporting having received health education; using groundwater (any type) during the study period; and the observation of human or animal feces inside the household at one or more visits (Figures 8 and 9).

Adjusting for clustering within households and within individuals over time, negative associations with diarrheal disease were observed with the following factors: living in the wealthiest, peri-urban province, Kandal; living in a house that is constructed primarily of brick or concrete, a positive wealth indicator; the household caregiver having attained at least primary school education;

Coming out of this filter, the water will be crystal-clear

Table 5: Selected characteristics of the intervention (households with CWPs) and control (without CWPs) groups from the longitudinal study of water quality and health impacts

Characteristic	Intervention group (79 households*)	Control group (80 households)
Number (percent) of households by province		
Kandal	40 (51%)	40 (50%)
Kampong Chhnang	18 (23%)	20 (25%)
Pursat	21 (27%)	20 (25%)
Total number of people in group	528	479
Mean number of individuals per household	6.68	5.98
Number (percent) female	280 (53%)	243 (51%)
Number (percent) children < 5 years of age	77 (15%)	86 (18%)
Number (percent) children 5-15 years of age	143 (27%)	148 (31%)
Formal education level of primary caregiver[a]		
Some or all primary school	19 (24%)	27 (34%)
Some or all secondary school	59 (75%)	52 (65%)
More than secondary	1 (1%)	1 (1%)
Caregiver reported receiving health education[b]		
Yes	23 (29%)	60 (75%)
No	56 (71%)	30 (25%)
Self-reported total household income (US$/month)		
<$50	13 (16%)	19 (24%)
$50-$99	41 (52%)	39 (49%)
$100-$149	15 (19%)	18 (22%)
$150-$200	9 (11%)	4 (5%)
>$200	1 (1%)	0 (0%)
Soap observed in household[c]		
Yes	62 (77%)	70 (87%)
No	18 (23%)	10 (13%)
Access to sanitation[d]		
Yes	44 (56%)	35 (44%)
No	35 (44%)	45 (56%)
Caregiver reports washing hands "always"[e]		
Yes	33 (42%)	29 (36%)
No	46 (58%)	51 (64%)
Main drinking water sources during study (dry season)[f]		
Surface water	43 (54%)	48 (60%)
Groundwater	32 (40%)	34 (43%)
Deep well (≥10m)	13 (16%)	12 (15%)
Shallow well	19 (24%)	22 (28%)
Rainwater	6 (8%)	2 (3%)
Safe storage practices observed[g]		
Yes	56 (71%)	50 (63%)
No	23 (29%)	30 (37%)
Observed method of collecting household stored water[h]		
Use hands	35 (44%)	30 (38%)
Pour, tap, or designated dipper	44 (56%)	50 (62%)

*One intervention households was lost to follow up.

a. Usually an adult female who is responsible for child care.

b. Water, health, hygiene, or sanitation education from any source (school, NGO, media, etc).

c. Respondents were asked to demonstrate that soap was present in the household.

d. Shared or own latrine.

e. Caregiver responded that s/he washes hands “always” with soap at critical points such as after defecating and before preparing food.

f. Multiple answers possible.

g. Safe storage was defined as using a covered or narrow mouth water storage container and a designated water dipper to collect water.

h. Respondents were asked to demonstrate their usual method of gathering water from the storage container.

Water, water everywhere around floating homes such as these– a filter is the ideal investment for making it safe to drink

the use of rainwater as a primary (non-exclusive) drinking water source during the study; reporting that the household boils its drinking water regularly; reporting that the household treats all drinking water that is consumed "always"; access to a latrine; and the adult caregiver reporting that she or he washes hands with soap "always" at critical points such as after cleaning a child or before preparing food (Figures 8 and 9).

Table 6: Diarrheal disease prevalence and filter effect estimates by age and sex of individuals and province

	Mean diarrheal disease prevalence over 2.5 month study period[a]		Adjusted risk ratio (RR)[b]	95% CI[c]
	Intervention	Control		
Age[d]				
All ages	0.10	0.18	0.54	0.41-0.71
<5 years	0.19	0.37	0.52	0.32-0.86
5-15 years	0.07	0.10	0.72	0.39-1.3
>=16 years	0.09	0.16	0.52	0.35-0.76
Sex				
Male	0.10	0.19	0.51	0.34-0.75
Female	0.10	0.17	0.57	0.38-0.84
Province				
Kandal	0.08	0.13	0.63	0.41-0.97
Kg Chhnang	0.12	0.18	0.70	0.42-1.2
Pursat	0.10	0.27	0.37	0.22-0.62

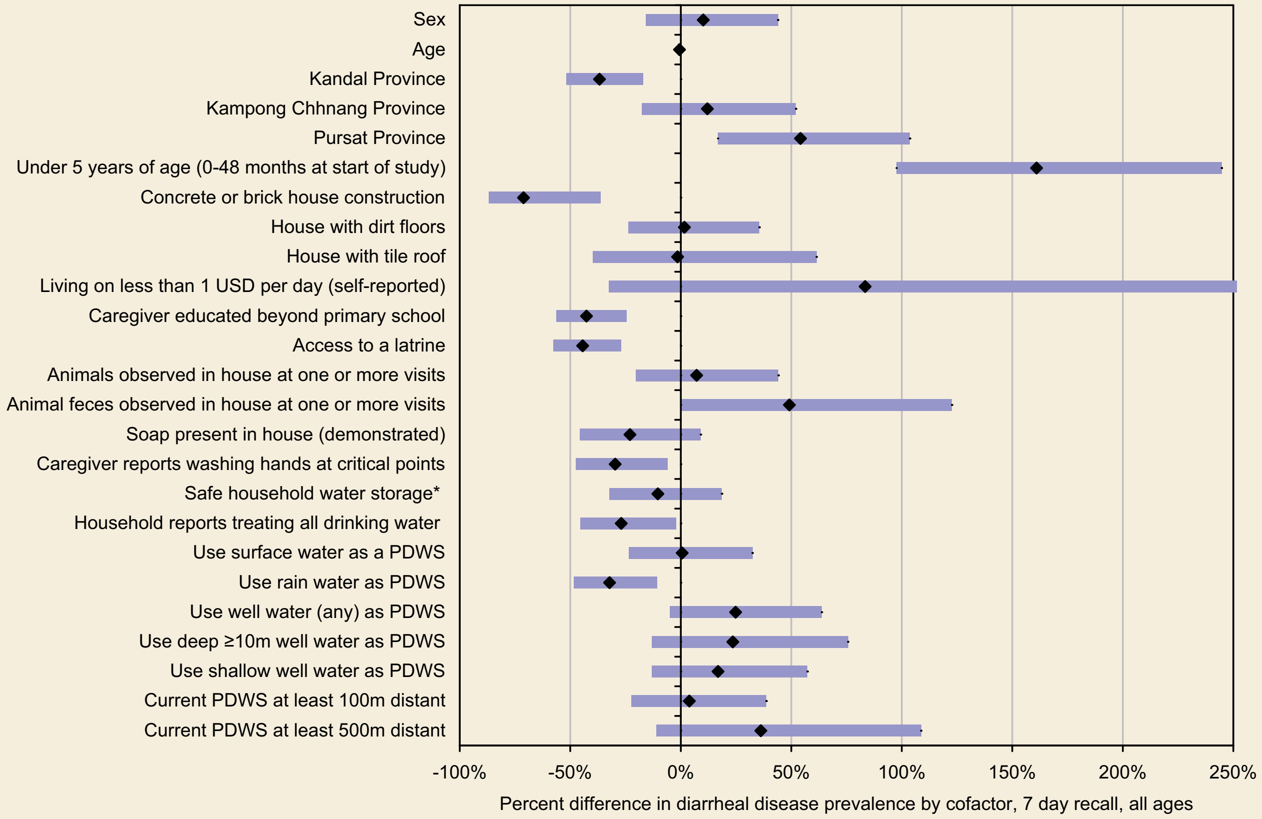
a. Two sampling rounds, February-April 2006 (dry season). Figures represent the proportion of individuals reporting diarrhea in the previous 7 days.
b. Adjusted for clustering of diarrheal disease within households and within individuals over time.
c. 95% confidence interval.
d. Age in years at the time of the first household visit.

> The CWP impact on diarrheal disease was comparable to the reduction in diarrhea reported by those households in the study who reported boiling their drinking water "always".

Discussion

Results suggest that ceramic water filters are more likely to be used by households that (i) already have some knowledge of safe water, sanitation, and hygiene practices; (ii) invest in (purchase) the technology; (iii) use surface water sources for drinking water; and (iv), do not use deep wells (≥10m) as a primary source of drinking water. The high rate of breakage of the filters suggests that the availability of replacement parts and access to or awareness of distribution points may limit the sustainability of ceramic filter intervention efforts. This is because a predicted 2% of filters may fall into disuse each month after implementation due primarily to breakage. It is recognized, however, that NGO filter (hardware) models and implementation

Figure 8: Associations between measured cofactors and diarrheal disease (with 95% confidence intervals) adjusting for clustering within households and within individuals over time (all ages).



PDWS = Primary drinking water source (non-exclusive)
* Covered household water storage container

Villagers returning home with newly bought filters

strategies are improving and this study accounts only for those already in use for varying periods of time up to 4 years. Despite the declining use rate, user satisfaction with the filters was generally very high, and a high percentage of users reported a willingness to purchase additional filters or replacement parts. Time in use for filters in households was about 2 years, on average, before disuse (figure 3). This suggests that filters can be used reliably for extended periods and also that users valued the filters enough to keep using them, usually until breakage. Greater availability and accessibility of spare parts, especially the ceramic filter elements themselves, should enhance the sustainability of the intervention.

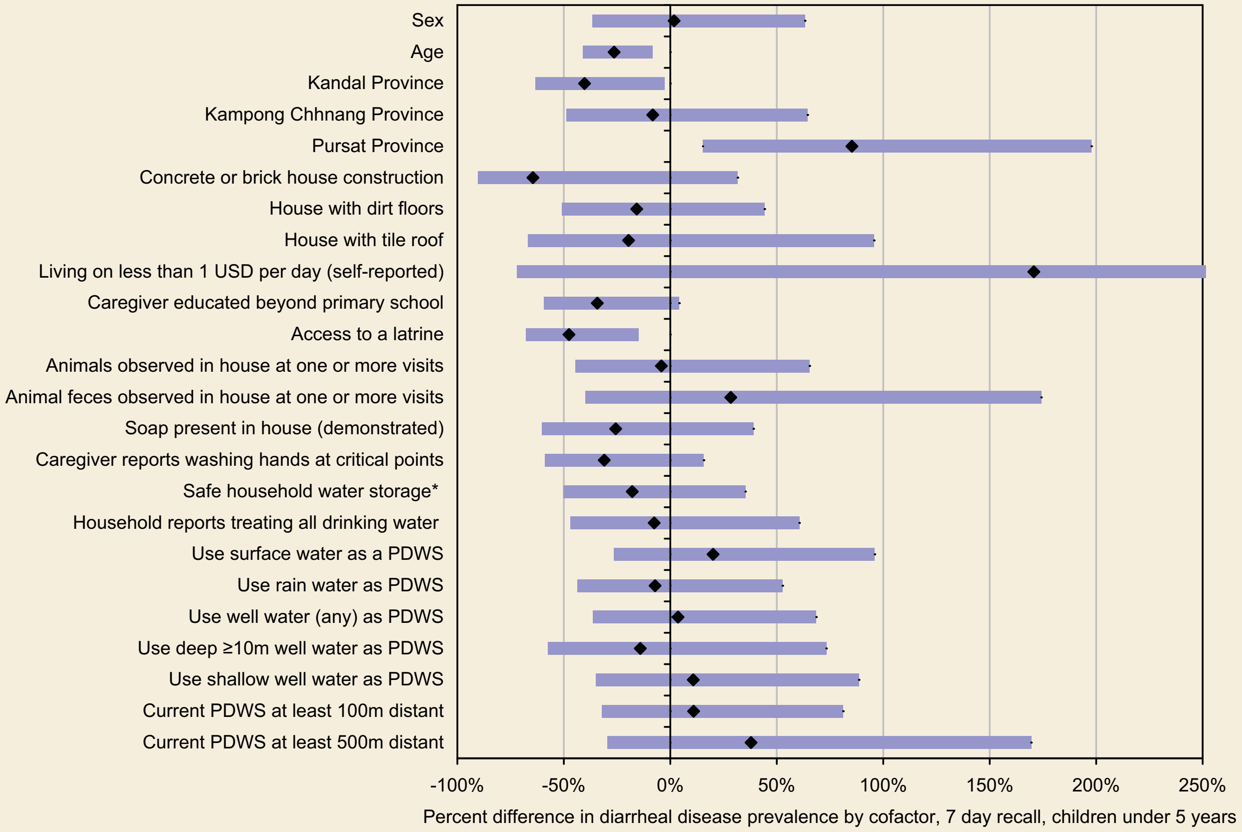
The declining use rate of 2% per month is consistent with the findings of one other ceramic filter implementation study that reported a decline in use of approximately 20% after 9 months in Bolivia in the absence of replacement filters (Clasen et al. 2006a). Several studies have examined uptake of interventions for household water use and safe storage by measuring continued use of the technology or method (Luby et al. 2001; Mong et al. 2001; Parker et al. 2006; Clasen et al. 2006a). Often uptake and use of technologies is a complex process that involves many socio-cultural factors (Wellin 1955; Rogers 2003). There is some evidence that this is a major factor limiting the success of household water treatment, for all technologies. More research is clearly needed on the long term sustainability of this strategy for providing access to safe water, although some method of household water treatment may be the only option for many lacking access to this basic need.

Anecdotal evidence in the study region suggests low flow rates and rapid clogging of ceramic filters are associated with the use of groundwater from deep wells, which suggests these factors may explain the lower use of CWPs among those using deep wells as a primary water source. This may be the result of insoluble ferric (Fe^{3+}) iron formation from dissolved Fe^{2+}, which occurs in high concentrations in many Cambodian groundwaters (Feldman et al. 2007). The same association was not observed with households reporting use of shallow wells (OR: 0.91, 95% CI 0.50-1.7), possibly due to iron oxidation and precipitation that occurs in the water of open wells before water is drawn. Another explanation for the difference is that deep wells

Cleaning the filter can restore the flow rate, but is also a possible pathway for recontamination of treated water (e.g. if a dirty cloth is used)

The high rate of breakage of the filters suggests that the availability of replacement parts and access to or awareness of distribution points may limit the sustainability of ceramic filter intervention efforts.

Figure 9: Associations between measured cofactors and diarrheal disease (with 95% confidence intervals) adjusting for clustering within households and within individuals over time among children under 5 years of age (0-48 months at the first household visit).



PDWS = Primary drinking water source (non-exclusive)
* Covered household water storage container

are perceived to be cleaner and therefore filter use was not seen as critical to protecting water quality.

Use of a CWP was associated with a substantial improvement in drinking water quality at the household level compared to a matched control group not using filters, reducing E. coli by a mean of 98% with reductions as high as 99.99%. Use of the filters was also associated with a reduced diarrheal disease burden during the study, with diarrhea prevalence in filter households being only 54% of that in the control (non-filter) households. The filter's demonstrated effectiveness in improving water quality and health, over a wide range of conditions, makes it among the best available options for household water treatment. There does not appear to be a change in the relationship between filter effectiveness and time, supporting the hypothesis that the filters can maintain effectiveness for up to 4 years (and potentially longer) in house-

Breakage of filter pots is a concern, and cardboard boxes and woven baskets have been used successfully to protect pots during transport

hold use. For this reason and because 5% of households surveyed indicated filter "expiration" as a reason for not continuing to use it (Figure 2), existing recommendations by manufacturers and implementers on filter replacement (usually every 1-2 years) should be reconsidered.

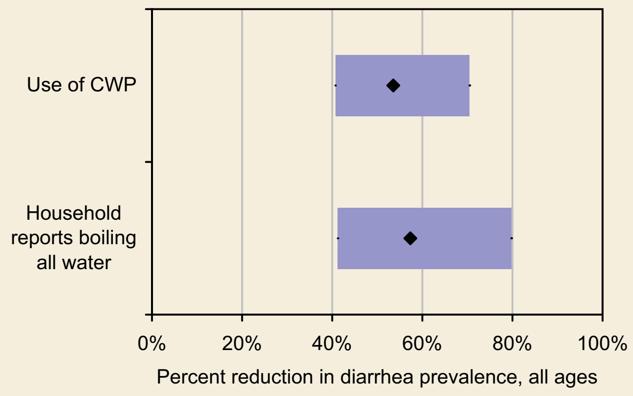
The treated water may be susceptible to re-contamination, however, as are all household water treatment methods, including the most microbiologically effective method (boiling), as was observed in this study. Results suggest that, although both boiling and treatment via CWPs can improve water quality, there is a potential risk of recontamination of water through unsafe filter handling and water storage practices. Education and training in proper technology use and safe water storage practices should be part of any effective program to improve water quality in the home.

These results are consistent with several studies (e.g., Wright et al. 2004 and Jensen et al. 2002) showing that recontamination of stored water in the home could significantly impact the quality of potable water used in the household. While improving the technology is important, it must also be stressed that proper use of the technology is as critical as the technology itself. Behavioral change and education “software” accompanying interventions may increase proper use of the filters and result in lower levels of recontamination and possibly lower risks of waterborne diarrheal disease.

Log$_{10}$ Reduction Values (LRVs) and Filter Performance

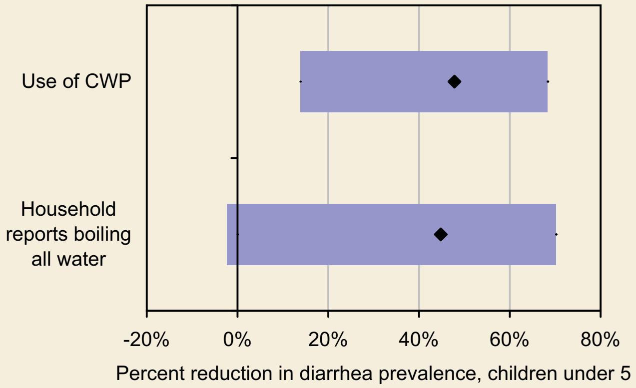
A common method for evaluating performance is the computation of log$_{10}$ reduction values (LRVs; Table 4, Figures 6 and 7), which correspond to percent reductions of some measure (e.g., E. coli/100ml, turbidity) due to treatment. The occurrence of negative LRVs is an important finding and merits further discussion here. In this case filters

Figure 10: Diarrheal disease reduction estimates (with 95% confidence intervals) for water treatment options (all ages), adjusted for clustering within households and within individuals over time.



> Use of a CWP was associated with a substantial improvement in drinking water quality at the household level compared to a matched control group not using filters.

Figure 11: Diarrheal disease reduction estimates (with 95% confidence intervals) for water treatment



Options among children under 5 years of age (0-48 months at the first household visit), adjusted for clustering within households and within individuals over time.

may produce water of worse apparent quality than the untreated (raw) water, resulting in negative $\log_{10}$ reductions of E. coli. These results could be explained in several ways, but for this system two explanations are most likely. The first is variation in the E. coli concentration in the untreated water over time. That is, when filter effluent is sampled, the filtered water sample is by no means "the same" as the water in the household storage container or even perhaps as the water in the filter element above. Since E. coli concentrations are known to vary greatly over time, a simple comparison between the untreated and treated water in samples taken simultaneously will not always be a valid measure of difference attributable to the performance of the filter. Negative LRVs may be observed when the concentration of E. coli in water being put through the filter has substantially declined over the duration of the filter run (which could be hours). Water in the top of the filter may also be from a different, less contaminated source, or from the same source storage container that has been exposed to microbe-inactivating sunlight, to sedimentation (settling out of bacteria associated with larger particles in the water) or some other factor influencing the presence or culturability of the microbe sought in the water sample. Regrowth of the indicator in the stored water is also possible and could lead to observed negative $\log_{10}$ values (Desmarais et al. 2002).

The second explanation for negative LRVs is filter recontamination during use, for example due to improper cleaning or handling. While the storage system used with the ceramic water filters is generally thought to be safe (closed storage container, water dispensed via a tap), contamination of the filter could be introduced through frequent cleaning or cleaning with a contaminated cloth. As indicated previously, E. coli in filtered water could also multiply during storage. Seventy-seven (77%) percent of households in the intervention group reported cleaning the filter element with a cloth or krama (n=79) and 71% reported cleaning the storage container with a cloth or krama (n=79). Eighty-nine percent (89%) of users reported cleaning the filter and 29% reported cleaning the storage container with raw water only, with the remainder using soap and raw water. The mean reported frequency of cleaning the filter was 2.3 times per week. Kramas are multi-use traditional cloths used around the household in Cambodia, which are

More new filter owners on the way home

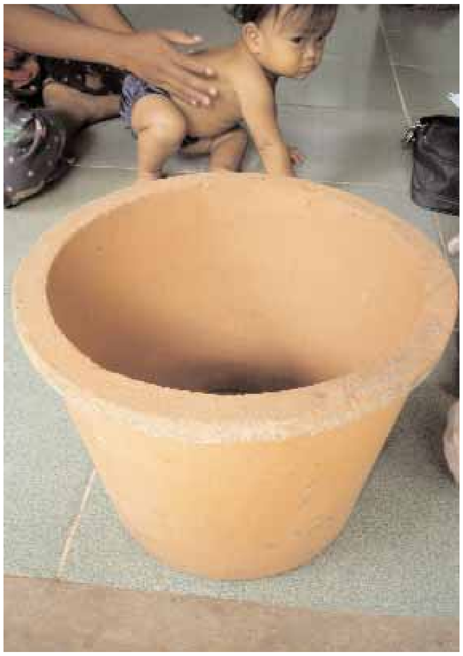
Rice husk mixed into the clay burns out during firing of the pot. The resulting small pores give the pot its essential filter characteristics

thought to be important vectors for fecal microbes and possibly other pathogens. Cleaning the filters with these cloths may be one means of compromising the filter and recontaminating the stored water. No clear associations were observed, however, between the probability of negative LRVs (achieving $<0 \log_{10}$ reduction of E. coli) and measured parameters such as reported frequency of use, frequency of cleaning, method of cleaning the filter or bucket, number of people in the household, manufacturer, time in use, or other factors as determined by logistic regression.

Study Limitations

Selection bias can threaten the validity of studies when study inclusion is predicated upon technology uptake and use. In this study, selection bias may arise because households that received filters or are still using the filters after some intervening time may be fundamentally different from those in the control group, who never received filters. Control selection was used to counter this potential bias by matching intervention and control households by potentially important characteristics such as socio-economic status and water source, although this bias may not have been eliminated wholly from the study.

Seasonal effects on diarrheal disease prevalence or microbiological water quality were not accounted for in this study, conducted entirely in the dry season. Annual rainfall is not evenly distributed throughout the year in Cambodia: during the rainy season (June – October) it rains between 15 and 30 cm per month, with dry season (December – March) averages of 0-5 cm per month. Water use practices, water treatment practices, diarrheal disease rates, and the presence of microbial pathogens and indicators in potential drinking water sources can vary greatly depending upon the season. In the study areas, diarrheal disease prevalence may be higher in the dry season, when users shift away from the use of relatively safe rainwater to relatively unsafe surface water sources, and because water availability may limit hygiene practices. Longitudinal studies such as this one that attempt to capture the protective effect of an intervention on diarrheal disease are subject to possible effect measure modification by seasonal effects, resulting in very different quantitative findings or even outcomes over the course of a year as conditions change.



Filter pot

> The filter's demonstrated effectiveness in improving water quality and health, over a wide range of conditions, makes it among the best available options for household water treatment.

Box 4: Research Needs and Program Evaluation

Despite widespread and increasing international attention given household-scale water quality interventions, basic gaps in knowledge of the microbiological effectiveness and associated health impacts of the technologies limit investment in this method for safe water provision. There is a pressing need for better, more rigorous research, including: (i) studies that transcend spatio-temporal variability (regional, cultural, water source characteristics, target microbes, time in use, and other key variables); (ii) studies that compare technologies and strategies to identify appropriate hardware/software for successful implementation, long-term use, and scale-up; (iii) studies that link these interventions to health outcomes using rigorous epidemiological methods, specifically randomized, blinded, controlled intervention trials; and (iv) critical evaluations of past intervention programs to identify successes, failures, and challenges for current and future efforts in increasing effective HWTS coverage.

To date, no standard method for program evaluation has been used by implementers of household-scale water quality interventions. Unfortunately, looking back at previous projects to assess performance has not been a priority in the sector, perhaps as the problems of safe water access are so urgent the focus remains, justifiably, on new interventions and expansion of programs. While scaling up is critical in contributing to the MDGs and increasing access to safe water, critical program evaluation can ensure that interventions are working to protect users from waterborne disease. Good post-project appraisals (PPAs) use standard or other easily interpretable measures for purposes of comparison and include a representative sample from the target population. They may also be led by an entity independent of the implementer, which can make the study more objective for the organization and potentially more credible to outside observers. For household water treatment interventions, objective PPAs should assess water quality improvements at critical points between the source water and consumption, health impacts at the household and population level, and sustainability of the intervention through measurable uptake and use rates and in relation to economic, environmental, and socio-cultural criteria.

Summary and Recommendations

Major findings of this study were that (i), the rate of filter disuse was approximately 2% per month after implementation, due largely to breakages; (ii), controlling for time since implementation, continued filter use over time was most closely positively associated with related water, sanitation, and hygiene practices in the home, cash investment in the technology by the household, and use of surface water as a primary drinking water source; (iii), the filters reduced E. coli/100ml counts by a mean 98% in treated versus untreated household water, although demonstrated filter field performance in some cases exceeded 99.99%; (iv), microbiological effectiveness of the filters was not observed to be closely related to time in use; (v), the filters can be highly effective in reducing microbial indicator organisms but may be subject to recontamination, probably during "cleaning" with soiled cloths; and (vi), the filters were associated with an estimated 46% reduction in diarrhea in filter users versus non users, placing them among the most effective water quality interventions at the household level. Other significant associations were observed with water, sanitation, and hygiene-related factors that were also measured as part of the study, such as handwashing, education, measures of SES, and access to sanitation (Figures 8 and 9).

The filter's demonstrated effectiveness in improving water quality and health, over a wide range of conditions, makes it an attractive option for household water treatment in Cambodia. Results suggest more work is needed, however, in order to ensure the intervention's continued effectiveness and sustained use in households. Programmatic recommendations follow. CWP technology and implementation methods have evolved substantially in Cambodia since program inception; some of these considerations have already been incorporated into current CWP efforts. Current models for scale up are presented in Table 7.

Table 7: Scaling Up Strategies for CWPs in Cambodia: Advantages and Disadvantages of Current Approaches

Model for CWP scale up	Advantages	Disadvantages
Market-based, with full cost recovery + small profit; no NGO support to target communities	May create profitable local enterprises (manufacturing and distribution) that will contribute to the economic sustainability of the technology and benefit the local economy	May lead to poor quality of filters as producers compete to increase production to meet demand, or as copycat manufacturers enter the market. Quality control is an essential element to manufacturing, very much open to abuse NB: there is no feedback available to users to check microbiological effectiveness of filters
	Possible to reach a large proportion of the population, quickly and relatively inexpensively compared to other water quality improvements	Users may not get the education & training needed to ensure proper use of the filter
	Local vendors ensure that parts, replacements, and knowledge of the filters are available	Unscrupulous vendors or manufacturers may claim effectiveness of the filter against chemical contaminants, notably arsenic and pesticides; vendors are not educating but advertising
	Cash investment in the filter is associated with longer and more conscientious use of the technology	The poorest will probably not be able to afford full-price filters
	Can sell to other NGOs and government agencies, who can use filters as part of their own WSH programs, increasing coverage	Other entities distributing the filters may do so irresponsibly (e.g., giving them away to those who can pay), and therefore may be counterproductive to sustainability
Community intervention-based, with some subsidies for the poorest; NGO program support at the village level	Filters may be more effective within a broader effort to improve WSH, as a result of the added benefits of health education, sanitation, and other interventions	Difficult to create a large-scale distribution network when the CWP is bundled with other interventions that are potentially costly and time consuming
	Can have a potentially greater impact on household water quality and health with proper use; proper and sustained use can be encouraged through NGO-led support and presence in the community (high impact for limited numbers per unit of implementation time)	Much more costly per household impacted, and difficult over a broad distribution area (low impact on a population level)
	Subsidized distribution can help the poorest families afford the filter	Subsidized (especially free) distribution leads to (i) undervaluation of the technology, contributing to high rates of disuse and corresponding lower net effectiveness; and (ii) undermining of market-based approaches in the target area with artificially low prices

Education and training in proper technology use and safe water storage practices should be part of any effective program to improve water quality in the home.

Program Recommendations

- Filter parts and replacements must be available and accessible. As units are subject to breakage over time, replacement parts and units are needed. Users should know where distribution points are located. The high number of filter breakages in the cohort and the low number of purchased replacement filters suggests that users did not want to or could not access repairs or replacement filters, suggesting either problems of acceptance or of access. Both IDE and RDI now have supply chains and distributors in place to ensure availability in target areas. More work is needed on willingness to pay and affordability of CWPs.

- Filters maintain effectiveness when used properly. Since time in use was not shown to be strongly related to performance, recommendations that users replace the ceramic filter elements every one or two years (as is current practice) may not be necessary. Further work is needed to substantiate how the filter performs against other microbes over time and for durations of more than 4 years. Moreover, this study found that 5% of users were not using filters that were otherwise in working condition because they believed the filter to be "expired" according to the manufacturer's instructions.

- Focus on proper use of the technology. Recontamination of the filter and storage receptacle through improper handling practices is a real threat to the effectiveness of this technology. Education and support may help improve performance through the reinforcement of proper use and hygienic behaviors. Compliance has been shown to be positively associated with health gains due to water quality improvements at the point of use (Clasen et al. 2006b).

- Consider bundling interventions. Continued use of the filters was associated with awareness of other water, sanitation, and hygiene behaviors and improvements, suggesting possible synergies between CWP implementation and successful long-term use by users. Where possible, filters

After being pressed into shape, the pots need to dry before they can be fired

Ceramic filters keep the water cool; a feature liked by young and old alike

should be integrated into a comprehensive WSH intervention program. Evidence suggests, however, that stand-alone water quality interventions can also be effective independent of other improvements (Clasen et al. 2006b; Fewtrell 2005), although more work is needed to sort out appropriate software (behavior change) for the successful introduction of HWTS technology interventions.

- Using boiled drinking water, handwashing, access to sanitation, and other factors were also associated with reduced diarrheal disease, although more analytical work is needed to sort out these associations and potential confounders.

- Although results from this study suggest that the CWP is as effective as boiling in household use, CWPs should not be marketed as a replacement technology for boiling until more extensive studies have shown that the CWP is also consistently effective against viruses and protozoan parasites when used properly.

- Filters should be sold to users. Continued use of the filters was positively associated with cash investment in the technology, although continued use was not observed to be closely related to price in this study.

- Include all stakeholders in scale up. NGOs and government agencies who purchase filters from producers to use in their own distributions should be educated about appropriate intervention models and involved in country-wide planning for scale up. As manufacturers increase production and sales to external entities, there is a risk that free distribution of filters by other NGOs could undermine market-based programs. Appropriate intervention training and contracts between

Finished pots awaiting packing and shipment

While scaling up is critical in contributing to the MDGs and increasing access to safe water, critical program evaluation can ensure that interventions are working to protect users from waterborne disease.

manufacturers and distributors may help ensure that filters are implemented sustainably and in coordination with other efforts, and that lessons learned in implementation are incorporated sector-wide.

■ More research is needed on the microbiological effectiveness of the CWPs both in the laboratory and in the field. Although filters performed well based on two bacterial indicators in this study, the performance of the filters in reducing viruses, protozoan parasites, and potentially important bacterial pathogens has not been adequately characterized. Evidence suggests that filter effectiveness may be improved through systematic testing and optimization of key parameters, such as: pore size, flow rate, base clay, burnout material, and microbiocidal surface treatments or additives. Because each manufacturer of CWPs in Cambodia and worldwide uses different materials and QA/QC procedures, effectiveness is also likely to vary, potentially considerably. Each CWP program will thus need to perform adequate testing of filters before field implementation. Although standardized protocols for microbiological testing of household-scale water treatment devices do exist and are applied in wealthy countries (e.g., EPA 1987), these have not been widely used in developing countries due to resource limitations and other reasons. There is a WHO-led effort underway now to introduce

The pots are shaped by hydraulic press, operated by a skilled worker

Demonstrations are an important part of the marketing effort

research is necessary before or concurrent with the inception of any household water treatment program. Appropriate and effective implementation strategies can help ensure high quality filters are produced within an economically sustainable program, resulting in long-term and widespread availability of new filters, replacements, parts, and facilitating and supporting expertise.

flexible, standardized criteria for water treatment technology testing with specific application in developing countries and in compliance with the WHO risk-based framework for drinking water quality as articulated in the Guidelines for Drinking Water Quality, 3rd Ed. (WHO 2006).

- More research is needed on the health impacts of the CWPs. Specifically, randomized, controlled, blinded intervention trials should be performed in order to assess the effectiveness of the CWPs in reducing diarrheal diseases. The study described here may be subject to reporting bias and selection bias, which can be further minimized through appropriately-designed trials that include a placebo filter and randomized treatment arms. Because health impacts may vary from population to population, several studies may be needed to adequately characterize the effectiveness of the intervention on diarrheal diseases among users.

- More research is needed on appropriate scale-up strategies, understanding cultural and social limitations to use of the technology, how to achieve positive behavior change and the development of appropriate 'software' that may be highly context-specific. These considerations may not be applicable from one target population to another, so local

Pots are inspected and smoothed manually after pressing

The filter's demonstrated effectiveness in improving water quality and health, over a wide range of conditions, makes it an attractive option for household water treatment in Cambodia.

Results suggest more work is needed in order to ensure the intervention's continued effectiveness and sustained use in households.

Glossary

Water Quality	
E. coli	Originating in the gut of all warm-blooded animals, E. coli is a standard bacterial indicator of fecal contamination in water. Its presence indicates the possibility of disease causing microbes in the water and associated risk to human health.
pH	Measure of the acidity of a solution. Aqueous solutions with a pH below 7 are considered acidic, while a value higher than 7 is considered basic.
Total coliforms	Group of common bacteria which is not exclusively fecal in origin. Because treated water is not expected to contain any bacteria, this group used to be used to indicate effectiveness of treatment. Use is declining in favor of better indicators however. Levels in water do not generally correlate well with risk to human health.
Turbidity	Measure of the cloudiness of water, caused by very small suspended and dissolved solid matter.

Blocks of clay (mixed with rice husk) are shaped and weighed before being pressed into the final pot shape

Survey Terminology	
A priori change in effect criterion	This is the criterion that is established before the study (a priori) that determines what constitutes a confounder in the analysis. In this case, a confounder is any variable that changes the outcome measure (the risk ratio or odds ratio) by 10% or more when included in the analytical model, and that also conforms to other criteria used to identify confounders.
Binary outcome variable	An outcome which has one of two possible values ('yes' or 'no', 'true' or 'false')
Categorical variable	A variable which has two or more categories, but without an ordering to the categories. For example the variable 'gender' has the categories 'female' and 'male', but there is no ordering to them. A variable with categories which can be ordered is called an 'ordinal' variable (e.g. low, medium, high).
Cohort	A group. In this report, the group of people studied sharing a particular characteristic (e.g. all households with filters).
Confounding variable (or confounder)	This is a variable that influences perceived associations between some exposure (e.g., drinking water from a filter) and an outcome (e.g., diarrheal disease). Confounding variables should be identified and controlled for, although this is not always possible. For example, the fact that households with filters experience less diarrhea than households without them may in part be due to the fact that filter owning households are richer (richer families have better health). This can be controlled for in the analysis if we know the income of each family. Another part of the difference may be explained by the fact that filter owning households have better "hygiene awareness". This cannot be measured directly, and is thus much harder to identify and control for.
Control group	A group that is observed under ordinary conditions, while another group is subject to some change. The control group thus provides the baseline data against which all other outcomes are compared. In this report, the studied group consists of people with water filters, while the control group does not have water filters (but is otherwise as much as possible similar to the studied group).
Cross Sectional Study	A study carried out at one point in time, or over a short period. Often used to determine prevalence and distribution of particular health conditions.
Longitudinal Study	A study that is repeated over time, normally to show changes and/or the impact of those changes in an intervention group (using water filters) versus a control group (not using filters).

Data Analysis

<table>
<tr><td>95% Confidence Interval</td><td>In this study, estimates are presented with 95% confidence intervals to indicate a range of possible values, due to random error underlying any estimation. The narrower the confidence interval, the more precise the estimate. One way of interpreting this is that if the experiment were repeated many times under the same conditions, the correct value would fall within the specified confidence interval 95% of the time.</td></tr>
<tr><td>Covariate</td><td>A variable that is possibly predictive of the outcome being studied.</td></tr>
<tr><td>Independent association</td><td>An association between two variables, where there is no cause and effect relationship (for example, the study found there is a positive association between living in a poor community and having diarrhea, but living in a poor community is not what causes the diarrhea).</td></tr>
<tr><td>Log$_{10}$ reduction values</td><td>A way of expressing reduction in value. In this report used to express the reduction in bacterial counts between filter influent and filter effluent. The table below shows Log$_{10}$ reduction values and percentages assuming 1000 bacteria in the filter influent:
<table>
<tr><th>Bacteria in effluent</th><th>Reduction</th><th>Log$_{10}$ reduction value</th></tr>
<tr><td>100</td><td>90.0%</td><td>1</td></tr>
<tr><td>10</td><td>99.0%</td><td>2</td></tr>
<tr><td>1</td><td>99.9%</td><td>3</td></tr>
</table></td></tr>
<tr><td>Logistic regression</td><td>Part of statistical analysis dealing with generalized linear models. It allows the prediction of a discrete outcome (“yes” or “no”) from a range of variables. In the study, used to predict continued filter use based on a number of variables, and used (unsuccessfully) to try to predict negative filter performance based on a number of variables.</td></tr>
<tr><td>Odds Ratio</td><td>The ratio of the odds that a condition exists in one group (group 1) and the odds that the same condition exists in another group (group 2). An odds ratio of 1 indicates that the condition is equally likely to occur in both groups. An odds ratio smaller than 1 indicates a bigger likelihood of the condition existing in group 2, while an odds ratio larger than 1 indicates a greater likelihood of the condition existing in group 1.
In this study, if one group is made up of all filter users using surface water, and another is made up of all filter users in total, the first group has a greater likelihood to still be using the filter after a specific period than the second group. There is this an odds ratio of surface water users vs. all filter users > 1</td></tr>
<tr><td>Poisson Distribution</td><td>A discrete probability distribution used to model the number of events occurring in a given time interval.</td></tr>
<tr><td>Generalized Estimating Equations (Poisson Extension of)</td><td>GEE are a statistical method often used for the analysis of longitudinal data, or other correlated response data.</td></tr>
<tr><td>Prevalence</td><td>The proportion of a population with a given condition at one specific time, usually expressed as a percentage. For example the DHS in 2000 reported a 20% prevalence of diarrhea in children.</td></tr>
<tr><td>Risk Ratio (RR)</td><td>The ratio of risk in one group (e.g., the group with filters) to the risk in another (e.g., the control group, without filters). In this study, used as a ratio of risk of diarrhea in filter users to risk of diarrhea in non-filter users, so that a RR of <1 is indicative of a protective effect.</td></tr>
<tr><td>Stratified Data</td><td>Data grouped into similar subgroups (e.g. stratified by age, or height).</td></tr>
<tr><td>Stratum</td><td>A subgroup (plural: strata)</td></tr>
</table>

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Song Kimsrong, field interviewer
Uon Virak, lab team
Van Sokheng, GIS specialist
Douglas Wait, UNC environmental microbiology laboratory manager

Filters maintain effectiveness when used properly.

Where possible, filters should be integrated into a comprehensive WSH intervention program.

More research is needed on the health impacts of the CWPs.

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What is on the Disc?

The disc included in the pocket below is of the DVD format.
It can be played in any DVD player, and on any Windows computer or Apple computer with a DVD drive.
The DVD contains a number of CWP related documents in addition to 4 short movies:

Title	Subject	Language	Duration
The Pot with the Silver Lining (E)	This short documentary shows the production, testing, marketing and use of ceramic water purifiers. The voice-over describes and summarizes the main assessment findings presented in this report. Commissioned by WSP.	English	16 min.
The Pot with the Silver Lining (K)		Khmer	
Flow on Through	A further CWP story wrapped in a depiction of the life of a Cambodian village family.	Khmer with English subtitles	16 min.
Clean Water in Every Home	Low cost ceramic water filters allow rural households to produce safe drinking water in their own homes. Produced by DANIDA.	English	11 min.

ABOUT THE SERIES:

WSP Field Notes describe and analyze projects and activities in water and sanitation that provide lessons for sector leaders, administrators and individuals tackling the water and sanitation challenges in urban and rural areas. The criteria for selection of stories included in this series are large-scale impact, demonstrable sustainability, good cost recovery, replicable conditions and leadership.

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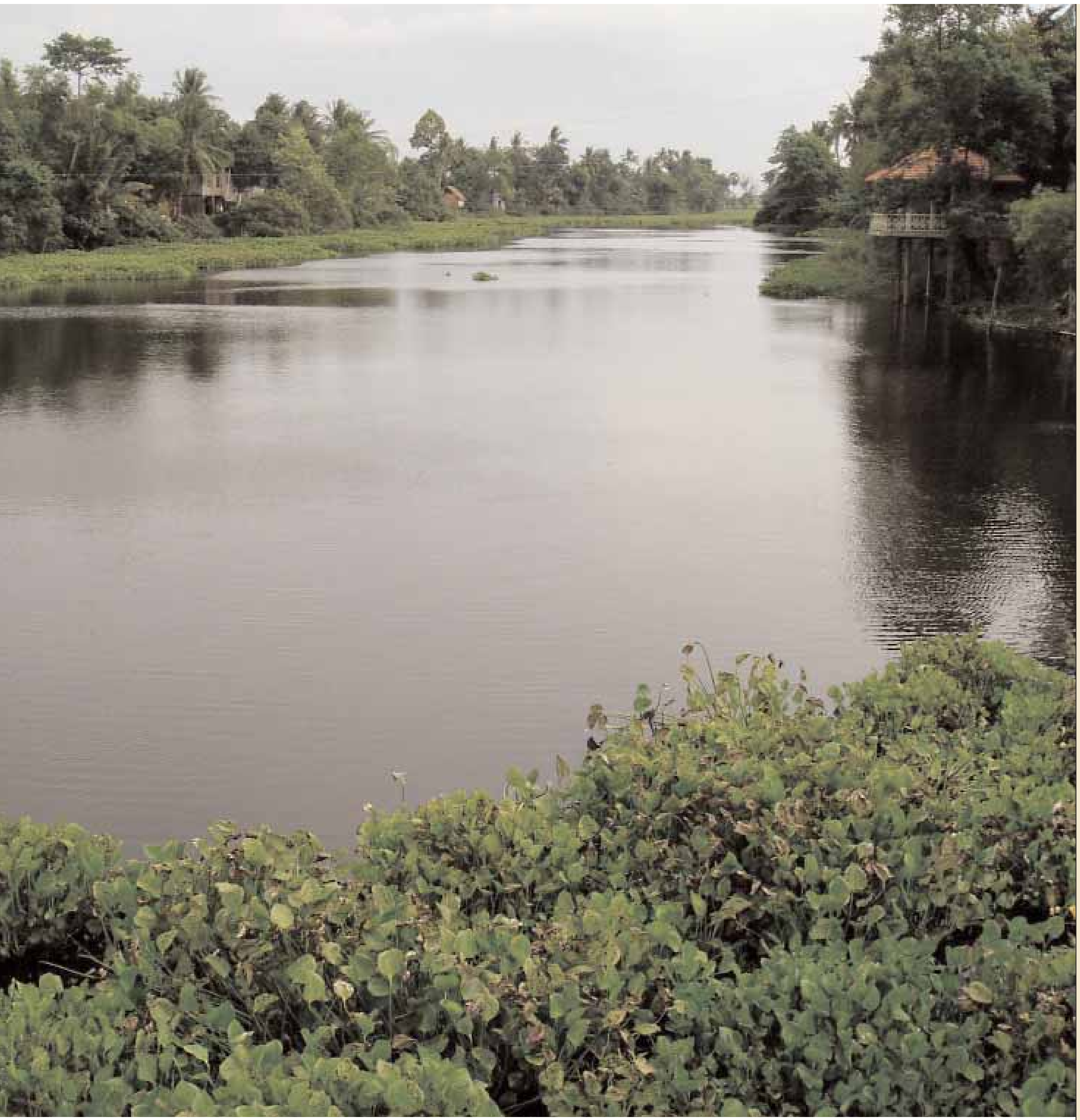

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