Cost-effectiveness of water quality interventions for preventing diarrhoeal disease in developing countries

Thomas Clasen, Laurence Haller, Damian Walker, Jamie Bartram and Sandy Cairncross

ABSTRACT

Using effectiveness data from a recent systematic review and cost data from programme implementers and World Health Organization (WHO) databases, we conducted a cost-effectiveness analysis to compare non-piped in source- (dug well, borehole and communal stand post) and four types of household- (chlorination, filtration, solar disinfection, flocculation/disinfection) based interventions to improve the microbial quality of water for preventing diarrhoeal disease. Results are reported for two WHO epidemiological sub-regions, Afr-E (sub-Saharan African countries with very high adult and child mortality) and Sear-D (South East Asian countries with high adult and child mortality) at 50% intervention coverage. Measured against international benchmarks, source- and household-based interventions were generally cost effective or highly cost effective even before the estimated saving in health costs that would offset the cost of implementation. Household-based chlorination was the most cost-effective where resources are limited; household filtration yields additional health gains at higher budget levels. Flocculation/disinfection was strongly dominated by all other interventions; solar disinfection was weakly dominated by chlorination. In addition to cost-effectiveness, choices among water quality interventions must be guided by local conditions, user preferences, potential for cost recovery from beneficiaries and other factors.

Key words | cost-effectiveness, diarrhoea, drinking water, household treatment, microbial water quality, water supplies

Thomas Clasen (corresponding author)
Sandy Cairncross
London School of Hygiene & Tropical Medicine,
Keppel St., London, WC1E 7HT,
UK
Tel: +44 (0) 20 7636 8636
Fax: +44 (0)20 7436 5389
E-mail: thomas.clasen@lshtm.ac.uk

Laurence Haller
Jamie Bartram
World Health Organization,
Avenue Appia 20, CH - 1211 Geneva 27,
Switzerland

Damian Walker
Johns Hopkins University School of Public Health,
615 N. Wolfe Street / Room E8616, Baltimore,
MD 21205,
USA

INTRODUCTION

Diarrhoeal diseases kill an estimated 1.8 million people each year (WHO 2005). Among children under five years in developing countries, diarrhoea accounts for 17% of all deaths (United Nations 2006). Oral rehydration therapy has dramatically decreased mortality associated with diarrhoea, but has had little effect on morbidity estimated to be approximately 4 billion cases per year (Kosek et al. 2003). With continued high attack rates, diarrhoeal disease is also an enormous economic burden, resulting in significant direct costs to the health sector and patients for treatment, as well as in lost time at school, work and other productive activities (Mulligan et al. 2005).

The infectious agents associated with diarrhoeal disease are transmitted chiefly through the faecal-oral route (Black 2001). An estimated 94% of the diarrhoeal burden of disease is attributable to the environment, and associated with risk factors such as unsafe drinking water, lack of sanitation and poor hygiene (Prüss-Üstün & Corvalán 2006). While conventional interventions to improve water supplies at the source (point of distribution) have long been recognized as effective in preventing diarrhoea (Esrey et al. 1985, 1991), more recent reviews have shown household-based (point-of-use) interventions to be significantly more effective than those at

the source (Fewtrell *et al.* 2005; Clasen *et al.* 2006b). As a result, there is an increasing interest in such household-based interventions.

Previous cost-effectiveness analyses (CEAs) of water interventions, though limited to conventional source-based improvements to increase water supplies, found such interventions to be cost-effective (Varley *et al.* 1998; Cairncross & Valdmanis 2006). In its *2002 World Health Report*, the WHO assessed the cost-effectiveness of interventions to increase coverage of water and sanitation services, concluding that the most cost-effective strategy was the provision of a disinfection capacity at the point of use (WHO 2002). Household-based disinfection was also found to be among the most cost-beneficial of the water and sanitation interventions (Hutton & Haller 2004). A recent CEA assessed the cost-effectiveness of home-based chlorination among HIV-affected households in Uganda (Shrestha *et al.* 2006). Our study builds on previous research by (i) using more broad-based estimates of cost and effectiveness of the interventions, (ii) comparing conventional non-reticulated source- and four household-based interventions to improve water quality, and (iii) employing the generalized CEA methodology developed by WHO-CHOICE to permit a comparison of each of these interventions in the context of other Millennium Development Goal (MDG) health initiatives.

METHODS

Generalized CEA

Our methodology was based on generalized CEA, an approach developed by the WHO which allows for a comparison of the various interventions being considered for implementation (including no intervention or the 'null' scenario) on a sector-wide basis for a group of populations with comparable health systems and epidemiological profiles (Tan-Torres Edejer *et al.* 2003). Generalized CEA is used by the Global Programme on Evidence for Health Policy (GPE) under WHO-CHOICE (Choosing Interventions that are Cost Effective) (http://www.who.int/choice/en/) to produce regional cost-effectiveness estimates for a variety of interventions against more than a dozen diseases, including diarrhoea. As part of a recent series

on the costs and effectiveness of interventions to achieve the MDGs, the WHO-CHOICE MDG Team used generalized CEA to estimate the cost-effectiveness of strategies to combat malaria and HIV/AIDS, control tuberculosis, improve child health and promote maternal and neonatal health (Evans *et al.* 2005). The process for conducting a generalized CEA consists of five basic steps: (i) defining the interventions to be investigated, as well as the counterfactual (null) or baseline state; (ii) estimating the costs associated with the interventions; (iii) estimating the effectiveness of the interventions; (iv) modelling the study population based on demographic, exposure and risk data, and (v) using the effectiveness data to determine the disability adjusted life years (DALYs) averted by each intervention compared to the counterfactual and calculating the cost per DALY averted.

Interventions and coverage level

We evaluated five interventions to improve water quality to prevent diarrhoea. The interventions consisted of conventional non-piped in systems to improve water supply at the source (dug wells, boreholes or stand posts) and four approaches to treating water at the household: chlorination, filtration, solar disinfection and combined flocculation/disinfection. The source-based interventions excluded household connections, since the interventional studies used in estimating their effectiveness investigated non-reticulated systems only, and there is evidence from observational studies that household connections may be more effective in preventing diarrhoeal disease than these non-reticulated systems (Cairncross & Valdmanis 2006). Similarly, we limited the analysis to four types of household water treatment. Although there are numerous other approaches for treating water at the household level (Sobsey 2002), only those which have been evaluated in randomized or quasi-randomized controlled trials were included in the systematic review that formed the basis for the effectiveness estimates used in our analysis. Finally, as these interventions were unlikely to be combined we considered them to be mutually exclusive.

All the intervention scenarios are compared to the situation in 2002, which was defined as the baseline (null/counterfactual) scenario. The baseline scenario represents the situation in which water and sanitation coverage

levels in the year 2002, as estimated in the Global Water Supply and Sanitation Assessment (WHO/UNICEF 2005), would be sustained.

While CEAs are often presented assuming different levels of coverage (conventionally, 50%, 80% and 95%), we limited our analysis to a single coverage level of 50%. As none of these interventions have yet reached a majority of the population in any country, and few environmental health interventions have demonstrated extensive uptake, broader coverage cannot yet be assumed in practice.

Cost and cost offsets

The mean annual cost per person was estimated for each intervention using full economic costing and a "societal perspective" which includes all costs regardless of whether they are incurred by a government, donor, programme implementer or beneficiary. Start-up activities were assumed to have an effect over 10 years and were annualised over this period using a 3% discount rate. Other capital costs were annualised over the useful life of the asset using a 3% discount rate. Central administration, research and professional development costs were excluded. Costs were collected using an ingredients approach and assuming 80% utilization of capacity. While we calculated mean annual cost per person for each intervention (in 2002 US$s), we also calculated a range around this estimate and included this range in the calculation of cost-effectiveness ratios (CERs) for each intervention.

For source-based interventions, we calculated the mean cost of the region-specific estimates for constructing and maintaining protected wells, boreholes and stand posts. Following the approach used in a cost-benefit analysis of water and sanitation interventions (Hutton & Haller 2004), we started with the initial investment cost per capita from the Global Water Supply and Sanitation 2000 Report (WHO/UNICEF 2005), estimated the useful life of the systems (20 years), added 5% for operation and maintenance, and an additional 5% (dug wells and boreholes) or 10% (stand posts) for water resource protection to arrive at an annual cost per person reached. While the costs of these three types of source intervention vary, a mean cost estimate was used since the effectiveness estimates combined source interventions due to limited data. The

variation is nevertheless captured in the range around the mean cost which is shown in the cost estimates and used in the calculation of the CERs.

For household-based interventions, published or reported estimates of cost also exist (Sobsey 2002; Hutton & Haller 2004). However, these estimates mainly reflect product (hardware) costs and do not include personnel and other programmatic (software) costs of the complete intervention. As a result, we independently collected cost information directly from programme implementers using a detailed set of guidelines and worksheets developed in accordance with WHO-CHOICE methods (Clasen 2006a). We also endeavoured to collect information on who pays these costs. For household-based chlorination, costs were based on the "Safe Water System (SWS)" developed by the Centers for Disease Control and Prevention (CDC) and implemented in 19 countries by Population Services International (PSI). For household filtration, the cost estimates were procured from 4 programmes involving either free distribution or social marketing of commercial candle-style and locally-fabricated pot-style filters. For solar disinfection, the cost estimates came from "Sodis" programmes operated by Swiss-based EAWAG/SANDEC and its partners in 13 countries. For household flocculation/disinfection, cost estimates were from 4 country programmes involving the social marketing of PUR® sachets (Procter & Gamble Company) by PSI. More complete details on the calculations are available elsewhere (Clasen 2006a). Due to limited data, estimates were not region-specific.

In addition to the programme costs described above, we calculated the cost offsets (savings) that would accrue to the health sector or households in the form of direct costs averted due to reduced levels of disease. We calculated health cost offsets by multiplying the estimated number of cases averted by the estimated cost per case using mid-point estimates for each case based on WHO databases and methods (Mulligan *et al.* 2005). Health care costs assume that 30% of cases visit a health care facility and 8.2% require 5-day hospital stay (rates that the authors acknowledge may be too high in some regions), and include regional estimates for health care costs (consultation, medication, overheads, etc.). Patient costs include the cost of attending health posts, including transportation, subsistence and region-based estimates for medical costs incurred by the patient. As

some of these savings more than offset the full cost of the interventions in certain cases, we have reported them separately below, keeping the CERs on a gross cost basis. Such health cost savings do not include other possible savings, for example, from substituting solar disinfection for boiling with its associated costs of buying or collecting fuel and its environmental impact. As few programme implementers have attempted to capture and report these additional cost savings and the actual amounts are likely to vary significantly depending on the setting and current practices, there are currently no accurate and comprehensive data available on which to estimate these non-health cost savings. Accordingly, these additional savings are not included in this analysis. Finally, it is noted that health cost offsets represent only cash saved from payment for health services and transport. It does not include any representation of the human cost of suffering and death due to a preventable disease. This is represented in DALYs.

Effectiveness

The effectiveness data used in this analysis are based on a recent systematic review of interventions to improve water quality to prevent endemic diarrhoea conducted under the auspices of the Cochrane Collaboration (Clasen *et al.* 2006*b*). The review includes 38 trials from 30 randomized and quasi-randomized controlled studies covering more than 53,000 persons in 21 countries. The review found substantial differences in the interventions and the settings and other conditions in which they were implemented; it also found important methodological differences in the studies themselves. As a result, only limited meta-analysis of the studies included in the review was possible. The review also cites important limitations on the ability to generalise the results of the underlying studies to longer-term, programmatic (non-research driven) settings. Nevertheless, the review did find significant differences in the pooled measures of effect between source- and household-based interventions and among the four types of household interventions. The review provides the best evidence to date on the effectiveness of interventions, including those at the household level, to prevent diarrhoea by improving the microbial quality of water.

The systematic review segregates studies by measure of effect (rate ratios, risk ratios, longitudinal prevalence ratios, odds ratios and means ratios) to avoid overestimating the pooled effect by the homologous treatment of measures of effect for interventions against common diseases such as diarrhoea. Nevertheless, for purposes of this analysis we have combined all such measures of effect into a single measure of relative risk and sub-grouped the studies by type of intervention (source, household chlorination, household filtration, household solar disinfection and household flocculation/disinfection). Also, as described more fully in the review, one study which reported a very substantial protective effect from household flocculation/disinfection was identified as a possible outlier (Doocy & Burnham 2006). For purposes of this analysis, we have excluded this study in arriving at the pooled measures of relative risk for each type of intervention. The estimated relative risk (and 95% confidence interval) used in this analysis are summarized in Table 1.

Table 1 │ Pooled estimates of effect (and 95% confidence intervals) of water quality interventions for the prevention of endemic diarrhoea (adapted from Clasen 2006*a*)

Intervention type (no. of trials)	Relative risk estimate	95% confidence interval
Source (6)	0.73	0.53 to 1.01
Household chlorination (16)	0.63	0.52 to 0.75
Household filtration (6)	0.37	0.28 to 0.49
Household solar disinfection (2)	0.69	0.63 to 0.74
Household flocculation/disinfection (6)	0.69	0.58 to 0.82

DALYs averted

Using PopMod, a software modelling programme developed by the WHO (Lauer *et al.* 2003), we assessed the health impact of the interventions assuming they are implemented for 10 years on an evolving population in two WHO epidemiological sub-regions (Afr-E and Sear-D). The regions were selected to represent major geographical areas in which the burden of diarrhoeal disease is heaviest; the countries comprising each region appear in Table 2. By entering the incidence or prevalence, remission and case-fatality rates associated with diarrhoea, both under the null (baseline) conditions and with one intervention in place, the model can be used to calculate the population-level health gain (or disease burden averted) as a result of a given intervention relative to doing nothing.

Population figures by sex and age were entered using WHO estimates from the Global Burden of Disease (GBD) (Murray & Lopez 1996). As the risk of diarrhoea varies with water and sanitation coverage levels, the population was then distributed among the relevant exposure scenarios for water and sanitation as defined by Prüss *et al.* (2002), which constitutes the null (baseline) condition against which the intervention is compared: VI (no improved water supply and no basic sanitation in a country which is not extensively covered by those services,

and where water supply is not routinely controlled; Vb (improved water supply and no basic sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled); Va (improved sanitation but no improved water supply in a country which is not extensively covered by those services and where water supply is not routinely controlled); IV (improved water supply and improved sanitation in a country which is not extensively covered by those services, and where water supply is not routinely controlled. Allocation of populations to the various exposure scenarios was based on the Global Water Supply and Sanitation Assessment (WHO/UNICEF 2005). The relative risk of diarrhoea was then entered for each sub-population based on WHO estimates for risks associated with unsafe water (Prüss-Üstün *et al.* 2004). These, in turn, are based on published reviews, large surveys and multi-country studies.

PopMod was then run to estimate the healthy life years for each sub-population. This follows a simplified three-box model which (i) adjusts the susceptible population by the birth rate and mortality rate, (ii) calculates morbidity by applying the disease incidence rate and remission rate against the susceptible population, (iii) and calculates mortality based on the diarrhoeal disease case fatality rate. This provides the counterfactual or baseline rate prior to the introduction of the

Table 2 | Gross cost (and range of cost), health cost offsets and net cost for water quality interventions at 50% coverage in Afr-E and Sear-D

Epidemiological sub-region (and countries)	Intervention	Gross annual cost (and range of cost) in US$ millions	Annual health cost offsets in US$ millions	Net annual cost in US$ millions
Afr-E (Botswana, Burundi, Central	Source	128.4 (50.6–336.8)	121.0	7.3
African Republic, Congo,	Household chlorination	104.7 (104.7–599.4)	229.9	−125.2
Cote d'Ivoire, Democratic Republic	Household filtration	480.5 (320.3–610.5)	391.4	89.1
of the Congo, Eritrea, Ethiopia,	Household solar disinfection	101.5 (76.1–139.5)	192.6	−91.1
Kenya, Lesotho, Malawi, Mozambique,				
Namibia, Rwanda, South Africa,	Household flocculation/disinfection	785.0 (157.0–785.0)	192.6	592.4
Swaziland, Uganda, United Republic				
of Tanzania, Zambia, Zimbabwe)				
Sear-D (Bangladesh, Bhutan, Democratic	Source	222.4 (87.6–582.8)	292.0	−69.6
People's Republic of Korea, India, Maldives,	Household chlorination	374.8 (374.8–499.7)	563.8	−189.0
Myanmar, Nepal)	Household filtration	1,720.6 (1,147.0–2,186.2)	960.0	760.6
	Household solar disinfection	363.4 (272.6–499.7)	472.4	−109.0
	Household flocculation/disinfection	2,810.9 (562.2–2810.8)	472.4	2,338.5

interventions. For non-fatal outcomes, the population model also contains a "health state valuation" (formerly, a "disability factor") to account for the percentage of disability for persons living with and ultimately recovering from diarrhoea. The incidence of disease is then adjusted to reflect the reduction in risk associated with each water quality intervention under investigation. Under this model, the household-based interventions were extended to populations in exposure scenarios IV-VI (households without improved or controlled water supplies) since the household interventions reported in the systematic review encompassed all such scenarios; source-based interventions were extended to populations in exposure scenarios V and VI only, since households in scenario IV already have improved water supplies. PopMod is then run again, with the difference in incidence rates impacting morbidity and mortality throughout the sub-populations. The difference between the number of healthy life years lived by the population with and without the intervention is the number of DALYs averted as a result of that intervention.

Under definitions established by the WHO Commission on Macroeconomics and Health (CMH), interventions are deemed "cost effective" or "highly cost effective" for a given country if results show that they avert one DALY for less than three or one times the per capita national gross domestic product, respectively (CMI 2001). Based on these CMH benchmarks, interventions would be considered "highly cost effective" in Afr-E and Sear-D if the cost of averting one DALY is no more than US$369 and US$276, respectively, and "cost-effective" if less than the product of three times these figures.

RESULTS

Costs and cost offsets

Figure 1 shows the mean annual cost per person covered for each of the interventions, together with the range around this cost. For source-based interventions, the annual costs per person in Afr-E were US$1.55 for a dug well, $1.70 for a borehole and US$2.40 for a communal stand post, yielding a simple mean cost of US$1.88. In Sear-D, the mean annual cost per person for source-based interventions was US$2.61; the borehole cost was lowest (US$1.26), followed by dug wells (US$1.63) and the communal stand post (US$4.95). In practice, these costs are paid by the public sector, an NGO or other implementer, the users or some combination thereof. Therefore, a particular cost profile ascribing these costs to the different payers is not possible.

For household-based interventions, the annual cost per person covered was lowest for solar disinfection (US$0.63) and chlorination (US$0.66), and highest for flocculation/-
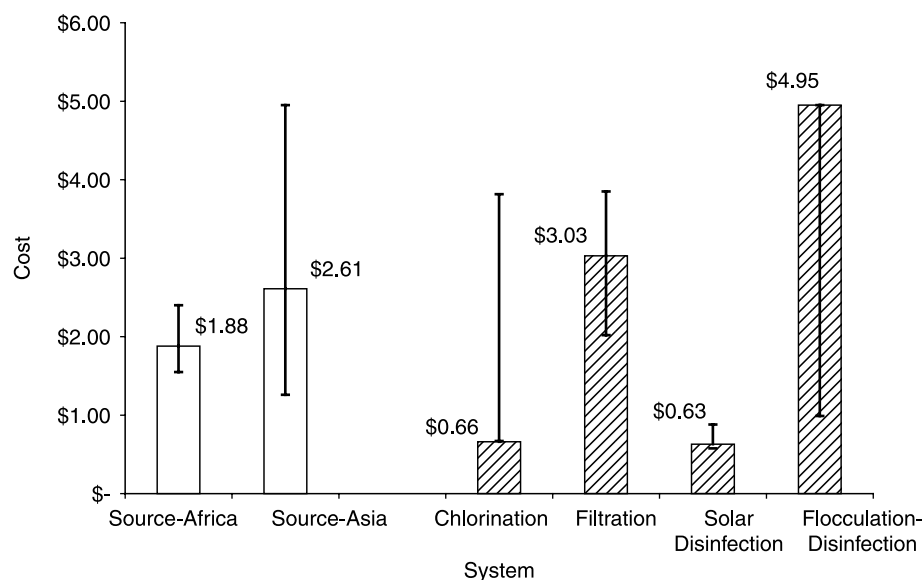

Figure 1 | Annual mean cost per person and range for source-based (solid bars) and household-based (hatched bars) interventions to improve water quality.

disinfection (US$4.95) and ceramic filtration (US$3.03). The cost estimate for chlorination was at the lowest end of its cost range because cost estimates reflect the economies of scaled-up volume where demonstrated in actual practice, as was the case for this intervention. The cost estimate for flocculation/disinfection is at the high end of its range; this reflects the use of five sachets per household per week which more closely corresponds to the amount of product used in health outcome trials even though recent experience has shown that less product is used in practice. The variation in filtration costs reflects the difference between commercial (higher) and locally-fabricated (cheaper) filter systems, and the range for solar disinfection represents variations in bottle and other costs across different countries where programmes have been implemented.

Like source-based interventions, there is no uniform profile for who incurs these costs. In most cases, however, at least part of the cost of household-based interventions was paid directly or indirectly by the beneficiary. For its SWS products, PSI reports an average cost recovery from 19 country programmes of 97% of the production cost, relying on donor funding in most countries to cover indirect costs (Abt Associates 2007). Householders in Cambodia pay 100% of the production cost for commercially-distributed ceramic filters, but only 30.6% for socially-marketed products which are subsidized by donor contributions; programmatic costs are covered by donor funding in both cases (Michael Roberts, personal communication). Solar disinfection programmes sometimes require beneficiaries to purchase the required plastic bottles which represent an average of 71% of the total intervention cost (Martin Wegelin, personal communication). Consumer contributions towards flocculant/disinfectant products range from 35% to 100% of the delivered cost of the sachets (Hanson & Powell 2006).

Table 2 shows the gross aggregate annual cost (and range of cost) in millions of US$s for implementing each of the interventions at the 50% coverage level. As noted above, source-based interventions are applied to populations without improved water supply (exposure scenarios V and VI), while household-based interventions extend not only to these but also to populations with improved but unregulated supplies (exposure scenario IV).

Table 2 also shows the estimated health cost offsets (savings) to the patient and health sector from implementing each intervention at the same 50% coverage level, and the resulting net costs of the intervention after such savings have been subtracted. Most of these costs are currently incurred by the health sector. For Afr-E, the mean cost offsets per case of diarrhoeal disease averted was US$2.77, of which US$2.46 (88%) is borne by the health sector; for Sear-D, the corresponding estimates were US$2.90 and US$2.60 (89.5%), respectively. As Table 2 illustrates, the costs of extending household-based chlorination or solar disinfection to 50% of the population are more than offset by the health cost savings in both epidemiological sub-regions. The cost of source-based interventions is nearly offset by the health savings in Afr-E, and more than offset by such savings in Sear-D.

DALYs averted and CERs

Table 3 shows the annual DALYs averted and gross annual cost per DALY averted for each intervention in Afr-E and Sear-D. It is emphasized that these CEA ratios are based on gross costs and do not include the cost offsets shown in Table 2. For sensitivity analysis, Table 3 also shows (i) the range of annual DALYs averted using the full 95% confidence interval around the pooled estimate of effect for each intervention, and (ii) the range of annual cost per DALY averted using the full 95% confidence interval around the pooled estimate of effectiveness and the upper and lower cost estimates for the intervention shown in Figure 1.

DISCUSSION

In the two epidemiological sub-regions included in this analysis, source- and two household-based interventions (chlorination and solar disinfection) are highly cost effective under CMH benchmarks; household filtration is highly cost effective in Afr-E and cost effective in Sear-D, while household flocculation/disinfection is cost effective in Afr-E but not in Sear-D.

Sensitivity analysis shows the robustness of these conclusions. In Afr-E, source- and all four household-based interventions remain at least cost effective even at the lower range of their effectiveness estimates and upper range of their cost estimates. In Sear-D, source- and two household-based interventions (filtration and solar disinfection) remain at least

Table 3 | Gross annual DALYs averted (and range) and gross annual cost per DALY averted (and range) for water quality interventions at 50% coverage in Afr-E and Sear-D

Epidemiological sub-region	Intervention	Annual DALYs averted (and range) in millions	Gross annual cost per DALY averted (and range) in US$s
Afr-E	Source	1.05 (0 to 3.65)	123 (14–322)
	Household chlorination	1.99 (1.34–2.58)	53 (41–447)
	Household filtration	3.39 (2.74–3.87)	142 (83–223)
	Household solar disinfection	1.67 (1.34–1.99)	61 (38–104)
	Household flocculation/disinfection	1.67 (0.97–2.26)	472 (70–813)
Sear-D	Source	1.56 (0–5.42)	143 (16–375)
	Household chlorination	3.01 (2.03–3.9)	125 (96–1058)
	Household filtration	5.13 (4.14–5.85)	336 (196–528)
	Household solar disinfection	2.52 (2.03–3)	144 (91–246)
	Household flocculation/disinfection	2.52 (1.46–3.41)	1117 (165–1925)

cost-effective throughout their range of cost and effectiveness estimates; at the lower estimates of effectiveness and higher estimates of their costs, however, household-based chlorination and flocculation/disinfection would not be cost effective in Sear-D. While CEA is normally accompanied by considerable uncertainly, the fact that these interventions generally meet the CMH thresholds under a broad range of cost and effectiveness assumptions provides greater confidence of their cost-effectiveness.

With an average cost-effectiveness (ACER) ratio of US$53 and US$125 per DALY averted in Afr-E and Sear-D respectively, household-based chlorination was the most cost-effective intervention in both regions. This result was consistent with the conclusions reached in the 2002 WHO *World Health Report* (WHO 2002). While a recent CEA of home-based chlorination among HIV-affected households in Uganda found a significantly higher cost per DALY averted, the authors ascribed the result to lower than expected mortality in the study setting (Shrestha *et al.* 2006). Cost estimates for the intervention were higher in Uganda due to the inclusion of a vessel with the chlorine and to additional programmatic costs resulting from the home-based care context in which the intervention was delivered.

Household-based filtration presents an opportunity to avert more DALYs with additional investment. The incremental cost-effectiveness ratio (ICER) for household-based filtration is US$268 and US$636 per DALY averted in Afr-E and Sear-D, respectively. This represents additional costs and benefits beyond household-based chlorination. An expansion path for choosing among water quality interventions to prevent diarrhoea would begin with household-based chlorination and end with household-based filtration, the other interventions being dominated (i.e. more costly and less effective) by these approaches.

Combined flocculation-disinfection was strongly dominated by all other interventions except under an assumption in which it can be implemented at its minimum cost. Source-based interventions as well as household-based solar disinfection are weakly dominated by household chlorination and household filtration at their respective point estimates for cost and effectiveness, but such dominance is lost when comparing interventions at their respective ranges of effectiveness and cost. In addition to this uncertainty about their actual cost-effectiveness, there are other reasons not to rule out these interventions completely or to choose among options solely on the basis of cost-effectiveness. Firstly, not all interventions are equally suitable under all circumstances. Household interven-

tions may not be an effective alternative to source-improvements when water quantities are inadequate (Clasen *et al.* 2006*b*). Household chlorination may not be suitable in settings where the water contains a high level of turbidity or chlorine-resistant pathogens, challenges for which the flocculant/disinfectant was specifically designed (Souter *et al.* 2003). Secondly, source-based interventions yield important benefits in terms of convenience and improved productivity which are not measured in this CEA (Hutton & Haller 2004). Thirdly, user preferences may be more important than cost and effectiveness in scaling up these interventions on a sustainable basis (DuBois *et al.* 2003).

Direct cost savings from implementing an intervention, even if limited to the WHO estimates of health cost savings, offset much (and in some cases, more than all) of the costs of implementing interventions to improve water quality. This means that governments, which chiefly incur the costs of health care provision in developing countries, would reduce their overall outlays by increasing investment in the implementation of such preventative interventions to complement and reduce demand for the treatment of cases of diarrhoeal disease. While a finding of such negative costs (i.e. savings) are not uncommon in CEAs with high DALYs averted for relatively low costs, it should be noted that these estimates include only health cost offsets, and not other savings which are likely to accrue to householders as they begin to adopt household water treatments. As a cost-effectiveness rather than cost-benefit analysis, this study also omits the economic value of other benefits (including time savings) which have been shown to ensue from improvements in water supplies (Hutton & Haller 2004).

Insofar as this CEA is based on effectiveness data which concern only the prevention of diarrhoeal diseases, it does not address diseases such as typhoid, hepatitis A and E and polio which may be transmitted by the ingestion of unsafe water but whose pathology does not consist of diarrhoea. While the burden of disease associated with diarrhoea dwarfs any other waterborne disease, these other diseases cannot be ignored. Moreover, because the systematic review on which the effectiveness data in this CEA were based was limited to endemic diarrhoea, the impact of such interventions on epidemic diarrhoea will not be included in the DALYs averted. In these respects, this CEA understates the true impact of such interventions.

Finally, by assuming the all inclusive "societal perspective" in determining costs, this CEA does not address the important issue of who pays for the intervention. While only limited information on cost recovery was available, certain programmes have required contributions from the beneficiaries. Studies suggest that beneficiaries will pay at least a portion of the cost of both source- and household-based interventions (Hutton 2000; Harris 2005). This potential for cost recovery could have important implications regarding the net cost of implementing these interventions. It may also present important advantages in terms of financing, sustainability and scalability.

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DISCLAIMER

L. Haller and J. Bartram are staff members of the World Health Organization. They and the other authors alone are responsible for the views expressed in this publication and such views do not necessarily represent the decisions, policy or views of the World Health Organization.

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