

# A reassessment of the cost-effectiveness of water and sanitation interventions in programmes for controlling childhood diarrhoea

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*Cost-effectiveness analysis indicates that some water supply and sanitation (WSS) interventions are highly cost-effective for the control of diarrhoea among under-5-year-olds, on a par with oral rehydration therapy. These are relatively inexpensive "software-related" interventions such as hygiene education, social marketing of good hygiene practices, regulation of drinking-water, and monitoring of water quality. Such interventions are needed to ensure that the potentially positive health impacts of WSS infrastructure are fully realized in practice. The perception that WSS programmes are not a cost-effective use of health sector resources has arisen from three factors: an assumption that all WSS interventions involve construction of physical infrastructure, a misperception of the health sector's role in WSS programmes, and a misunderstanding of the scope of cost-effectiveness analysis. WSS infrastructure ("hardware") is generally built and operated by public works agencies and financed by construction grants, operational subsidies, user fees and property taxes. Health sector agencies should provide "software" such as project design, hygiene education, and water quality regulation. Cost-effectiveness analysis should measure the incremental health impacts attributable to health sector investments, using the actual call on health sector resources as the measure of cost. The cost-effectiveness of a set of hardware and software combinations is estimated, using US\$ per case averted, US\$ per death averted, and US\$ per disability-adjusted life year (DALY) saved.*

## Introduction

Cost-effectiveness analysis (CEA) is commonly used as a major criterion for the allocation of resources within health programmes and related research activities. Child health programmes sponsored by the U.S. Agency for International Development (USAID) and other organizations generally rely on oral rehydration therapy (ORT) for the control of infant and childhood diarrhoeal disease and do not include water supply and sanitation (WSS) interventions. A principal reason for this is that WSS interventions are not perceived to be cost-effective, nor are they considered the responsibility of health service providers and donor- or NGO-financed child survival programmes. The origins of this view can be traced to an influential article by Walsh & Warren. (1). Using the logic of cost-effectiveness and the goal of decreasing infant and child mortality, Walsh & Warren argued against a broad public health strategy in favour of a strategy of selective primary health

care: with a limited budget, select only the most cost-effective interventions to achieve maximum health impact. In the analysis presented by Walsh & Warren, the gross disparity between the cost-effectiveness of WSS, estimated at US\$ 3600 per death averted (approximately US\$ 10000 in 1996 prices), and selective primary health care, estimated at US\$ 200–250 per death averted (US\$ 600–750 in 1996 prices), seemed a strong justification for ignoring WSS interventions.

This article argues that the conclusions about WSS interventions made by Walsh & Warren are incorrect because they assumed that the full cost of the WSS infrastructure should be paid by the health programme. While the infrastructure component of WSS has an impact on child health, providing infrastructure is not the responsibility of the health sector or child health programmes. If the WSS interventions that are the responsibility of the health sector are identified, and only their costs assigned, health-sector WSS interventions are more cost-effective than generally perceived and are comparable to those for ORT (2).

The consensus treatment of WSS is not to dismiss it as unimportant but to treat it as an exception for the purposes of CEA (3–5). Feachem states the following:

*'Special difficulties are inherent in applying cost-effectiveness analysis to interventions having multiple*

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Reprint No. 5903

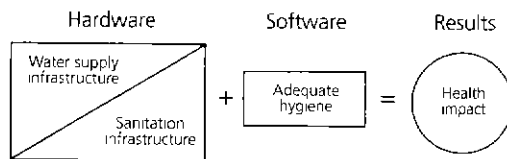
benefits, and water supply and sanitation present these difficulties in an extreme form (Berman, 1982, Briscoe 1984). In addition to their impact on diarrhoea rates among young children, these interventions may avert diarrhoea in other age groups, reduce the incidence of other infectious diseases and have a variety of benefits unrelated to health." (3)

Briscoe's suggested approach was to separate private and social benefits and argue that, from a government perspective, the costs relevant to the cost-effectiveness calculation are those of WSS, minus the amount that users are willing to, and should, pay themselves (6, 7). Our alternative approach, which relates to the potential for using WSS-related interventions as part of child survival programmes, is to focus on WSS interventions that can be implemented by the health sector and limit the costs to those coming directly from the health programme budget, while retaining the use of an appropriate health impact measure of effectiveness. "Improving water supplies and sanitation" and "promotion of personal and domestic hygiene" have been distinguished as two separate types of intervention, each with its own costs and effects (8). The effectiveness of each appears to be enhanced by the presence of the other. Even if there is no positive synergy between "software" and "hardware" interventions (i.e., if their joint effect is the same or less than the sum of the separate effects), a CEA that uses only the costs over which the health programme decision-maker has some control will yield results that are more informative and useful for allocating health programme resources.

## WSS measures as preventive interventions for control of childhood diarrhoea

WSS interventions are fundamental to public health. They prevent illness by reducing exposure to disease agents through physical isolation of faecal waste and changing people's behaviour. WSS interventions include hardware (physical infrastructure), which alters and protects the environment, and software (hygiene education, social marketing, surveillance, monitoring), which transfers knowledge and induces the changes in behaviour that are required to improve health outcomes. Hardware and software components (as shown in Fig. 1) normally have maximum impact in combination; however, independent effects on health status are also possible. Since hardware and software interventions have different health impacts as well as different costs, their

Fig 1. Hardware and software components of water supply and sanitation.



cost-effectiveness in improving health conditions can be very different.

The hardware components are usually not health-sector interventions,<sup>a</sup> although the health sector should influence the design of infrastructure and even how it is operated and maintained in order to maximize positive and avoid negative health impacts. Only the software component is clearly a responsibility of the public health agency. In different countries and at different stages of development, the amount of public interest in and the proportion of the public health budget allocated to the following software interventions will vary:

*Project design:* modifying the design and implementation of development projects (water supply, sanitation, drainage, irrigation, roads, dams, housing, etc.) to achieve positive health impacts and avoid negative impacts.

*Education:* providing information to individuals and community-based groups to improve hygiene-related behaviour.

*Marketing:* using social marketing to increase proper use of water supply and sanitation hardware.

*Regulation:* establishing and enforcing norms for drinking-water and food safety.

*Surveillance:* monitoring and reporting on water quality and water-related diseases.

*Advocacy:* promoting public health as a governmental (public) priority.

## Applying cost-effectiveness analysis to WSS interventions

Planners and programme designers in most health agencies use at least some implicit form of CEA for deciding which interventions to include in their pro-

<sup>a</sup> This is clearly true in urban areas, where health ministries are virtually never responsible for water supply and sewerage systems. Health programmes are sometimes responsible for providing basic water supply and sanitation facilities in rural areas.

grammes and which to exclude (9, 10) CEA compares programme costs to programme performance, measured by some nonmonetary indicator of impact. CEA is more easily understood, is easier to perform, and is less contentious in its interpretation than cost-benefit analysis (CBA).

In CBA, all the benefits and costs of an investment are expressed in monetary units, adjusted for "economic distortions," and discounted by the opportunity cost of capital. The costs (negative) and benefits (positive) are then added to estimate the net present value of the proposed intervention. This estimate represents the net increase in economic welfare that would result from implementing the intervention. Assuming that the goal of society is to maximize economic welfare, the decision to go ahead with the investment requires that the benefits exceed the costs, i.e. that the net present value is more than zero.

CEA, on the other hand, estimates the unit cost of achieving a particular effect (e.g., the cost per child death averted) by a particular means. It does not attempt to determine the monetary value of the effect or judge whether the value of the effect is more or less than the cost of the intervention and cannot, therefore, be used to make an absolute judgement about the desirability to society of making the investment. Rather, CEA is used to determine which means should be employed to achieve a pre-determined goal and to which a level of funding has usually already been allocated. Essentially CEA says that once a decision-maker has decided what to do (maximize health impact), then it should be done at the least programme cost. CBA helps a decision-maker determine *whether* to pursue a particular goal, CEA helps a decision-maker determine the least-cost approach for achieving that goal (see ref. 12 for a concise summary of the difficulties of applying the various rationales for decision-making in public health).

"Cost-effectiveness" (the cost per unit of effect) is a quality of every intervention, however costly, and the cost-effectiveness of a particular intervention may be compared either to that of alternative interventions that produce a similar effect or to a specific programme cut-off value (11). If an intervention's cost-per-unit-effect is less than that of one or more alternative interventions, it will be judged the "more cost-effective" or "most cost-effective" alternative. If its cost-per-unit-effect is less than a test or cut-off value that is applied to all potential interventions, it may simply be judged "cost-effective." Either result provides support for using the intervention as part of a health programme, ensuring that the desirable effect is maximized subject to the constraint of a fixed budget. CEA is often used to com-

pare the cost-effectiveness estimates of a relatively small set of alternative interventions. If a cut-off value is used, it should be determined after considering all feasible interventions (9, 11).

A cut-off value of US\$ 150 per disability-adjusted life year (DALY) was suggested in the *World development report (5)* as the defining criterion for "cost-effective" interventions that should be included in child survival programmes. This value appears to have been widely accepted as a loose definition of "cost effective." More recently, several different "cost-effective" interventions have been described for the control of childhood diseases by applying the DALY methodology to measure effectiveness (14). For diarrhoeal diseases, pneumonia, measles, malaria and malnutrition, the main intervention is the Integrated Management of Childhood Illness (IMCI) approach, with a cost effectiveness of US\$ 30-100 per DALY. For comparison, in 1990 prices the value for the Expanded Program of Immunization (EPI) is US\$ 12-30, and for iodine supplementation, US\$ 20-34, both per DALY saved; in 1996 prices the costs would be approximately 20% higher.

In the following sections, a CEA model is applied to two WSS interventions: construction of facilities (hardware) and provision of hygiene education (an example of software). The cost-effectiveness of the two interventions is estimated separately and jointly.

CEA as applied in this article uses financial and not economic costs. This should have little impact on the conclusions, since there are no *a priori* reasons for assuming that the two costs are very different. Furthermore, a CEA approach which included all indirect economic costs (and benefits) would be equivalent to CBA. As outlined below, there are three critical distinctions between this and previous analyses of the costs and impacts of WSS interventions.

- Investments in hardware are treated as being largely outside the responsibility and control of health programme officials, and hence the cost to the health sector of resources used in the construction and operation of facilities is zero.
- Health impact is measured by three variables, including DALYs and the two more traditional measures, reductions in mortality and morbidity. The DALY combines objective epidemiological parameters with subjective judgements about the relative value of different health outcomes (13).
- Cost is the net cost to the health sector budget, i.e. the actual cost of the software intervention minus any savings realized by the health sector due to

Table 1: Assumed incidence of diarrhoea/year per child for four scenarios<sup>a</sup>

Combinations	SW <sup>-</sup> (No hygiene education)	SW <sup>-</sup> (Hygiene education programme in place)
HW <sup>-</sup> (Inadequate or no hardware)	Base case	10% less than base case 5% (pessimistic) 15% (optimistic)
HW <sup>+</sup> (Adequate hardware present)	10% less than base case 5% (pessimistic) 15% (optimistic)	30% less than base case 20% (pessimistic) <sup>b</sup> 40% (optimistic) <sup>c</sup>

<sup>a</sup> HW = hardware, SW = software.

<sup>b</sup> Sum of the pessimistic assumptions (5% + 5%) plus 10% positive synergistic effect.

<sup>c</sup> Sum of the optimistic assumptions (15% + 15%) plus 10% positive synergistic effect.

the reduction in the number of cases requiring treatment.

## Effectiveness of WSS interventions: summary of empirical findings

There is a considerable literature on the effectiveness of WSS interventions, both software and hardware, for preventing diarrhoeal disease in children, and we used a review of 65 studies (15) to generate a plausible range for the minimum effectiveness of WSS interventions (see Table 1).<sup>b</sup> Hardware is defined as the presence of adequate WSS facilities, while software, for the purpose of this exposition, is limited to hygiene education (disposal of excreta,

water storage and handling, and personal, food and domestic hygiene) (see (16) for definitions). An intervention is defined by two states — before (or without) and after (or with) the intervention. The preventive effectiveness, measured as a reduction in incidence, is the difference in the number of cases occurring before (without) and after (with) the intervention. Below, HW is used for hardware and SW for software, “+” for the presence of and “-” for the absence of:

Adding software to hardware. (HW<sup>-</sup> SW<sup>-</sup>) → (HW<sup>+</sup> SW<sup>-</sup>)  
Adding software to inadequate hardware: (HW<sup>-</sup> SW<sup>-</sup>) → (HW<sup>-</sup> SW<sup>+</sup>)

There are four possible combinations or “states” of HW and SW. By definition HW<sup>-</sup> SW<sup>-</sup> is the base case associated with the maximum incidence of disease. The combination HW<sup>-</sup> SW<sup>+</sup> defines the most desirable state and is associated with minimum incidence and maximum preventive effectiveness (30% reduction in incidence vs. the base case). The states HW<sup>+</sup> SW<sup>-</sup> and HW<sup>-</sup> SW<sup>+</sup> are assumed to have equal effectiveness (10% reduction in incidence vs. the base case) as independent interventions. These values reflect a mild positive synergy between the HW and SW interventions (the joint effect is 30% compared to 20% for the sum of the independent effects). These estimates are used as the basis for the cost-effectiveness calculations.

For comparison, Table 2 shows some of the estimates of preventive effectiveness cited in the literature. In view of the difficulty of comparing the different studies and estimates given, this analysis has employed optimistic and pessimistic scenarios to examine the sensitivity of the results to changes in the assumed values for effectiveness.

## The cost of WSS interventions

A range of representative costs for WSS hardware has been derived from published values. For peri-

<sup>a</sup> Hardware and software interventions may, of course, be implemented separately or in combination. For this analysis we need to characterize their effectiveness under both arrangements. Most of the available literature, however, uses methodologies that do not allow the effects to be measured both separately and in combination. There is therefore some controversy regarding estimates of the preventive effectiveness of WSS hardware and software as independent interventions and, furthermore, whether joint interventions have an effectiveness greater or less than the sum of the separate effects (i.e. whether there is positive or negative synergy). None the less, the uncertainty in estimates of effectiveness does not affect the validity of conclusions from this analysis, for the following reasons:

- First, cost-effectiveness is most useful as a categorical indicator, not a precise cardinal measure. An accurate point estimate of effectiveness is not necessary in an analysis that is intended to categorize interventions broadly as “clearly not cost-effective,” “of doubtful cost-effectiveness,” or “clearly cost-effective.”

- Second and most important, the conclusion that WSS software interventions are cost-effective investments for the health sector rests primarily on the appropriate allocation of costs for health sector and nonhealth sector activities, not on the estimates used for effectiveness.

- Finally, we have deliberately used effectiveness estimates that are conservative (i.e. low) in order to demonstrate that WSS software interventions are cost-effective even under the relatively modest assumptions made here about their preventive effectiveness.

Table 2: Representative studies measuring the preventive effectiveness of water and sanitation interventions<sup>a</sup>

Intervention scenario	Change in status	Preventive effectiveness assumed for the model	Examples of estimated preventive effectiveness			Ref.
			Initial HW coverage	Intervention	Example of impact	
I. SW added to HW	(HW/SW) → (HW/SW') From 10% less than base case to 30% less than base case	20%	Tube well/tap access for 17% of population	Education re: Hand-washing Child defecation and disposal of child faeces	↓ Diarrhoea incidence 26%	(17)
II. SW and HW added	(HW/SW) → (HW/SW') From base case to 30% less than base case	30%	None	Combined SW + HW	↓ Diarrhoea morbidity 25%	(18)
III. HW added	(HW/SW) → (HW/SW') From base case to 10% less than base case	10%	None	Combined SW + HW	↓ Diarrhoea morbidity 30–50%	(3)
			None	HW only	↓ Diarrhoea incidence 20–30% (median from 7 studies)	(19)
			None	HW only	↓ Diarrhoea morbidity 22–25%	(20)
IV. SW added	(HW/SW) → (HW/SW') From base case to 10% less than base case	10%	Not described	Education re Hand-washing Disposal of child and animal faeces	↓ Diarrhoea incidence 11%	(21)

<sup>a</sup> HW – hardware, SW – software

urban conditions, a range of US\$ 10–50 per capita per annum covers the hardware technologies likely to be feasible on a large scale (see for example 14, 22, 23). Costs for piped water systems in rural areas tend to be higher. Because costs for WSS are conventionally expressed as per capita per annum for the whole population, costs per household must be calculated by multiplying the per capita cost by an assumed average number of members per household; this analysis assumes five people per household. The basic analysis uses the lower end of the range of costs (US\$ 14.40 per person  $\times$  5 people = US\$ 72 per household per annum) to reflect peri-urban conditions in which only low-cost, lowtechnology systems are viable. A discount rate of 3%, the same as used in the DALY methodology (10), is used to annualize WSS investment and operational costs. For a simple technology, the infrastructure lifetime may be 5–10 years. For internal consistency when using the DALY measure of effect, where health impact is estimated over a lifetime, the analysis assumes that infrastructure is replaced every 5–10 years. Thus, over an 80-year time frame, the HW infrastructure would need to be replaced between 8 and 16 times.

WSS hardware cannot be supplied only to under-5-year-olds. Although some households will have no children under the age of 5 years, the public health benefit of having complete coverage is high, so all households must be included in the coverage target and hence the cost basis.<sup>c</sup> It should be noted that because the target group for health impact is children under the age of 5 years, the health impact on adults is an irrelevant side-effect for the purposes of this analysis.

To determine the costs for software interventions to be used in the model, a costing matrix for providing hygiene education to households through health extension programme was developed (24). The most important cost component is labour and the total cost of a hygiene education programme is proportional to the number of households with whom contact must be made, rather than the total population. Cost variables include health extension worker to client ratios, number of contacts per year, and the time required for programme implementation. The costs for hygiene education in the short to medium term are best thought of as the costs of carrying out ongoing campaigns of hygiene promotion and maintaining contact with target clients. The cost estimate derived for hygiene education is US\$ 3 per household per year with a lower limit of US\$ 2

and a higher limit of US\$ 5. In a city with 1 million inhabitants (200 000 households), this would mean allocating an average annual budget of US\$ 600 000 for hygiene education related to diarrhoeal disease prevention in peri-urban areas.<sup>d</sup>

## The cost-effectiveness model

Using the information presented above, we developed a spreadsheet model to estimate the cost effectiveness of four WSS intervention scenarios. The data used assume a city with 1 million residents of slum or peri-urban areas who receive few formal services from central or local government. The analysis was conducted for the base year 1996. The calculation of health impacts is in terms of deaths averted, cases averted, and the additional health utility index, DALYs saved. Health impact is defined as the difference between incidence, deaths, or DALYs before and after the intervention. A detailed summary of the calculations for one scenario is presented in the Annex.

The first step is to calculate the incidence of diarrhoeal disease among under-5-year-olds for each of four HW/SW states. The number of cases resulting in death is obtained by multiplying the number of cases by the case fatality rate (CFR), and adjusting the resulting number for deaths averted by treatment with ORT. DALYs are then calculated as follows:

$$\text{DALYs} = \text{Deaths averted} \times \text{YLL} + \text{Cases averted} \times \text{YLD}$$

where

YLL = disability-adjusted years of life saved per death averted

YLD = disability-adjusted years of life spent with the disability per case averted.

<sup>d</sup> This estimate may be on the high side. A recent World Bank WSS project in Indonesia, intended to benefit a rural population of 2 million, costed the hygiene and sanitation education component at US\$ 7 million or US\$ 3.50 per person (25). This cost is for a one-off investment over 5 years, and on an annualized basis (e.g. 30 years at 3%) would amount to less than US\$ 1 per household per year for 30 years. Even if the investment in hygiene education were written off over a 10 year period (i.e. the education campaign was repeated every 10 years) the cost per household per year would only be US\$ 2.05.

As with the costing of many health interventions, there is no single appropriate number, a location-specific order of magnitude is the best most programme analysts can hope to obtain. Estimates reflect differences in cost accounting, programme efficiency, and country characteristics. One study of the costs of oral rehydration therapy (ORT) programmes (26) cites a range of US\$ 0.70 to US\$ 9.66 (in 1982 prices) for the average cost of treatment with ORT from studies in eight different countries; another quotes a range for immunization programmes from US\$ 0.89 to US\$ 15.60 per fully immunized child (27).

<sup>c</sup> Walsh & Warren (7) appear to have used per capita WSS costs multiplied by the population of infants alone, thereby underestimating the costs of achieving child survival impacts.

In other words, DALYs from mortality are combined with DALYs from morbidity to give total DALYs. The formulas for calculating YLL and YLD are taken directly from Murray et al. (13, 28) and are shown in the Annex. The YLL formula provides the average number of years of life to be lived by children currently under the age of 5 years, which is then adjusted using an age-weighting formula that reflects subjective judgements about the relative value of life lived at each age and a time-discounting factor (3%) for future years. The YLD formula provides the time spent with a disability only in the year of intervention, which is reduced by a severity factor (one of six discrete values ranging from 0.096 to 0.920) and by the age-weighting formula.

The data needed to calculate total DALYs associated with each of the four combinations of hardware and software are shown below. The values in parentheses indicate the range of values used for sensitivity analysis.

#### Location-specific epidemiological data

- Incidence: 5 cases per child per year (3, 10).
- CFR: 0.5% (0.3%, 0.7%).
- Age, median age at the onset of the disease: 1 year.
- Duration: 8 days on average per episode or 8/365 years.
- Coverage by ORT: 30%.
- ORT reduction in CFR: 50%.

For the median age at onset, it should be noted that although the midpoint of the under-5-year-old group is 2.5, the distribution of morbidity will not be the same across this age span. The model assumes that not all children up to the age of 2 years are benefiting from the protective effects of exclusive breastfeeding, and that the bulk of morbidity would occur during weaning (6–18 months). Therefore, 1 year is used as the median age of onset.

#### Subjective parameters set by the DALY convention

- Life expectancy: 80 years.
- Severity: disability weight of 0.60 for infant diarrhoea.
- Age-weighting factor: the same age-weighting function used in the *World development report* (14).
- Discount rate: 3%.

In principle, all the locally specific epidemiological data are verifiable empirically. The subjective parameters used in the DALY calculation were devel-

oped by polling experts in a systematic manner (13, 28). The discount rate, age-weighting function, severity and life expectancy are assumptions of the methodology and cannot be verified empirically.

#### Comparison with ORT

The cost-effectiveness of ORT, a curative intervention, is estimated using the model and compared to the cost-effectiveness of WSS interventions, which are preventive. The effects of ORT and WSS interventions are not independent, however. Since ORT treatment is financed from the health budget, a reduction in the number of cases of diarrhoea resulting from a preventive WSS measure will yield a cost saving to the health agency by reducing the number of cases that need to be treated with ORT. Conversely, use of ORT has an impact on the mortality rates and DALYs in the presence of WSS interventions, by reducing the CFR for diarrhoeal disease cases that are treated. Treating a case of diarrhoea with ORT is assumed to cost US\$ 0.50–2.00. For example, in a population of 1 million people with an average of five cases of diarrhoea per child per year, the budget required for ORT would be US\$ 510 000 (assuming the treatment cost is US\$ 2, 30% of the cases are treated, and 17% of the population is under 5 years of age (i.e.  $170\,000 \times 5 \text{ episodes} \times 30\% \times \text{US\$ } 2$ ). Therefore, the savings in ORT costs resulting from a 10% reduction in the number of cases would be US\$ 51 000.

#### Cost-effectiveness of the four WSS scenarios

The results of applying the model to the four WSS scenarios and ORT are presented in Table 3 and discussed below.

#### Scenario 1. Software added to hardware: (HW<sup>+</sup> SW<sup>-</sup>) → (HW<sup>-</sup> SW<sup>+</sup>)

This scenario is the most appropriate for considering health sector-financed interventions. Under the conservative assumptions adopted for this analysis, the effect of adding hygiene software to existing hardware (i.e. of establishing hygiene education programmes in areas where WSS infrastructure already exists or is being built) is to reduce cases by 20%, i.e. the difference between 30% effectiveness for hardware and software combined and 10% for hardware alone. Using these figures, the cost per case averted is US\$ 2.93, the cost per death averted is US\$ 689, and the cost per DALY saved is US\$ 20. The gross

Table 3 Cost-effectiveness of the four WSS scenarios and oral rehydration therapy (ORT)

PERI-URBAN (Population = 1 million, under-5 population = 170 000, households = 200 000)	SW added to HW (Scenario I)				HW and SW combined (Scenario II)		HW only (Scenario III)		SW only (Scenario IV)		ORT	
	Base		Pessimistic		Optimistic		HW-SW <sup>-a</sup>		HW-SW <sup>-b</sup>		base	
	HW-SW <sup>-c</sup>	HW-SW <sup>-d</sup>	HW-SW <sup>-e</sup>	HW-SW <sup>-f</sup>	HW-SW <sup>-g</sup>	HW-SW <sup>-h</sup>	HW-SW <sup>-i</sup>	HW-SW <sup>-j</sup>	HW-SW <sup>-k</sup>	HW-SW <sup>-l</sup>	HW-SW <sup>-m</sup>	HW-SW <sup>-n</sup>
Reduction in the number of episodes per year per child	1.00	0.45	2.50	1.50	0.50	0.50	0.50	0.50	0.50	0	0	0
Cases averted	170 000	76 500	425 000	255 000	85 000	85 000	85 000	85 000	85 000	0	0	0
Deaths averted	723	195	2 529	1 084	361	361	361	361	361	2 125	2 125	2 125
DALYs from deaths averted	24 553	6 629	85 539	36 830	12 277	12 277	12 277	12 277	12 277	72 216	72 216	72 216
DALYs from cases averted	360	162	899	540	180	180	180	180	180	0	0	0
Total DALYs saved	24 913	6 791	86 836	37 370	12 457	12 457	12 457	12 457	12 457	72 216	72 216	72 216
Total cost: SW to health sector (US\$)	600 000	1 200 000	400 000	600 000	0	0	0	0	600 000	0	0	0
Total cost: HW to health sector (US\$)	0	0	0	14 400 000	14 400 000	14 400 000	14 400 000	14 400 000	0	0	0	0
Savings from reduced need for ORT (US\$)	(102 000)	(45 900)	(255 000)	(153 000)	(51 000)	(51 000)	(51 000)	(51 000)	(51 000)	(1 700 000)	(1 700 000)	425 000
Net cost of intervention to health sector (US\$)	498 000	1 154 100	145 000	14 949 000	14 349 000	14 349 000	14 349 000	14 349 000	549 000	1 700 000	1 700 000	425 000
Cost per case averted (US\$)	2.93	12.47	0.34	60.58	168.81	168.81	168.81	168.81	6.46	NA <sup>1</sup>	NA <sup>1</sup>	NA
Cost per death averted (US\$)	689	4 891	57	14 253	39 720	39 720	39 720	39 720	1 520	800	800	200
Cost per DALY saved (US\$)	20	140	1.67	413	1 152	1 152	1 152	1 152	44	24	24	6

<sup>a</sup> Software added to hardware Incidence = 5 episodes per year Effectiveness = 30% - 10% - 20% SW cost = US\$ 3 per household per year Case fatality rate = 0.5%  
<sup>b</sup> Software added to hardware Incidence = 3 episodes per year Effectiveness = 20% - 5% = 15% SW cost = US\$ 6 per household per year Case fatality rate = 0.3%  
<sup>c</sup> Software added to hardware Incidence = 10 episodes per year Effectiveness = 40% - 15% = 25% SW cost = US\$ 2 per household per year Case fatality rate = 0.7%  
<sup>d</sup> Software and hardware added Incidence = 5 episodes per year Effectiveness = 30% - 0% = 30% SW cost = US\$ 3 per household per year HW cost = US\$ 14.40 per capita per year

<sup>e</sup> Hardware only Incidence = 5 episodes per year Effectiveness = 10% HW cost = US\$ 14.40 per capita or US\$ 72 per household per year

<sup>f</sup> Software only Incidence = 5 episodes per year Effectiveness = 10% HW cost = 0 SW cost = US\$ 3 per household per year

<sup>g</sup> Provide 100% coverage for ORT Incidence = 5 episodes per year CFR = 0.25% with ORT and 0.50% without. ORT cost = US\$ 2 per episode.

<sup>h</sup> Provide 100% coverage for ORT Incidence = 5 episodes per year. CFR = 0.25% with ORT and 0.50% without. ORT cost = US\$ 0.50 per episode

<sup>i</sup> NA = not available



cost of the intervention (US\$ 600 000) is partly offset by savings in ORT costs of US\$ 102 000 (which the example assumes are paid for by the public health agency), resulting in a net cost to the health sector budget of US\$ 498 000.

A version of this scenario based on more pessimistic assumptions increases the cost of hygiene education to US\$ 53 per household per year, lowers pre-intervention incidence to three episodes per infant per year, and reduces the CFR to 0.3% and preventive effectiveness to 15%. This still yields US\$ 140 per DALY saved, which is below the WDR US\$ 150 cut-off value for being "cost-effective." A version of this scenario based on more optimistic assumptions lowers the cost of hygiene education to US\$ 2 per household per year, raises pre-intervention incidence to 10 cases per infant per year, and increases the CFR to 0.7% and effectiveness to 25%. In this version, which is not unrealistic for a peri-urban environment, the preventive WSS intervention costs only US\$ 1.67 per DALY saved, US\$ 57 per death averted, and US\$ 0.34 per case averted.

**Scenario II. Hardware and software combined:**  
(HW- SW-) → (HW SW')

The second scenario is to add both hardware and software. This case contains assumptions used in previous cost-effectiveness analyses for WSS as a health intervention, both hardware and software costs are assumed to be paid out of the health sector budget. The hardware chosen for this example is an intermediate technology, which would cost US\$ 72 per household or US\$ 14.40 per capita per year. It would be combined with software costing US\$ 3 per household per year to yield total costs of US\$ 75 per household or US\$ 15 per capita.

This type of intervention is not cost-effective compared to the US\$ 150 per DALY criterion recommended in the *World development report*. The cost per DALY saved is US\$ 413 while that per case averted is US\$ 60.58. The cost per death averted of US\$ 14 253 is comparable to Walsh & Warren's estimate of US\$ 3400–US\$ 4000 per infant death averted in 1975 prices (1) (approximately equal to US\$ 10 000–12 000 in 1996 prices). Even with optimistic assumptions, this intervention is not a cost-effective investment for the health sector aiming to improve infant and child health.

**Scenario III. Hardware alone:**  
(HW- SW-) → (HW SW)

Not surprisingly, the least cost-effective of all scenarios for the health sector is to provide hardware

alone. At a cost of US\$ 14.40 per capita and with preventive effectiveness of 10%, the cost-effectiveness is US\$ 168.81 per case averted, US\$ 39720 per death averted, and US\$ 1152 per DALY saved.

**Scenario IV. Software alone:**  
(HW- SW-) → (HW- SW')

The last scenario is to provide software alone. The cost per DALY and per life saved are US\$ 44 and US\$ 1520, respectively. This qualifies software alone as a "cost-effective" intervention compared to the *World development report* criterion. However, the costs per DALY and per life saved are more than twice those in scenario I in which software is added to existing hardware. This indicates that software interventions alone are a reasonable use of health sector funds, but health agencies would be well advised to target their WSS health education efforts to areas where hardware already exists or is being built, as well as encouraging households to invest their own resources in WSS hardware.

**The cost-effectiveness of ORT**

The last two columns of Table 3 show the cost-effectiveness of ORT for comparative purposes. The assumptions used in the analysis are as follows: five episodes per child per year, a reduction in the CFR from 0.50% to 0.25% for cases treated, a total health-sector cost of US\$ 2 per case treated, and 100% coverage (treatment provided for all cases). The cost-effectiveness is US\$ 24 per DALY saved and US\$ 800 per death averted. If the cost of ORT is lowered to US\$ 0.50 per treatment, the cost per DALY falls from US\$ 24 to US\$ 6 and the cost per death averted falls from US\$ 800 to US\$ 200. The presence of WSS does not change the cost-effectiveness of ORT. It does, however, reduce the total number of cases that have to be treated, and therefore the total budget required to cover the whole population.

**Should WSS construction, operation, and maintenance be considered public health interventions?**

The results of the analysis above confirm that WSS hardware by itself or in combination with software is not a cost-effective intervention for child survival projects, which measure the effect of their investments in terms of reduced morbidity and mortality in

children. However, the proposition that hardware interventions are appropriate investments for the health sector could almost be viewed as a "straw man", i.e. an easy target to strike down. The assertion that the health sector either does or should pay the costs of WSS hardware is not warranted. WSS infrastructure is almost always financed by a combination of user fees and public investment subsidies. Even if such subsidies are granted for public health reasons, they are generally provided through channels other than the health budget. The financing of WSS coverage never has been, and probably never will be, a significant item in the budgets of health authorities, which are more concerned with building and operating facilities for health services. For example, average health expenditures in sub-Saharan Africa were estimated to be US\$ 22 per capita in 1990. Of this only US\$ 10 per capita represented government expenditure on health (29); only a tiny fraction of public health budgets is allocated for the direct provision of WSS services. Furthermore, even these allocations arise mostly from counterpart funding for development projects. To assume that even 5% or US\$ 0.50 per capita of the US\$ 10 is spent on WSS services is probably an overestimate. On the other hand, for even low cost WSS technology, costs vary from around US\$ 15 to US 60 per capita per annum (30).

CEA excludes non-health benefits and uses an index limited to mortality, morbidity or some combination of these (e.g. the DALY). From a consumer's, rather than the health agency's, perspective, the benefits of WSS infrastructure include the accessibility and convenience of safe and clean water and the convenience of waste disposal. People will pay for these benefits, and demand analysis is the proper basis for imposing user fees and/or providing public subsidies.

The significant demand for water supply and the ease and equity of imposing sanitation costs in proportion to water consumption explain why WSS investment is almost never considered a public health agency responsibility. Certainly it is wrong to draw conclusions about the appropriateness of WSS-related health interventions based on a CEA that primarily or solely addresses WSS physical infrastructure.

## **WSS hygiene education interventions are highly cost-effective**

It is equally clear from the results of the CEA presented here that WSS hygiene education interven-

tions are extremely cost-effective for controlling childhood diarrhoea. When hygiene education is added to WSS hardware that already exists or is being funded with non-health monies, the cost of water and sanitation hygiene interventions per DALY saved is comparable to the cost of ORT: US\$ 20 compared with US\$ 24. Using the optimistic variation of this scenario, the cost of hygiene education interventions per DALY saved (US\$ 1.67) is lower than that for ORT as calculated under the low-cost scenario (US\$ 6). Using the pessimistic scenario, the cost per DALY saved is seven times higher than that of the base scenario, or US\$ 140. But even this intervention is still cost-effective according to the *de facto* World health report criterion of US\$ 150 per DALY.

Our results were obtained using conservative assumptions about the effectiveness of WSS hygiene interventions and this makes a strong case for such interventions. Furthermore, it should be pointed out that not all health benefits have been incorporated in the analysis. WSS hygiene interventions also reduce the rate of adult diarrhoea. The cost per DALY saved of WSS hygiene interventions would certainly have been lower had their impact on adult health been included in the analysis. In addition, it could be argued that the changes in cultural practices and attitudes required to change hygiene behaviour are so fundamental, that these changes would be transmitted to future generations without the same need for sustained public intervention. If the US\$ 600 000 per annum discussed above had to be spent every year for only 5 years, the present value of those costs (at a 3% discount rate) would be US\$ 2.75 million. When this sum is annualized (converted to an equivalent annual spending) to match an 80-year time period for the benefits (the time span for DALY health impact), and using the same 3% discount rate, the cost would be only US\$ 91 000 per annum and the cost per DALY saved would be reduced by 85%. The same argument cannot be made for ORT, which requires repeated interventions every year for an indefinite period of time.

When preventive and curative interventions are compared, and if reducing mortality is used as the sole measure of effectiveness, curative interventions tend to be favoured. Conversely, if reducing morbidity is the sole measure, preventive interventions will be favoured since curative interventions do not significantly prevent new cases. DALYs represent a compromise in which both morbidity and mortality are considered in assessing health impact. However, changing the values of the "subjective parameters" used in computing DALYs (severity factor, age weight, and discount rate) can drastically change the relative value of the health impact of preventive and curative interventions. For the DALY parameters

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**Table 4: Cost-effectiveness of WSS intervention to reduce cholera in Mexico, 1991 and 1993**

	1991	1993	Change in conditions
	A	B	A-B
Incidence (episodes/infant/year)	4.50	2.25	2.25
No. of cases	55 531 980	27 765 990	27 765 990
No. of deaths	14 438	7 219	7 219
Loss of DALYs from deaths	490 669	245 335	245 335
Loss of DALYs from morbidity	117 518	58 759	58 759
Total DALY loss	608 187	304 093	304 093
Total cost of SW (US\$)	0	88 146 000	88 146 000
Total cost of HW (US\$)	0	0	0
Total cost of ORT (US\$)	194 361 930	97 180 965	-97 180 965
<i>Cost-effectiveness</i>			
US\$ per case averted			-0.33
US\$ per death averted			-1 252
US\$ per DALY saved			-29.71

used in the *World development report*, the health impact of diarrhoeal disease control interventions is almost entirely due to mortality effects. For example, these subjective parameters imply that one child death averted has the same health impact as preventing 14 443 episodes of diarrhoea, or 115 000 days of diarrhoeal disease in children.<sup>a</sup> If more weight were given to morbidity, the cost-effectiveness of WSS hygiene relative to curative interventions would be even more impressive.

### Applying CEA to other software interventions

WSS conditions have a critical impact on public health and child survival. However, governments usually choose to manage WSS through non-health agencies and by the judicious use of subsidies and regulation of the infrastructure sector. In Mexico, for example, the development of WSS infrastructure has not been financed by the ministry of health, but public health officials' advocacy of better sanitation has influenced government policy. A recent article stated that diarrhoea incidence and mortality among

under-5-year-olds was reduced by 40–50% over a 2-year period by regulatory measures (31):

*"Fostered by a fear of the devastating effects of cholera, several interventions, such as the widespread chlorination of water for human consumption and an effective prohibition on irrigating fruit and vegetables with sewage water, were implemented by the government in June 1991. The results were marked: over the 2-year period 1991–93, the annual mean number of episodes of diarrhoea among under-5-year-olds decreased from 4.5 to 2.2, while the corresponding mortality rate fell from 101.6 to 62.9 per 100 000."*

Table 4 shows indicative estimates for the health cost-effectiveness of these Mexican public health regulations. In 1991 the population of 86.3 million was growing at 2.1% per annum and approximately 14% of the population was aged under 5 years. Using the incidence and mortality data, and the assumption that 70% of the under-5-year-old population receive ORT (reducing the CFR for treated cases by 50%), the CFR in 1991 was 0.023% (12 559 deaths ÷ 55.6 million cases) and 0.029% in 1993 (7925 deaths ÷ 27.7 million cases). The model abstracts from population change and only permits a constant CFR. The average CFR of 0.026% and the mid-period population of 88.1 million were used in deriving estimates. The CFR for the model's input parameters has to be corrected for the effect of ORT and yields a gross CFR of 0.04% (i.e. the CFR assuming no ORT at all.) The pre-intervention state assumes 100% coverage of HW<sup>-</sup>, SW<sup>-</sup> while the post-intervention coverage is 100% HW<sup>-</sup>, SW<sup>-</sup>. The intervention has a preventive effectiveness of 50% compared to hardware only — corresponding to the reduction in cases per infant from 4.5 to 2.25.

<sup>a</sup> A child death averted is worth 30 DALYs. One episode of diarrhoea lasts 8 days and has a severity of 0.6 = 4.8 days multiplied by an age-weighting factor of 0.158 (for the median age of onset of 1 year) = 0.758 = 365 = 0.002077 DALYs. Hence 30 DALYs = 14 443 episodes or 1 DALY = 481 episodes. In other words if DALYs are used as a measure of programme performance, then measured in health units, averting a child death is equivalent to preventing 115 000 child-diarrhoea days.

The cost-effectiveness or impact on the health budget was US\$ 0.33 per case averted, US\$ 1252 per death averted, and US\$ 7.87 per DALY saved. The brackets indicate negative values. The cost-effectiveness estimates are all negative values because of the savings in the total costs of ORT brought about by the intervention — these more than offset the SW costs. The intervention is not only cost-effective, but pays for itself. The assumption that 70% of all ORT costs are paid by the public health budgets may be wrong. Even disregarding the budgetary savings from ORT, the cost-effectiveness of the intervention would be US\$ 3.17 per case averted, US\$ 7937 per death and US\$ 202 per DALY saved. It appears that a 50% reduction in cases at a health sector cost of US\$ 93 million (for regulation and surveillance) would be offset by savings in treatment costs of US\$ 125 million. Including the impact of the intervention on children aged over 5 years and adults would increase the savings and the health impact.

Historically, public health improvement in the developed world required political commitment to establish environmental ownership rights, enshrine them in legislation, and then enforce the relevant regulations. Public health interventions have to keep up with dynamic growth in the WSS sector. Increased water supply precedes sanitation: more water consumed means more wastewater to dispose of. The drinking-water sector requires no financial assistance from the health sector, because demand is nearly always sufficient to cover costs. Sanitation, however, may justify some public intervention in the form of a public health subsidy for construction of sewerage systems, although this is unlikely to be channelled through the budget of a health agency. To ensure that the WSS infrastructure is able to provide substantial health benefits for both children and the general public requires the health sector to devote resources to project design, surveillance, marketing, regulation, education and advocacy.

## Summary and conclusions

Several policy- and programme-related conclusions can be advanced, based on this reassessment of the cost-effectiveness of WSS interventions for improving the health of children under 5 years of age.

- WSS software interventions — those paid for by the health sector — are highly cost-effective in reducing childhood diarrhoea, and are comparable to that of ORT. Using conservative assumptions about the effectiveness and cost of such interventions, the cost of WSS hygiene education interventions per DALY saved is comparable to

that for ORT: US\$ 20 compared with US\$ 24. A sensitivity analysis was carried out by assuming a lower effectiveness and a higher cost for software. In this pessimistic scenario, the cost per DALY saved is seven times higher than that in the base scenario, but even at this lower cost-effectiveness the cost per DALY (US\$ 140) is lower than the cost-effectiveness criterion proposed by WHO and the World Bank (US\$ 150/DALY).

- Huge investments in WSS hardware over the past 20 years in many countries present a favourable opportunity for highly cost-effective WSS software interventions. The presence of existing WSS hardware provides a tremendous opportunity for these countries or communities to invest relatively small amounts in WSS software to achieve significant health impacts.
- Health policy-makers and planners should seriously consider WSS software interventions as part of the overall strategy for improving child health.
- The method of estimating cost-effectiveness that we have described should be applied to other software interventions for preventing diarrhoeal diseases, as well as to those for malaria and acute respiratory infections, the two other major diseases of under-5-year-olds. As in the case of hygiene education for diarrhoea prevention, there is a range of public health interventions for these diseases that do not require the health agency to invest heavily in hardware.

## Acknowledgements

Development of the approach described in this article was funded by the US Agency for International Development (USAID) through the Environmental Health Project (EHP), a USAID contractor sponsored by the Office of Health and Nutrition, Bureau for Global Programs, Field Support and Research (Contract No HRN-C-00-93-00036-11). The views expressed are those of the authors and do not necessarily represent USAID policy. The authors gratefully acknowledge the valuable assistance of Eugene P. Brantly and Diane B. Bendahmane in the preparation of this article.

## Résumé

### Réévaluation de la rentabilité des interventions "eau/assainissement" dans les programmes de lutte contre les diarrhées de l'enfant

Une analyse coût-efficacité montre que les interventions du type *approvisionnement en eau*

assainissement (AEA) sont extrêmement rentables dans le cadre de la lutte contre les diarrhées chez les moins de 5 ans, à égalité avec la thérapie par réhydratation orale. Il s'agit là d'une intervention de nature "logicielle" comme peuvent l'être l'éducation à l'hygiène, le marketing social en faveur de bonnes habitudes d'hygiène, la réglementation touchant l'eau de consommation ou encore la surveillance de la qualité de l'eau. Ces interventions sont nécessaires pour pouvoir tirer pleinement parti des effets bénéfiques que l'infrastructure de l'approvisionnement en eau et de l'assainissement est susceptible d'avoir sur le plan sanitaire. Trois facteurs expliquent que l'on ait pu considérer les programmes AEA comme une utilisation non rentable des ressources du secteur sanitaire: l'hypothèse selon laquelle toute intervention de type AEA supposerait la construction d'une infrastructure, une idée erronée du rôle joué par le secteur sanitaire dans les programmes AEA et une mauvaise interprétation de la portée de l'analyse coût-efficacité. L'infrastructure AEA (le "matériel") est en général construite et exploitée par un organisme public et financée par des subventions à la construction, des subventions d'exploitation, des taxes payées par l'utilisateur ou les impôts fonciers. Aux organismes du secteur sanitaire de se charger de la partie "logicielle", c'est-à-dire le dossier du projet, l'éducation à l'hygiène et la réglementation de la qualité de l'eau. L'analyse coût-efficacité doit permettre de déterminer le gain sanitaire résultant de l'investissement consenti par le secteur de la santé, en considérant que les prélèvements effectifs sur les ressources de ce secteur constituent la mesure du coût. La rentabilité d'un ensemble de combinaisons logiciel-matériel se calcule en utilisant le coût par cas de diarrhée évité, le coût par décès évité et le coût par année de vie ajustée sur l'incapacité.

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number of cases averted. The second step is to translate deaths averted and cases averted into DALYs saved. These three terms become the denominators of the three forms of the cost-effectiveness equation used in this analysis. The third step is to calculate the net cost of the intervention to the health sector budget; this becomes the numerator of the cost-effectiveness equations. Finally, the fourth step is to divide costs by the three separate measures of health effect to yield the cost-effectiveness of the intervention in terms of US\$ per death averted, US\$ per case averted, and US\$ per DALY saved.

Recapitulation of parameters:

Preventive effectiveness	SW <sup>-</sup>	SW <sup>+</sup>
HW <sup>-</sup>	0%	10%
HW <sup>+</sup>	10%	30%

Assumptions for diarrhoeal disease: Incidence = 5 episodes per child per year  
Case fatality rate (CFR) = 0.500%

Assumptions for oral rehydration therapy (ORT): ORT coverage (present) = 30.00%  
ORT reduction in case fatality rate = 50.00%  
ORT coverage (future) = 30.00%

Assumptions needed for DALY calculation:  
D (severity factor) = 0.60  
r (discount rate) = 3.00%  
β (age weighting constant) = 0.04  
a (median age at onset and death) = 1 year  
L (life expectancy) = 80 years  
Duration of an episode = 8 days = 0.022 (8/365) years  
Constant, C = 0.1658  
Age weighting modulation factor K = 1

K = 0 if no age-weighting is applied, but we use K = 1 to maintain consistency with the *World development report* (5) and Murray & Lopez (28). C is a constant, which is taken to be equal to 0.1658 and ensures that total years of life lost/lived with a disability produce the same burden of disease total as when no weighting is used (see Murray (13)).

## Annex

### Sample calculation for scenario 1

Taking scenario 1 (adding SW to existing HW) as an example and the details as specified in Table 3, we illustrate the calculation of cost-effectiveness by splitting it into four separate parts. The first step is to estimate the number of deaths averted and the

**Water and sanitation interventions: cost-effectiveness for controlling childhood diarrhoea**

Cost basis	
Population	1 000 000
No. of households	Population ÷ 5
No. of children under 5 years	17.00% of population
Per annum:	
cost of software	US\$ 3.00 per household
cost of hardware	US\$ 14.40 per capita total population
ORT treatment	US\$ 2.00 per case treated

The analysis of all interventions is done by comparing two states — without (or before) and with (or after) the intervention.

Step I. The number of cases before the intervention is obtained by multiplying the population of children under 5 years of age (17% × 1 million = 170 000) by the number of episodes per year and by the preventive effectiveness of hardware alone = 170 000 × 5 × (1 - 10%) = 765 000.

With the intervention (HW+SW<sup>+</sup>), the preventive effectiveness rises to 30%. Thus, after the intervention, the number of cases = 170 000 × 5 × (1 - 30%) = 595 000.

Therefore, the number of cases averted = 765 000 - 595 000 = 170 000

Deaths averted are equal to cases averted times the case fatality rate = 170 000 × 0.5% = 850.

We know, however, that 30% of all cases are treated with ORT both before and after the intervention, which reduces the case fatality rate for treated cases by 50%. ORT does not affect the number of cases but the preventive WSS software intervention does. Accounting for treatment with ORT, the number of deaths would be 3251.25 before the intervention and 2528.75 after the intervention.

The net deaths averted by the WSS software are thus 3251.25 - 2528.75 = 722.5.

Step II. The following equations for DALY equivalents per death and case averted (*YLL* and *YLD*, respectively) are given by Murray (13):

$$YLL = \frac{KCe^{ra}}{(r + \beta)^2} \left[ e^{-(r + \beta)(L + a)} \left[ -(r + \beta)(L + a) - 1 \right] - e^{-(r + \beta)a} \left[ -(r + \beta)a - 1 \right] \right] + \frac{1 - K}{r} (1 - e^{-rL})$$

$$YLL = 33\,983 \text{ DALYs}$$

$$YLD = D \left[ \frac{KCe^{ra}}{(r + \beta)^2} \left[ e^{-(r + \beta)(L + a)} \left[ -(r + \beta)(L + a) - 1 \right] - e^{-(r + \beta)a} \left[ -(r + \beta)a - 1 \right] \right] + \frac{1 - K}{r} (1 - e^{-rL}) \right]$$

$$YLD = 0.002116 \text{ DALYs}$$

where *a* is now the age of onset of the disability, *L* is now the duration of disability (8 days), and *D* is the disability weight. For simplicity we take the age of onset as the same as median age of death (i.e. 1-year old) — otherwise the calculation must be repeated for each age group (i.e. the 0-1s, 1s, 2s, 3s and 4s) using weights based on relative frequency of cases.

The impact in terms of DALYs is thus 722.5 × 33.983 + 170 000 × 0.002116 = 24 912 DALYs. Over 98% of the DALYs saved are from deaths averted.

Both the *YLL* and *YLD* formulae can easily be programmed in spreadsheet or calculator.<sup>a</sup>

Step III. Hardware costs are for a population of 1 million × per capita cost of US\$ 14.40 per annum = US\$ 14.4 million per annum. The total is the same with and without the intervention. Costs to the public health agency, which pays for the software, are composed of software costs, net of savings in ORT treatments from the decline in the number of cases.

Incremental software costs = (200 000 households × US\$ 3 per household) - (30% × 170 000 × US\$ 2 per ORT treatment) = US\$ 498 000 per annum

Step IV. Cost-effectiveness

$$\begin{aligned} & \text{US\$ } 498\,000 \div (722.5 \text{ deaths or } 170\,000 \text{ cases or } 24\,912 \text{ DALYs}) \\ & = \text{US\$ } 689 \text{ per death averted} \\ & = \text{US\$ } 2.93 \text{ per case averted} \\ & = \text{US\$ } 19.99 \text{ per DALY saved} \end{aligned}$$

<sup>a</sup> A spreadsheet with instructions is available from the Environmental Health Project, 1611 North Kent Street, Suite 300, Arlington VA 22209 USA.

