Health impact of water and sanitation infrastructure reconstruction programmes in eight Central American communities affected by Hurricane Mitch

Deborah M. Moll, Rebecca H. McElroy, Raquel Sabogal, Lana F. Corrales and Richard J. Gelting

ABSTRACT

In response to Hurricane Mitch, which struck Central America in October–November 1998, the American Red Cross (ARC) and the Centers for Disease Control and Prevention (CDC) collaborated on a 3-year evaluation of the public health impact of ARC's water, sanitation and hygiene education activities in eight study areas in Honduras, Nicaragua, El Salvador and Guatemala. The evaluation compared: 1) access to and use of water and sanitation facilities, 2) the use of hygienic behaviours, and 3) diarrhoeal prevalence in children younger than 3 years of age before (February 2000) and after (February 2002) the interventions had been implemented. The evaluation included household and key informant interviews designed to measure these three components. Water quality of community water sources and household water was evaluated by measuring levels of indicator bacteria. During the final survey, an infrastructure evaluation provided a review of the design, construction, and current operation and maintenance of the water systems and latrines. The integrated water and sanitation infrastructure interventions and hygiene education programmes implemented following Hurricane Mitch effectively decreased diarrhoea prevalence in the target communities.

Key words | Central America, Hurricane Mitch, hygiene education, public health, sanitation, water

Deborah M. Moll
2103 Dancing Fox Road, Decatur GA 30032, USA
E-mail: *dmmoll@bellsouth.net*

Rebecca H. McElroy
Raquel Sabogal
Lana F. Corrales
Centers for Disease Control and Prevention, National Center for Environmental Health, Division of Environmental Hazards and Health Effects, Health Studies Branch,
4770 Buford Highway, NE, MS F-46
Atlanta GA 30341, USA
Tel.: (770) 488-3410
Fax: (770) 488-3450

Richard J. Gelting (corresponding author)
Centers for Disease Control and Prevention, National Center for Environmental Health, Environmental Health Services Branch,
4770 Buford Highway, NE, MS F-28
Atlanta GA 30341, USA
Tel.: (770) 488-7067
Fax: (770) 488-7310
E-mail: *rug7@cdc.gov*

INTRODUCTION

From 26 October to 1 November 1998, Hurricane Mitch struck Central America and became one of the most devastating hurricanes of the 20th century. Hurricane Mitch killed approximately 10,000 people, caused regional damage to infrastructure, and destroyed nearly 100,000 homes (USAID 1999), affecting an estimated 3.6 million people. People affected by disasters are more likely to become ill and to die from diarrhoea and other diseases related to inadequate sanitation and water supplies than from any other single cause (The Sphere Project 1998). Therefore, in response to Hurricane Mitch, the American Red Cross (ARC) developed water and sanitation interventions for more than 100 communities in four countries in the region: Honduras and Nicaragua, which suffered extensive country-wide damage and casualties; and El Salvador and Guatemala, which were impacted to a lesser extent. These interventions were developed based on the communities' existing resources and needs, and consisted of drinking water supply systems, latrines, and health promotion and education. ARC took a participatory approach to the interventions, in which the costs and benefits of all feasible options were presented to the communities, then the communities decided on the level of services they were willing and able to support.

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The goal of the ARC post-hurricane interventions was to sustainably improve the health of the people living in the affected areas by focusing on three objectives: 1) establish sustainable access to water; 2) provide sustainable access to sanitation services; and 3) provide community education in basic sanitation and hygiene practices. Providing such barriers to the spread of fecal pathogens by improving water supply, sanitation facilities and hygiene behaviour has been shown to decrease the transmission of diarrhoea, reduce the overall burden of disease and result in higher child survival rates (Esrey *et al.* 1990; Fewtrell *et al.* 2005).

ARC and CDC (Centers for Disease Control and Prevention) collaborated on an evaluation of the public health impact of ARC's post-hurricane water, sanitation and hygiene education activities in eight study areas in Honduras, Nicaragua, El Salvador and Guatemala. The purpose of the surveys was to compare the prevalence of diarrhoea in children < 3 years of age, access to water and sanitation facilities, and the use of hygienic facilities and behaviours before the interventions were initiated (baseline survey – February 2000) and after the interventions had been completed (final survey – February 2002). A mid-term survey was also conducted to inform ARC of progress towards the goals and to help it make decisions about how to refine the interventions to best meet the public health needs of the communities. Water quality measurements of all community water sources and a subset of household water sources provided additional information about the impact of the interventions and allowed us to investigate the association between water quality of stored household water and childhood diarrhoea. An infrastructure evaluation was included in the final survey not only to determine whether the water and sanitation interventions were appropriate and were well designed and well constructed, but also to determine whether the communities were operating and maintaining them properly. We present only the results of the baseline and final surveys here, for brevity and because the differences between these two surveys best convey the overall impact of the programme.

METHODS

Two study areas were evaluated in each of the four countries (Figure 1). A study area was a single community or two communities with similar demographics in the same

Figure 1 | Study areas chosen for evaluation of water and sanitation interventions.

geographic region, which were selected by ARC to receive water and sanitation interventions. The study areas were selected to represent the range of intervention technologies used, and the range of geographical regions, types of community (peri-urban vs. rural, existing vs. resettlement) and sizes of communities in which ARC worked. The study areas were: Las Lomas and Marcovia in Honduras, Nueva Segovia and Waspam (the communities of Kum and Andres) in Nicaragua, Las Pozas and La Ceiba in El Salvador, and Chiquimula (the communities of Plan Shalagua and Guayabo) and Huitzitzil in Guatemala. Table 1 lists the study areas and describes the water, sanitation and hygiene education interventions in each. ARC had completed all interventions in the eight study areas prior to the final survey. In Huitzitzil, Guatemala, baseline data were collected in February 2001 because of logistical constraints that precluded data collection in this study area during February 2000 when baseline data were collected in the other study areas.

The evaluation included: 1) a cross-sectional household survey, including a questionnaire and visual inspection to evaluate the availability of water and sanitation services and related hygiene behaviours; 2) sampling of community water sources and household water for indicators of microbial contamination; and 3) an infrastructure evaluation, including a questionnaire for the ARC water-sanitation programme coordinators in each country, and a detailed on-the-ground inspection of the infrastructure and community records. The infrastructure evaluation also included key informant interviews conducted with the water committee within each community and the country-specific ARC water-sanitation and/or health programme coordinator to assess the functioning, maintenance and sustainability of the water and sanitation interventions. The water committees consisted of local citizen representatives that were responsible for the administration, operation and maintenance of the water system for their community.

The United States Agency for International Development (USAID) Food and Nutrition Technical Assistance (FANTA) Project 'Water and Sanitation Indicator Measurement Guide' (Guide) provided the primary basis for the household survey (Billig *et al.* 1999). These guidelines were used at the request of the ARC because the indicators they contain relate specifically to measuring the performance of disaster-related water and sanitation programmes that are funded by USAID. In addition, they provided a consistent set of performance indicators for evaluating the ARC interventions. The performance indicators described in the Guide include 'impact indicators' and 'monitoring indicators' (Table 2). The impact indicators assess the effect of the interventions on the behaviours and health status of the beneficiaries, and include measures of disease burden, hygiene behaviour, and use of water supply and sanitation facilities. The monitoring indicators assess access to water and sanitation facilities and operation of those facilities. ARC's main health goal was to decrease cases of childhood diarrhoea by 25% (impact indicator 1), as suggested in the Guide. ARC also chose goals for the other indicators, as shown in the shaded columns in Tables 3 and 4.These goals were based on the Guide when information was available there, or were established by ARC. The methods used to measure the indicators are summarized in footnotes to Tables 3 and 4.

To choose a sample that was representative of the conditions in the region, the evaluation was conducted in two study areas in each of the four countries. The sample sizes required to detect an expected difference in each of the USAID indicators were calculated and compared to determine the sample size necessary for the cross-sectional household survey.

The sample size needed to detect a 25% decrease in diarrhoea in children < 3 years of age after a water-sanitation intervention was 717 households. The diarrhoea rate in this population was assumed to be 25% prior to the intervention (Billig *et al.* 1999), and the estimated sample size was calculated using a power of 80% and a confidence interval (CI) of 95%. To account for refusals, a required sample size of 800 households was estimated. This sample size was too large to feasibly cover in one study area. Therefore, this indicator was used as a global indicator, pooling all household data from all study areas to reach the required 800 households. Consequently, changes in the diarrhoea prevalence indicator can be compared statistically only when all of the study areas are pooled to give the required 800 households.

The sample size for the household survey was based on the indicator of hand washing behaviours before and after interventions, which required the largest sample size of the

Table 1 | Study areas and interventions

Country/study area	Type of community	Intervention	Status of intervention at final survey and immediate impact (February 2002)
Honduras			
Las Lomas	Peri-urban; existing community in hilly region	Upgrade water system – new tank and source, additional connections (spring-fed, gravity flow system to household taps)	Completed – water available 24 hours per day
		Household pour/flush latrines	Completed – improved coverage
		Education on hygiene, water use, and sanitation	Completed and ongoing
Marcovia	Peri-urban; resettlement community in flood plain	New water system (deep drilled well, pump to tank, gravity flow to household taps)	Completed – water available for 2 to 3 hours per day
		Household pour/flush latrines	Completed – improved coverage
		Education on hygiene, water use and sanitation	Completed and ongoing
Nicaragua			
Nueva Segovia	Peri-urban; existing community	Municipal water system installed (not by ARC); spring source, gravity flow to household taps	In need of improvement – water available 2 to 3 hours per day
		Household dry pit latrines	Completed – improved coverage
		Education on hygiene, water use and sanitation	Completed and ongoing
Waspam Kum/Andres			
	Rural; existing community in flood plain	16 bored wells in Kum and three bored wells in Andres	Kum: Completed – two pumps broken, some wells go dry
			Andres: No wells constructed by ARC
		Household ventilated improved pit latrines	Kum: Completed – improved coverage
			Andres: No latrine project by ARC
		Education programme on hygiene and sanitation in Kum by ARC. No education by ARC for Andres (provided by other NGOs)	Kum: Completed
			Andres: Other NGOs provided education

Table 1 | (*continued*)

Country/study area	Type of community	Intervention	Status of intervention at final survey and immediate impact (February 2002)
El Salvador			
Las Pozas	Peri-urban resettlement community	New water system (deep drilled well, water pumped to tank, gravity flow to household taps)	Completed – water available 24 hours per day
		Household composting latrines	Completed
		Education programme on hygiene	Completed
La Ceiba	Rural existing community in hilly region	New water system (spring source, pumped to tank, gravity flow to household taps)	Completed
		Additional household composting latrines	Completed
		Education programme on water, sanitation and hygiene	Completed
Guatemala			
Chiquimula Plan Shalagua	Rural; existing community in mountains	Upgrade water system (spring-fed, gravity flow system to household taps)	Completed
		Household VIP latrines	Completed
		Education program on hygiene, water use and sanitation	Completed and ongoing
Chiquimula Guayabo	Rural; existing community in mountains	New water system (spring-fed gravity flow system to household taps)	Completed
		Household VIP latrines	Completed
		Education programme on hygiene, water use and sanitation	Completed and ongoing
Huitzitzil	Rural; existing community on coast	No water intervention planned	Interested in drinking water project, some use bottled water
		Household composting latrines	Completed

remaining indicators. The sample size was calculated by assuming that the practice of proper hand washing behaviours would occur in 20% of households before the intervention (Billig *et al.* 1999). Following the intervention, the percentage of households practising proper hand washing behaviours was predicted to increase to 40% (Billig *et al.* 1999). A sample size of 91 households was calculated, based on a power of 80% and a confidence interval (CI) of 95%. To account for refusals, a systematic sample (every Xth household, based on the size of the community) of 100 households was selected for each study area.

Table 2 | USAID food and nutrition technical assistance: Water and sanitation performance indicators (Billig *et al.* 1999)

Impact indicators	Monitoring indicators
1. Percentage of children aged < 3 years who had diarrhoea in the past 2 weeks	1. Percentage of households with year-round access to an improved water source
2. Per capita daily water use	2. Percentage of households with access to sanitation facility
3. Percentage of food preparers and child care givers with appropriate hand washing behaviour	3. Percentage of recurrent costs for water supply services provided by the community served
4. Percentage of population using hygienic sanitation facilities	4. Percentage of constructed water supply facilities adequately maintained by the communities served

Each community water source and stored water from a subset of households in all communities in each study area was sampled for indicators of fecal contamination. A sample size of 10 households was calculated based on a CI of 95%, a power of 80% and the assumption that water, sanitation and educational interventions would decrease the contamination of stored household water by 67% (Pinfold 1990). To account for refusals, the CDC targeted a representative sample of 12 households from the 100 households participating in the survey in each community. During the baseline survey, CDC investigators collected the water samples and sent them to in-country laboratories. The data reported from some of the labs was questionable (i.e. one lab reported that all samples analysed were negative for fecal coliforms and *E. coli*); therefore, during the midterm and final surveys, the CDC investigators collected and analysed the water samples to quantify *E. coli* using portable Oxfam-DelAgua Water Testing Kits (Robens Centre for Public and Environmental Health, Surrey, UK) and sterile ampulated M-coliBlue media (Millipore, Burlington, Massachusetts). We present here the midterm and final survey results for *E. coli* in stored household water.

Water and sanitation infrastructure was evaluated using a systems analysis approach, which assessed whether the entire infrastructure system (from water source to user to final disposal) was protecting public health and preventing the spread of disease or disease-causing agents. A systems approach has been utilized by WHO (1994) in developing guidelines for the management of water supply and sanitation programmes, as well as by other organizations in approaching both health and environmental issues (see, for example, Stockton 1973; Laporte *et al.* 1996). We also analysed the existence and effectiveness of barriers put in place at each step (water collection, storage, distribution) to prevent or eliminate contamination of the water.

The final survey results were compared statistically with the baseline results using the Chi-square test in SAS 8.02 (SAS Institute Inc. 1999) to determine whether the goals set by ARC for each indicator were met. Univariate analysis and logistic regression were used to determine the strength of association between diarrhoea and each of the indicators, the household water quality, and possible modifying and confounding factors.

RESULTS

Comparison of the status of indicators during baseline and final surveys

Table 3 summarizes the results of monitoring indicators 1 and 2 from the baseline and final surveys. Monitoring indicators 3 (recurrent costs for water supply services provided by the community served) and 4 (percentage of constructed water supply facilities adequately maintained by the communities served) are primarily aimed at measuring longer-term programme management issues related to the ability of the community to sustain water and sanitation interventions over time. This evaluation was limited in its ability to measure these longer-term sustainability issues because of the time frame in which it took place. At the time of the final survey, approximately three years after

Table 3 | Summary of monitoring indicators as reported in the household surveys during the baseline (2000) and final (2002) surveys

			Honduras		Nicaragua		El Salvador		Guatemala	
			Las Lomas	Marcovia	Nueva Segovia	Waspam	Las Pozas	La Ceiba	Chiquimula	Huitzitzil†
Performance indicator	**USAID Guide***	**Year**	**Monitoring indicators**							
1 Households with year-round access to improved water‡	100%§	Baseline 2000	59%	59%	38%	15%	36%	6%	23%	15%
		Goal for 2002	100%	100%	100%	100%	100%	100%	100%	100%
		Final	**80%¶#**	**100%#**	41%	35%#	**90%¶#**	**96%¶#**	**97%¶#**	7%‖
2 Households with access to sanitation facility∫	100%§	Baseline 2000	64%	27%	96%	21%	55%	18%	43%	58%
		Goal for 2002	100%	100%	100%	100%	100%	100%	100%	100%
		Final	**94%¶#**	**97%¶#**	**100%¶**	59%#	**100%#**	**96%¶#**	**97%¶#**	**97%¶#**

Notes: Figures in bold indicate that the goal was met.

*USAID Guide is either a goal or the necessary change in percentage in the population for a specific indicator.

†The baseline survey in Huitzitzil was performed in 2001.

‡Protected water source is less than 200 metres away from the household and there is access to water year-round.

§Goal is not defined in the USAID guide. Goal established by the American Red Cross.

∫Private or shared latrine.

‖Reflects the percentage of households that had access to an improved water source that they used for most household water needs; 40% of households reported buying bottled water for drinking and/or cooking.

¶ARC Goal of 100% coverage of baseline homes was achieved. This percentage reflects the actual reported coverage from the household surveys at the time of the final survey, and is lower than 100% because conditions changed in the community. See further discussion in text.

#Statistical significance of Chi-square statistic < 0.05 for difference between baseline survey and final survey.

Table 4 | Summary of impact indicators as reported in the household surveys during the baseline, mid-term and final surveys, 2000–2002

			Honduras		Nicaragua		El Salvador		Guatemala	
			Las Lomas	Marcovia	Nueva Segovia	Waspam	Las Pozas	La Ceiba	Chiquimula	Huitzitzil†
Performance indicator	**USAID Guide***	**Year**	**Impact indicators**							
1. Children <3 years w/diarrhoea in past 2 weeks‡	25% decrease in no. of cases	Baseline 2000	27	29	27	48	40	25	33	30
		Goal for 2002	≤20	≤22	≤20	≤36	≤30	≤19	≤25	≤23
		Final	**19**	**11**	**12**	**36**	44	24	**22**	31
2. Per capita daily water use (50 lpd)§	100% using 50 lpd	Baseline 2000	27%	29%	16%	0%	23%	6%	4%	57%
		Goal for 2002	100%	100%	100%	100%	100%	100%	100%	100%
		Final	25%	71%¶	13%	0%	29%	21%¶	12%	88%¶
3a. Food preparer with appropriate hand washing behaviour∫	50% increase	Baseline 2000	18%	20%	33%	15%	20%	31%	11%	29%
		Goal for 2002	≥27%	≥30%	≥50%	≥23%	≥30%	≥47%	≥17%	≥44%
		Final	**54%¶**	**63%¶**	**60%¶**	**59%¶**	18%	29%	**92%¶**	**79%¶**
3b. Child caregiver with appropriate hand washing behaviour	50% increase	Baseline 2000	19%	20%	32%	17%	20%	32%	11%	28%
		Goal for 2002	≥29%	≥30%	≥48%	≥26%	≥30%	≥48%	≥17%	≥42%
		Final	**59%¶**	**79%¶**	**61%¶**	**58%**	18%	30%	**92%¶**	**82%¶**
4. Population using hygienic sanitation facilities‖	75% usage	Baseline 2000	23%	16%	72%	14%	6%	11%	15%	37%
		Goal for 2002	≥75%	≥75%	≥75%	≥75%	≥75%	≥75%	≥75%	≥75%
		Final	**88%¶**	**86%¶**	**85%¶**	39%¶	**90%¶**	**77%¶**	**91%¶**	**90%¶**

Figures in bold indicate that the goal was met.

*Notes: USAID Guide is either a goal or the necessary change in percentage in the population for a specific indicator.

†The baseline survey in Huitzitzil was performed in 2001.

‡Goal is a 25% reduction in the number of cases of diarrhoea per 100 children in the study population.

§Percentage of households that can obtain 50 l per person per day of water, measured as reported volume of water collected in one day divided by the reported number of persons who sleep in the house.

∫Assessed on the basis of the interviewees' ability to recite critical times at which they wash their hands and to demonstrate specific hand-washing techniques.

¶Statistical significance of Chi-square statistic < 0.05 for difference between baseline survey and final survey.

‖A facility was considered hygienic if there were less than three flies present and no excreta were found outside the latrine. A latrine was considered operational if one or more of the following conditions were met: recently cleaned with water, presence of a path to the latrine, signs of recently being swept, in repair and no spider webs.

Hurricane Mitch, some of the projects had been operating for about one year, while others had been online for only a period of weeks. Therefore, a meaningful evaluation of longer-term sustainability as measured by these impact indicators was not possible.

At the time of the final survey, five of eight study areas met the ARC goal for monitoring indicator 1, year round access to an improved water source within 200 metres of the home. This result contrasts with zero of eight study areas meeting this goal during the baseline survey.

Two of the study areas that did not meet the indicator goal, Waspam, Nicaragua, and Huitzitzil, Guatemala, did not have water projects in part or all of the study area. The third study area that did not meet the goal, Nueva Segovia, Nicaragua, had a water system that was not properly designed or constructed and did not provide adequate service. Four of the five study areas that met the goal had reported coverage less than 100% at the time of the final survey, but this lower reported coverage resulted from growth in the community; 100% of homes that were counted at the time of the baseline survey had access to water at the time of the final survey or had refused to participate in the intervention.

Seven of the eight study areas met the ARC goal for monitoring indicator 2, 100% of households having access to a sanitation facility (functioning toilet or latrine). The study area that did not meet the goal (Waspam, Nicaragua) did not have a latrine project in one of its component communities (Andres). As with the goal for access to water, reported coverage in five of the seven study areas that achieved the goal for access to sanitation was less than 100% at the final survey. The low reported coverage resulted from growth in these communities or from refusal to participate.

Table 4 summarizes the results of the four impact indicators from the baseline and final surveys. The health impact of the interventions was directly measured by impact indicator 1, which measured the percentage of children < 3 years of age with diarrhoea in the 2 weeks preceding the evaluation (for this study, diarrhoea was defined as three or more loose stools in a 24-hour period). The prevalence of diarrhoea decreased regionally from 35 per 100 children to 26 per 100 children, a 26% decrease in prevalence between the baseline and the final survey, which met the ARC goal of a 25% decrease.

For impact indicator 2 (per capita daily water use), none of the eight study areas met the ARC goal of collecting 50 litres of water per person per day (lpd) during the baseline or final surveys. This goal was inappropriate for many of the study areas because of the proximity of the communities to rivers that provide much of the communities' non-potable water needs (e.g. bathing, washing clothes), or the presence of taps or private wells that are capable of providing 50 lpd. Water use in these communities may be underreported because people may not accurately recall the amount of water they collect and store for home use when water is readily accessible.

At the time of the final survey, six of the eight study areas met the USAID target of a 50% increase in the number of food preparers and child caregivers demonstrating knowledge and practice of appropriate hand-washing behaviours after a hygiene education programme (impact indicator 3). The hygiene education programmes in the two communities that did not meet the target for improved hand washing at the final survey (Las Pozas and La Ceiba, El Salvador) ended 5–11 months before the final survey. No further education programmes had been given in those two communities. Most of the communities that met the goal had ongoing hygiene education programmes.

Seven of the eight study areas met the goal for impact indicator 4 (at least 75% of the population use hygienic sanitation facilities). Hygiene education that included a latrine maintenance component played a critical role in the communities' ability to achieve the goal of this indicator, particularly in the study areas that received composting latrines, the proper maintenance and use of which require intensive community education.

Statistical analysis of relationship of intervention components and childhood diarrhoea

Univariate analysis of the indicators for diarrhoea among children < 3 years of age over all years and communities indicated that access to sanitation, access to water and hand washing behaviour contributed to a decreased risk of diarrhoea (Table 5). Years of education of the interviewee and the number of people in the household were not associated with diarrhoea in children < 3 years of age. We constructed a logistic regression model that included each

Table 5 | Univariate analysis of intervention inputs and selected risk factors for diarrhoea among children under 3 years of age in all study communities over all study years

Intervention input/risk factor	*N*	Estimated odds ratio	95% CI	*P* value
Monitoring indicator 1: Water access*	1,272	0.61	0.47, 0.78	<0.0001
Monitoring indicator 2: Sanitation access†	1,296	0.73	0.57, 0.94	0.015
Impact indicator 3: Food preparer with appropriate hand washing‡	1,292	0.68	0.53, 0.90	0.006
Impact indicator 3: Child caregiver with appropriate hand washing‡	1,289	0.67	0.52, 0.87	0.002
Impact indicator 4: Use of hygienic latrine§	834	0.74	0.51, 1.08	0.12
Stored household drinking water contaminated¶	98	0.32	0.11, 0.93	0.03
Stored household water covered	1,186	0.58	0.43, 0.78	0.0004
Handsoap available	1,080	0.70	0.52, 0.94	0.02
Number of users of latrine∫	834	1.08	1.01, 1.15	0.03
Years of education∫	1,184	0.99	0.95, 1.05	0.93
Number of persons in household∫	1,294	0.99	0.96, 1.04	0.94
Animals have access to water source/pumps	1,215	1.48	1.15, 1.90	0.002

*Notes: Protected water source is less than 200 metres away from the household and there is access to water year-round.
†Private or shared latrine.
‡Assessed on the basis of the interviewees' ability to recite critical times at which they wash their hands and to demonstrate specific hand-washing techniques.
§A facility was considered hygienic if there were less than three flies present and no excreta were found outside the latrine. A latrine was considered operational if one or more of the following conditions were met: recently cleaned with water, presence of a path to the latrine, signs of recently being swept, in repair and no spider webs.
¶*E. coli* in stored water during midterm and final surveys (2001 and 2002).
∫Continuous variables.

of the statistically significant indicators and other significant variables. We included hand-washing data only for the child caregivers in the model because the food preparer was usually the same person as the child caregiver.

Multivariate analysis of this model showed that none of the indicators was independently associated with lower prevalence of diarrhoea in children $<$ 3 years of age. Covering household drinking water and access of animals to water sources or pumps were each independently associated with diarrhoea and appeared to modify the association of the intervention indicators with diarrhoea seen in the univariate analysis.

Microbial quality of stored household water

The percentage of contaminated household water samples, expressed as presence of *E. coli* in 100 ml samples, decreased in each of the study areas between the 2001 midterm survey and the final survey, conducted in 2002 (Table 6). Five of the eight study areas achieved a statistically significant decrease in the number of household water samples tested that were contaminated with *E. coli*. Over all communities, in 2001, samples of water reported to have been treated were slightly less likely to be contaminated than water that was reported as untreated (74% and 85% of samples, respectively, $P = 0.27$). The percentage of contaminated samples in 2002 decreased for both water that was reported treated and untreated water (19% and 43%, respectively), and the percentage of samples that were contaminated was significantly lower in the water that was reported treated ($P = 0.03$). The percentage of water samples taken from households that reported that they treated their drinking water on the day of the survey declined slightly between 2001 and 2002.

Table 6 | Comparison of the percentage of stored household water samples testing positive for *E. coli* during midterm (2001) and final (2002) surveys*

Study area	2001	2002	Chi square statistic	*P* value
Las Lomas	11/12 (92%)	2/10 (20%)	11.6	0.0007
Marcovia	4/5 (80%)	1/10 (10%)	7.35	0.007
Chiquimula	6/8 (75%)	4/9 (44%)	1.64	0.20
Nueva Segovia	11/11 (100%)	6/7 (86%)	1.66	0.19
Waspam	11/12 (92%)	5/11 (45%)	5.79	0.02
Huitzitzil	7/8 (88%)	6/10 (60%)	1.68	0.20
Las Pozas	5/9 (56%)	1/10 (10%)	4.55	0.03
La Ceiba	6/10 (60%)	1/9 (11%)	4.87	0.03

*No goal set for household water quality. For the purposes of this analysis, communities that achieved statistically significant reduction in the number of stored water samples testing positive for *E. coli* were considered to meet the input goal.

DISCUSSION

Intervention inputs and health output implications

This study highlights some interesting aspects of the linkage between the inputs of water and sanitation infrastructure, household water quality and hygiene education to the health output of childhood diarrhoea. An integrated programme containing all of the elements of water and sanitation infrastructure and hygiene education led to the most successful health outcome, as illustrated by the three communities in which all of the input goals and the output goal were met (Las Lomas and Marcovia, Honduras, and Chiquimula, Guatemala). These additive impacts seem to contradict the results of several other intervention studies done in lower-income countries. Reviews and meta-analysis of multiple concurrent interventions have indicated that multiple interventions do not show an additive effect (Esrey 1996; Fewtrell *et al.* 2005). Fewtrell and colleagues surmised that this may be due to lack of focus on peripheral components of the programme such as sanitation and hygiene education or because the interventions studied did not assure water quality of household water. Conversely, we found that the communities that had well-integrated programmes in which the water supply, sanitation and hygiene education aspects of the intervention were undertaken by ARC and in-country Red Cross society partners more successfully met the project goals. The conceptual model in Figure 2 illustrates a theory about how the inputs of hygiene education, infrastructure and improved water quality interact and how they affect the health outcome.

In some communities, high quality, well-operated infrastructure interventions (such as those installed in Las Pozas and La Ceiba, El Salvador) were not sufficient to meet the health goals specified for this evaluation when hand-washing behaviour did not improve. In these communities, hand-washing education had been terminated 5 to 11 months prior to the final survey. In Waspam, where the health outcome goal was met even though only the hand washing input goal was met, an established long-term hygiene education programme was in place. These results highlight that lack of ongoing hygiene education can hinder sustainable behavioural changes and health improvements initially achieved by intervention projects. In future projects, the sustainability of improvements in appropriate hand washing and in positive health outcomes may be enhanced by allocating resources to ongoing hygiene education specifically targeted at hand washing after the water/sanitation infrastructure components of the interventions are complete. This approach would take a long-term commitment from implementing agencies, and is often

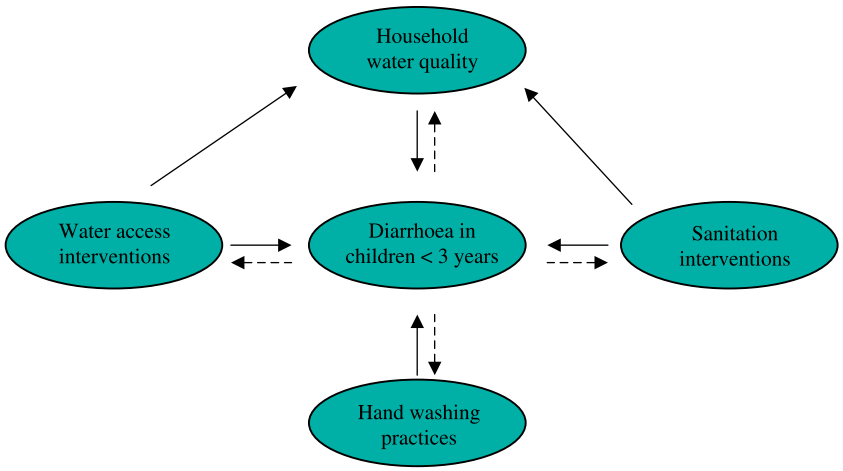

Figure 2 | Conceptual model of intervention inputs/health output relationship.

overlooked after a disaster. Post-disaster interventions provide a largely untapped opportunity to develop long-term local support for and capacity to provide hygiene education and promotion as well as other services to intervention communities, such as ongoing monitoring of infrastructure and water quality.

Another implication of the fact that the health output goal was met in some communities in which all of the input goals were not met is that the input goals may not need to be at the levels specified for this evaluation to achieve the desired health outcomes. It is beyond the scope of this evaluation to specify exactly what input goals would be required to achieve the specified health output of a 25% reduction in childhood diarrhoea. However, access to water and sanitation apparently can be lower than specified for this evaluation to achieve that health outcome. In fact, the levels specified for this evaluation did not appear to be feasible or realistic. The USAID guidelines do not give target values for the monitoring indicators, and ARC decided to use 100% access to water and sanitation facilities as targets for these indicators. Because a considerable amount of manual labour was required from each participating household to complete most of the water and sanitation facilities constructed under this programme, some residents were unable or unwilling to contribute the required labour and therefore were not included in the project. These limitations to access were based on characteristics of the potential user and were not limitations of the interventions.

Statistical analysis

In the univariate analysis, we saw that access to a sanitation facility, provision or availability of an improved water supply, and appropriate hand washing behaviour all contributed significantly to the decrease in diarrhoea in children $<$ 3 years of age in communities recovering from a devastating natural disaster. However, absence of the water quality indicator organism *E. coli* in stored household water was not associated with a decrease in childhood diarrhoea. A meta-analysis of recent studies of the relation between point-of-use water quality, and diarrhoea among pre-school children also found no clear relation between indicator organisms (fecal coliforms and *E. coli*) and diarrhoea incidence (Gundry *et al.* 2004). Our results support two of the explanations for the lack of association that were postulated in that paper: 1) there is a mismatch between water quality indicators and diarrhoeal pathogens; and 2) hygiene education done as part of water/sanitation/hygiene interventions rather than specific improvements in water quality may lead to reductions in diarrhoea. Further research is needed to elucidate the relationship between hygiene education and childhood diarrhoea.

Factors other than the intervention indicators were associated with a decrease in childhood diarrhoeal incidence. In the univariate analysis, access of animals to water sources or water pumps, and presence of a cover on the household water storage container were associated with decreased childhood diarrhoea. In the multivariate analysis,

these variables were shown to have significant independent protective associations with diarrhoeal incidence. Securing water sources from animal access is an integral part of guidelines developed to improve water quality (i.e. WHO 2004) with the ultimate goal of improving health. However, as articulated recently (Clasen & Bastable 2003; Wright *et al.* 2004), water supply interventions need to be extended to ensure the microbial quality of water obtained from these protected water sources. ARC attempted to provide protection on a community level by implementing chlorination in community water storage tanks, with mixed success. On a household basis, covering water (Pinfold 1990) and using improved storage vessels, particularly along with disinfection at the point-of-consumption (such as in CDC's Safe Water System), have shown promise in decreasing diarrhoeal disease in field trials in a variety of settings (i.e. Quick *et al.* 1999; Sobsey *et al.* 2003; and reviewed by Gundry *et al.* 2004); intervention efforts may focus more on ensuring water quality at the point of consumption.

Water quality

Contamination of household water samples decreased in each of the study areas between the midterm and final surveys. Protection of the water sources in the seven study areas where water interventions were performed, and provision of chlorine disinfection in five of the eight community water supplies may have contributed to this improvement in household water quality. While the ARC intended to provide chlorine disinfection for all of the water supplies, the available chlorine supply and delivery technologies varied substantially across the region, and affected the ability to provide continuous disinfection of all but a few of the water supplies in the communities we studied. As noted above, high quality water at the source may be contaminated during collection and handling, resulting in unsafe water at the point of consumption.

Although the percentage of contaminated samples decreased for water that was reported as both treated and untreated at the household level, our study found that contamination of stored household water was significantly lower when the stored water was treated (usually with chlorine). However, the percentage of water samples taken from households that reported they treated their drinking water on the day of the survey declined between 2001 and 2002. In 2002, after the interventions were complete, 63% of people who reported not treating their household water believed their community water supply was treated. Efforts to promote safe storage and in-home treatment should emphasize that household-level treatment is important even when the water source is protected and/or community water is chlorinated.

LIMITATIONS

The overall sample size was designed to evaluate whether the interventions resulted in a statistically significant difference in childhood diarrhoea over the entire regional evaluation, which included study areas in four countries. In contrast, the sample sizes for the household surveys within each individual study area were designed to detect expected differences in the other USAID indicators. Therefore, the analysis of the inputs and output examines the relationships between statistically significant differences in the inputs but only trends in the output of childhood diarrhoea at the level of the study area.

Limitations in the indicators chosen to measure the inputs and outputs may have affected the results of the evaluation. Some of the USAID indicator goals had serious flaws. For example, the per capita water use goal of 50 l day^{-1} was unrealistic. The 15 l day^{-1} Sphere Project goal (Sphere Project 1998) or the 20 l day^{-1} basic access standard advocated by WHO (2004) would have been far more realistic goals for water use in a post-disaster developing world setting.

In addition, although we controlled for seasonal changes in diarrhoeal prevalence by conducting our surveys at one year intervals, we did not account for factors other than water and sanitation interventions that may impact diarrhoea prevalence, such as population density, vector control, and changes in food supply and nutrition, which may have changed from year to year.

We evaluated knowledge of appropriate hand washing behaviour using the USAID guidelines for the child caregivers and the food preparers in each household. The evaluation assessed the percentage of these individuals with appropriate hand washing behaviour at the time of the interview on the basis of the interviewees'

ability to recite, un-prompted, critical times at which they wash their hands and to demonstrate specific hand washing techniques. Respondents may report or modify their hand washing techniques because they are being evaluated.

In many of the study households with children, the primary food preparer and child caregiver were the same person; for these households, the data were recorded for both variables. Because of the colinearity of these variables, we left the food preparer variable out of the multivariate analysis of the independence of the input indicator associations with diarrhoea because child cargiver behaviour was more directly related to the outcome in children $<$ 3 years of age.

The household surveys were conducted as administered interviews with the person in each household who was responsible for the storage and handling of water and the preparation of food. Self-reported data are subjective in that each person responding to the question interprets it in his or her own way. We attempted to reduce the variability in the interpretation of the questions by thoroughly training interviewers from the country or region where the surveys were being conducted. The questionnaires were translated into Spanish (and Miskito for use in Waspam, Nicaragua) and reviewed with the interviewers in each country to account for local dialects. In addition, the questionnaire allowed for more objective observations by the interviewer, such as the distance to the nearest latrine and the cleanliness of the sanitary facilities.

CONCLUSIONS

The post-Hurricane Mitch water and sanitation programme undertaken by the American Red Cross in four countries in Central America met its regional goal of improving the health of the communities receiving interventions. That goal was measured as a greater than 25% decrease in a health impact indicator, diarrhoea in children $<$ 3 years of age. Despite the limitations discussed above, we believe that the measured reduction in diarrhoea is related to the interventions undertaken by ARC, as the indicators used were specifically chosen for their relevance to water and sanitation projects.

Improvements in access to sanitation and household water quality were independently associated with reduced diarrhoea in children $<$ 3 years of age. Access to water and improved hand washing behaviour also contributed to diarrhoea reduction, but were not statistically significant when multivariate analysis was performed. Those study areas where goals for improved water, sanitation and hygiene were all met achieved most of the highest success rates in decreasing childhood diarrhoea.

The goal for reduction of childhood diarrhoea was met in some communities where the goals for access to water and/or sanitation were not met. This result suggests that access to water and sanitation does not need to be met at the levels of coverage specified for this evaluation to achieve the goal of a 25% reduction in diarrhoea. This is a useful finding because the USAID Title II guidelines do not give target values for these indicators, leaving individual organizations to set their own goals. While it is tempting to set goals of 100% coverage, such aspirations are neither realistic nor necessary to achieve health outcome goals such as significant reductions in childhood diarrhoea. Although it was beyond the scope of this evaluation to specify exactly what levels of coverage for water and sanitation would be required to achieve specified health outcomes, it appears to be an area worthy of further research. Identifying threshold levels of coverage necessary for meeting health outcome goals may allow more efficient use of resources for meeting those goals.

REFERENCES

Billig, P., Bendahmane, D. & Swindale, A. 1999 *Title 2 Indicator Guidelines: Water and Sanitation Measurement Guide*. United States Agency for International Development, Washington, DC.

Clasen, T. F. & Bastable, A. 2003 Faecel contamination of drinking water during colelction and household storage: the need to extend protection to point of use. *J. Wat. Health* **1**(3), 109–115.

Esrey, S. A. 1996 Water, waste, and well-being: A multicountry study. *Am. J. Epidemiol.* **143**(6), 608–623.

Esrey, S. A., Potash, J. B., Roberts, L. & Schiff, C. 1990 *Health Benefits from Improvements in Water Supply and Sanitation: Survey and Analysis of Literature on Selected Diseases*. *WASH Technical Report No. 66*. Water and Sanitation for Health Project, Washington, DC.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L. & Colford, J. M., Jr 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect. Dis.* **5**, 42–52.

Gundry, S., Wright, J. & Conroy, R. 2004 A systematic review of the health outcomes related to household water quality in developing countries. *J. Wat. Health* **2**(1), 1–13.

Laporte, R., Barinas, E., Chang, Y. & Libman, I. 1996 Global epidemiology and public health in the 21st century: Applications of new technology. *Ann. Epidemiol.* **6**(2), 162–167.

Pinfold, J. V. 1990 Faecal contamination of water and fingertip-rinses as a method for evaluating the effect of low-cost water supply and sanitation activities on faeco-oral disease transmission. II. A Hygiene intervention study in rural north-east Thailand. *Epidemiol. Infect.* **105**, 377–380.

Quick, R. E., Venzcel, L. V., Mintz, E. D., Soleto, L., Aparicio, J., Gironaz, M., Hutwanger, L., Greene, K., Bopp, C., Maloney, K., Chavez, D., Sobsey, M. & Tauxe, R. V. 1999 Diarrhoea prevention in Bolivia through point-of-use water treatment and safe storage: a promising new strategy. *Epidemiol. Infect.* **122**, 83–90.

SAS Institute, Inc. 1999 *The SAS System for Windows*. *Release 8.02*. SAS Institute, Inc., Cary, North Carolina.

Sobsey, M. D., Handzel, T. & Venczel, L. 2003 Chlorination and safe storage of household drinking water in developing countries to reduce waterborne diease. *Wat. Sci. Technol.* **47**(3), 221–228.

Stockton, E. 1973 The systems approach yields solution choices for environmental quality control. *Am. J. Public Health* **63**(3), 216–223.

The Sphere Project 1998 *Humanitarian Charter and Minimum Standards in Disaster Response*. The Sphere Project, Geneva.

USAID 1999, *BHR/OFDA Annual Report, FY 1999*. US Agency for International Development, Washington, DC, www.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/publications/annual_reports/pdf/AR1999.pdf.

WHO 1994 *Operation and Maintenance of Urban Water Supply and Sanitation Systems: A Guide for Managers*. World Health Organization, Geneva.

WHO 2004 *Guidelines for Drinking-water Quality*, Volume 1, *Recommendations*, 3rd edn. World Health Organization, Geneva.

Wright, J., Gundry, S. & Conroy, R. 2004 Household drinking water in developing countries: a systematic review of microbiological contamination between source and point of use. *Trop. Med. Int. Health* **9**(1), 106–117.

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