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A systematic tool to assess sustainability of safe water provision in healthcare facilities in low-resource settings

Katharine Robb, Lindsay Denny, Samantha Lie-Tjauw, Marisa Gallegos, James Michiel, and Christine Moe

Abstract: *To achieve safe water for all (Sustainable Development Goal (SDG) 6), many healthcare facilities (HCF) will require onsite water treatment. We describe a systematic tool to assess the sustainability of safe water provision in HCFs. Data from surveys, water quality testing, and observations are summarized into scores across four domains: technical feasibility; onsite capacity; financial and operational accountability; and institutional engagement. Lessons learned over five years and multiple assessments across twenty hospitals in three countries are presented. Despite onsite treatment, persistent challenges were identified, including inconsistent water supplies and insufficient funding for maintenance. Across the assessments, 82 per cent of tap water samples met WHO guidelines for* E. coli. *Over time, sustainability improved in most studied hospitals through targeted improvements based on the tool's results. Given the vulnerability of populations in HCFs and greater investment in HCF water infrastructure as part of SDG 6, systematic sustainability assessment and an evidence-based response is critical.*

Keywords: Sustainability; WASH; healthcare facilities; water treatment; mHealth

Introduction

Water crisis in healthcare facilities

Lack of safe water in healthcare facilities (HCFs) in low- and middle-income countries (LMICs) represents a neglected crisis. Instead of being models of safe water practices for communities, many HCFs suffer from water shortages, poor water quality, and deteriorating water infrastructure. A recent secondary analysis reported that only half of HCFs across 78 LMICs have access to piped water (Cronk and

Katharine Robb (kar057@mail.harvard.edu), Center for Global Safe Water, Sanitation, and Hygiene, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA and Harvard T.H. Chan School of Public Health, Boston, MA, USA; Lindsay Denny (lindsay.m.denny@emory.edu); Samantha Lie-Tjauw (slietjauw@gmail.com); Marisa Gallegos (marisa.n.gallegos@emory.edu); James Michiel (jmichiel@bu.edu); Christine Moe (clmoe@emory.edu), all at Center for Global Safe Water, Sanitation, and Hygiene, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA

Bartram, 2018). Another report estimated that less than two-thirds of hospitals providing surgical care in 19 LMICs had a reliable water source (Chawla et al., 2016). Insufficient quantity and poor quality of water pose risks of failed medical treatment and hospital-acquired infections. These problems may discourage use of HCFs and contribute to delays in seeking care and staff absenteeism (Freeman et al., 2013; Velleman et al., 2014). As a 2006 World Health Report puts it, 'no matter how motivated and skilled health workers are, they cannot do their jobs properly in facilities that lack clean water' (WHO, 2006: 81).

The 2015 Sustainable Development Goals (SDGs) include a target for universal access to safe drinking water for all (Goal 6.1) (United Nations, 2015). The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) have committed to the goal of universal access in all facilities by 2030 and have launched a global action plan placing water, sanitation, and hygiene (WASH) in HCFs at the centre of healthcare delivery. This action plan links WASH in HCFs to other WHO priorities including Universal Health Coverage, Antimicrobial Resistance, Infection Prevention and Control, Outbreaks and Emergencies, and Maternal and Newborn Health (WHO/UNICEF, 2016).

However, to achieve universal access to safe water for all, the majority of HCFs will not only need access to a reliable water source, but most will require onsite treatment to meet WHO and national drinking water guidelines. Achieving the target of universal access to safe water for all necessitates a better understanding of the sustainability of onsite water treatment systems in HCFs in LMICs. Given the vulnerability of the populations utilizing healthcare services and the opportunity for HCFs to serve as models for the broader community, sustaining safe water provision in HCFs is an even greater imperative. Further, inclusion of safe water for all under SDG 6 and the launch of the UN's International Decade for Action on Water for Sustainable Development (Guterres, 2018) will lead to greater investment in water in HCFs over the next decade. The process of ensuring the sustainability of water infrastructure needs to be based on systematic assessment and evidence.

Safe water sustainability challenges

HCFs need robust technologies that can reliably deliver sufficient quantity and quality of water. Yet, sustaining safe water infrastructure and practices poses complex and persistent challenges for communities, development partners, and governments. Failure rates for community-level water systems in LMICs are estimated at around 40 per cent, and this percentage has decreased only slightly in the last two decades (Davis, 2014). Such failings result not only in the loss of millions of dollars in community and donor investments, but also threaten human health and well-being. Increasingly, donors and development partners are concerned about the sustainability of WASH interventions, represented by a gradual shift from installation of basic infrastructure to facilitation of sustained provision of services (Boulenouar et al., 2013; Calderon et al., 2016).

Measurement of sustainability

Sustainability of water services is often examined in relation to sociocultural, financial, technical, environmental, and organizational factors (Parry-Jones et al., 2001). It is recognized that sustainability depends on interrelated components, such that sustainability cannot be achieved by focusing on individual factors in isolation (Harvey, 2004). In addition to a body of research identifying the factors that influence the sustainability of safe water provision, the last decade has also seen a proliferation of tools to evaluate sustainability (Schweitzer et al., 2014). A report by Schweitzer et al. identified 25 such tools that were not limited to a particular technology or organization (2014). The tools considered financial, institutional, environmental, technical, and social factors, and results were presented as composite sustainability scores. Application of the tools triggered improvements in programme design or identified remedial actions. However, the tools were oriented toward community-level water points or systems. A study by Saboori et al. examined the sustainability of school hand washing and water treatment programmes and identified six aspects of enabling environments that promote sustainability: financial capacity; technical feasibility; accountability; community support; institutional leadership and management; and participant engagement (2011). The findings of both Saboori et al. and Schweitzer et al. highlight the importance of an enabling environment for the continuation of activities related to an intervention.

However, community- and school-level tools are inadequate to evaluate the sustainability of safe water provision in HCFs, due to critical differences in financing and beneficiaries. Further, HCFs have more complex water needs given the requisite for high-quality water for different healthcare water uses (e.g. irrigation of wounds, during surgeries, in devices such as nebulizers, for laboratory analyses) and the vulnerability of the water users (e.g. very old, very young, immunocompromised). In addition to high-quality water, HCFs require large quantities of lesser-quality water for activities such as cleaning (e.g. floors, other surfaces), toilet flushing (if applicable), laundry, and other uses. While tools now exist to assess WASH conditions in HCFs, such as the WASHCon and WASHFIT tools (Emory University, 2016; WHO/UNICEF, 2018), these tools do not measure sustainability. Our review of existing frameworks and tools revealed the need for a sustainability assessment tool designed for the unique characteristics of sustaining safe water provision in HCFs.

Objective

Reliable, safe water in HCFs is critical for medical, hygiene, and drinking purposes, and achieving it will require many HCFs to add onsite treatment. In recognition of this need, the General Electric Foundation donated water treatment systems to HCFs in several LMICs beginning in 2005. In 2012, the General Electric Foundation engaged the Center for Global Safe Water, Sanitation, and Hygiene at Emory University (CGSW) to assess the sustainability and impact of the donated water treatment systems. The CGSW developed the Safe Water Sustainability Metric (SWSM), a systematic tool to assess the sustainability of safe water provision in HCFs in LMICs. This paper describes the tool's development and application, as well as key findings about the sustainability of safe water provision in HCFs with onsite water treatment systems in Honduras, Ghana, and Cambodia.

The General Electric Foundation water treatment system donation programme

The General Electric Foundation donated water treatment systems to six hospitals in Ghana in 2005, four hospitals in Honduras between 2009 and 2011, and ten hospitals in Cambodia in 2015. The treatment systems consisted of a pre-filter, hollow-filter ultrafiltration membranes, and an automatic chlorine dosing device. Installation of the water treatment systems and initial technical and operational support was provided by an international non-governmental organization, Assist International. In Honduras, assessments using the SWSM were conducted in July 2012, July 2013, and February 2015. Security concerns in Honduras prevented a site visit in 2014. In Ghana, the assessments were conducted in July 2013, July 2014, and May 2015. At the time of the first assessment, the water treatment systems in Honduras had been in place for one to three years, and the systems in Ghana had been in place for eight years. In Cambodia, the SWSM was used during the implementation phase of the donation programme, before full responsibility for the water treatment systems was transferred from Assist International to the hospitals. The assessments were conducted three to six months after installation of the water treatment systems, in August 2015 (in four of the Cambodian study hospitals) and February 2016 (in six of the Cambodian study hospitals).

The hospitals under study in each country were selected through consultation between the Ministry of Health and General Electric Foundation representatives. In Cambodia, the CGSW and Assist International were also involved in the site selection process. In order to ensure the hospitals had a good chance of being able to sustain and benefit from the water treatment systems, the hospitals in Cambodia met an additional set of selection criteria based on lessons learned about facilitators of sustainability in Honduras and Ghana. These criteria included the reliability of the power and water supplies, the availability of at least two staff members to maintain the water treatment system, the hospitals' commitment to paying the operating costs of the treatment system, and a hospital director who was motivated to provide safe water.

The SWSM was developed in two iterations. Version 1 of the SWSM was used in both Honduras and Ghana during the three assessment periods. Based on lessons learned about the sustainability of safe water provision and growing global interest in assessing the sustainability of water systems in HCFs, the SWSM was revised (Version 2) to be applicable to HCFs of various sizes, country contexts, and types of water treatment technology. Version 2 was used in Cambodia.

Methods

The Safe Water Sustainability Metric (SWSM)

The SWSM was designed to systematically assess the sustainability of safe water provision from water treatment systems within HCFs. Sustainability was defined as the likelihood of safe water provision being maintained over time given the technical, capacity, financial, and institutional environment. The tool measures sustainability in 4 domains and 16 sub-domains. Inputs for the SWSM include surveys, observations, and water quality test results. Version 2 of the tool can be used with a range of water treatment technologies, from simple chlorination of stored water to sophisticated membrane filtration systems. Additionally, Version 2 uses a mobile data collection platform and incorporates only closed-ended survey questions and observations, which allows for automated data analysis and rapid data visualization. Due to content and scoring differences between Versions 1 and 2, direct comparisons between the results from these two versions cannot be made; however, general conclusions can be drawn. The SWSM is designed for third-party evaluations by donors, government agencies, or implementers, but it can be adapted for HCF self-assessment. Sustainability can be assessed at a single time point or tracked over time. The SWSM data collection forms are available at: www.washconhcf.org/research-tools/sustainability-metric/.

Tool development and structure

Through literature review and field research on the sustainability of safe water in HCFs, four domains of sustainability were identified: technical feasibility; onsite capacity; financial and operational accountability; and institutional engagement. Each of these domains was divided into four sub-domains. Descriptions of each domain and sub-domain are provided in the supplemental material. The domains and sub-domains were field tested in Version 1 of the SWSM at the 10 HCFs in Honduras and Ghana, and the definitions refined in Version 2. Hereafter, SWSM refers to Version 2 unless otherwise specified.

The tool contains three types of inputs, namely the results from: 1) multiple surveys; 2) an observation checklist; and 3) microbiological and chemical water quality tests. The survey section is administered to the HCF director (46 questions), the maintenance person in charge of the water treatment system (40 questions), and up to 10 HCF staff (7 questions posed to both clinical and non-clinical staff) selected through convenience sampling. The observation section includes a checklist to assess water infrastructure and access to water in key wards. The water quality section involves the collection and analyses of water samples from locations within the HCF, such as the inpatient and outpatient wards, surgical theatre, kitchen, and laboratory, if present. Water samples (approximately 10 per site) are tested for indicators of water quality and effective water treatment processes (e.g. residual chlorine and *E. coli*). The surveys, observations, and water sample collection take approximately one half-day at each HCF.

The outcome of the SWSM is a composite index that comprises indicators grouped around sub-domains. The indicators correspond to survey questions, observations, or water quality results. Each is associated with a score ranging from 0 through 4 (Figure 1). The higher the score, the greater the evidence of an enabling environment for sustainability. An enabling environment is defined as a set of interrelated conditions that facilitate sustainability of safe water provision. A sub-domain score is given by the average score of the associated indicators. Sub-domain scores are

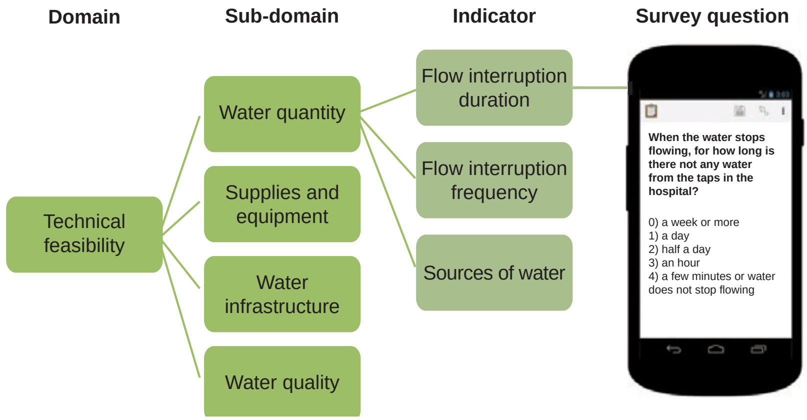
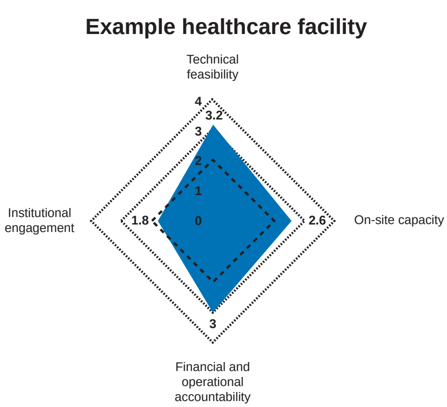


Figure 1 Safe Water Sustainability Metric structure (example from technical feasibility domain)

averaged to form domain scores. Each domain score contributes equally to the overall score. Data is collected on smartphones using CommCare (Dimagi Inc, Cambridge, MA), an open-source mobile data collection platform. The data flows into Microsoft Excel where a summary dashboard (Figure 2) displays the overall domain and sub-domain scores for each HCF. Users can explore each of the 4 domains, 16 sub-domains, and 32 indicators to learn more about the activities and factors that contribute to, or limit, sustained safe water provision. The main output of the SWSM is a radar plot with a sustainability score for each domain (Figure 2). The grid marks range from 0 (no evidence of an enabling environment) to 4 (strong evidence of an enabling environment). A score of 2, indicated by the dashed black line, is defined as meeting basic criteria for an enabling environment for sustainability.



Overall sustainability	2.6
Domain scores	
Technical feasibility	3.2
On-site capacity	2.6
Financial and operational accountability	3.0
Institutional engagement	1.8
Subdomain scores	
Water quantity	4
Supplies and equipment	3
Water infrastructure	3
Water quality	3
Communication	4
Operation	2
Maintenance and repair	1
Training	4
Monitoring performance	4
Internal oversight	4
External oversight	0
Financial management	4
Ownership	2
Satisfaction	3
Participation	2
Awareness	0

Figure 2 Example of Safe Water Sustainability Metric score visualization (left) and dashboard (right)

Data collection methods in Honduras, Ghana, and Cambodia

In Honduras, Ghana, and Cambodia, an average of 10 water samples were collected from different points of use within the hospitals during each data collection period. Sample numbers per hospital varied based on the number of wards and water availability. Samples were collected in 100 ml Whirl-Pak bags containing sodium thiosulfate to neutralize chlorine before microbiological analysis (Nasco, Fort Worth, TX). A separate water sample was collected to test for residual chlorine. Samples were transported on ice to a field laboratory and processed within eight hours of collection. The undiluted water samples were analysed with the IDEXX Quanti-Tray/2000 system for total coliforms, *E. coli*, and *Pseudomonas aeruginosa* using Colilert-18 and Pseudalert reagents (IDEXX, Westbrook, ME). Total coliforms were selected as indicators of the effectiveness of the water treatment system. *E. coli* was selected as an indicator of recent faecal contamination and risk for waterborne disease (Eaton et al., 1995). *Pseudomonas* was selected as an indicator of biofilm and microbial re-growth within the piped network (Eaton et al., 1995). Microbial concentrations were estimated using the most probable number (MPN) method where the lower and upper detection limits were <1 and 2419.6 MPN per 100 ml. Total and free residual chlorine was analysed using a digital colorimeter (DPD method, HACH, Loveland, CO).

Alongside the SWSM, data was also collected on demographic and physical characteristics of the facilities. All data was collected by one or two members of the CGSW research team. In Ghana and Cambodia, a translator was used when the respondent was not fluent in English. In Honduras, surveys were conducted in Spanish by bilingual CGSW staff. The research protocol was approved by the Institutional Review Board (IRB) at Emory University (IRB00057332) as exempt, and in-country IRB approval in Honduras and Ghana was not required. In Cambodia the protocol was approved by the National Ethics Committee for Health Research (114NECHR and 334NECHR).

Results and discussion

Hospital sites

The HCFs included in the study were district-level, government-run referral hospitals located in a range of geographic and climatic conditions. Some were close to capital cities while others were in more remote areas (Figure 3). The hospitals in all three countries provided maternal and child health services, surgical care, and some offered additional medical services, such as eye, dental, and HIV clinics. All had a medical laboratory and pharmacy. With respect to water access and water quality, the hospitals in this study are not representative of the majority of government-run HCFs in LMICs, nor in Honduras, Ghana, or Cambodia. Rather, they likely represent best-case scenarios, as they were selected by their respective ministries of health for inclusion in the donation programme and, in the case of Cambodia, met additional selection criteria.

Water supply and access

Water supply and access varied by country. In Honduras, municipally supplied piped water was the primary water source for each hospital in the study. In Ghana,

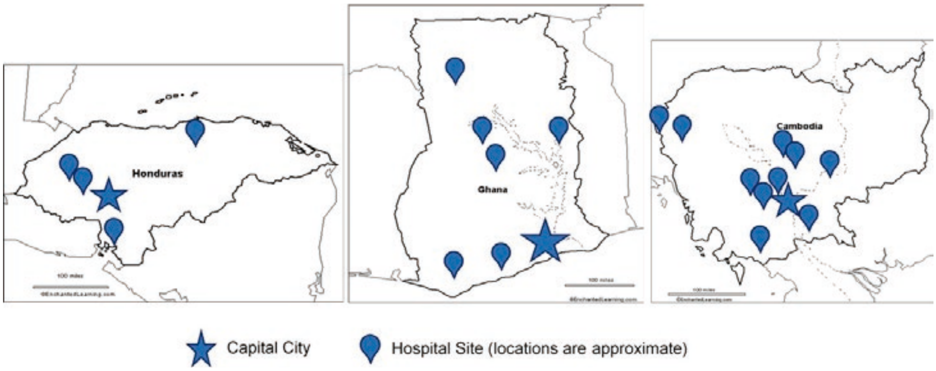


Figure 3 Location of studied hospitals in Honduras (N = 4), Ghana (N = 6), and Cambodia (N = 10)

four of the studied hospitals used an onsite borehole and two used municipally supplied piped water as their primary water source. In Cambodia, five of the studied hospitals received municipal piped water, the other five used onsite boreholes as their primary water source. Despite on-premises water, periodic water outages presented a challenge for both Honduran and Ghanaian hospitals. In Ghana, the hospital directors reported that the water stopped flowing, on average, once per week and would remain off for hours or even days. In Honduras, the hospital directors reported that the water stopped flowing once every two months, on average, and stayed off for less than one day. Commonly reported reasons why the water stopped flowing in both countries were water scarcity in the dry season and power outages. In Ghana, water outages also occurred when the water utility shut off service due to unpaid water bills. None of the hospitals in Cambodia reported problems with their water supply. When water outages did occur, they did not affect water access due to the short duration or sufficient onsite storage capacity.

The hospitals under study developed various strategies to cope with intermittent water supply. Most hospitals stored water in large cisterns and had smaller water storage buckets in patient care areas. In Honduras and Ghana, all hospitals reported purchasing water from tanker trucks during prolonged water outages, which led to increased costs to the hospital. Water access for activities such as hand hygiene was compromised not only by intermittent water supplies but also by broken water infrastructure. Across the three assessments, an average of 63 per cent (ranging from 28–90 per cent) of the taps were functional at the studied hospitals in Ghana, and an average of 87 per cent (ranging from 70–96 per cent) of the taps were functional at the studied hospitals in Honduras. Poor availability of soap further limited hand hygiene. In the studied hospitals in Ghana, across the three assessments, an average of 28 per cent (ranging from 4–47 per cent) of the functional taps in patient care areas had soap present. In Honduras, 62 per cent (ranging from 42–82 per cent) of the functional taps in patient care areas had soap present. The availability of soap was not included in Version 2 of the SWSM used in Cambodia.

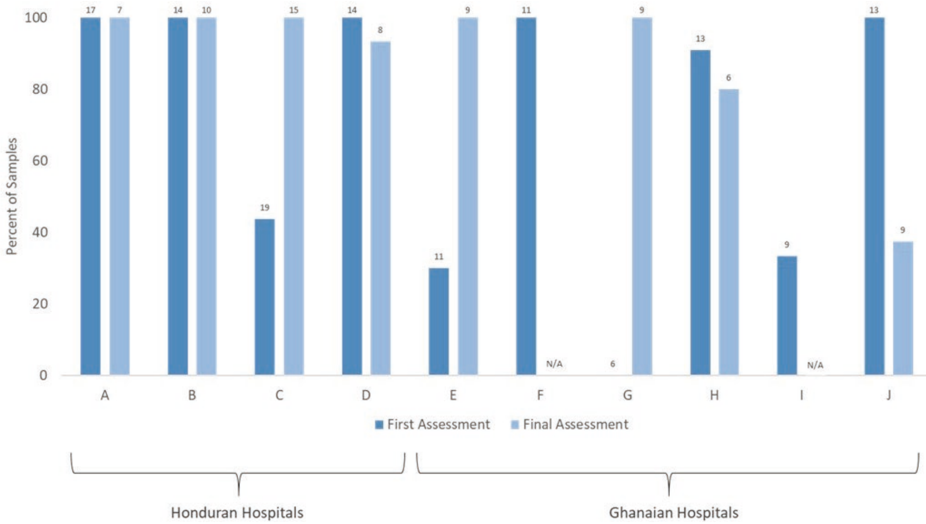


Figure 4 Percentage of hospital tap water samples in Honduras and Ghana at first and final assessments that met WHO guidelines for *E. coli* levels in safe drinking water
Note: Sample numbers are shown above each bar. During the final assessment, no samples were collected from Hospital F and only two samples were collected from Hospital I due to water outages. These water quality results are recorded as N/A. The first assessments occurred in Honduras in 2012 and in Ghana in 2013. The final assessments occurred in 2015

Water quality

During each assessment period, water samples were collected from multiple taps serviced by the water treatment systems in the studied hospitals (overall N = 460). Water quality results from studied hospitals in Honduras and Ghana demonstrate that, even with onsite treatment, many water samples did not meet WHO guidelines for safe drinking water (<1 MPN *E. coli*/100 ml) (Figure 4). In Ghana, the proportion of samples from each hospital that met WHO guidelines for *E. coli* levels ranged from 0–100 per cent. In Honduras, this range was 44–100 per cent. In Cambodia, 100 per cent of the tap water samples met the WHO guidelines for *E. coli* levels.

While water quality improved at some of the studied hospitals in Honduras and Ghana, it decreased in others. From the first to the final assessment, the overall proportion of water samples that met WHO guidelines for *E. coli* levels increased from 90 to 97 per cent in Honduras and from 66 to 74 per cent in Ghana. However, this change was not statistically significant (p-value = 0.1 in Honduras and p-value = 0.4 in Ghana). The overall proportion of water samples that met WHO guidelines for total coliforms also improved between the first and final assessment, from 72 to 95 per cent in Honduras and from 55 to 57 per cent in Ghana. This change was statistically significant for the Honduran hospitals (p-value <0.01) but not for the Ghanaian (p-value = 0.8). There was not a significant difference in the average concentration of total coliforms or *E. coli* in the water samples between the first and final assessments in Honduras (total coliforms mean difference = –108 MPN/100 ml; p-value = 0.06; *E. coli* mean difference = –5.2 MPN/100 ml; p-value = 0.2) or in Ghana (total coliforms mean difference = +90.7 MPN/100 ml; *p*-value = 0.4; *E. coli* = +117.7; *p*-value = 0.2).

Most water samples from Honduras and Ghana were considered to be in a low-risk category (90 per cent of the 329 tap water samples had less than 10 MPN *E. coli* per 100 ml). However, 6 per cent of samples had concentrations between 10 and 99 MPN; 3 per cent between 100 and 999 MPN; and 1 per cent had greater than 1,000 MPN *E. coli* per 100 ml. The mean concentration of *E. coli* and total coliforms was highest in the water samples from the hospitals in Ghana (Table 1). The mean concentration of free chlorine was within the acceptable range (0.2–2.0 ppm) during all three assessments in Honduras and Ghana and the assessment in Cambodia. *Pseudomonas* was present at most hospital sites, and the concentration was high in Cambodia, despite newer water pipes. *Pseudomonas* indicates biofilm and microbial

Table 1 Concentrations of total coliforms, *E. coli*, *Pseudomonas aeruginosa,* and free chlorine in tap water samples from hospitals studied in Honduras, Ghana, and Cambodia

Water quality parameters	*Honduras N = 160 samples 4 hospitals*	*Ghana N = 169 samples 6 hospitals*	*Cambodia N = 131 samples 10 hospitals*
Total coliform (MPN/100 ml) **arithmetic mean** (standard deviation) range	**93.7** (340.8) 0–2419.6	**142.9** (441.0) 0–2419.6	**25.3** (216.0) 0–2419.6
E. coli (MPN/100 ml) **arithmetic mean** (standard deviation) range	**3.4** (20.1) 0–238.2	**49.2** (278.1) 0–2419.6	**0.0** (0) 0–0
Pseudomonas aeruginosa (MPN/100 ml) **arithmetic mean** (standard deviation) range	**39.9** (167.9) 0–1281.1	**164.6** (551.3) 0–2419.6	**98.0** (448.03) 0–2419.6
Free chlorine (ppm) **arithmetic mean** (standard deviation) range	**0.72** (1.88) 0–12.6	**0.44** (1.02) 0–8.8	**0.57** (0.73) 0–3.0

Note: All water samples were collected from point-of-use taps that received water from the treatment systems. The sample size for *Pseudomonas aeruginosa* is 120 in Honduras, as samples were not tested for this target organism during the first assessment. The sample size in Cambodia is 122 because testing for *Pseudomonas aeruginosa* occurred in the month preceding the sustainability assessments regrowth within the water pipes. Biofilm can harbour opportunistic waterborne pathogens that could be a serious threat to immunocompromised patients in the hospitals (CDC, 2018).

While the average microbial concentrations were low, concentrations at the upper limit of detection (2419.6 MPN/100ml) were recorded in 2 per cent of samples tested for *Pseudomonas*, 1 per cent of samples tested for *E. coli*, and 2 per cent of samples tested for total coliforms. As water samples were only tested once per year, we do not know how representative these high values are of the water quality throughout the year. However, they do indicate the potential for surges of high contamination in the hospital water systems that could be a serious health risk to all users. Further, while on average free chlorine concentrations were in the acceptable range, 16 per cent of samples had no detectable chlorine and 3 per cent had concentrations over 5 ppm, indicating poor chlorine solution preparation or dosing.

In Honduras and Ghana, water quality testing, observations, and surveys with maintenance staff and directors revealed that poorly maintained water infrastructure, frequent bypassing of the filtration systems due to reduced water pressure or flow, improper chlorination, and mixing of treated and untreated water within the piped network resulted in poor water quality at the point of use. In both Honduras and Ghana, unreliable water supplies and broken taps contributed to degradation of water quality due to unsafe storage and abstraction practices. In Cambodia, these issues were avoided due to improvements made to the hospitals' piped networks and greater time devoted to the training of maintenance staff.

Water use

Despite the variable quality, tap water was used for drinking and a variety of hygiene and medical purposes (Table 2). The percentage of staff that reported drinking the hospitals' tap water was highest in Cambodia (46 per cent of staff) and lowest in

Table 2 Self-reported use of tap water for drinking, hygiene, and medical purposes by hospital staff in Ghana, Honduras, and Cambodia

Water use activity	*Honduras % (N)*	*Ghana % (N)*	*Cambodia % (N)*
Drinking	**24** (57)	**5** (87)	**46** (79)
Handwashing	**100** (57)	**100** (87)	**93** (80)
Food preparation	**100** (4)	**100** (4)	N/A
Giving medication	**23** (19)	**14** (29)	
Wound care	**0** (19)	**19** (21)	**66** (53)
Burn care	**0** (19)	**6** (19)	

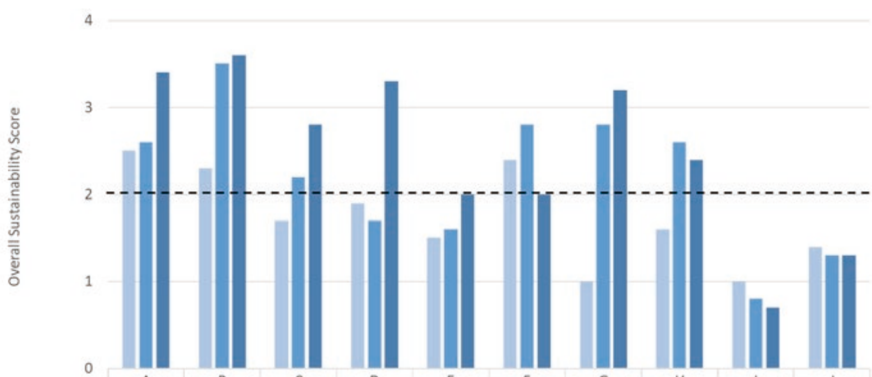
Note: N indicates the number of staff who were asked about their water use. All surveyed staff were asked about water use for drinking and handwashing. Only clinical staff were asked about water use for patient care. Only kitchen staff were asked about water use for food preparation. Data is from the midline assessment in Honduras and Ghana and the first assessment in Cambodia. In Cambodia, staff were asked about tap water use for any patient care activity. In Honduras and Ghana, they were asked about specific patient care activities. In Cambodia, staff were not asked about water use for cooking

Ghana (5 per cent of staff). For patient care activities, most staff reported using purchased water or applying additional treatment (e.g. boiling, distillation) rather than using the tap water directly. Staff, especially in Ghana, cited challenges in accessing sufficient treated water for patient care and described resorting to inferior water sources when necessary. A midwife at hospital G in Ghana reported:

> Since the morning, we have water here, but many times late in the day the tap does not flow. We use a lot of water to deliver babies and to wash mothers and to decontaminate tools and surfaces. For now, we store water so we don't fall short. Sometimes we have to open the PolyTank [where extra water is stored], but sometimes the water there gets finished too. So we fetch water from the front of the hospital [a public standpipe] if we don't have water coming from the tap.

Sustainability scores

Across the three- and four-year assessment periods, an increase in the overall sustainability score was observed in all the Honduran hospitals studied and in two of the six Ghanaian hospitals studied (Figure 5). At the first assessment in Honduras, two of the four hospitals had overall sustainability scores above the sustainability cut-off of 2.0. The average overall sustainability score for the Honduran hospitals at the time of the first assessment was 2.1; by the final assessment the average score had increased to 3.3. At the first assessment in Ghana, one of the six hospitals had a sustainability score above 2.0. By the final assessment, four of the six hospitals were at or above the cut-off. In Ghana, the average overall sustainability score was 1.8 at the first assessment and 2.0 at



	A	B	C	D	E	F	G	H	I	J
First Assessment	2.5	2.3	1.7	1.9	1.5	2.4	1	1.6	1	1.4
Second Assessment	2.6	3.5	2.2	1.7	1.6	2.8	2.8	2.6	0.8	1.3
Final Assessment	3.4	3.6	2.8	3.3	2	2	3.2	2.4	0.7	1.3

Honduran Hospitals (A–D) — Ghanaian Hospitals (E–J)

- - - Cut-Off for Evidence of Enabling Environment for Sustainability

Figure 5 Overall sustainability scores across three assessment periods in Honduras and Ghana
Note: Assessments in Honduras occurred in 2012, 2013, and 2015. Assessments in Ghana occurred in 2013, 2014, and 2015

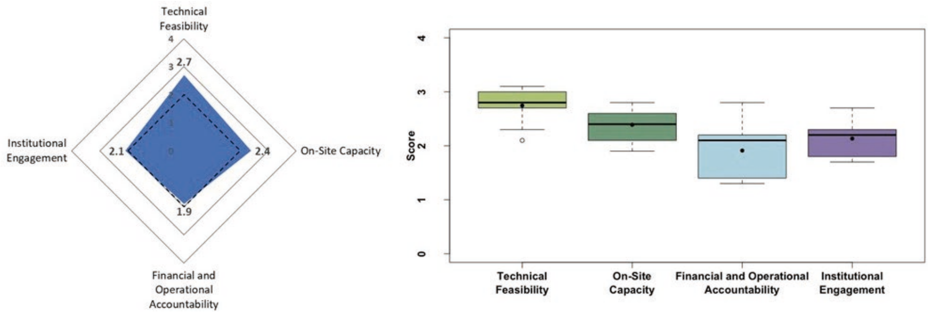


Figure 6 Average sustainability scores (left) and score distribution by domain (right) at studied hospitals in Cambodia
Note: The survey data were incomplete at one hospital site, therefore the figures show results from 9 of the 10 hospitals

the final assessment. The sustainability scores decreased from the first to the final assessment in half of the Ghanaian hospitals. Each Cambodian hospital studied received an overall sustainability score of 2.0 or greater (range 2.0–2.6). The average domain scores are shown in Figure 6. One hospital was excluded from the sustainability score analyses due to incomplete survey data.

Determinants and differences in sustainability across the three countries and lessons learned

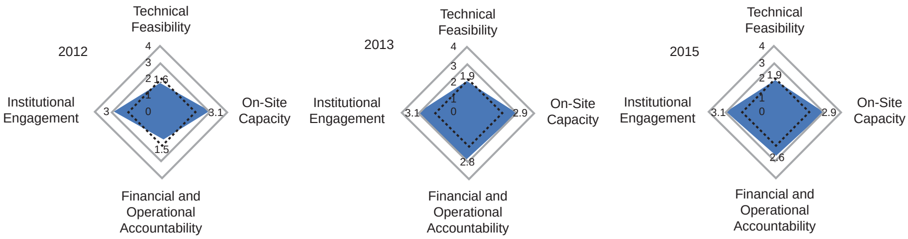
Based on five years of fieldwork and multiple assessments in three countries, key determinants of the sustainability of safe water provision in HCFs were identified, as well as key differences in sustainability across the three countries. The core recommendations are described in Figure 7. Figure 8 presents case studies from three hospitals, depicting how barriers to and facilitators of sustainability were captured by the sustainability scores and how the scores were used for targeted action.

Findings from Version 1 of the SWSM in Honduras and Ghana informed the General Electric Foundation's water treatment system donation programme

Figure 7 Recommendations for sustained safe water provision

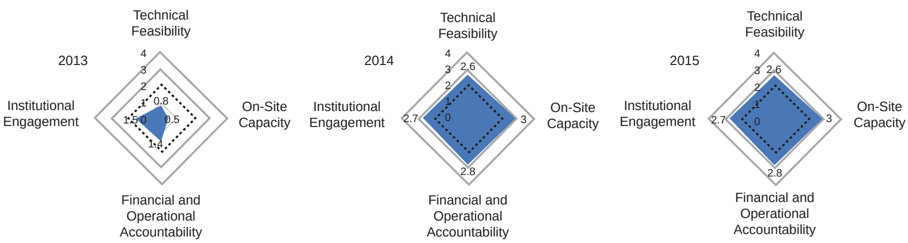
Case 1: Honduran Hospital A showed modest improvement in sustainability from 2012–2015

In Hospital A in Honduras there was not an enabling environment for sustainability in the domains of financial and operational accountability and technical feasibility during the first assessment. However, through targeted interventions, led by the hospital staff and Assist International, sustainability scores improved over time. Alterations to the piped network were made to increase water flow and pressure. After water quality results were shared at a meeting of clinical staff, the staff advocated to the hospital director that water quality be prioritized alongside water quantity. The clinical staff at the meeting also began an initiative to educate other staff on the importance of safe water for patient care through posters and during team meetings.



Case 2. Ghanaian Hospital G showed substantial improvement in sustainability from 2013–2015

Hospital G in Ghana had some of the lowest sustainability scores at the time of the first assessment. The water treatment system was not being used and, due to staff turnover, most staff did not know it existed. With help from Assist International, the system was rehabilitated, and staff were re-trained in operation and maintenance. Guided by low scores in the domains of financial and operational accountability and institutional engagement, the hospital director created a safe water team with clearly defined roles and responsibilities. The director monitored maintenance tasks and offered public recognition to staff when the tasks were completed properly. Over time, sustainability improved dramatically with little additional funding.



Case 3. Ghanaian Hospital J showed no change in sustainability from 2013–2015

At Hospital J in Ghana, improvements to the piped network, operation and maintenance trainings, and workshops to raise awareness about the importance of safe water did not improve sustainability. Ultimately, the water treatment system was not the appropriate technology for this hospital. High iron levels in the water fouled the ultrafiltration membranes, and the reddish colour of the water made staff distrust its safety. Capacity of the maintenance staff did not improve with training and the hospital director did not hold them accountable. However, analyzing the reasons that sustainability was not achieved helped to tailor the site selection criteria used in Cambodia in the subsequent donation program.

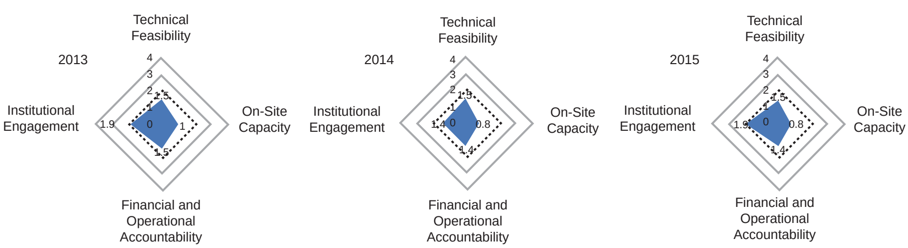


Figure 8 Example case studies of changes in sustainability scores over time

in Cambodia. The donation programme in Cambodia reflects a shift away from the stand-alone installation of water infrastructure, as was carried out initially in Honduras and Ghana, to a focus on sustained safe water provision that includes repeat training, awareness building, and specification of the roles and responsibilities of the donor and recipient over an agreed time horizon in advance of the donation. This shift exemplifies the change that has occurred in the hydro-philanthropy sector over the last decade (Calderon et al., 2016; Schweitzer et al., 2014). The higher water quality and sustainability scores in Cambodia demonstrate the impact of the new donation strategy and the use of systematic site-selection criteria that included meeting basic requirements for sustainability in the areas of technical feasibility, capacity, accountability, and engagement.

Technical feasibility

In Honduras and Ghana, when the score for technical feasibility was low and did not improve, progress in the other three domains was less likely. However, when technical feasibility improved the other domains usually improved as well. This finding is consistent with previous literature that shows that sustainability consists of interrelated factors (Harvey, 2004) and that when basic technical requirements are not met, water treatment is unlikely to be sustained (Saboori et al., 2011). In some hospitals studied, the donated water treatment systems did not meet the technical feasibility recommendations described in Figure 7. In Ghana, several study hospitals lacked reliable water sources or had local water characteristics (e.g. high iron content) that clogged the filtration membranes (described in Case C in Figure 8). Poor technical feasibility was a major driver of lower overall scores in Ghana, especially in facilities with low technical feasibility scores during the first assessment (Figure 5). In Honduras, the average technical feasibility score across the three assessment periods was 2.5 and increased by 1.1 points between the first and final assessments. In Ghana, the average score was 1.6 and decreased by 0.1 points from the first to the final assessment. The hospitals studied in Honduras had better access to water and power than the hospitals in Ghana. Another advantage in Honduras was the hospitals' proximity to major cities, facilitating better access to replacement parts and chlorine. Additionally, the Honduran hospitals had, on average, more functioning taps and newer water infrastructure compared to the hospitals studied in Ghana.

In Cambodia, a major emphasis was placed on technical feasibility during site selection, and only sites that met the basic technical feasibility requirements, such as consistent water and power supplies and access to chlorine and spare parts, were considered eligible. Further, Assist International undertook significant re-piping work at nearly all the hospitals. It is therefore not surprising that in Cambodia technical feasibility scored the highest of the four domains, an average score of 2.8, and higher than the average technical feasibility scores in Honduras and Ghana.

Onsite capacity

The staff responsible for the operation and maintenance of the water treatment systems were hospital employees trained, informally or formally, as plumbers, electricians, or biomedical technicians. On average, the maintenance staff in the studied hospitals in Honduras had completed higher levels of education compared to staff in the studied hospitals in Ghana and Cambodia. The higher education level may have facilitated proper performance of operation and maintenance, as well as empowering these staff to navigate the organizational hierarchy within the hospital and advocate for the resources needed to resolve or prevent problems. The maintenance staff in the studied hospitals in Honduras and Ghana received hands-on training between the first and final assessments. Over this period, onsite capacity rose 1.1 points in Honduras but only 0.2 points in Ghana, possibly due to differences in training levels of the maintenance staff. This contributed to larger increases in overall scores in Honduras (Figure 5). In Cambodia, the assessment helped to focus the attention of the hospital leadership and Assist International on capacity strengthening needs before the period of donor support ended. Hospitals in all three countries had higher overall sustainability scores when the responsibilities of maintenance staff were clearly outlined and an internal communication structure to report problems was in place.

Financial and operational accountability

WASH in HCFs is generally a low priority for ministries of health, or the responsibility is diluted across two or more government institutions (USAID, 2017). This presents challenges for the financial and operational accountability for WASH at the HCF level. The United States Agency for International Development (USAID) recommends that ministries of health ensure each facility has a budget for WASH (USAID, 2017). In Honduras, Ghana, and Cambodia, there were no ministry of health budgets specifically allocated for WASH in HCFs. In Honduras, accountability scores rose 2.1 points over the study period while in Ghana the score rose 0.3 points. The increase in accountability scores was a main driver in overall increases in sustainability scores in Honduras (Figure 5). A notable difference within the accountability domain was that each hospital studied in Honduras received some of its funding, organizational direction, and management from a private foundation. This assistance allowed the hospitals in Honduras to devote greater resources to WASH operating costs, such as chlorine and water infrastructure upkeep, without reducing the budget for other priorities. In Honduras, the studied hospitals reported that water quality had been monitored at least once in the last five years by a government health or water authority, although only one hospital reported that they received the results. In Ghana, none of the studied hospitals reported that water quality had been monitored by an outside entity. In Cambodia, financial and operational accountability was the lowest scoring domain. However, the low scores may reflect the timing of the assessment, which occurred during the transition of responsibility for safe water provision from Assist International to the hospital leadership.

Institutional engagement

Sustaining safe water in HCFs requires sustained engagement by hospital staff. WASH frequently falls under the domain of technicians and outside the mandate of health professionals (USAID, 2017). The ‘Clean Clinic Approach’ developed by Save the Children has found that aligning safe WASH targets with specific health agendas (e.g. Quality of Care) can help to improve ownership among hospital staff

(Save the Children, 2016). Another study in Liberia reported that healthcare worker engagement and hospital-level ownership of WASH issues were drivers of improvements in water infrastructure (Abrampah et al., 2017).

Overall, institutional engagement scores increased between first and final assessments in both Ghana and Honduras but were higher in Honduras. The increase may in part be attributed to the annual SWSM assessment and one-on-one meetings with hospital leadership to review the results, which motivated hospitals to make targeted improvements. The average increase in institutional engagement score was small (0.6 in Honduras, 0.3 in Ghana) but ranged from no change to an increase of 1.5 in Honduras and 2.1 in Ghana. In Ghana, where water outages were more severe, the hospital leadership was more focused on ensuring sufficient water quantity and less concerned about water treatment and the quality of the water. Our data also indicates that consistent chlorine dosing, and consequently safe water, was observed more often when the hospital director lived on the hospital campus, as was the case in four out of the six hospitals studied in Ghana. In Cambodia, significant care was taken to engage the hospital leadership from the onset of the programme. Ensuring support and ownership from leadership was not only a key lesson for sustaining water infrastructure in HCFs, but has been shown to be important for sustaining water infrastructure in schools (Saboori et al., 2011).

Strengths and limitations

The SWSM provides a rapid and systematic method to assess the sustainability of safe water provision in HCFs. To the authors' knowledge, it is the only sustainability tool designed specifically for the HCF setting. The tool has been used in countries across three continents to identify areas for improvement and facilitate sustained safe water provision. The tool is designed to be flexible for different contexts while still providing automated, pre-programmed data analysis. The development of this tool included extensive field testing and was informed by existing literature. The SWSM output identifies specific problem areas and provides evidence for informed action that facilitated improved sustainability over time in most of the hospital sites. The SWSM also helped guide constructive dialogue within the hospitals and between the hospital administration, Assist International, and General Electric Foundation representatives regarding challenges and improvements. The use of a sustainability assessment to facilitate improvements or trigger remedial action has been documented in other studies in the water sector (Schweitzer et al., 2014).

A limitation of the SWSM is that the score calculation assumes that all sub-domains and domains of sustainability are equally important (weighted equally), which may not always be the case. As discussed, technical feasibility may be a necessary, but not sufficient, factor for sustainability. Future iterations of the tool may consider variable weights for each domain given differing contexts and stakeholder priorities, and might also test whether similar results could be obtained with fewer survey questions or indicators. Another limitation is that the survey data is self-reported and subject to recall and social desirability biases. Further, outside of the director and maintenance staff surveys, convenience sampling is used rather than random sampling, which may limit the representativeness of the responses. The water quality data is collected at single time points and does not capture seasonal variation. While the tool has been applied in several HCFs with water treatment systems different from the ones donated by the General Electric Foundation, further testing with other types of water treatment systems should be conducted. Additionally, the assessment of sustainability is limited to the purview of the HCF itself and does not include assessment of the enabling environments at the policy or government level.

A limitation in the application of the SWSM described in this paper is the variation in the number of years, by country, that the water treatment systems had been in place at the time of the first sustainability assessment (eight years in Ghana, one to three years in Honduras, three to six months in Cambodia), which may confound comparisons of scores across the three countries. Additionally, the data collection team's association with the donor and implementing partners may have led to bias in the hospital staff's reporting on subjects such as the frequency of maintenance activities and satisfaction with the water treatment system.

Conclusions and recommendations

SDG 6 includes a target to achieve universal access to safe drinking water for all. To achieve this goal, many HCFs will not only need to gain access to a reliable water source but will also require onsite treatment to meet safe drinking water guidelines. Sustainability of water infrastructure presents complex challenges. Despite improved water sources and onsite treatment systems at the HCFs described in this paper, persistent challenges to sustained safe water provision were identified. These challenges impact quality healthcare service delivery. Lack of reliable water, broken water infrastructure, and inadequate availability of soap and chlorine led to poor water storage practices, degradation of water quality, and opportunities for hospital-acquired infections. The SWSM summarizes the complex ecosystem of factors that influence the sustainability of safe water provision into outputs that are manageable and actionable. Given the vulnerability of the populations utilizing healthcare services, increased investment in WASH in HCFs in the SDG era, and the ability of HCFs to serve as models for surrounding communities, understanding and responding to the drivers of sustained safe water provision in HCFs is critical.

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About the authors

Katharine Robb was the Associate Director of Research Projects at the Center for Global Safe Water, Sanitation, and Hygiene at Emory University and led the development and implementation of the Safe Water Sustainability Metric. She is currently a doctoral candidate at the Harvard T.H. Chan School of Public Health. E-mail: kar057@mail.harvard.edu

Lindsay Denny was the Program Manager for The Center for Global Safe Water, Sanitation, and Hygiene's Safe Water in Hospitals Program in Cambodia. She is currently the health advisor for Global Water 2020, advocating for water, sanitation, and hygiene in healthcare facilities. E-mail: lindsay.m.denny@emory.edu

Samantha Lie-Tjauw, Center for Global Safe Water, Sanitation, and Hygiene, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA. E-mail: slietjauw@gmail.com

Marisa Gallegos, Center for Global Safe Water, Sanitation, and Hygiene, Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA. E-mail: marisa.n.gallegos@emory.edu

James Michiel was the Senior mHealth and Informatics Analyst at the Center for Global Safe Water, Sanitation, and Hygiene. He is currently the Mobile and Digital Health Lead for the UC Davis Health System. E-mail: jmichiel@bu.edu

Christine Moe is the Eugene J. Gangarosa Professor of Safe Water and Sanitation in the Hubert Department of Global Health and the Director of the Center for Global Safe Water, Sanitation, and Hygiene at Emory University. Her research focuses on environmental transmission of infectious agents, in particular foodborne and waterborne diseases. E-mail: clmoe@emory.edu

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