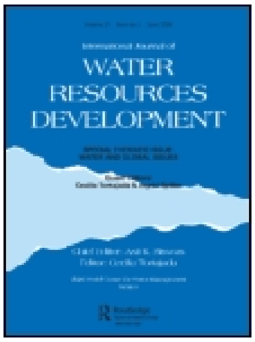

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Developing sustainable and replicable water supply systems in rural communities in Brazil

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This article examines the challenges and opportunities for developing rural water supply programs that can meet multiple sustainability criteria (including social, technical/administrative and environmental criteria) and can be replicated beyond individual communities. It draws lessons from a water supply development project in Northeast Brazil, identifying how environmental and community assessments, community engagement in planning, as well as training, capacity building and monitoring can help meet sustainability criteria. The article further explores how an institutionalized planning process and partnerships with public agencies and donors are integrated into the project design to support replicability.

Keywords: rural water supply; water development framework; water supply sustainability

Introduction

One of the United Nations 2000 Millennium Development Goals (MDGs) is to increase the proportion of the world's population that has access to safe drinking water and basic sanitation (United Nations, 2010). While the international community has made advancements toward this goal over the past decade, progress in rural areas is lagging relative to urban areas (United Nations, 2011). Worldwide, 80% of the people who have limited access to drinking water supplies live in rural areas (United Nations, 2010). Even where rural supply systems are developed, many are in disrepair or not functioning properly (Brikke & Bredero, 2003; Moe & Rheingans, 2006; Rural Water Supply Network, 2012).

Various factors may contribute to the difficulty in developing sustainable rural water supply systems. For instance, rural communities are likely to be less capable of achieving economies of scale in water supply and treatment (State of Ceará, 2009). At the same time, households and businesses in rural areas may have more limited capacity than wealthier urbanites to raise the capital needed for water infrastructure, or they may lack the technical expertise needed to operate and maintain water systems. In rural areas that are arid or subject to hydrologic variability, reliable water supply systems may require more energy-intensive infrastructure (e.g. to access and deliver distant surface or groundwater sources or to allow for multi-season or multi-year storage), which can add to the financial and technical difficulties facing these communities.

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In light of these challenges, a primary goal of this article is to offer a framework for sustainable rural water supply development and explore how the framework can be applied in a semi-arid region. Another goal of this paper is to incorporate within the framework a set of tools that allow water supply development to be implemented in diverse physical and social settings. The framework we present was initially implemented and tested in the state of Ceará, in Northeast Brazil, between 2008 and 2011. The region is representative of many of the challenges facing rural, semi-arid regions around the world. On average, the rural interior of the state receives between 400 and 800 millimetres of rainfall per year, most of which comes in the rainy season between February and May. About 35% of Ceará's 8.5 million residents live in rural areas (State of Ceará, 2009), and on average the incomes in rural communities in this region are only 50% of those in urban areas (Kassouf, 2005). Approximately 19% of the rural population in Ceará lacks access to safe and reliable drinking water supplied to their homes (State of Ceará, 2009).

A number of efforts have been undertaken to establish rural water supply systems in Ceará – most of which emerged since Brazil's shift to democracy in 1988. Some examples include the Integrated Rural Sanitation System (SISAR), created in 1991 with financial support from the German government and the state government of Ceará (Global Water Partnership, 2012); the São José Project, organized by the state of Ceará with funding from the World Bank to improve the living conditions (including water supply) of poor rural families in Ceará (Binswanger-Mkhize, Bourguignon, & van den Brink, 2009); and the federal government's program known as Training and Social Mobilization for Coexistence in the Semi-Arid: One Million Rural Cisterns, which began in July 2003 to provide rural populations with clean water for drinking and cooking (Gnadlinger, 2003). Despite these efforts, the state still lacks universal access to reliable and safe drinking water, and where water supply systems have been developed, they are often unsustainable (State of Ceará, 2010).

Below we describe the rural water supply project that was instituted in the state of Ceará and the framework that informed the project. Before examining the case study, we describe the components of the framework, which include criteria for sustainable rural water supply systems, as well as mechanisms that support replication of rural water supply projects across multiple communities. We conclude by identifying opportunities and challenges for applying the framework beyond Ceará, Brazil.

A framework to address the challenges of rural water supply

Multiple sustainability criteria

Since the 1990s, with increased recognition of the poor performance and periodic failures of water supply development projects around the world, academics and practitioners have become concerned with understanding the factors that support sustainable rural water supply systems (see e.g. Katz & Sara, 1998; Kleemeier, 2000; Serageldin, 1994). In general, the endurance of a water supply system, as well as the system's ability to adapt to changing consumer needs or preferences for water quality and quantity, are defining features of water system sustainability (Carter, Tyrell, & Howsam, 1999). This paper argues that various interrelated criteria underlie these features of sustainable water supply systems, as described in Figure 1.

Among the criteria that appear in the literature on sustainable rural water supply systems are social dimensions of project planning and the communities served by the systems. For example, various scholars recognize that when local communities participate directly in planning their own water supply systems, these systems are more likely to

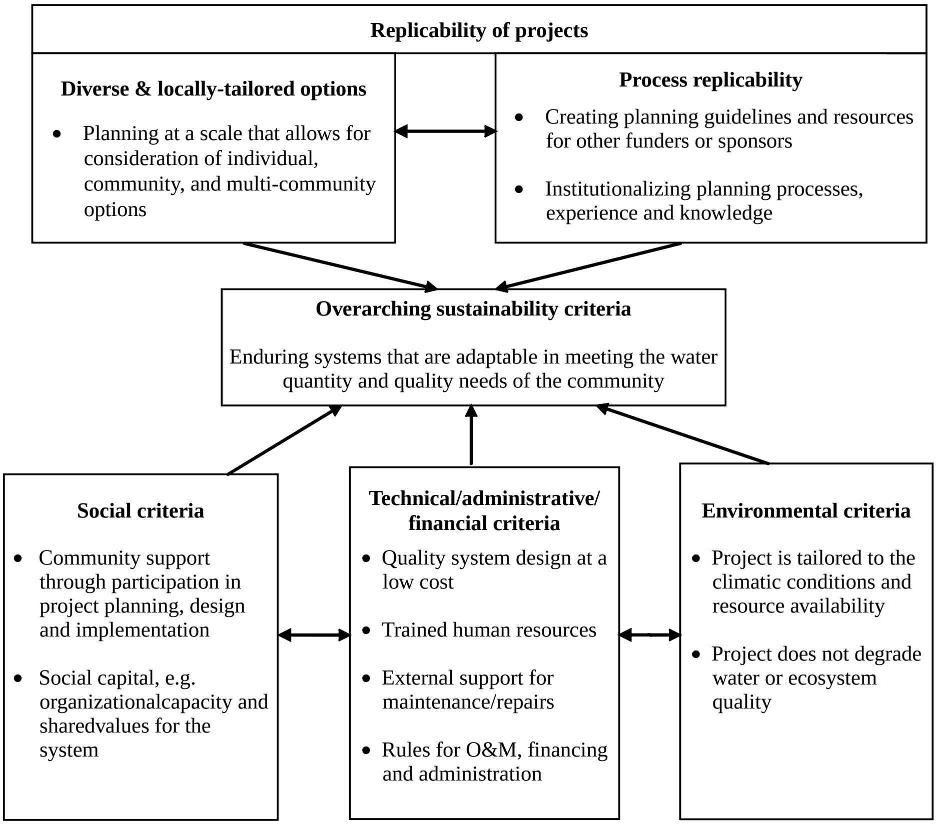

Figure 1. A framework for sustainable and replicable rural water supply systems.

be sustainable than systems that are imposed by the government or donor organizations (Barnes & Ashbolt, 2010; Carter et al., 1999; Gleitsmann, Kroma, & Steenhuis, 2007; Katz & Sara, 1998). To a large extent this is because communities engaged in the planning process are more likely to select supply options that they are willing and able to operate and maintain (Montgomery, Bartram, & Elimelech, 2009). This is not to suggest that the process must be entirely community-driven; "polycentric" approaches that engage the private sector, government actors and communities together can work (Falk, Bock, & Kirk, 2009). Successful community engagement goes beyond mere consultation. At a very basic level, it may even start with the community coming to a shared understanding of water as a vital resource for a community's health and growth (Nayar & James, 2010). It can also include dialogue with the community to explore ideas about infrastructure options, ascertain the community's preferences for service levels, and clarify the community's preferences and responsibilities for financing operations and maintenance (Katz & Sara, 1998). Since community members may not quickly or readily agree upon preferred alternatives, successful engagement may also require facilitation and conflict resolution (Gleitsmann et al., 2007).

Another dimension of the social context that affects sustainable rural water supply systems is the availability of social capital within a rural community. Social capital can be defined as the set of shared community norms, expectations and patterns of interaction (Ostrom, 2000). Social capital can help a community develop and deploy its own administrative and financial capital to manage a system. For instance, research on irrigation systems in rural areas has shown that when infrastructure development does not consider the availability of social capital in a community, systems are less likely to be sustainable (Lam, 1998; Ostrom, 2000). Communities may have differing degrees of social capital, depending on their prior experience working together on water infrastructure or other community projects. Social capital is more likely to be present in a community that has established rules and practices for using water or has organizational bodies capable of making decisions about water management and administration. At the same time, active communication by local leaders with community members regarding the planning and operations of a water system can help engender the trust that is essential for social capital building (Montgomery et al., 2009).

In addition to social factors, the technical, administrative and financial capacities to ensure that a system operates effectively over time and at a reasonable cost are important criteria for sustainable rural water supply systems (Harvey & Reed, 2004). Technical capacity depends on the availability of equipment for operating the system, people who can be trained to operate equipment, and the quality of construction of the system (Katz & Sara, 1998). Additionally, sustainable systems are more likely to be found where communities and project operators have adequate administrative and financial capacity for system operations and maintenance (Montgomery et al., 2009). Technical, administrative and financial capacities are not independent from the social factors previously discussed. For instance, the presence of social capital, via prior organizational experience, can make it easier for communities to devise rules for ongoing operations and system administration. At the same time, community engagement in the planning process can contribute to training and skill building that might be needed for technical capacity. Still, communities may not always have the technical capacity on their own for extensive system repairs and maintenance (Kleemeier, 2000). Thus, external technical support needs to be available to help communities maintain and monitor system performance (Gelting & Ortolano, 1998; Lockwood, 2002).

The third set of criteria presented in Figure 1 focus on the environmental considerations of sustainable rural water supply systems. First, the system must be suitable to the climatic or environmental conditions of the region in which it is located. Second, the system should not degrade the quantity or quality of source water or the ecosystems surrounding it (Carter et al., 1999; Serageldin, 1994). With respect to the first feature, note that infrastructure choices must be balanced against the other criteria of sustainability, both technical and social. This is because community preferences and technical capacity may not always match the type of system that may be deemed optimal for a given climate or location. In terms of the second feature, it should be recognized that the environmental impacts or potential degradation of a water source in rural communities are likely to be much lower than in urban settings. However, in semi-arid regions such as Northeast Brazil, the limited availability of freshwater supplies requires attention to the potential for any new system to degrade or overuse those supplies.

Finding replicable approaches that meet sustainability criteria

It may be difficult to identify a single design or model for a water supply system that can meet all of these criteria across multiple communities. A wide range of technical, institutional and management options might be deemed appropriate, depending upon the environmental context of the rural community, as well as the community's social, technical, administrative and financial capacity. Therefore, as presented in Figure 1, one of the criteria for project replication is a planning procedure that can accommodate diverse and locally tailored options. A diversity of options would be important not only for the water supply infrastructure, but also for the financing and management of the infrastructure.

However, processes that allow for such diverse options can be costly, due to the time and effort needed for collecting information, negotiating, coordinating activities and monitoring. Thus, replicating the process, rather than a specific project, may help minimize some of these constraints to replication. Creating planning guidelines and resources, such as information about local resource constraints, may allow project sponsors to work with or transfer the approach to community-based organizations, contractors and government agencies that may be involved in project expansion. Given the diversity of actors who may be involved, it may also be necessary to build common support structures among participants and to institutionalize a shared planning process among them (Lockwood, 2004). Institutionalizing the experiences of the different actors involved in project replication through training and knowledge building may also be essential (Uvin, Jain, & Brown, 2000; Uvin & Miller, 1996).

The rural water supply project in Ceará

The rural water supply project discussed herein stemmed from a collaborative effort between the Columbia University Water Center (CWC) and the Federal University of Ceará (UFC). The research team, which included engineers, sociologists and policy scholars, sought to identify and test a rural water supply planning approach that meets sustainability criteria and can be replicated across multiple communities in the region. It targeted rural communities in the interior of the state of Ceará, specifically the municipal district of Milhã. (See Figure 2 for a map of the area.) Two other municipal districts were included in the initial phase of project scoping and background research, Senador Pompeu and Deputado Irapuan Pinheiro. Project scoping included a diagnosis of the supply system of virtually all rural communities (defined as a cluster of at least three homes) within these three municipal districts (see Table 1). Next, the research team selected a cluster of small communities within the municipal district of Milhã for piloting infrastructure options that were identified in the planning stages. Among the three municipal districts, the project

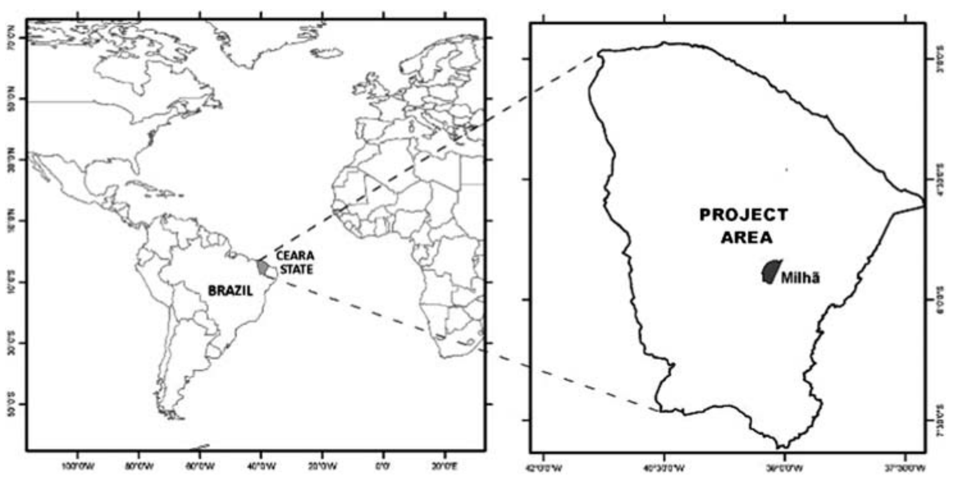

Figure 2. Map of the project area.
Source: Renata Luna, Federal University of Ceará.

Table 1. Municipal districts in Ceará included in the rural water supply study.

Municipality	Total population	Urban		Rural		Without access to safe water	
		Population	%	Population	%	Population	%
Milhã	13,078	5,969	45.6	7,109	54.4	4,275	32.6
Senador Pompeu	26,494	15,715	59.3	10,779	40.7	4,280	16.1
Deputado Irapuan Pinheiro	9,094	4,131	45.4	4,963	54.6	1,910	21.0
Total	48,666	25,815	53.0	22,851	47.0	10,465	21.5

Source: Data compiled from Brazilian Institute for Geography and Statistics (2012), Census 2010.

team selected the communities in Milhã for the pilot infrastructure because they had the highest percentage of homes lacking access to water supply systems or infrastructure.

The CWC-UFC project team developed two demonstration systems within the Milhã municipal district. One involved the design and construction of a new water supply system in the small community of Ingá (13 families). The second involved expanding an existing water supply distribution system, previously implemented under a government program, which connected three small communities (115 families) in Milhã: Pedra Fina, São João and Transval e Valentim dos Sabinos. The CWC-UFC team designed and participated in the planning, implementation and monitoring of the projects. The infrastructure for these demonstration projects was built with funds from the CWC-UFC research project, which was supported by a grant from the PepsiCo Foundation. The team worked with a local contractor in the Milhã municipal area to construct the infrastructure. In addition to the demonstration systems installed in the selected communities in Milhã, the project team incorporated the data and information from the project assessment and planning phase, which included a community engagement and survey effort (described in more detail below), to develop a 'municipal water plan' for the entire municipal district of Milhã, as well as a 'manual of best technology practices'. Both the municipal water plan and the manual were intended to aid in the replication of the pilot project. Below we describe the details of the project planning and implementation and how the project meets the criteria for sustainability and replicability (also summarized in Table 2).

Project planning process

The first step in the project planning process was to conduct an assessment of the current water supply methods used or available in the central region of Ceará (focusing on the three municipal districts previously mentioned), through surveys of the communities. These surveys, conducted in 2008 and early 2009, found that the commonly used supply methods include small wells, rainwater collection, surface water collection by individual households (e.g. carrying water in barrels from nearby ponds or small reservoirs, or relying on trucked delivery of water collected from distant reservoirs), and small reservoirs. The surveys also examined the effectiveness of these measures, as well as potential interest in alternative methods of capture, distribution and treatment. For instance, community members reported that one common water supply distribution method in rural areas – government-sponsored water trucks that distribute water collected from reservoirs – has caused public health problems because the water is often untreated. Similarly, communities are dissatisfied with wells as a water supply source because the highly

Table 2. Ceará rural water supply project: criteria considered and project components.

Criteria considered	Project components
	Project planning
Social, technical/admin/financial	Survey of multiple communities in close proximity (rural municipal district scale) to identify existing water supply infrastructure and preferences and demands
Technical/admin/financial, environmental	Diagnosis of water supply conditions available to communities, water quality, topography and infrastructure costs
Social	Diagnosis of communities' social capital
Technical/admin/financial; diverse and locally tailored options	Completion of a municipal district plan that identifies infrastructure alternatives for communities in the district, including opportunities for economies of scale
Social	Community selection of preferred alternatives for infrastructure within pilot communities
	Pilot project implementation
Social, technical/admin/financial	Community selection of O&M and financing and administration rules
Social, technical/admin/financial	Training of system managers
Technical/admin/financial	Identification of external technical support
Social, technical/admin/financial	Ongoing operations and administration of system
Technical/admin/financial, environmental	Periodic monitoring and feedback by community and project team
	Replicating the pilot
Diverse and locally tailored options; process replicability	Development and dissemination of municipal water plan for public/private partners
Process replicability	Partnership with municipal district leader to build infrastructure across all communities considered in the plan
Process replicability	Partnerships with state agencies and donor organizations to facilitate project planning in other municipal districts
Diverse and locally tailored options; process replicability	Development of technical manual to inform agencies and communities of infrastructure costs, management requirements and construction specifications

saline groundwater in this region is non-potable without expensive treatment. Rainwater collection through cistern tanks, another common approach, was reported to be inadequate for supplying water for an entire year and susceptible to leakage. During the project planning phase, residents further expressed their desire for systems that allow flexibility, given that most rainwater is available during only a short period of the year, and that the area is subject to periodic droughts.

After assessing existing water supply sources and community preferences for household water systems, the project team conducted a diagnosis of the physical conditions of the Milhã municipal region to determine opportunities for developing different supply options for the cluster of communities selected for the pilot study. This included analyses of the availability of source water and an in-depth understanding of (1) the topography of the area between the water sources and the communities, which affects the cost of the energy needed for pumping; (2) the local geology and road networks, which influence selection of pipeline pathways; and (3) land tenure/ownership and rights of way. This assessment further helped the project team consider environmental criteria, as well as technical and administrative needs for the pilot area. To complement this diagnosis, the research team interviewed community members and leaders of the local community association. The interviews were designed to assess the social capital in the communities in Milhã, specifically their experience and knowledge with managing community-level supply systems and their activity and membership within community associations (created in order for community members to receive benefits and incentives from government programs designed to alleviate rural poverty).

Following the initial surveys and the physical and social diagnoses, the project team selected the communities – Ingá and Pedra Fina – to pilot-test the construction of water supply infrastructure. Both communities had expressed significant needs for improved water supply access and had also demonstrated that social capital was available to support pilot infrastructure projects. The project team members together visited the pilot locations on 36 separate occasions between 2009 and 2010 to interview individuals, hold meetings with community associations to identify preferred infrastructure and management options, and discuss the options for maintaining and operating different alternatives. The alternatives were discussed in popular assemblies where all members of the community were invited, including local leaders. When the meetings were held during the day, most of the participants were women or homemakers. Therefore, later in the process more meetings were held in the evenings so that more family members could participate.

During the meetings, the research team provided design specifications, cost considerations and water treatment requirements for different supply options, in detail, to the communities. In response to the discussions at the earlier meetings, the project team developed alternative designs that were discussed later on. One of the water supply options discussed with the community was to link water supply infrastructure between Ingá and Pedra Fina (and its two neighbouring villages) to achieve economies of scale and reduce the costs of operation and maintenance for the communities served by the system. Connecting the communities to a municipal system (via a major pipeline) and to an integrated regional system (via pipelines between several municipalities) were also considered. While individual household options were not preferred by the pilot communities, they also decided not to have a system that connected the two communities. Instead, Ingá decided to establish its own community system. Pedra Fina and its two neighbouring communities, which already had a partial system, decided to expand their system and add water treatment infrastructure to it.

A key part of the planning and infrastructure selection process included discussions with community members about their ability to fund the operation and maintenance (O&M) of infrastructure. Given that capital costs of construction for this project were covered by the project funders (and that most water infrastructure projects in Brazil are financed by state or federal governments), O&M costs were of greater importance than capital costs. Included in the discussions with the communities was the importance of trade-offs between the project design and the resulting O&M costs. For example, a water source (e.g. a small reservoir or pond) more distant from the community might actually have a lower pumping height gauge, reducing the energy costs to be paid by households in the community, compared to a closer source.

In summary, the planning stages of the project included mechanisms to meet the social criteria for sustainability through community engagement. Also, by considering community preferences, physical conditions and social capital in the design of the project, the project team was better equipped to ensure that the project could meet the technical and environmental criteria of sustainable water supply systems.

Project implementation

During the implementation phase of the project, which began in late 2010, additional steps were undertaken to support project sustainability. First, both communities worked together through their community associations to decide on rules and procedures for managing project operations and financing, which helped build social capital in the communities. For both projects, the community members entrusted the leadership of the Pedra Fina and Ingá community associations to manage day-to-day system operations, which provided administrative capacity. Additionally, to support technical capacity, the research team provided training on the operation of the supply systems in the two pilot locations. This involved instruction on the operation of pumps, regulators and valves in treatment stations and the distribution network.

A maintenance plan also was developed with the communities to ensure that any technical support needed would be available, both from the research team and from the local contractors who worked on the project. For instance, the projects might need an electrician to maintain the electrical system for the pumps, a plumber to service the hydraulic pipes and accessories, and a mechanic to repair or replace pumps periodically. The education level required for this maintenance is rare in the small rural communities of Ceará. In considering the goal of ultimately expanding the project, the team explored the possibility of creating a municipal institution or office that could provide technical assistance to rural supply systems. This is a model that has worked with larger-scale systems built through the state's SISAR program, but has not yet been applied to small rural communities.

With respect to the financing of operations and maintenance, the communities involved in the pilot projects decided on their own how to allocate costs and administer payments. Monitoring of water meters and collection of payments is undertaken by a community association member. Prior to this decision, the project team discussed likely operations and maintenance costs of the selected infrastructure, so expected total monthly and episodic costs of electricity, supplies and labour were understood. Alternatives to self-financing are available, such as subsidies from the municipal district or from the federal program that pays for barrel trucks to deliver drinking water to rural communities. However, as recognized in the water development literature, self-financing can support sustainability because it can build community and administrative capacity. The fee implemented in both communities is about US$6.00 per household per month. In the integrated system (Pedra Fina and its two neighbours), this charge covers up to 10,000 litres of water; any usage that exceeds this amount is charged on a per-litre basis. In a follow-up survey, a couple of households reported paying up to US$30 per month because they used water for agricultural purposes. In the community of Ingá, the charge is fixed at about US$6.00 per household per month regardless of usage. For both projects the communities have successfully covered the costs of operating the system (including energy costs and treatment), as of one year after implementation. They also have saved funds that can pay for replacement of depreciated equipment when needed.

Notably, this project found that self-financed and self-managed systems can pose some risks to the sustainability of the project if community social capital is low. For instance, in our research, community members expressed concerns that when leaders for some reason leave the community, a power vacuum or conflicts between members of the community can emerge that threaten the success of the project. There is also the possibility of opportunist leadership among individuals wanting to be in charge of the community associations, who then have no interest in maintaining the system.

Given that both the social and the climatic conditions in communities can change, the research team recognized that infrastructure design and operations may need to be adapted over time. Thus, this project includes monitoring and project evaluation that are conducted by local community members and project staff together. Project staff meets with and interviews community members every three to six months to discuss system performance, review any problems identified by the community members, and provide technical advice when operational, maintenance or financing issues arise. These findings are made available to project funders and state government partners to provide evidence of possible pitfalls and areas for adaptation and improvement.

A monitoring survey conducted between six and nine months after project implementation found that 95% of the residents in both communities were satisfied with the quantity of water they received from the system and 100% felt that the system had improved their quality of life. Some examples of improvements were having more time to work outside the home and the capacity to add new sinks, showers and toilets to their houses since water was now piped directly to the home. The Ingá community leader also reported in an interview with the Columbia Water Center that the high frequency of common intestinal illnesses such as diarrhoea had been practically eliminated after the water supply project came online. Some 30% of residents, however, felt the system could be improved. The project team collaborated with the community to install a new filtration system and modified the pump location in Ingá in response to these concerns. The modifications did not add to the costs of operations and maintenance for the community. One of the challenges with implementation that has arisen in Ingá stems from their choice to have fixed rather than variable fees for water use. The community association reported that one family had begun to use the system for livestock watering rather than just household consumption and thus their usage far exceeded that of other community members. The community association recognized that it needs to tailor the fees or set rules on the types of uses deemed appropriate for the household supply system.

Project replication and expansion

The ultimate success of developing water supply infrastructure for rural communities depends not only on the long-term sustainability of the system, but also on the ability to replicate the project so that other communities can be served as well. Replicating a project in other locations requires tools for analyzing and identifying diverse, locally tailored options, as well as process replication mechanisms.

To meet the criteria for replication, the project team first created and disseminated a municipal water plan or *plano das agues municipals* (PAM), which shows how the planning processes and management and financing models can be identified and assessed at the scale of a rural municipal district. The focus is on the municipal district because in

Brazil the municipal government is the primary level of political jurisdiction over small rural communities. Therefore, municipal governments have the capacity to seek different financing alternatives that can serve multiple community-level projects, as well as to provide technical and implementation support to the rural systems.

To devise a municipal water plan, the team used the data from the initial assessment conducted in the municipal district of Milhã prior to the pilot infrastructure projects. The data included the water supply demands, the quality and quantity of the available water sources for all of the small communities in the district, and indicators of social capital in these communities, such as the existing community associations. These data were used to recommend options for new water infrastructure in the communities, including options at local, regional and municipal levels and alternative management and financing models to support these systems.

The project team also engaged with government actors and donors to facilitate the project replication process. This included partnering with the Milhã mayor to identify ways to implement water supply infrastructure from the Milhã municipal water plan in the other communities that were not part of the pilot study. It also involved working closely with the Ceará secretary of agriculture's staff, which has been engaged in the São Jose project (aimed at assessing needs and helping fund new water infrastructure in Ceará) to support the Milhã mayor and to identify opportunities for replicating the municipal water plan process in other rural municipal districts. These efforts have fostered additional linkages between the project and possible funders, including development banks such as the Banco do Nordeste do Brasil (Brazilian Northeast Development Bank), who can then work with the state in replicating project planning and implementation. Finally, as mentioned previously, the project team created a technical manual that provides detailed information on diverse water supply infrastructure design specifications, costs and reliability for the rural semi-arid region of Northeast Brazil.

Efforts to establish a planning process and partner with the mayor of the Milhã, the secretary of agriculture and funders have proven successful in expanding the project. Since the municipal water plan for Milhã included technical options for all 82 communities in the municipal district, in 2010 the mayor of Milhã was able to begin planning water infrastructure projects across Milhã, with the support of the state. In 2011 infrastructure was completed in three other Milhã communities beyond the initial two pilot locations, serving over 1,200 people.

Beyond Milhã, the efforts to engage with the secretary of agriculture's office and potential funders resulted in support for municipal water plans in two other municipal districts – Senador Pompeu and Deputado Irapuan Pinheiro – where the project team had conducted initial scoping and community assessments. (The total population in the 3 municipal districts is 48,626.) To extend these efforts, the state government has begun a process for municipal water plans in 24 additional municipalities in Ceará.

Discussion and conclusions

Developing water supply systems for small communities dispersed in rural areas, especially in semi-arid regions, is an increasing challenge because of the need to meet multiple sustainability criteria – social, technical/administrative/financial, and environmental – as well as to ensure that projects can be replicated. To date, actions taken by public authorities and donors have not been able to adequately meet this challenge in Northeast Brazil, as in many rural areas in developing regions of the world. Our research and analysis of a planning and water supply demonstration project in rural areas in the state of Ceará, Brazil, identified a framework for meeting multiple sustainability criteria while also creating opportunities for replication.

Specifically, the planning process developed and implemented in the Ceará project emphasized community engagement in both the assessment and diagnosis of water supply needs, as well as in the selection of preferred alternatives. As discussed, the project team spent over one year in the field interviewing community members and participating in 36 separate meetings with community association members. This participation in the planning stage addressed the social criteria for sustainable water supply systems. At the same time, technical and environmental dimensions of sustainability were addressed through analyses of the available water supply sources, alternative types of infrastructure for delivering those sources, and the diverse infrastructure in use and its limitations. During implementation of the pilot infrastructure, the project team undertook a number of steps to promote project sustainability. These included engagement with the community in selecting the rules and procedures for operations, management and financing. These steps also involved training community leaders on operations and creating linkages to external technical support and ongoing monitoring. Given that the long-term impacts of the demonstration projects are not yet known, ongoing monitoring of the systems and of community perceptions of water quality and quantity are needed. Such monitoring should include assessing the sustainability of the systems over periods of drought and identifying any long-term impacts the systems may have on social and environmental conditions in the communities.

Project replication was facilitated through the creation of a municipal water plan that could be implemented by local government with support from larger-scale public agencies and external donors. The process established through the municipal water plan allows communities to explore a suite of water supply options that may be feasible in the semi-arid region of the state. The plan also offers a set of procedures that can help reduce the time and effort needed to identify and select appropriate infrastructure. Furthermore, it recognizes that each design may have unique technical and management requirements. The technical manual helps further reduce the information costs of implementing projects in other communities. Finally, key partnerships were established to help institutionalize the process with potential funders and state-level actors with the political and administrative capacities needed for replicating the municipal water planning process in other communities in the state.

How effectively this framework can be applied throughout other states in Northeast Brazil and beyond remains to be seen. Indeed there are likely to be limitations and challenges with this approach, including the initial start-up costs of diagnosing and assessing water supply conditions and community needs in a particular region, the need for trained interdisciplinary technical staff who can understand the physical, infrastructural and social systems of rural communities in the region, and the time and effort required for effective and enduring community engagement and monitoring. Additionally, as new water systems are constructed, monitoring by the project staff and technical team becomes more costly and time-consuming. Therefore, more effort is likely to be needed in training communities on monitoring and communication with project sponsors. Related to this issue, project sponsors may need to invest more time than perhaps anticipated on social-capital development and community capacity building. Both of the pilot projects were located in communities with some pre-existing community capacity and experience, either from working with existing water supply infrastructure (in the case of one community) or from working together on other community issues. Such experience and social capital make it easier for communities to develop management capacity, including the new rules needed for governing the new systems.

Despite these challenges, we argue that this paper can offer an important contribution to the literature on rural water supply management and development. It draws together multiple criteria for sustainability from the literature into a framework and considers how the criteria for sustainability interrelate and support one another. That is, investments in one set of sustainability criteria (e.g. social capital) can enhance other categories of criteria (e.g. technical capacity). The reverse could also hold true; a failure to pay attention to one category of sustainability criteria could diminish the effectiveness or contributions of investments made in another area. The second contribution of the framework is that it points to some of the ways in which systems can be designed to meet sustainability criteria, while taking into account the importance of project replicability. As such, it provides a novel approach for both practitioners and researchers seeking to develop, implement and assess rural water supply projects. We hope that future research will test this framework in other regions facing similar water scarcity and access challenges.

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