

Surrounded by sun and water: development of a water supply system for riverine peoples in Amazonia

ABSTRACT

This article presents an analysis of the historic, technical and environmental factors that influenced the development of a water supply system for small rural communities in seasonally flooded areas of Amazonia. Data was gathered from internal reports, interviews and water quality analysis. Principal factors identified included: the use of photovoltaic energy, well and rain water quality, the use of mobile equipment and floating structures, and community participation in equipment construction and management. We believe that the developed model is a possible solution to problems related to water access in remote flooded areas of Amazonia.

KEY WORDS: Water access. Photovoltaic. Rural communities. Amazonia.

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INTRODUCTION

The Amazon basin contains 81% of all the fresh surface water available in Brazil (ANA, 2010) and the region is home to 9% of the national population (17.7 million people). Twenty six percent of the population is rural (4.6 million people) and 74% is urban (13.1 million people) (IBGE, 2014a). Just 18% of rural households and 66% of urban households are connected to water supply systems (IBGE, 2014b). The rest of the population uses alternative sources, such as shallow wells, springs and streams, lakes and rooftop rainwater harvesting.

Most part of population lives along the main rivers. Some of these areas pertain to the seasonally flooded várzea (floodplain), covering 800,000 km² or 14% of the Amazon River Basin. Here floods occur in unimodal predictable wide pulses (MELACK and HESS, 2010). Examples of this rural reality are the Amanã and Mamirauá Sustainable Development Reserves (RDS Amanã and Mamirauá), protected areas in Central Amazonia. In general the region is considered remote and difficult to access.

A socio-demographic survey conducted in 2011 showed that more than 90% of reserve communities did not have piped water. Rather, residents transport water from rivers to their residences in buckets and/or plastic bottles to meet their basic needs.

As Moura et al. (2013) points out, these groups, face challenges of technical, environmental and socioeconomic nature, including: a) questions of seasonality, with periods of water abundance and scarcity, b) lack of reliable and constant energy services, c) the predominance of small and dispersed settlements at a distance from principal regional urban centres, d) the need to move settlements to new locations when riverbanks fall due to natural processes (denominated as *terras caídas*), occurring over periods of less than two generations.

In consideration of these conditions, researchers proposed a technological model for supplying water, developed over 15 years in collaboration with diverse national and international institutions. The initiative integrates empirical knowledge in the areas of sociology, community health, and technology.

The system consists of the distribution of pre-treated water and provides incentives for further treatment at the household level for drinking water and water used in food preparation. In all, 21 units were assembled and installed in small settlements of up to 35 residences (locally referred to as communities) as part of an innovative research and action campaign in the region.

The issue in question was sketched out in the area of knowledge production, where science and society are jointly reflected upon, and where academic and non-academic knowledge (also called traditional or local knowledge) converge. In this area, the relationship between science, technology and society assumes a political role, the aim of which is to leverage local transformations, citizenship and social inclusion, coordinating knowledge and practices that encourage social emancipation. Based on an experience led by a research institute, the analytical framework incorporated the “environment-technology-society” nexus as a key tool in apprehending the encounter between technical and scientific approaches to problems like the lack of adequate solutions for water supply in the Amazon rainforest. The experience dialogues with theoretical foundations of Science, Technology and Society studies and the sociology of translation (CALLON, 2004).

This article aims to analyze the factors that influenced the configuration of the water supply system currently used in rural floodplain communities, considering the technical, environmental and historical factors involved in its development.

METHODS

The following principal characteristics of water supply systems were identified considering phases of: the choice of water source type, material and equipment used, management arrangements and community participation and changes in prototypes over time.

After identifying these characteristics, we sought to highlight the principal factors that influenced the current model. Recorded variables were of technical, environmental and historical nature. General information was collected from: (1) Review of documents, specifically, project reports from 1997 to 2015, where we identified the motivations and difficulties recorded during each phase of the specified project; (2) Semi-structured interviews with technicians involved in different phases of water supply projects—including professionals from the fields of health, technology and management—where they reported on their experiences and perceptions on the process of developing specific technologies.

WATER ANALYSIS

Water quality monitoring: samples were collected from 12 communities for 19 months, including rainy and dry periods. Two sample points were defined in each community to verify water quality from the source (river water at the point of uptake) to its point of use (tap water). Water samples were analyzed in the field using portable equipment (Hanna Turbidimeter e Hach pH meter) and in the Mamirauá Institute laboratory in Tefé, using standard methods (APHA, 2005): color method SMEWW 2120 C; total coliform and *Escherichia coli* in membrane filtration method SMEWW 9222.

RESULTS

COSTS AND COMPONENTS OF THE CURRENT MODEL

The current water supply system has the following components (Figure 1): (a) a floating wooden raft located in the front of the community that serves as a support base for the photovoltaic energy generator (6 to 8 modules of 75 or 85 Wp) and a solar pump, helical and submerged, connected directly to the generator; (b) a water reservoir (tank) with a 5-thousand-liter storage capacity supported by an elevated wooden base; (c) a pressure sand filter located beneath the reservoir to remove coarse solids; (d) gravitational distribution network with central piping and branches feeding one faucet per residence. Supply is intermittent. Figure 1(e) displays a floating raft and community during the dry season.

Some of the items integral to each component are acquired regionally, such as material for hydrologic installation and distribution; others, such as the material used to build floating rafts to support generators and the reservoir tank,

are provided by the community (as a collaborative contribution). Equipment needed to generate solar photovoltaic energy was generally purchased from retailers located in the Centre-West or Southern regions of Brazil.

Figure 1. Water supply system operating in RDS Mamiraua



Source: Authors.

For installed systems, the manometric height (between pump and reservoir inlet) ranged from 6.5 to 20 meters and the distance from the pump to the reservoir ranged from 5 to 285 meters (maximum distance recorded: 1000 meters).

Table 1 presents the average acquisition costs of materials needed for installation based on project reports. Values refer to projects providing water for communities with 05 to 35 residences.

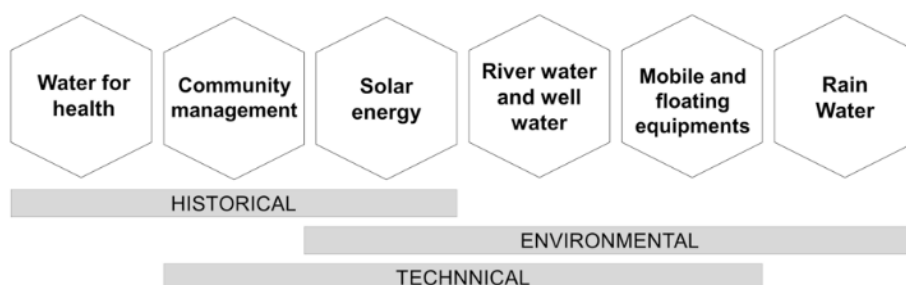
Table 1. Equipment and service costs for the installation of solar photovoltaic water supply systems

| Category | Component | Cost (US\$)* | Cost (%) |
|--|---|--------------|----------|
| Material for hydraulic installation and distribution | Adduction pipe and distribution network (500m, including hoses, pipes and fittings) | 2,222.00 | 15 |
| | Reservoir | 656.00 | 4 |
| | Filter Jacuzzi with sand | 700.00 | 5 |
| | Elevated reservoir base | 656.00 | 5 |
| | Accessories (nails, screws etc.) | 306.00 | 2 |
| Solar photovoltaic material | Solar Water Pump (Grundfos SQFlex) | 4,592.00 | 31 |
| | Photovoltaic generator (6 modules of 75 Wp) | 1,181.00 | 8 |
| | Pumping base (floating wood device for water supply and support of solar modules) | 131.00 | 1 |
| | Accessories for electrical installation (wires, connectors, dis-connector, aluminium support for modules) | 437.00 | 3 |
| Labour | Helpers to dig and set-up network** | 328.00 | 2 |
| | Technicians (photovoltaic and sanitation systems) | 2,624.00 | 18 |
| | Hydraulic and carpentry services | 945.00 | 6 |
| Total cost | | 14,777.00 | 100 |
| Cost per home connection : US\$ 422.00 (35 residences) to US\$ 2,955.00 (5 residences) | | | |

Note: Values based on installations conducted between 2010 and 2013. Costs of transporting materials from city to rural communities were not included. Minimum salary in Brazil, 2013: US\$ 296.00. Source: Federal Government, Decree No. 7.872, (2012). *Average dollar conversion rate in 2013: 1 US\$ = 2.87 R\$. Source: Central Bank of Brazil (www.bcb.gov.br). **Usually local work force, offered as a contribution by community members.

Figure 2 presents a graphic diagram of the factors that influence water supply system development; in the sections that follow, we present in detail the results of each item illustrated below.

Figure 2. Factors influencing the development of floodplain water supply systems



Source: Authors

THE USE OF SOLAR PHOTOVOLTAIC ENERGY FOR WATER PUMPING: HISTORICAL ASPECTS AND DIMENSIONS

Efforts to develop water supply systems in the region began in 1995. During this period, a work group called the Mamirauá Project (Projeto Mamirauá) made-up of scientists and technicians was inspired by the experiences the Prelature of Tefé (Catholic Church) and a group from the Federal University of Pará for the construction of groundwater wells. Members of this working group drilled a 30-meter well by hand with local equipment in the small community of Vila Alencar, RDS Mamirauá. It was the first experience with drilling wells in a small floodplain community. Water was withdrawn with a manual pump. According to the team's technical reports, residents complained that the pump demanded a lot of physical strength and time (up to 8 hours) to fill a 5-thousand-liter reservoir. Additionally, the pump had a leather piston valve that deteriorated after five days of use. In less than six months, the pump malfunctioned and was abandoned by the community.

In 1996, an electric pump was installed in the same well. The electric pumping allowed the reservoir to be filled in two hours, decreasing families' labour output. The pump had $\frac{3}{4}$ of HP of power, was an injection type model, and was powered by the community's thermoelectric generator – for which residents frequently ran out of fuel (diesel) to power. For this reason, most of the time water pumping did not occur. Based on this experience, a search for solutions to the “energy problem” (or lack of) in small rural communities began.

In 1998, Winrok International conducted a diagnosis of the energy needs of communities in the region through a consultancy funded by the United States Agency for International Development (USAID). The group identified energy for water pumping as a principal demand; energy to power lights in schools and community-meeting halls was also highlighted. At the end of the consultancy, solar photovoltaic was recommended as a good alternative, presenting several advantages, such as zero costs for operation (despite the high costs of installation), the promotion of communities' independence in relation to diesel (customarily used an instrument in political bartering in regional rural communities) and that the technology does not generate pollution.

In 2000, Mamirauá Institute known experimental water supply systems powered by solar photovoltaic energy in Peru and Colombia, presented by Institute for Environment and Energy, University of São Paulo (IEE/USP). From this contact, the first surface water capture system (river) using the solar photovoltaic energy was designed and installed in a floodplain area of the middle Solimões region (Boca do Mamirauá community) with resources from the United Kingdom Department for International Development (DFID).

The following year, a research project financed by the Humid Tropics Program PTU (MCT/CNPq) began. With this project, five water-pumping systems were installed in RDS Mamirauá, two relying on ground water catchment and three on surface water use. This project lasted one year and generated important technical knowledge (such as defining the best position between the pump, generator and reservoir [tank]), as well insights into social aspects (as the need for simple systems to facilitate community management) on the use of solar photovoltaic energy in Amazonia.

Later prototypes (financed with resources from PRODEEM until 2004; USAID, the Ministry of Science, Technology and Innovation/MCTI and Sustainable Amazonas Foundation-FAS between 2010 and 2014) followed the same proposal developed by the IDSM technical team, the leading institution, and in collaboration with IEE/USP consolidated photovoltaic energy as a viable option to meet local needs. Decisive factors included the abundance of this renewable energy source in the region and greater dissemination of photovoltaic technology across the globe, making equipment more accessible and affordable. From 2002 to 2014, 18 systems were installed with this configuration in various communities in the RDS Amanã and Mamirauá.

To maintain the simplicity of the system, solar pumps that could be connected to a photovoltaic arrangement were always chosen. The AY McDonald, Anauger (Brazilian) and Grundfos pumps were tested. The Grundfos SQFlex pump was used first by way of suggestion by the Institute for Sustainable Development and Renewable Energy (IDER, member of the Clean Energy Program financed by USAID). The same pump was used in most of the systems installed and in the current prototype—because it presented the best performance, even with manometric height variation. The pumps in operation are in use of 4.3 years on average. However, out of a total of 17 acquired, 12 failed and could not be fixed. Of the 12 pumps that stopped running, the maximum operating time was 5.5 years, with 33% running for up to 2 years and 42% running for 2 to 4 years. Technicians working at the authorized service centre (where one broken pump was sent) have not provided clear explanations as to why pumps malfunctioned.

INFLUENCE OF GROUND WATER QUALITY

The difficulties to drilling wells in a floodplain area were firstly related to pumping. However additional problems were identified regarding the quality of well water, which presented an unpleasant odour and taste. Empirically, technicians believed that these characteristics were related to the short depth of the well, which was just 30 meters.

The first type of water treatment tested was chlorine disinfection. For this, an electrolyte-based chlorine production device was made using a salt solution (sodium chloride) and water. Required electrical energy was produced with a 30 Wp photovoltaic module. This system only operated during the day. The equipment was used for just a few months and then quickly deactivated because the community and team had doubts about the correct form of use, the dosage and replacement of salt, and the efficiency of treatment—since they did not observe chlorine taste in the water.

Subsequently, to improve water quality, a cascade aerator was constructed with wooden planks. In addition to aeration, water passed, via gravity, through a sand-based filter (pool filter type). The filter and aerator did not present problems during use but were no longer used when the well was deactivated due to the unpleasant odour and taste of water.

In 2001, two additional groundwater wells, with an average depth of 37.5 meters, were installed in other communities. A water sample was analyzed and presented values higher than those of the legal limit (MINISTÉRIO DA SAÚDE, 2000, Portaria No. 1469) for parameters iron (12.19 mg /L; acceptable limit = 0.3

mg/L) and ammonia (2.18 mg /L, acceptable limit = 1.5 mg/L). Due to these results, project coordinators decided to stop water pumping and residents were advised not to drink well water. Over time, residents completely abandoned the wells.

COMPLEMENTARY USE OF RAINWATER

In the middle of the 1990s, rainwater use was promoted by IDSM's health education team. In recent years, the availability of reservoirs (tanks) with storage capacities of 500 and 1000 litres has favoured rain water capture and this practice has become routine for many families. Given the availability of rainwater, this source is preferred for consumption. On the other hand, due to storage capacity limitations and limited rainfall from September to November, rainwater does not meet all the household needs along the year, and thus the use of water from other sources, such as rivers and streams is also necessary.

In 2010 and 2012, two hybrid water supply systems were installed experimentally that combine the surface system, described above, with rainwater use. In each community, a cistern was built on the ground (not buried) using the ferrocement construction technique, with a capacity of 25 thousand litres, receiving water from the roof of adjacent community houses. A device that automatically separates water was installed to ensure the disposal of water that first falls and washes the roof. With the use of a low capacity solar pump, water is pumped from the cistern to the raised reservoir (tank) of the system, mixing with river water.

This hybrid system aimed to give families greater storage capacity, especially during the dry season, and to improve the quality of drinking water, requiring only a simplified treatment. The technical team is currently analyzing the feasibility of the use of ferrocement cisterns in floodplain regions, in terms of resistance and cost.

IMPROVING WATER QUALITY AND HEALTH CONDITIONS IN THE VÁRZEA

According to IDSM's technical team, the objective behind investments in water pumping systems has always been to improve health conditions for the local population. Records show that cases of diarrhea and malnutrition were frequent in the past and basic public health services were precarious or non-existent. It was initially believed that only the coarse sand filter, installed after the raised reservoir, removed all water impurities, requiring only subsequent chlorine treatment. To verify, in 2013 and 2014, periodic water quality analysis were performed; some results are presented on Table 2. We show data for tap water originating from the water supply system and water obtained directly from the river in three communities. In general, tap water presented better quality than river water, however, it still did not meet national Quality Standard, which require the absence of *Escherichia coli* and total coliforms in 100 mL and a turbidity of less than 5 NTU.

Table 2. Water quality in select communities with pumping systems in 2013-2014, RDS Amanã and Mamirauá

| Community | Sample | Turbidity | | Total coliform bacteria | | Escherichia coli | |
|--------------------------|-------------|-----------------|-------|-------------------------|---------------|----------------------|-------------|
| | | Mean ± SD (NTU) | | Min –Max (CFU/100mL) | | Min –Max (CFU/100mL) | |
| | | Period | | Period | | Period | |
| | | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Barroso (n=5) | River water | 116±23 | 70±2 | 9.200-9.200 | 400-11.200 | 3.700-3.700 | 1.400-1.400 |
| | Tap water | 37±8 | 26±11 | 2.400-7.200 | 5.500-23.000 | 700-4.700 | 300-1.200 |
| Jarauá (n=6) | River water | 9±4 | 14±13 | 5.900-40.400 | 19.400-42.000 | 800-3.400 | 700-5.700 |
| | Tap water | 28±49 | 7±8 | 2.000-43.700 | 1.700-1.700 | 600-600 | 400-4.200 |
| Vila Nova do Amanã (n=7) | River water | 50±39 | 11±1 | 3.600-17.200 | 3.700-27.100 | 700-8.700 | 200-2.400 |
| | Tap water | 32±4 | 4±3 | 2.200-48.100 | 17.700-19.800 | 400-16.900 | 400-13.400 |

CFU/100mL: colony forming unity per 100 mL water

As a result of these findings, two complementary steps were taken. First, workshops in communities were conducted on home water treatment and residents were encouraged to follow such recommendations. Additionally, a sand filter for household use was tested. A short-term experiment with three biosand filters showed positive results in removing water turbidity. However, during a large flood in 2013, when houses and filters were entirely inundated, families had difficulties operating them and soon lost interest.

About a year later, in 2014, a team began an experiment with a second sand filter for collective use to comprise the pumping system, using slow sand filtration process. The slow filter was to receive part of its water from the reservoir tank and would filter and pass water to a smaller tank with a public faucet. With this method, communities would have access to potable water and would not need domestic filters.

So far, analyzed samples have presented turbidity less than 5 UNT. However, residents have not entirely adapted to the required maintenance of the slow filter, which clogs in a few days and does not meet domestic water demands.

USE OF MOBILE EQUIPMENT AND FLOATING STRUCTURES (RAFTS)

The supply system is built with a floating water intake device. The team mentioned two reasons: the great water level variation in the floodplain and soil instability—which impedes construction on riverbanks. According to project reports, in 2001, an initial experiment was conducted testing the installation of modules on a floating base—made of recycled soda bottles (PET) united in a

wooden box and tarp forming a block. The floating structure was adequate; however, given its weight, it was not stable in the face of river currents and waves. With these oscillations, energy generation was compromised since the photovoltaic modules were not fixed in one direction and thus did not receive sufficient solar radiation.

The solution provided by the team was the substitution of the PET base with one made of assacú (*Hura crepitans*) logs. Assacú is traditionally used in the region to construct floating houses (*flutuantes*) due to their good buoyancy and durability while water submerged. The construction of a floating wooden structure also made it possible to install a pump underneath the raft. With this configuration – pump installed right under the generator – it was possible to avoid wasting energy with cabling. This design had a good performance and was adopted as a model in subsequent installations.

The floating raft is positioned close to the river margin in front of the community. After water uptake with the pump, retaining water is achieved through the use of hoses and PVC tubes. This configuration allows the linear piping/or plumbing to be changed from 5 to 285 meters throughout the year in accordance with river water level variation. In this way, manometric height also varies from 6.5 to 20 meters.

The elevated reservoir base (tank) is another system component that is mobile in nature, being 6 to 8 meters above the soil. The base is mounted on four wooden pillars of *piranheira* (*Piranhea trifoliata*), *acapu* (*Minquartia guianensis*) or *maçaranduba* (*Manilkara* spp). This set-up allows for an easy assembly and disassembly of the structure in case the community must move from one location to another due to environmental or social factors.

Based on residents' demands for the distribution of water in greater quantities, in 2010, reservoirs with 10-thousand-liter capacities were installed in two communities. However, the team identified that in one of the communities, waterlogged soils did not support the weight of the new tank, which sank around 10 cm. This problem was solved in future installations by combining the use of a main reservoir tank (5 thousand litres), along with recommending water storage in residences in smaller tanks with 300, 500 or one-thousand-litre storage capacities.

During the dry season (when river waters are low) the distance between the pump and the reservoir tank is at its maximum, as the pump is displaced in accordance with to the narrowing of the riverbed. When water levels rise (during the flood), residents must disconnect hoses and tubes and slowly approach the raft to the reservoir tank. This aspect of mobility proved fundamental to ensure a good use of the photovoltaic generator and was easily appropriated by user families.

MANAGEMENT AND COMMUNITY PARTICIPATION

As water systems are by character of collective use and management, the users were involved in all phases of installation, use and management. Family involvement is encouraged from the beginning—starting with the initial presentation of the project to the community. Residents participate in decisions regarding the installation local, get involved in building the distribution network

and the reservoir (tank) base and raft that supports the photovoltaic modules. Together with the project team, families develop local bylaws to guide the collective use of the system. A set amount that should be paid monthly per household (to guarantee a minimum level of maintenance of the systems tubes and cables) is also established collectively. However, in most communities this monthly contribution was not adopted. To resolve maintenance problems, community leaders or families seek the local government (Prefeitura Municipal) and/or institutions that support social projects to obtain needed materials or services.

Daily system maintenance consists in turning on and off the pump and managing the distribution network valves. Other necessary weekly adjustments include: the backwashing of the filter and the addition or removal of pipes in accordance with the river water levels and the movement of the raft that supports the pump. Residents should also clean the reservoir tank every 15 days.

During meetings, communities define who will be responsible for the daily operation of the system and for how long he/she will play this role. The project team often proposes task distribution, but the community is responsible for defining their specific management model and putting this into action. According to the team's reports, women actively participate in the daily care of the system. Over the years, communities have created their own ways of managing everyday tasks and of resolving maintenance problems. In terms of daily care, we identify two common scenarios: a) the election of three residents with turn taking every two years or b) or weekly management with teams formed by three residents of user families.

EVIDENCE SUPPORTING THE SUCCESS OF THE WATER SUPPLY SYSTEM

The long-term involvement of the technical staff in communities in the RDS Amanã and Mamirauá (from 1999 to the present) enabled them to identify and report improvements in personal hygienic care, especially with regard to children—all visibly apparent. Additionally, reductions in diarrhea and child malnutrition are also evident.

The installation of the 21 experimental water supply systems, using solar energy in riverine communities in the region was only possible because community associations gradually presented this demand to the responsible institution. The technical team reports effective resident involvement in system installation and management and the success of photovoltaic energy, making fuel consumption unnecessary, as indicative of the overall success of the technology.

DISCUSSION

Supplying water to residents in the floodplain demanded knowledge that local team did not have, and had difficulty accessing. Barriers included both the isolation of the region in relation to larger urban centres in Brazil, where technologies are available and communication difficulties. Given this situation, establishing a network of collaborators with universities and financiers played a fundamental role in this process, allowing for an exchange of academic and

technical knowledge—the latter accumulated by IDSM’s technical team in relation to regional needs and demands.

The cooperative network established by the IDSM constituted an important contribution. Mainly, it reinforced a model of technical dissemination that demands the creation of associations to mobilize interests that aggregate diverse types of knowledge. As affirmed by Akrich et al. (1988), a project’s outcome depends on the alliances that are created, the mobilization of interests and the capacity to make oneself interesting to attract new allies. Thus, it is possible to affirm that the successful replication of a technology characterized by social inclusion depends on its technical efficiency, the cooperative network established around it, and users’ interactions with and appropriation of the technology.

Technical-scientific knowledge is the outcome of diverse interactions. According to Callon (2004) interactions can be denominated socio-technical and analyzed from the perspective of the sociology of translation (CALLON, 2004). This helps in explaining, for example, how a technological innovation attains its empirical environment. In this process, socio-technical networks are established between the several actors involved—both human and non-human.

A water supply system can be considered an example of connection between human and non-human actors and a socio-technical network that surrounds this experiment. A set of factors contribute to making the technology suitable in relation to different interests, be they of a technological, social or political nature. This perspective of socio-technical changes is influencing the direction of research in Brazil, particularly of studies seeking to respond to local needs, such as access to water in households. Such research incorporates a new conception of science that puts the principles of social inclusion and human dignity at the center of the issues in focus. In this connection, the role of science and technology in the Amazon rainforest is fundamental to contribute, along with policies for the region’s social development, through research and the implementation of technological and social innovations.

For Baumgarten (2006), this point of view allows the idea of strategic planning to be rethought as collective action. In this regard, paths for human behaviour and social relations could be sought out through structures capable of ensuring human dignity and social and natural sustainability (BAUMGARTEN, 2006).

Concern over water consumption was prompted in relation to health conditions reported in the middle of the 1990s when the prevalence of diarrhea-related illnesses was 89% and polyparasitism was present in 41% of reserve residents (PERES et al., 2001). Research informants presented this local reality as the principal factor that motivated the institution to conduct described interventions. Similarly, during the same time, the World Health Organization (MURRAY and LOPEZ, 1996) highlighted diarrhea-related sicknesses as the second main cause of health incapacitation in developing world countries (using the DALY coefficient) – second only to respiratory illnesses. Therefore, lack of sanitation, clean water and hygiene was considered the second most important factor in accessing risk of incapacitation.

In populations that use “unimproved” water sources (defined as unprotected springs and dug wells, surface water and water stored in a tank), improving infrastructure that brings running water to residences results in a 23% reduction

(on average) in the prevalence of diarrhea (PRÜSS-USTÜN et al. 2014). In our case, while the technical team we interviewed pointed to improvements in health and well-being in participating communities, a causal relationship between improvements in water supply and the reduction of diarrhea-related sicknesses is still being analyzed locally by impact studies.

Other positive outcomes related to water access, in addition to reducing illnesses, are not commonly quantified. One additional effect of water pumping in a rural community was registered by Crow et al. (2012) who showed how piped water improved income generation and allowed for livelihood diversification.

In this article, we identified that all technological components of the water supply system—those related to water distribution (pumping and piping) were quickly improved. These improvements were of principal benefit to women and children due to a rapid reduction in physical force needed to transport water; however, this effect was not quantified. Generally, women suffer high levels of physical stress from the frequent lugging of heavy recipients of water (POND and PEDLEY, 2011). However, according to Hunter and Resebro (2011), the global health burden (i.e. related illnesses) attributed to hauling water is still uncertain.

In the late 1990s, when the technical team first attempted to improve water access, they dug wells; however, well water was of poor quality, and users quickly abandoned them for this reason. This situation was also reported by Azevedo (2006) in other floodplain regions of Amazonia, whose study showed that wells of less than 80 meters in depth tend to yield water with high concentrations of iron. The author suggests digging deeper wells and treating water. To date, however, no records of research or extension activities seeking to improve results by digging deeper wells in the region exist.

One of the most important factors in the success of this water supply system is solar photovoltaic energy. While globally more than 10 thousand photovoltaic water pumping systems were already installed by the beginning of 1990 (FEDRIZZI, 1997), only in the early 2000s was the first wide-scale application of this technology made possible in this region of Brazil, by a rural electrification program of the Federal Government (PRODEEM). Regarding the energy aspect, the relevance and influence of collaborators in the development process were especially evident. Since collaborators were from the principal research centre on photovoltaic energy in Brazil (IEE/USP), this technology could be used in a pioneering way in this part of the world. The potential use of photovoltaic energy, especially in hybrid solar + diesel systems, was demonstrated in Martins et al. (2008), who established this model as a solution for energy generation in isolated regions of the Amazon, where the costs of transmission and distribution of conventional energy are prohibitive.

By choosing to use solar pumps, the team was limited to a few brands. Considering available and tested pumps, the Grunfos pump presented the best performance. On the other hand, it did not respond to operational and environmental conditions; in fact, $\frac{3}{4}$ of all pumps collapsed after four or less years of use. Thus, pumps were the most fragile and limiting aspect of the described model. As an interesting comparison, Foster and Cota (2014) present a case in which a pump of the same brand operated for 14 years in a Mexican well.

New pumping configurations can be used with the utilization of a more robust photovoltaic generator, current invertors (CC to CA) and conventional

pumps, or even with the addition of charge controllers and batteries (CHANDEL et al., 2015). However, these changes represent an increase in system complexity and costs, making them unviable for the riverine communities. Researchers at collaborating universities (IEE/USP and Federal University of Pará/UFPA) have been dedicated to the technological development of alternative equipment, seeking efficiency and cost reduction. At the same time, the local IDSM team has conducted tests with a simplified arrangement of a solar pump and charge controller.

By choosing the appropriate pump and improving the water quality, the intervention can achieve its goal of improving residents' health. For this, available treatment technologies should be adapted to local realities and slow filters are a possible solution. The development of this supply system follows the tendency of many water sources for many purposes, such that the quality of supplied water is defined by its intended use. Traditional water use by riverine peoples, as reported by Moura (2007) has a common principle, families administer available water according to use: water for drinking, cooking or bathing. In addition, they manage scarcity and abundance in dry and rainy seasons. This commonality is a positive factor motivating technological appropriation.

Household water treatment is a common practice in the region. According to a survey, in 2292 residences (GOMES et al. 2014), 96% of families conduct at least one form of water treatment at home; cloth filtering (coagem com pano) (67% of households) and use of sodium hypochlorite (55% of households) were the most popular recorded methods. Domestic water treatment has a proven potential to improve water quality in developing world countries; however, Sobsey et al. (2008) highlight that 100% regularity in practice is necessary for such treatment to have desired health effects. In this case, the use of technologies, such as sand and ceramic filters tend to be more sustainable because once they are acquired they can be used for a long time.

The use of traditional regional knowledge was another relevant factor, which eventually brought a technical solution for an environmental challenge. The construction of a support raft for the pump using the same type of wood used by riverine peoples (to build their floating homes) brought forth better efficiency of solar radiation capture and helped facilitate the uptake of water.

Along the years, the team chose to pump surface water, using flexible piping and cabling. During the dry season (low water level) the distance between the pump and the reservoir (tank) is at its maximum. With the rising of river water level (flood period), the community should disconnect hoses and tubes and slowly approach the raft to the reservoir tank. This mobile aspect proved fundamental for a good use of the photovoltaic generator. According to Fedrizzi, Ribeiro and Zilles (2009), this technical configuration is adequate where there are great oscillations in river water levels and the use of well water is not accepted by or accessible to the population. This mobility was also important for the protection of equipment against robbery or accidents—since the pump and generator could stay as close to the community.

Considering costs of installation materials and labour, the pump component is the most costly, representing 31% of the total cost. Since pumps are imported and have advanced technology, if a problem occurs, they must be removed and replaced; no repairs can be made in the region. Lookwood (2004) presents this

situation as an inherent challenge in achieving true community management; given the technical specifications, long-term support and external assistance to address major repairs, conflicts, and problems related to system improvement and expansion will always be necessary.

The management and maintenance of water supply systems were proposed as community tasks, and as such, families should elect representatives to work voluntarily to maintain commonly owned goods. Based on information gathered here, we verified that water users did indeed organize themselves for this purpose. However, financial contribution systems to enable replacement of parts and equipment were rarely defined and maintained. Additional studies should be conducted to identify effective and innovative forms of community management and participation, observing local livelihoods and successful experiences.

Experimenting with the water supply system indirectly served to establish a repressed demand for running water in the communities. A little more than 15 years ago, this was not an issue for rural communities in Amazonia since they are surrounded by water almost all year long; however, they were also excluded from access to almost all public services, such as household water supply servicing.

Following this experience, today, the main challenge is inserting this model system into a floodplain-focused sanitation system, so that it can be replicated in several other small rural communities along Amazon basin. Instruments for replication could be government, private non-profit sector investments or investments by companies or communities themselves. A successful case of public policy aiming to improve access to water in rural Brazil is identified in the semi-arid state of Ceará (ENÉAS DA SILVA et al. 2013). Key to their success is the creation of federations of community associations that demonstrate sustainability due to community involvement and local capacity building. Experiments such as these demonstrate the capacity for local mobilization to address the problems of perpetual water shortages and thus have a high potential for wide-scale replication.

A key factor to consider in developing a regional sanitation system in the future is the establishment of clear rules regarding the responsibilities of all stakeholders—in consideration of state and local governments—in the quest for a financially sustainable model. According to Fedrizzi, Ribeiro and Zilles (2009) solar water pumping projects should establishment commitments and responsibilities of different actors including funders, in accordance to their circumstances, skills and ability to pay.

CONCLUSION

With this article, we conclude that technological development was dependent on environmental factors within a specific historical-social context, as well as the availability of existing technology. In terms of the historical context, poor health conditions, household water management practices, and the possibility of community management of the system were the relevant factors. In terms of the environment, river water level variations, poor quality of groundwater and the availability of rain and sun were decisive factors. Finally, related to technical aspects, the use of local materials, use and configuration of

mobile and floating equipment, as well as the integration of solar photovoltaic energy stand out as other essential factors. Studies are still needed on the use of more durable pumps and on more advanced treatment of tap water for users of the proposed model. We believe that the model developed should be considered one of the solutions for access to water in the remote areas of the Amazon floodplain.

Cercados por sol e água: desenvolvimento de um sistema de abastecimento de água para comunidades ribeirinhas na Amazônia

RESUMO

Este artigo apresenta uma análise dos fatores históricos, técnicos e ambientais que influenciaram o desenvolvimento de um sistema de abastecimento de água para pequenas comunidades rurais, em áreas sazonalmente alagadas na Amazônia. Os dados foram obtidos de relatórios, entrevistas e análises de qualidade da água. Os principais fatores identificados foram: o uso de energia fotovoltaica, a relação entre a qualidade da água subterrânea e da chuva, o uso de equipamentos móveis e estruturas flutuantes, e a participação comunitária na construção e gestão das estruturas. Nós acreditamos que o modelo de abastecimento de água desenvolvido é uma possível solução para o problema do acesso à água em comunidades rurais remotas da Amazônia.

KEYWORDS: Acesso à água. Energia fotovoltaica. Comunidades rurais. Amazônia.

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