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Low-Cost Household Groundwater Supply Systems for Developing Communities

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Low-Cost Household Groundwater Supply

Systems for Developing Communities

by

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ABSTRACT

Self-supply is widely reported across various contexts, filling gaps left by other forms of water supply provision. This research assesses low-cost household groundwater supply technologies in markets in developing country contexts of sub-Saharan Africa and Latin America, with a focus on the potential for improving Self-supply technology implementation and markets in sub-Saharan Africa. Specifically, a mature and unsubsidized Self-supply market for Pitcher Pump systems (suction pumps fitted onto hand-driven boreholes) is studied in an urban context in Madagascar, EMAS low-cost water supply technologies are assessed in Bolivia, and a technical comparison is completed with manual EMAS Pumps and family versions of the Rope Pump in Uganda.

In Madagascar, locally manufactured Pitcher Pump systems are widely provided by the local private sector, enabling households to access shallow groundwater. This market has developed over several decades, reaching a level of maturity and scale, with 9000 of these systems estimated to be in use in the eastern port city of Tamatave. The market is supplied by more than 50 small businesses that manufacture and install the systems at lower cost (US$35-100) than a connection to the piped water supply system. Mixed methods are used to assess the performance of the Pitcher Pump systems and characteristics of the market. Discussion includes a description of the manufacturing process and sales network that supply Pitcher Pump systems, environmental health concerns related to water quality, pump performance and system management.

The research additionally considers the potential of EMAS low-cost household water supply technologies in accelerating Self-supply in sub-Saharan Africa, and consists of a field assessment of EMAS groundwater supply systems (handpumps on manually-driven boreholes) and rainwater harvesting systems as used at the household level in Bolivia, focusing on user experiences and the medium/long-term sustainability of the pump (cost, functionality, etc.).

The EMAS Pump is a low-cost manual water-lifting device appropriate for use at the household level. Developed in the 1980s, the EMAS Pump has been marketed extensively for local manufacture and use at the household level in Bolivia, and marketed to a lesser extent in other developing countries (mainly in South and Central America). The simple design of the EMAS Pump, using materials commonly found locally in developing countries, allows for it to be fabricated in many rural developing community contexts. Its capability for pumping from significant depths to heights above the pump head makes it quite versatile (e.g. for pumping to household tanks, reservoirs at higher elevations, or for installing multiple pumps on wells). A survey/inspection of 79 EMAS Pumps on household water supply systems in areas of three regions of Bolivia (La Paz, Santa Cruz and Beni regions) showed nearly all EMAS Pumps (78 out of 79) to be operational. 85% of these operational pumps were found to be functioning normally, including 72% that were reported to have been installed eleven or more years earlier. It is shown that rural households in Bolivia are able to maintain EMAS Pumps. The EMAS Pump can be installed and repaired by local technicians, and numerous examples were seen of small groups of local technicians that operate small businesses installing and repairing such systems. The cost of a new EMAS Pump was reported by users to be US$ 30-45. Maintenance and repair costs of the EMAS Pump were found to be reasonable, with pump valve replacement (the repair most commonly reported by users) costing an average of US$9 (materials and labor).

The Rope Pump has some similar attributes to the EMAS Pump, in that it is can be made locally from materials commonly available in developing communities, it has a relatively low cost, and is simple to understand. The Rope Pump is well-known among international rural water supply professionals, and thus serves as a good baseline to compare the lesser-known EMAS Pump. A technical comparison completed in Uganda of the EMAS Pump and the Rope Pump considered performance (flow rates and energy expended, pumping from various depths), material costs, and requirements for local manufacture. The study concluded that, based on its relative low-cost (material costs ranging from 21-60% that of the family Rope Pump, dependent on depth and pumping pipe size), similar technical performance to the Rope Pump when pumping from a range of depths, and the minimal resources needed to construct it, the EMAS Pump has potential for success in household water supply systems in sub-Saharan Africa. Combined with the conclusion from the research in Bolivia, it is believed that there is considerable potential for the EMAS Pump as a low-cost option for Self-supply systems in sub-Saharan Africa.

Recommendations for further research focus on: (1) improvements to the Pitcher Pump system (focusing on reducing risk of water contamination); (2) formative research to identify factors that have led to the sustainability of the Pitcher Pump market in eastern Madagascar, and (3) development of the Self-Supply Market in Madagascar beyond Pitcher Pump systems.

CHAPTER 1: INTRODUCTION

Lack of access to adequate water supply and sanitation results in more than one million preventable deaths throughout the world each year (Montgomery et al., 2009). In attempt to reduce this mortality statistic, and additionally to decrease morbidity caused by water-borne diseases, the United Nations' Millennium Development Goal (MDG) target (Goal 7, Target 7C) for water supply aims to halve, between 1990 and 2015, the proportion of the world's population without access to improved drinking water (UN, 2010). To date, efforts to achieve this target, by local and national governments as well as international actors, have largely focused on the implementation of new water supply infrastructure projects to serve populations suffering from inadequate access to drinking water. Much of the world is currently on target to reach or surpass the MDG drinking water target by 2015. However, despite laudable efforts, in many countries in sub-Saharan Africa this target will unfortunately not be met by 2015.

A primary reason for the forecasted failure of these sub-Saharan African countries to reach their MDG drinking water target is that a significant portion of previously implemented community-managed water systems have proven to be non-sustainable (Carter et al., 1999). According to the Rural Water Supply Network (RWSN, 2010), existing rural water supply infrastructure has proven to be far more difficult to keep operational than planned for, and, largely due to poor maintenance, these systems often fail completely prior to the end of their design lifetime.

1.1 Rural Water Supplies for Developing Communities

1.1.1 Community-Managed Rural Water Supply Systems

The use of community-management models for the operation and maintenance of rural water supply projects has become increasingly popular in developing countries over the past several decades. During the 1980's and 1990's, various types of major actors (e.g., governments, donors, non-governmental organizations, and multilateral lending institutions) agreed to community-management concepts (Lockwood, 2004). Despite their popularity, however, the long-term sustainability of community-managed water systems is less than impressive. In Africa, studies have shown community-managed rural water supply systems to have failure rates of between thirty and sixty percent (Baumann, 2005; Harvey and Reed, 2007). Multiple recent studies of community-managed water supply systems in parts of Latin American countries show failure rates reaching twenty to forty percent (Reents, 2003; Suzuki 2010; Schweitzer and Mihelcic, 2012).

Carter et al. (1999) propose several main causes of the non-sustainability of community-managed water and sanitation systems in developing countries. These causes of failure most applicable to water supply projects can be summarized as follows:

1. Lack of willingness or ability of community members to pay user fees,
2. Lack of perceived ownership by the community,
3. Lack of perceived health benefits from the water system,
4. Behavior change strategies, e.g. community education, are insufficiently implemented, and,
5. Community members involved have moved away.

Well-designed community-managed water supply projects aim to address each of the above issues during project design, planning and construction phases. However, it is often not reasonable for issues such as these to be overcome during relatively short design, planning and construction periods. Therefore, to increase the chance of system sustainability, it is necessary for communities to receive medium- to long-term support (often termed "post-construction institutional support") after the construction phase (Lockwood, 2004).

1.1.2 Improving Sustainability of Rural Water Supplies

Harvey and Reed (2007), in discussing the need to improve sustainability of community-managed water supplies in sub-Saharan Africa, propose three categories of solutions: (1) Institutional support to communities (as described above), (2) Private sector service delivery models, and, (3) Household and small-group water supplies, which is the focus of this research.

While 'community participation' in the implementation of rural community water supply projects has proven important to system sustainability, this does not mean that communities should be obligated to manage the operation and maintenance of systems themselves (with or without external support). Rather, communities should have the option to essentially contract out these services to the private sector. Because the community would be making the decision on who manages their system, and would have the right to take management control back, "this should not be seen as disempowerment" (Harvey and Reed, 2007). Limited evidence from rural water supply projects in developing countries managed by private sector entities has shown potential for this strategy to be a sustainable alternative to the community-management model.

1.1.3 Household Water Supplies

Private household and small-group water supplies offer the potential to complement community-managed water supply systems, either in their place (when community-managed systems are non-existent or not accessible), or as secondary sources for households to use in combination with community systems. When used in combination with community systems, household systems offer several advantages, including taking pressure off of community systems that have difficulty in supplying sufficient quantities of water to all users.

Over the past decade, there has been increased emphasis on household water supply as a means of improving access to drinking water in developing countries. This strategy is often a focus in rural areas, but can also be beneficial in many peri-urban and some urban contexts in developing countries. 'Self-supply' is a term that is commonly used, and is defined as "the improvement to household or community water supply through user investment in water treatment, supply construction and upgrading, and rainwater harvesting" (Sutton, 2009).

Self-supply is based on the idea of users making affordable, incremental improvements to their private family or neighborhood (i.e. small group) water supply systems. While it is not a feasible option in every context, where it is possible implementation of Self-supply can result in "the obstacles to sustainability created by a lack of trust, cohesion, and co-operation within communities" being greatly reduced (Harvey and Reed, 2007). Self-supply projects can be complementary to community water supply systems, and can play an important role in helping developing countries to reach the MDG target for improved drinking water supply coverage, as conventional community water supplies often bypass the poorest and most remote communities. This potential improved coverage will additionally impact most of the main MDG objectives, including reduction of poverty and child mortality (Sutton, 2010).

1.2 Low-Cost Household Water Supply Technologies

Low-cost household water supply technologies often make use of either groundwater in the immediate vicinity around a household, or rainwater that falls in a similar area. Common low-cost household water supply technologies include: (1) family wells, which can be either hand-dug or manually drilled; (2) water-lifting devices, which can range from being as simple as a rope attached to a bucket, to a manually-operated pump; and (3) rainwater harvesting systems. While more advanced technologies, such as electric or fuel-powered pumps or drills, may in some cases be relatively inexpensive, for the purpose of this research they are not considered to be low-cost water supply technologies. In this context, low-cost water supply technologies are defined as *manually-operated* set-ups which owners in developing communities can feasibly purchase or construct and use either with minimal or no subsidies, or through micro-credit loan programs.

Low-cost water supply technologies are increasingly being promoted as sustainable solutions when implementing water supply projects at the small-community or household level in developing areas. Specific types of low-cost technologies, as mentioned above, are often based on concepts or technologies that have been used in water supply or other sectors for hundreds of years or more, such as the Rope Pump and manual percussion drilling, both of which are based on technologies that were originally developed in China over a thousand years ago (Missen, 2003; Sutton and Gomme, 2009).

1.3 Benefit of the Study

This research focuses on sustainable implementation of low-cost household groundwater supplies in developing communities. Low-cost household water supply technologies are studied in the field at two primary field locations (i.e., Bolivia and Madagascar) and one secondary field location (Uganda), for their suitability to use in developing communities. Through these studies, possibilities for further research and introduction of improved household water supply technologies to developing communities are recommended. The research emphasizes applicability of such technologies in sub-Saharan Africa.

Chapter 2 assesses the sustainability of a specific type of low-cost groundwater supply system, the Pitcher Pump system, which has been marketed in Madagascar for more than five decades. This type of low-cost water supply system, which is built independently by more than fifty small businesses in eastern Madagascar and sold to private users at unsubsidized prices, provides an example of Self-supply in a sub-Saharan African context that has proven to be sustainable over many years. Mixed methods are used to assess the Pitcher Pump technology and market in eastern Madagascar, including Pitcher Pump system construction practices, performance, system management, water quality, and household drinking water treatment practices. The study provides recommendations for potential improvements and further research.

Chapter 3 provides an overview of three types of low-cost water supply technologies appropriate to Self-supply (manual water pumps, manual well drilling techniques, and rainwater harvesting systems), in the context in which specific models of these types of technologies have been developed by the organization EMAS and implemented for use in household water supply systems in Bolivia. Through assessing the technical capabilities and the context in which these technologies have proven to be effective in Bolivia, the research provides insight into the potential for use of these technologies in other developing community contexts.

A third topic of the research, *Chapter 4*, considers the potential of a type of manual water pump that was developed in Bolivia, the EMAS Pump, for use in Self-supply in developing community contexts, and emphasizes the potential for use of this type of pump in sub-Saharan Africa. A technical comparison is done between the EMAS Pump and another type of manual water pump, the Rope Pump, which has been most successfully marketed as a household-level pump in Nicaragua. The Rope Pump has been introduced in many other developing countries in recent years, with varying degrees of success (Sutton and Gomme, 2009). The study provides an analysis that allows researchers and development practitioners to better understand the technical attributes and capabilities of the EMAS Pump, as well as socio-economic considerations related to its introduction and use, and to compare it with the Rope Pump (as well as other documented low-cost pumping devices) as a Self-supply option for developing communities.

The lessons learned from the various aspects of the proposed research help to form recommendations for further research, introduction of low-cost water supply technologies, and improvements to Self-supply markets, as summarized in *Chapter 5*. These recommendations focus on the potential for use of low-cost water supply technologies in Self-supply projects in sub-Saharan Africa.

1.4 Guiding Framework

This study focuses on researching appropriate low-cost household water supply technologies and markets. The presented topics (*Chapters 2, 3, and 4*) are components of a broader trans-disciplinary research that has been developed at the University of South Florida (and led by the author of this dissertation) with the aim of improving health and livelihoods of vulnerable populations in developing countries through improved access to water supply at the household level. This research theme focuses on using qualitative and quantitative formative research to assist local actors in developing communities find appropriate solutions through better understanding communities and their needs, helping them to engineer improvements, and working with them to promote behavior changes that can lead to improved health and livelihoods.

Instrumental in this process is Social Marketing, which has been a guiding framework in the development of the research, and plays a larger role in on-going and future research related to this work. Social Marketing is a behavior change planning process that uses marketing principles and techniques to develop new markets and design and deliver socially beneficial products and practices. Social Marketing's consumer orientation is essential for understanding how to motivate target markets, overcome barriers, and make socially beneficial products and practices uniquely better than those that compete with them.

1.5 Research Questions

The overall goal of the proposed research is to assess low-cost household water supply options for their suitability to sustainable use in developing communities, particularly in sub-Saharan Africa, and evaluate possibilities for the introduction of improved household water supply technologies to such contexts. The research aims to address the following research questions, each related to sustainable implementation of low-cost household water supply systems for developing communities:

1. What improvements can be made to the Pitcher Pump system used in Madagascar to improve the quality of the product (including reliability, pumping rates, and/or quality of extracted water)?

2. Are low-cost water supply systems that have been developed in Bolivia (EMAS technologies) suitable, affordable options for household water supply (Self-supply) for developing communities in sub-Saharan Africa?
3. Would EMAS manual water pumps be an effective, less-costly alternative to the Rope Pump, offering a better chance for households or small groups of families in sub-Saharan Africa to improve their private water supplies, while lifting water at an acceptable rate?
4. Based on the results of Research Questions 1 through 3, what recommendations can be offered to improve sustainable low-cost water supply systems for use at the household level in developing contexts in sub-Saharan Africa?

CHAPTER 2: UNSUBSIDIZED SELF-SUPPLY IN EASTERN MADAGASCAR[1]

2.1 Introduction

Self-supply – to develop private family or neighborhood (i.e. small group) water supply systems through own investment – typically relies on low-cost technologies to either extract shallow groundwater or collect rainwater. Some types of household water supply technologies include: 1) family wells (which can be either hand-dug or drilled), 2) water-lifting devices (which can range from being as simple as a bucket attached to a rope, to manually operated, electric or fuel-powered pumps), and 3) rainwater collection set-ups. Self-supply may also include household water treatment, which is commonly done through boiling, filtration or disinfection.

Self-supply is driven by households' interest to access an affordable and convenient water supply, independent of public investment in hardware. It is an alternative, and oftentimes more convenient option to using an improved communal water-point (a protected well, tap stand, or household connection from a piped water supply system), or an alternative to dependence on unprotected sources such as surface water. The willingness of households to bear the full costs of water supply comes with a strong sense of ownership in the developed infrastructure. This, and other attributes of Self-supply systems (e.g. non-donor-driven, building on local knowledge and

[1] This chapter was published as "Unsubsidised self-supply in eastern Madagascar" in Water Alternatives journal, volume 6, issue number 3, pages 424-438. The author of this dissertation retains the copyright of the journal article.

practices, etc.), have been reported to lead to such supplies being more sustainable than other options (Sutton, 2004).

Poor water quality and its associated health risks are commonly the main concerns about Self-supply (Sutton, 2009). This issue is much more complex than simply comparing the water quality of household and communal sources at the point of collection. Households may use water from multiple sources for different purposes, contaminate water between source and point of consumption, and treat water at household level by filtering or boiling. Furthermore, if Self-supply often delivers water supplies that are more accessible, convenient and reliable than alternative options (e.g. communal water supplies), the potential negative health effects of sub-standard water quality may be offset by potential positive health effects related to increased water usage. Previous studies have shown a link between increased domestic water usage and improved health, and that improvements resulting in the use of increased quantities of water have a larger impact on the burden of disease than improvements to water quality at the source (Esrey et al., 1985; Howard and Bartram, 2003).

While much of the literature on Self-supply has been focused on rural areas, Self-supply is also a common phenomenon in many peri-urban and urban communities. It is found where populations are either unserved, intermittently served, or where households cannot afford, or do not see value in, the communal water supply service. For example, a recent study in southwest Nigeria showed hand-dug wells to be very common in areas of a city unserved by community water supply systems (Oluwasanya et al., 2011). Using statistics from Demographic and Health Surveys, Gronwall et al. (2010) estimated that 269 million people in urban areas of 43 surveyed countries in sub-Saharan Africa, South and Southeast Asia, and Latin America (including the Caribbean) rely directly on Self-supply wells as their principal drinking water source.

In eastern Madagascar, there is a well-developed market for the locally manufactured Pitcher Pump. This chapter presents the findings of a study investigating this form of water supply and market, believed to be the first in-depth assessment of this type of system in Madagascar. It focuses on the port city of Tamatave (also commonly called Toamasina) and the nearby town of Foulpointe to assess the performance of Pitcher Pump systems (including delivered water quality), user acceptability of the technology, and sustainability of the market. The objectives of the research were specifically to: 1) assess user experience and associated water quality of locally manufactured household groundwater supply systems prevalent in eastern Madagascar and 2) assess local manufacturing practices and sales of these systems.

2.2 Background

2.2.1 Water Supply in Madagascar

According to the most recent Joint Monitoring Program (JMP) update, coverage of improved drinking water sources in Madagascar in 2011 was estimated to be 78% in urban areas and 34% in rural areas (JMP, 2013). JIRAMA, the national parastatal water and electric company, manages piped schemes that supply water to 65 urban municipalities. However, JIRAMA is plagued by operational inefficiencies and lacks the capacity to upgrade aging infrastructure. JIRAMA's poor performance is partly attributed to high operating costs, uneconomically low water rates, and affordability issues among target customers (USAID, 2010).

In rural areas, coverage numbers remain stubbornly low and considerable challenges persist in maintaining existing coverage and extending water supply services to the remaining majority of rural dwellers. Rural water supply systems have been commonly implemented using community water-management models, with questionable long-term sustainability rates. For example, a 2006 study reported that over 90% of donor-funded water projects in the Ikongo District in south-eastern Madagascar failed to develop or implement adequate financial management schemes to collect money from community members for routine maintenance and purchase of spare parts (Annis, 2006).

There is scope for alternatives in both urban and rural water supply. Piped water supply systems managed by public-private partnerships in rural communities have shown recent potential to be a more sustainable water delivery model (Annis and Razafinjato, 2012). Household investment in Self-supply continues to fill other gaps in service provision in both urban and rural areas.

2.2.2 Self-supply in Madagascar

Traditional Self-supply practices in Madagascar include the development of household wells and, to a more limited extent, household rainwater harvesting systems. Household hand-dug wells (typically with rope-and-bucket systems) are common in many areas of the high plateau region in the central part of the country. In coastal areas with shallow water table depths and sandy soils, manually drilled wells and suction pump systems – the focus of this study – are common at the household level. This type of low-cost system was reportedly first introduced to eastern Madagascar over 50 years ago by a French expatriate working for the national electricity company.

Over the past two decades, numerous other types of low-cost groundwater supply technologies have been introduced in various parts of the island, including two types of handpumps appropriate for household and small community use, and amenable to local manufacture. The Rope Pump was first introduced in Madagascar in 2000 by the national non-governmental organization Taratra (with support from the Swiss organization SKAT), and later by other international organizations (Daw, 2004). The Canzee Pump was initially introduced by the international organization MedAir during disaster relief efforts following a hurricane in 2004, and a commercial market for this pump was later developed by Bushproof, a national company founded during that same period (Mol et al., 2005). In the case of the Rope Pump, which is now manufactured by several local workshops throughout the island, a small private market for these pumps has developed for household and community water supply. The market for the Canzee Pump in Madagascar has been restricted almost exclusively to donor-supported community water supply projects. Several manual drilling techniques have also been introduced to Madagascar over the past decade, including hand-augering introduced by an FAO project (Naugle, 2006), jetting by MedAir, rota-sludge drilling by the Practica Foundation, and hybrid percussion-jetting-rotation manual drilling by Bushproof. While each of these technologies has played a role in increasing access to groundwater in parts of rural Madagascar, none of them have achieved scale in an unsubsidised Self-supply market.

2.2.3 Pitcher Pump Systems in Madagascar

The Pitcher Pump system (locally called *Pompe Tany*, combining the French word for pump with the Malagasy word for ground) consists of a small-diameter well fitted with a suction pump. Wells are drilled up to a depth of 12 meters. Figure 2-1 (a) shows a diagram of the Pitcher Pump system components while Figure 2-1 (b) shows a locally constructed Pitcher Pump in use in Tamatave.

As shown in Figure 2-1 (a), the Pitcher Pump has two check valves that are weighted (one on the lower end of the pump head, and a second one on a piston that attaches to the pump handle via a rod) and the pump is installed directly on a drilled well. The check valves are usually made of leather and weighted with lead (Pb). The well is installed by manually boring (coring) down to near the water table, then hammering into the ground a permanent galvanized iron casing pipe that includes a well screen and a pointed drill bit (well-point) at its lower end.

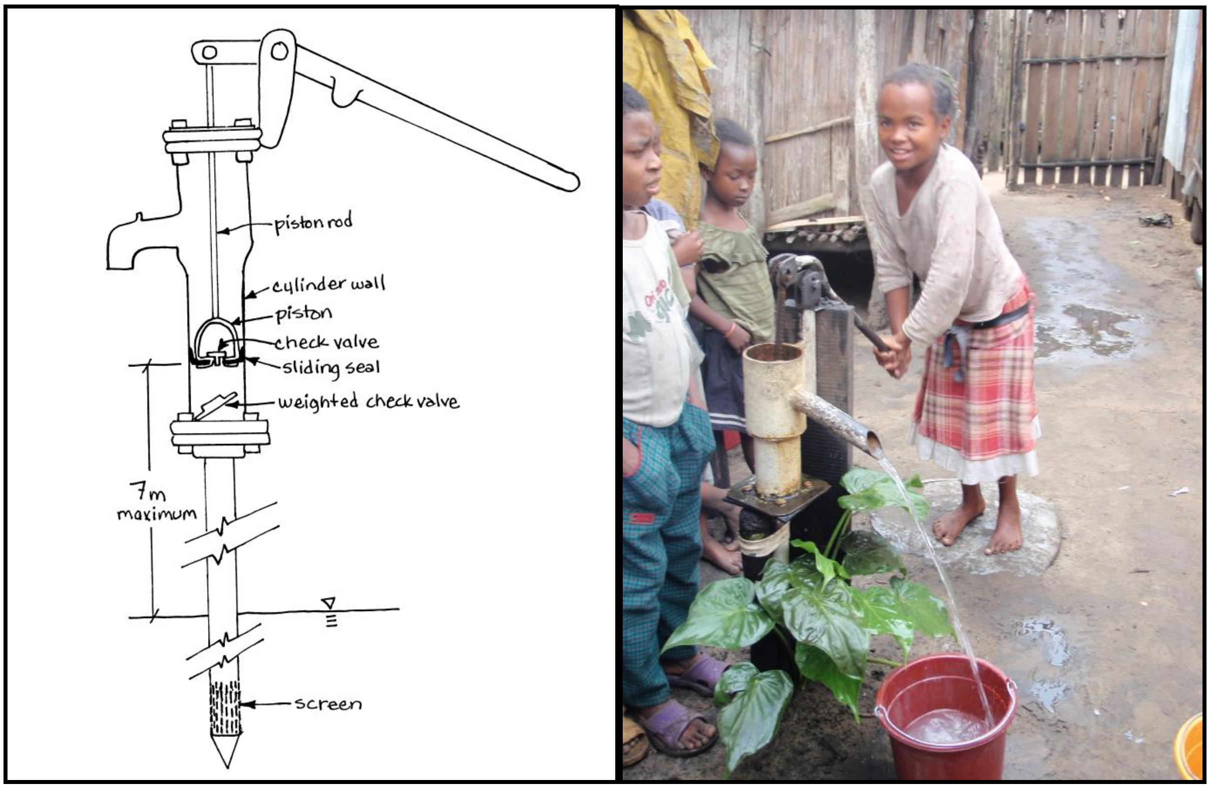

Figure 2-1. (a) Diagram of Pitcher Pump system (reprinted from Mihelcic et al., 2009, with permission of Linda D. Phillips); (b) Pitcher Pump in use in Tamatave, Madagascar.

2.3 Methodology

Data related to Pitcher Pump systems were collected in the city of Tamatave (estimated population of 280,000) and the nearby town of Foulpointe (estimated population of 15,000) in the Atsinanana Region of eastern Madagascar (see Figure 2-2). Primary field data were gathered over a four-week period in August-September 2011, and a local research assistant gathered additional data in 2012 and early-2013.

The field research made use of mixed methods, consisting primarily of a quantitative survey of households that owned Pitcher Pump systems, semi-structured interviews with pump manufacturers, inspection/observation of household water and sanitation infrastructure, and testing of water quality. Supplementary methods consisted of focus group interviews with owners of Pitcher Pump systems and observation of installation of Pitcher Pump systems. Prior to the actual collection of field data, the research objectives and a summary of the field data collection plans were submitted to the Institutional Review Board (IRB) of the University of South Florida (USF), who determined that it was not considered to be human-subjects research under the purview of IRB.

Household visits consisting of a household survey, water/sanitation infrastructure inspection, and water testing were conducted in three neighborhoods of Tamatave, and in the town of Foulpointe. These areas were chosen based on information from key informants indicating there would be significant numbers of Pitcher Pump systems operational in each area. Households visited within each neighborhood were identified using 'snowball sampling'. This technique was chosen due to the lack of any available records to locate wells that are often hidden behind walls and within courtyards. A first household in the neighborhood with a Pitcher Pump system was identified by the researchers, either through visually observing the Pitcher Pump from the road/path, or through talking to local residents of the area. At the end of the first household visit, the surveyed participant was asked if she/he could identify locations of other Pitcher Pump systems in the neighborhood, which were then visited by the field research team and included in the research sample. In cases where many systems existed in a small area, the field research team made efforts to distribute the sampling of households throughout the neighborhood.

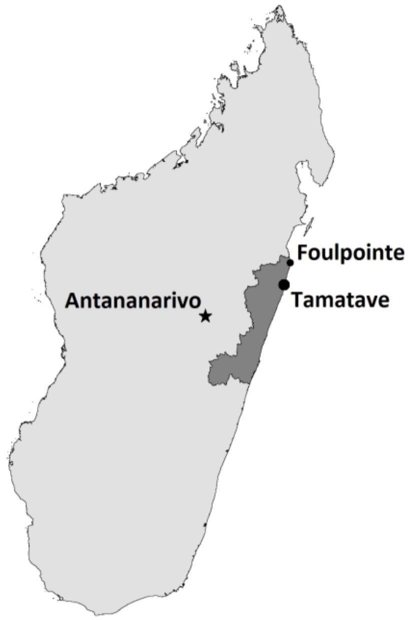

Figure 2-2. Map of Madagascar showing field research sites of Tamatave and Foulpointe, in the Atsinanana region (highlighted).

2.3.1 Household Surveys

The 53 surveyed owner-users of Pitcher Pump systems included adult female (32) and male (21) respondents. Survey questions focused on the following aspects of household water supply: 1) basics of water and sanitation infrastructure/technologies used by the household, including length of time the households had used the infrastructure and how it was obtained (e.g. self-financing, subsidy through a local grant or project, with microfinance, etc), 2) water usage by the household, and 3) maintenance, repair, or performance issues.

2.3.2 Observation/Inspection

Water supply and sanitation infrastructure were visually inspected at all surveyed households. Installed pumps were tested to confirm their state of operation. A sanitary survey of the area was performed, focusing on the area immediately around the pump head, and estimating its distance to the household latrine. The flow rates of ten Pitcher Pump systems in one neighborhood were also tested, representing a range of depths and pump attributes (pump head design, well diameter, etc).

Five local manufacturers were shadowed during construction of Pitcher Pump system components, to gain an understanding of construction techniques and materials used. Additionally, the research team observed the installation of three Pitcher Pump systems.

2.3.3 Water-quality Testing

Water-quality tests were performed on 51 Pitcher Pump systems to determine the basic microbiological and chemical characteristics of the water delivered. For comparative purposes, the same water-quality tests were run on samples taken from JIRAMA tap stands in each neighborhood visited in Tamatave, and a sample was taken from a community hand-dug well in Foulpointe. All water-quality testing was done in mid-August 2011, a time that generally coincides with the beginning of the driest period of the year (FAO, 2006). This period can be considered to be relatively favorable for microbiological water quality, compared to wetter periods of the year when there would be increased likelihood of contamination of well water from surface water run-off and shallower water-table levels.

Sampled water was collected and analyzed using portable field kits for thermo-tolerant coliforms, nitrates, nitrites, arsenic, alkalinity, and pH. Palintest® colorimetric methods were used to detect the presence of nitrate, nitrite and alkalinity, while the Palintest® VisuPass method was utilized to detect the presence of arsenic. An Oxfam Delagua portable water-testing kit was used to measure fecal coliforms in water samples through the membrane filtration technique. *Escherichia coli* and thermo-tolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures (WHO, 2011).

Ten water samples collected from a subset of the surveyed Pitcher Pump systems were also analyzed for lead (Pb). These water samples were collected in plastic bottles and tested in a laboratory at USF. From each of the sample bottles 5 milliliters (ml) were drawn with a syringe and filtered with a 0.2-µm filter into ten separate 10 ml glass containers. All filtered samples were acidified with 2 drops of 70% nitric acid to ensure a constant matrix between standards and samples, as well as to dissolve any particulate lead in solution. The acidified samples were left undisturbed for two days and then analyzed on an Atomic Absorption Spectrophotometer (Varian model AA240Z) for lead (Pb) concentration.

2.3.4 Semi-structured Interviews

Semi-structured interviews were also a primary tool used for data gathering. Sixteen such interviews were completed with various local water supply and development stakeholders in eastern Madagascar, including: 1) technicians involved in the construction, installation, and/or repair of Pitcher Pump systems, 2) agents involved in the promotion of water, sanitation, hygiene and/or health, and 3) a government water supply representative.

Interviews with Pitcher Pump system manufacturers/technicians yielded an understanding of practices related to both Pitcher Pump system manufacturing/installation and marketing/sales of the systems. Interviews with other stakeholders provided background on the water supply context of the study area.

2.3.5 Focus Groups

Three focus group interviews with Pitcher Pump system owners were organized as a supplementary methodological strategy to better understand owner-user management of Pitcher Pump systems, as well as to gain further insight into user appreciation of the Pitcher Pump technology. A focus group was held in each of the three surveyed neighborhoods of Tamatave.

2.3.6 Data Collection

Most of the collection of field data was carried out by a team of three researchers comprising the primary field researcher – a USF water supply specialist (civil engineer); a USF environmental health specialist; and a Malagasy research assistant experienced in the collection of social science research data. Additional collection of data in 2012 and early-2013 was coordinated by the primary field researcher and carried out by the local research assistant.

Table 2-1. Core data collection: quantities of household visits and semi-structured interviews performed in each location.

Location	**No. of household visits (including survey and inspection of water infrastructure)**	**No. of semi-structured interviews**
Tamatave (City)		15
– Mangarivotra South	18	
– Analankinina	20	
– Ambalakisoa	10	
Foulpointe (a small town)	5	1
TOTAL	*53*	*16*

2.4 Results and Discussion

2.4.1 Extent of Use, Well Reliability and Pump Attributes

According to the 2006 census carried out by the National Institute of Statistics of Madagascar (INSTAT), 60% of the population of Tamatave used Pitcher Pump systems (INSTAT, 2006). In 2009, INSTAT estimated the population of Tamatave as 232,568 (INSTAT, 2009). Considering this population estimate, the 60% usage of Pitcher Pump Systems, and assuming 5% annual population growth, there could be approximately 170,000 people in Tamatave using Pitcher Pump systems in 2013. Considering the average number of users per pump to be 19 (based on collected data showing an average of 4.6 households using a single pump, with an average of 4.2 persons per household in Tamatave as reported by INSTAT), around 9000 Pitcher Pump systems were estimated to be in use throughout the city.

Pitcher Pump systems are also commonly used in other areas along the East and South Coast of Madagascar. One such area, Foulpointe, was included in this field research, and several others have been confirmed during follow-up studies in 2012 and 2013. A conservative estimation of the number of Pitcher Pump systems installed in Madagascar outside of Tamatave is a few thousands. Combined with the estimated number of systems in Tamatave, the authors estimate that there are currently over 12,000 Pitcher Pump systems in use in Madagascar.

Of 53 households surveyed, 50 households (94%) reported that their Pitcher Pump wells provided water throughout the entire year. The other three households (6%) said that their Pitcher Pump wells provided water for 10-11 months per year. Households and manufacturers reported that if a well does not provide water, the casing can be removed and an additional length of pipe added to it, to allow it to be installed deeper in the ground, so that it could still provide water during seasonal low water-table levels.

Analysis of focus group interviews of Pitcher Pump system owners showed that the attributes pump owners found important were: 1) low purchase cost and low running (i.e. operation and maintenance) costs, 2) reliability compared to either a piped water supply system or a community well, and 3) convenience, i.e. ease of access and proximity of their system to the homestead compared to community water points.

In Tamatave, Pitcher Pump systems operate in many neighborhoods served by the JIRAMA-managed public water supply system. Here, there are commonly multiple houses built on one parcel of land (compound). Generally, a landowner who lives on the property will purchase a Pitcher Pump system for use by the entire compound. During household interviews numerous pump owners stated that they would prefer to have a household connection to the piped water network, if not for the prohibitively high connection costs and water tariffs. Focus group participants also expressed a preference to have a household connection if it was available at a similar price to a Pitcher Pump system. As of 2013, the minimum cost for installation of a household connection was reported to be approximately US$215. There are an estimated 10,000 household connections in Tamatave. Owners also frequently mentioned that Pitcher Pump systems were more reliable, as the utility water supply was often interrupted for several hours at a time. Additionally, Pitcher Pump systems were reported to be preferable to getting water from distant communal tap stands.

The researchers observed that numerous non-surveyed compounds with a household piped water connection also had a Pitcher Pump system. The extent to which Self-supply and piped supply might compete with or complement each other is an important question. Self-provision likely leads to lower per capita consumption from the piped system, and may potentially cause the utility company to increase water tariffs to compensate for the lost revenue as volumes supplied decline. Alternatively, Self-supply may equally supply volumes of water that are additional to, or are not supplied by, the piped system. Pitcher Pump systems in Tamatave appear to be filling a void created by the inability of the utility to provide desired service levels at an affordable price to potential customers in its catchment area. It is questionable if JIRAMA is capable of providing sufficient water and service levels to the entire population of Tamatave in the near future. In this context, Pitcher Pump systems offer an affordable, reliable and necessary domestic water supply option in the short term.

This highlights the need for regulation of both piped systems and Self-supply in urban and peri-urban situations, so as to complement long-term urban planning efforts to extend the customer base of piped water schemes. Such is the case in southwest Nigeria, where groundwater systems are not permitted in some areas that have access to a piped water supply system (Oluwasanya et al., 2011). There is no such regulation in Tamatave, and some government offices themselves use Pitcher Pump systems.

2.4.2 Local Construction, Installation and System Costs

Pitcher Pump systems were estimated to be built by more than 50 separate local small businesses in Tamatave. These fall into three categories: 1) welding workshops that manufacture and install Pitcher Pump systems as their principal activity or one of their primary activities (reported range of 12-30 systems sold per month), 2) welding workshops that fabricate and install Pitcher Pump systems as a secondary activity (these workshops commonly focus on other activities such as the construction of steel gates or repair of cars, bicycles and rickshaws; 4-12 systems sold per month), and 3) technicians/artisans who construct and install Pitcher Pump systems as a primary activity, but get the welding work done by a workshop (1-16 systems sold per month). Included in this third category are pump repair technicians who may occasionally also build Pitcher Pump systems.

Installation of Pitcher Pump systems (well drilling/installation, pump attachment) typically takes 1-4 hours on site, and is largely dependent on drilling depth and soils encountered (drilling through silt or clay layers takes longer than drilling through sand). When household Pitcher Pump systems were inspected it was found that any form of well-head protection was rare. Of the Pitcher Pump systems inspected during household visits, less than 4% (2 out of 53) had a sanitary apron (seal) at ground level around the well casing. One household in Foulpointe reported plans to install a concrete apron around their Pitcher Pump well within the next year.

The costs of a Pitcher Pump system were determined primarily from semi-structured interviews with local manufacturers in Tamatave (and one in Foulpointe), and household surveys were used to confirm the range of prices. Complete Pitcher Pump systems are commonly sold in Tamatave and Foulpointe at unsubsidized prices of US$35-100. This price includes system construction and installation, with the variance in cost largely dependent on well depth. The price of the Pitcher Pump itself is typically US$15-25, with well components and installation costing an additional US$5-7 per meter of depth (minimum 4 meters). Manufacturers generally make a profit of US$15-25 per Pitcher Pump system. All households surveyed (53 out of 53) reported paying the full purchase price of their Pitcher Pump system themselves, i.e. without subsidy.

Nearly half the number of Pitcher Pump system owners surveyed (49%; 26 out of 53) reported that they would have significant repairs/upgrades done to their systems over the next year. This included planning to purchase a new Pitcher Pump system (23%; 12 out of 53); well casing pipe addition or replacement (9%; 5 out of 53); and replacement of a pump head (4%; 2 out of 53). Of the Pitcher Pump system owners surveyed, 8% (4 out of 53) reported plans to install a household connection from the JIRAMA system within the next year. Despite an available adaptation to the Pitcher Pump system that allows water to be pumped to an elevated storage container (adding an estimated cost of US$80-150 to the price of a system, not including storage apparatus), none of the surveyed households mentioned any intention to make this investment within the next year.

2.4.3 Pump Performance and System Management

The performance of Pitcher Pump systems varied considerably and was related to: installed well depth; condition of the valves (if the leather seals in the valves are not sealing properly the pump needs to be primed at the start of use); and the material within the piston column of the pump head (e.g. mild steel, stainless steel, or PVC). Of 52 pumps tested during household visits, 12% (6 pumps) required priming by adding water through the top of the piston valve in order to function. Testing of pumping rates (single pumping subject – healthy adult female (29 years old, 50 kg)) from ten Pitcher Pumps showed a range from 4 liters/minute to 11 liters/minute.

Replacement of the leather pump valves was reported to be the most common maintenance/repair needed. Depending on the use of the pump, as well as the piston column material (that the piston valve makes contact with), this maintenance may need to be done as often as every few months. Other less frequent minor maintenance/repairs include replacement of the well screen, cleaning of the well pipe due to sand infiltration, and minor work to the pump head (e.g. replacing a nut and bolt, or the handle). All of these repairs are most commonly performed by local technicians (as reported by 75% of surveyed households, 40 out of 53) for total costs generally of US$2-6 for replacement of a leather valve. Some respondents (25%, 13 out of 53) reported doing at least some maintenance/repairs themselves. Other reported major repairs/changes to Pitcher Pump systems consisted of replacing the pump head and lengthening the well pipe (to deepen the well), done by local technicians/manufacturers.

Focus group data showed that, typically, Pitcher Pump system owners had general management rules for the use of their systems. The owner typically paid the entire cost of the system herself/himself, but maintenance and repair costs were commonly divided among all families using the system. Many owners said that activities such as washing clothes, bathing or cooking are not allowed within a radius of a couple of meters from the pump. Most owners explained that users who live within the compound where the Pitcher Pump system is located are allowed access at any time, night or day, while users outside the compound would be permitted to access it usually during the day (generally under the same conditions as other users, i.e. sharing maintenance and repair costs with other families). Public tap stands and private water vendors selling water from the piped network are open 8-10 hours/day, 6-7 days/week.

2.4.4 Water Quality and Household Water Treatment

Table 2-2 shows the distribution of fecal coliform counts in tested Pitcher Pump systems in Tamatave and Foulpointe. Fecal coliforms were detected above the WHO guideline of zero fecal coliforms/ 100 ml in 73% (37 of 51) of the Pitcher Pump samples tested. Some 55% (28 of 51) of the Pitcher Pump systems showed fecal contamination of between 0 and 10 coliforms/100 ml of water, which is considered low-risk. Five systems were severely contaminated with greater than 100 fecal coliforms/100 ml. Of the 23 households where Pitcher Pump system water samples showed greater than 10 fecal coliforms/100 ml, 16 households reported they drank water from their Pitcher Pump, and 13 of these 16 households reported treating their water by chlorination and/ or boiling prior to consumption. Pitcher Pump systems where the drilled well was reported to have been installed at a depth of more than 7 meters showed relatively little contamination (all showing either no growth or 1-10 fecal coliforms/100 ml). However, ongoing research commissioned after this study is apparently showing other wells in Tamatave with installed depths of more than 7 meters to have considerable microbiological contamination. The collected data did not show a correlation between microbiological water quality and the distance of the Pitcher Pump system from a latrine. Single water samples taken from JIRAMA tap stands in each of the three surveyed neighborhoods of Tamatave showed no contamination (i.e. no thermo-tolerant coliform growth). A sample from a community well in Foulpointe was highly contaminated (thermo-tolerant coliforms were 'too numerous to count').

Table 2-2. Microbiological water quality of Pitcher Pump systems.

Location	**No. of Pitcher Pump systems sampled**	**Measured thermo-tolerant coliforms (per 100 ml)**			
		No growth	**1-10**	**11-100**	**Greater than 100**
Tamatave (city)					
- Mangarivotra South	17	3	2	10	2
- Analankinina	19	2	7	8	2
- Ambalakisoa	10	8	2	0	0
Foulpointe (a small town)	5	1	3	0	1
TOTAL	*51*	*14*	*14*	*18*	*5*
Pitcher Pump systems sampled (%)		*27*	*27*	*35*	*10*

Nitrate was detected in all water samples. The nitrate concentrations ranged from 4.4 to 35 mg NO_3^-/l (average concentration = 23; standard deviation = 12), while nitrite was detected in four of the nine samples tested, though typical concentrations ranged from 0.1 to 0.2 mg NO_2^-/l. All these nitrogen samples are below WHO guidelines (50 mg NO_3^-/l and 3 mg NO_2^-/l) but suggest some impact on the groundwater supply by anthropogenic activities associated with waste disposal.

Each of the ten water samples tested for lead (Pb) was obtained from households that reported consuming water from their Pitcher Pump systems. All ten samples showed the presence of lead, including four samples that had lead levels higher than the WHO guideline of 10 µg/l (WHO, 2011). These four samples had Pb concentrations of 15, 31, 118, and 215 µg/l. The range of Pb concentrations in the tested samples is shown in Figure 2-3.

According to WHO, exposure to lead is related to numerous health issues, including neurological issues, cardiovascular disease and issues with fertility and pregnancy (WHO, 2011). The presence of lead in water extracted from Pitcher Pump systems may be due to a combination of three sources: 1) weights used to hold down the two leather valves, 2) brass well screens, and 3) solder used to attach the well screens to the galvanized iron well casing. USF is currently performing additional in-depth research on these three possible pathways of lead contamination from Pitcher Pump systems in Tamatave.

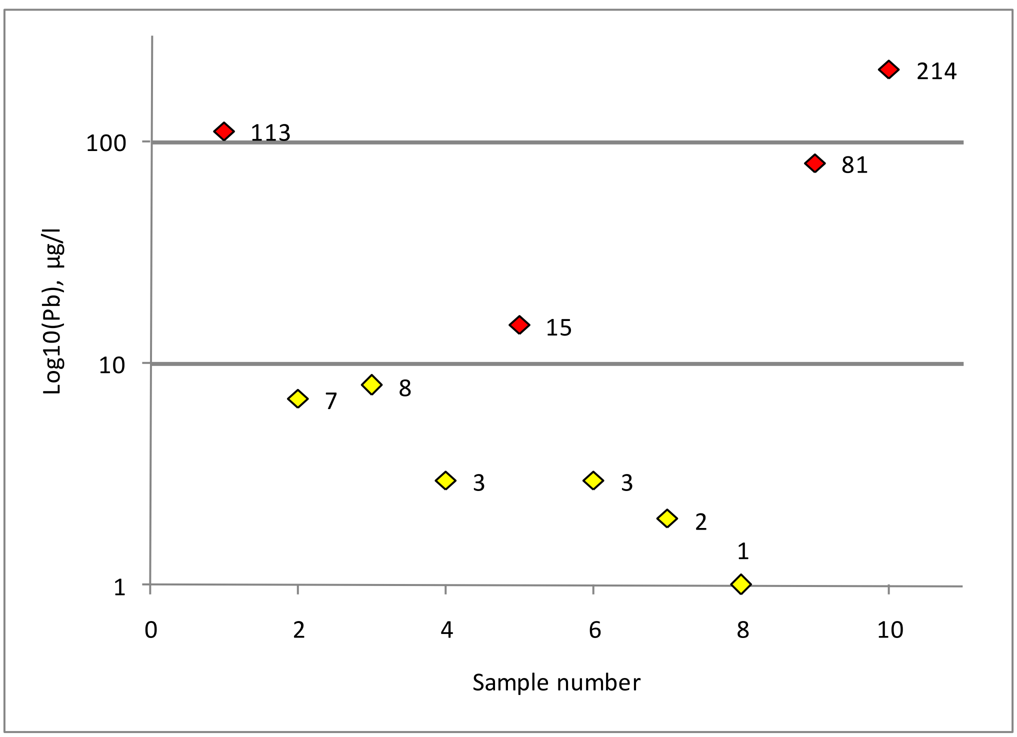

Figure 2-3. Lead (Pb) concentrations of 10 sampled Pitcher Pump systems in Tamatave and Foulpointe. The WHO guideline is 10 µg/l of lead.

In terms of other water-quality parameters, pH values were determined to be less than 6.8, the limits of the testing meter (follow-up testing in Tamatave has shown pH values in the 6.1-6.9 range). Alkalinity typically ranged from 150 to 250 mg/L CaCO3. Arsenic was not detected in any of the 51 Pitcher Pump system samples (detection level of 10 μg/l).

Regarding the local perception of quality of water delivered from their Pitcher Pump systems, focus group discussions revealed that a small number of owners insisted the water from their systems was potable (and of no risk to their health) without any treatment, while the great majority understood that the water from their systems was likely contaminated, yet said they commonly drink it without treating it. A minority of focus group participants reported the water from Pitcher Pump systems to be not of potable quality and reported either treating the water (through boiling) prior to drinking, or collecting drinking water from an alternative source.

Among surveyed households, 75% of households (40 of 53) reported that they drink water from their Pitcher Pump system. Of these, several (15%, 6 of 40) reported treating water with a chlorination product ('*Sur Eau*', marketed in Madagascar by the NGO PSI) prior to drinking, and 58% (23 of 40) reported boiling water prior to drinking, including two households that reported both boiling and treating the water with chlorine prior to consumption. It is also common practice in Madagascar to drink boiled rice water after each meal (*Ranon'ampango* in Malagasy – made from adding water to a pot with leftover cooked rice in it, and heating/boiling it). It is believed that this traditional practice is why the local population is open to boiling water (though it may also have led to over-reporting of the habitual practice of properly boiling water in household surveys). Table 2-3 shows reported drinking water treatment practices among surveyed households.

Table 2-3. Reported water treatment practices of Pitcher Pump users.

Location	**Nb. of house-holds**	**Reported data from household surveys**							
		Drink water from Pitcher Pump systems		**Pitcher Pump drinking water treatment method**					
				Boiling		**Chlorination**		**None**	
		Nb.	**%**	**Nb.**	**%**	**Nb.**	**%**	**Nb.**	**%**
Tamatave (city)									
– Mangarivotra South	18	15	83	8	53	1	7	6	40
– Analankinina	20	12	60	8	67	5	42	1	8
– Ambalakisoa	10	9	90	4	44	0	0	5	55
Foulpointe (a small town)	5	4	80	3	75	0	0	1	25
TOTAL	*53*	*40*	*75*	*23*	*58*	*6*	*15*	*13*	*33*

2.4.5 Potential Improvements and Further Research

Potential options for 'technology improvements' that focus on improving water quality include:

Adaptations to Pitcher Pump system components:

1. *Elimination of lead-containing pump components*. An ongoing study is identifying specific pathways of lead contamination from Pitcher Pump systems, and is considering the technical and social feasibility of using non-lead alternatives for each of the current Pitcher Pump system components that contain lead (e.g. using iron in place of lead for weights on pump valves).
2. *Installation of well-head protection*. Installation of a concrete sanitary apron (or, at minimum, a clay apron) to provide a sanitary seal needed to prevent microbiological (fecal) contamination from entering the well alongside the casing.
3. *Possible increased well-installation depth*. A separate study is being done to determine the change in water quality at different depths subject to the same environmental conditions.

4. *Boiling of water prior to drinking*. Many surveyed owners reported that they boiled water from their Pitcher Pump systems prior to consumption. Follow-up research is exploring local practices for making rice water – to determine if the water is sufficiently heated to allow for effective treatment of microbiological contamination, to find out if users later add non-boiled (and untreated) water for cooling down, etc.

5. *Household rainwater harvesting for drinking water*. Most (90%) of the households surveyed in Tamatave had houses with corrugated metal roofing, which is a very suitable surface for rainwater catchment, and several examples were seen of households practicing rainwater harvesting in basic forms (capturing rainfall off their roofs in buckets or larger containers, usually without any gutter system). Tamatave has an average annual rainfall of over 3000 mm, including 9 months with an average of at least 200 mm of rain, and a minimal average monthly reported rainfall of around 120 mm (FAO, 2006). Considering this rainfall amount and the common existence of corrugated metal roofs on houses in Tamatave, low-cost rainwater harvesting technologies could be further explored as a possible household drinking water supply option. This is particularly important for health improvements, as a previous study found that addition of water storage of as little as 400 liters integrated with household rainwater harvesting could reduce the diarrheal disease burden (measured as disability adjusted life years) by as much as 25% (Fry et al., 2010). Rainwater harvesting would also eliminate the nitrogen and lead contamination concerns uncovered in this study.

6. *Regulation of the Pitcher Pump system market*. This could include quality control support to technicians/manufacturers for construction and installation of Pitcher Pump systems (e.g. minimum standards to reduce health risks from lead contamination, improve microbiological well quality, etc), research of the potential for better complementarity

between the JIRAMA system and Self-supply, an environmental awareness campaign to educate users on the risks of using Pitcher Pump systems for drinking water, and monitoring the water quality of Pitcher Pump systems by local stakeholders.

The price of accessing water using Pitcher Pump systems in Tamatave is US$35-100 (initial cost) plus small running costs for maintenance and repairs. While changes in prices for potential improvements are to be determined through further research (e.g. evaluating well-water quality vs. depth, impact of sanitary aprons on water quality, etc), the aim should be to keep costs low while improving the Pitcher Pump system product.

The Self-supply market for Pitcher Pump systems in eastern Madagascar is well-developed. The research has shown there to be an established market for improving access to water for households in the study area at unsubsidized prices that are affordable for most landowners. The existing Pitcher Pump market should be further explored, to determine possibilities to build on existing capacities and practices to design low-cost Self-supply groundwater markets using drilling and pumping technologies which can be used in more diverse hydrogeological conditions, i.e. to drill to deeper depths and through harder soils, and to pump water from deeper depths. The ability to adapt the market to areas where water tables are deeper and soils are harder would be of great value to many areas of Madagascar.

Given the market success of the current Pitcher Pump systems in Tamatave, resistance to change could be expected if the benefits of proposed improvements are not well understood by consumers or Pitcher Pump manufacturers. This resistance could be in the form of unwillingness of consumers to invest in hardware improvements or to implement behavioral change(s) necessary to ensure consumption of water of a good quality. Resistance could also come from manufacturers and installation technicians, who may not be willing (or may be hesitant) to adopt changes to system construction and installation. The relative complexity of the Self-supply context in Tamatave makes further market research important, as the well-established market could be disrupted if changes are not well-designed/implemented.

2.5 Conclusion

Pitcher Pump systems are widely used in the research area of Tamatave and Foulpointe in eastern Madagascar and are shown to provide reliable and convenient access to water at a low cost relative to household connections to the piped water system. The Pitcher Pump market in the research area is unsubsidized, with system owners paying 100% of the initial cost. This market is believed to be the most significant documented example of an unsubsidized household handpump market in sub-Saharan Africa. Owners commonly share maintenance and repair costs with their tenants and/or neighbors. System maintenance is done by local technicians or family members, with more significant repairs undertaken by local technicians or manufacturers.

There are, however, concerns with the quality of water supplied through these systems (i.e. its suitability for drinking), specifically microbiological and lead contamination. Only 55% of wells sampled provided water associated with low-risk of microbial contamination for household systems, and four out of a small sample of ten wells contained lead in excess of safe limits. The market is also unregulated, neglected even, and there are several potential entry points for enhancements to current Pitcher Pump system construction and installation practices that could improve the quality of water delivered.

Results of this study are being shared with USAID and local government officials responsible for urban water supply and public health. Complementary research is ongoing to assess the cause of the lead contamination and make recommendations to mitigate exposure.

Follow-up efforts in urban Tamatave seek to support WASH (Water, Sanitation, and Hygiene) sector stakeholders and local government officials to increase regulation of the Self-supply market and address issues of quality of water delivered by Pitcher Pumps, including the important issue of lead contamination. Further research is needed to determine potential improvements to Pitcher Pump systems, to understand how to create synergies between the Pitcher Pump market and community piped water system, as well as to determine the feasibility of household water treatment and rainwater harvesting Self-supply options to improve access to drinking water.

CHAPTER 3: EMAS HOUSEHOLD WATER SUPPLY TECHNOLOGIES IN BOLIVIA – INCREASING ACCESS TO LOW-COST WATER SUPPLIES IN RURAL AREAS[2]

3.1 Summary

EMAS household water supply technologies have been developed in Bolivia, South America over the past three decades, and consist primarily of: (1) manually-operated water pumps made from materials commonly available in developing countries, (2) a hybrid percussion-jetting-rotation manual drilling method, and (3) rainwater harvesting systems that often use underground storage tanks. This research is the first published independent field assessment that considers users' and technicians' experiences with EMAS low-cost water supply technologies in Bolivia. Research methods consist of household visits that include a survey and observation/inspection, combined with semi-structured interviews with technicians and other stakeholders involved in implementation of EMAS technologies. Results of the investigation suggest the EMAS Pump to have low capital and maintenance costs, show the use of EMAS manually-drilled well systems with EMAS Pumps to be widespread in parts of Bolivia, show that EMAS well systems as used in the surveyed areas provide a reliable source of water, and demonstrate a willingness of households to invest in EMAS water supply systems. While EMAS rainwater harvesting systems (RWHS) exhibit potential to provide adequate household water

[2] This chapter was published as "EMAS Household Water Supply Technologies in Bolivia: Increasing Access to Low-Cost Water Supplies in Rural Areas", as RWSN Field Note No. 2013-4. It is included with permission from the copyright holders.

supply, the implementation of EMAS RWHS in Bolivia has been very limited. The paper considers the potential for increased use of EMAS technologies in Bolivia and internationally, and makes recommendations for further research.

3.1.1 Purpose

The purpose of this publication is to provide background on select EMAS household water supply technologies to the wider sector audience, and to assess and present experiences with these technologies as used in Bolivia. The document provides: (1) an overview of EMAS household water supply technologies (specifically the EMAS Pump, percussion-jetting-rotation manual drilling method, and rainwater harvesting systems) and of EMAS's approach to improving water supply, and (2) an independent assessment of these EMAS technologies as used in Bolivia. Reference is given to other available resources related to EMAS technologies, including EMAS training videos that are available on the internet.

3.1.2 Audience

The intended audience includes all actors involved in household water supply in Bolivia and throughout the developing world. The document is meant for users, technicians and field workers who may be interested in implementing low-cost water supply technologies, and for those involved in project design and policy-making (e.g. local and national government workers, development partners).

3.2 Abbreviations

- CABI – Grassroots indigenous organisation working in Izozog area [Spanish acronym,*Capitania del Alto y Bajo Izozog*]
- EMAS – Mobile Water & Sanitation School [Spanish acronym, *Escuela Móvil de Agua y Saneamiento*]
- EPARU – Non-Governmental Organisation associated with the Catholic Diocese [Spanish acronym, *Equipo Pastoral Rural*]

- HDI – Human Development Index
- JMP – Joint Monitoring Program for Water Supply and Sanitation
- MDG – Millennium Development Goal
- RWHS – Rainwater Harvesting System(s)
- SENASBA – National Service for Sustainable Sanitation Services (Bolivia) [*Spanish Acronym*]

3.3 Introduction

Assessing low-cost water supply technologies in developing world contexts where they have been in use over a significant time period can provide valuable insight into the potential for use of these technologies in similar contexts. The assessment can also act as a baseline for improving and/or expanding implementation of the technologies in the studied context. Known previous studies have focused mainly on the technological aspects of EMAS water systems in Bolivia (Tapia-Reed, 2008). This study is the first published independent field assessment that considers EMAS manual water supply technologies and users' and technicians' experiences with these systems in Bolivia. The research provides an overview description of the EMAS Pump, the standard EMAS manual drilling method, and EMAS Rainwater Harvesting Systems (RWHS). The study primarily assesses functionality of EMAS Pumps at the household level, common maintenance/repair issues including cost, reliability of EMAS manually drilled well systems, and financing of EMAS water supply systems.

3.4 Context

3.4.1 Bolivian Context

Bolivia, a landlocked country located on the continent of South America, has an estimated population of just over ten million people (World Bank, 2013). It ranks 108th out of 186 countries included in the Human Development Index (HDI) of the 2013 Human

Development Report, commissioned by the United Nations Development Program (UNDP, 2013). Within South America, Bolivia currently has the 3rd-lowest HDI ranking, just below Suriname (105) and above Paraguay (111) and Guyana (118).

3.4.2 Rural Water Supply in Bolivia

The most recent JMP (a program of the United Nations that reports progress towards the Millennium Development Goal [MDG] target for drinking water) estimate shows that as of 2010 71% of the rural population of Bolivia have access to improved drinking water sources. This rural water supply coverage statistic has increased significantly since 1990, when the percentage of rural users with improved drinking water sources was estimated at 43%. The improvement in water supply coverage puts Bolivia on track to meet its target for drinking water supply by the 2015 MDG deadline. However, rural drinking water coverage is still drastically less than the urban coverage for Bolivia, as the same report estimated that as of 2010 96% of the urban population have access to improved drinking water sources (JMP, 2012). Table 3-1 lists the types of drinking water systems that JMP considers to be improved or unimproved, along with the studied types of EMAS household water supply systems. By the JMP definition, all of the types of household water supply systems considered in this study are improved drinking water sources. The Bolivian government accepts these EMAS household water supply systems as improved drinking water sources.

Table 3-1. Categories of improved and unimproved water sources (JMP, 2013), and EMAS household water supply systems considered in the research

Improved drinking water sources	**Unimproved drinking water sources**	**EMAS household water supply systems studied**
- Piped water into dwelling - Piped water to yard/plot - Public tap or standpipe - Tubewell or borehole - Protected dug well - Protected spring - Rainwater	- Unprotected spring - Unprotected dug well - Cart with small tank/drum - Tanker truck - Surface water - Bottled water	- Manually drilled wells (i.e. tubewell or borehole) fitted with manual pump - Rainwater Harvesting Systems (including manual pump)

SENASBA is the Bolivian national government agency responsible for rural water supply. Newly created in 2009, SENASBA is a decentralized entity of the Bolivian National Ministry of Environment and Water. The mission of SENASBA is to strengthen operators and service providers of water supply and basic sanitation, through technical assistance, capacity building, information sharing, technology transfer, training, and policy/strategy implementation (SENASBA, 2012). SENASBA is a proponent of household water supplies as a sustainable service in rural areas, and is collaborating with actors involved in rural water supplies to develop strategies to effectively disseminate information on household water supply options. Other key stakeholders at the national level involved in the promotion of household water supplies include several non-governmental organizations, the Catholic University system, the Water and Sanitation Program of the World Bank, and the Inter-American Development Bank. These stakeholders support EMAS technologies, and SENASBA has co-sponsored EMAS's training of local technicians in Bolivia.

3.4.3 Low-Cost Water Supply Technologies in Bolivia

Bolivia has a significant recent history of development of low-cost water supply technologies, particularly of manual drilling and hand-pumps. Hand-augering drilling techniques have been largely promoted by a Mennonite missionary organization for several decades. EMAS has worked to develop manual drilling and hand-pump technologies in Bolivia, and it is estimated that over 20,000 manually drilled well systems have been installed in households throughout Bolivia using EMAS methods (Danert, 2009). Additionally, 'Water for All International' developed the 'Baptist' drilling technique and a low-cost water pump in Bolivia. EMAS Pumps (and variations) and Baptist Pumps are commonly used at the household level in numerous areas of Bolivia.

3.5 Methodology

The research includes an overview of EMAS low-cost water supply technologies and EMAS's approach to improving water supply, and provides an independent assessment of select EMAS water supply technologies as implemented at the household level in rural areas of Bolivia. Field data were gathered during two trips to Bolivia, in March-April 2011 and June-July 2011.

As part of the information-gathering process for the assessment, the primary researcher (an experienced water supply engineer from the United States) participated in a month-long (300-hour) EMAS-sponsored training workshop on low-cost water supply and sanitation technologies at the EMAS training center in Puerto Perez, Bolivia (La Paz region). The field assessment was subsequently carried out by a team of three researchers (the primary researcher and two colleagues: a civil engineering graduate student from the United States and an ecological engineering undergraduate student from Bolivia) from early-June to early-July 2011. EMAS provided information to the research team on EMAS-developed technologies, project implementation locations, and key stakeholders. EMAS also assisted with logistics in La Paz region.

Qualitative data collection involved mixed-methods, consisting of surveys, semi-structured interviews, and observation/inspection. The methodology for the field research was submitted to the Institutional Review Board of the University of South Florida, and determined to not meet the definition of human subjects research requiring review and approval. Table 3-2 shows the numbers of household visits and semi-structured interviews done in each region of Bolivia.

Table 3-2. Summary of number of household visits and interviews by region

Region	Research Sites	No. of household visits (including survey and water infrastructure inspection)	No. of semi-structured interviews
Santa Cruz	Santa Cruz (city), Izozog, Gutierrez, San Julian	36	3
Beni	Trinidad, Somopai, Reyes	35	6
La Paz	La Paz (city), Cachilaya, Pampa Chililaya, Huarina, Taquina	15	6
TOTAL		*86*	*15*

3.5.1 Surveys

Surveys at the household level of users of EMAS water supply technologies provided the primary data. Survey questions focused on water and sanitation infrastructure/technologies used by the household; water usage; and responsibilities and costs for installation and repair of EMAS technologies.

3.5.2 Semi-structured Interviews

Semi-structured interviews were conducted with rural water supply technicians and organizations involved in the promotion, construction, installation, and/or repair of EMAS household water supply systems. The interviews focused on the interviewees' experiences with EMAS technologies, including current prices for system installation.

3.5.3 Visual and Physical Inspection of Infrastructure

Household water and sanitation infrastructure was inspected for all surveyed households, including a sanitary risk inspection of the water system. Installed manual pumps were tested to determine state of functionality, by filling a bucket of water from the pump, observing flow and any above-ground leaking from the pump.

3.5.4 Research Locations

Research was carried out in three regions of Bolivia: Santa Cruz, Beni, and La Paz (Figure 3-1). In Santa Cruz, household visits were done in Izozog, an indigenous area located over 200 km southeast of the city of Santa Cruz. Additionally, the city of Santa Cruz and the towns of San Julian (100 km northeast of the city of Santa Cruz) and Gutierrez (175 km south of the city of Santa Cruz) were visited. In the city of Santa Cruz, interviews were done with the grassroots indigenous organization CABI, who works on economic growth and community development in the Izozog area. Experienced EMAS-trained technicians were interviewed in San Julian and Gutierrez.

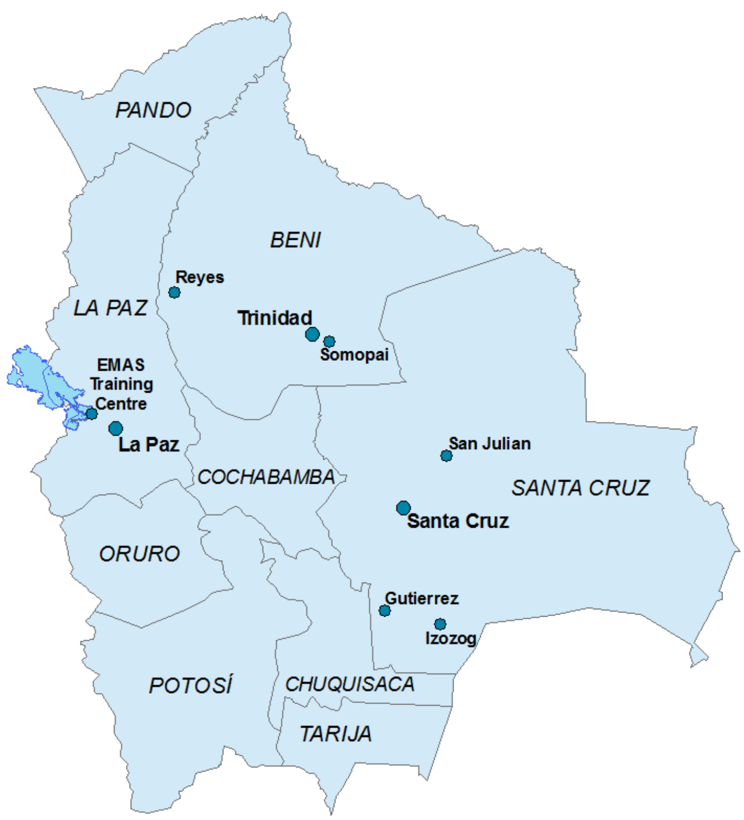

Figure 3-1. Map of Bolivia showing geographic regions and study locations (in La Paz, Santa Cruz, and Beni regions)

In the Beni region, research was carried out in the city of Trinidad, the village of Somopai (30 km southeast of Trinidad), and the town of Reyes (280 km west of Trinidad). In Trinidad, interviews were held with EPARU, a local development organization affiliated with the Catholic diocese that has been involved in manual drilling for over three decades, and independent technicians involved in the implementation of EMAS water supply technologies. In addition, installation of a borehole using the standard EMAS drilling method was witnessed in Trinidad. In Somopai, household visits were conducted, and installation of an EMAS Pump on a new manually drilled well was also observed. In the rural town of Reyes, families with EMAS manually drilled boreholes were visited. The boreholes were fitted with either EMAS Pumps (with locally-adapted pump valve designs, in some cases), or with small electric pumps. Manual drilling of an EMAS well was also observed in Reyes.

In the Lake Titicaca area of La Paz region, several small communities near the EMAS training center were included in the research. In Cachilaya village, RWHS using EMAS underground storage tanks and EMAS manual pumps were assessed. Cachilaya was chosen to assess household RWHS as this community provides the largest known sample of EMAS RWHS systems in Bolivia. (Uptake of this technology in Bolivia has been very limited to date.) Additionally, households were visited in Pampa Chililaya village, where EMAS manually drilled borehole and pump systems are used by many families. In Huarina and Taquina villages, interviews were conducted with technicians who had recently participated in EMAS trainings.

3.6 EMAS Approach to Improving Water Supply

To encourage families to use EMAS water and sanitation technologies, and to incrementally improve their household infrastructure, EMAS has adopted a strategy which focuses on the ‘added value’ of EMAS technologies towards improving household living conditions and lifestyles. This added value comes from the higher level of service that is provided largely through having a reliable water system and water piped to taps in the house. EMAS implements its strategy primarily through the training of local independent technicians from various parts of Bolivia (subsidized by EMAS), as well as through the broadcasting of EMAS training videos on Bolivian television and on the internet. Figure 3-2 is an example of EMAS promotional material, and illustrates RWHS with an underground storage tank and EMAS Pump, a shower with a small elevated tank and washing sink, and a ventilated latrine. EMAS’s strategy is further illustrated in Figure 3-2. In their work outside of Bolivia, EMAS typically partners with other organizations and local/national governments for implementation, and promotes the same strategy through trainings and assessment trips.

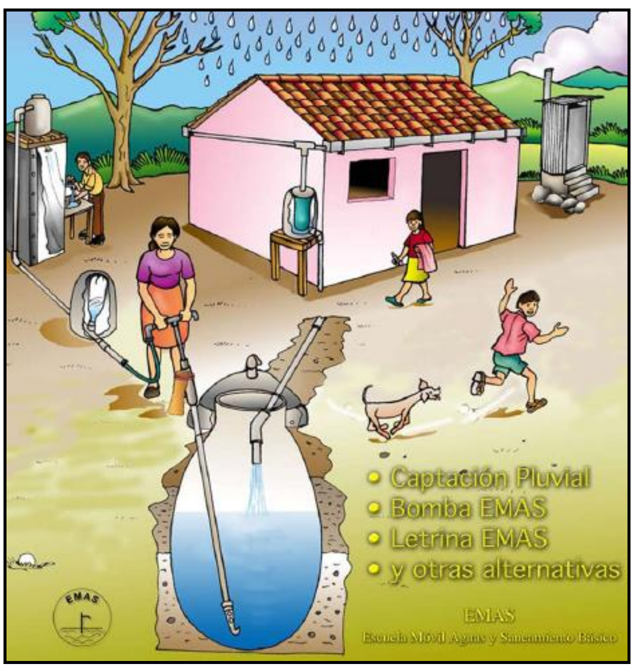

Figure 3-2. EMAS promotional material showing basic household water and sanitation technologies - RWHS with underground water storage tank; a manual pump to lift water to a small elevated tank for a shower and washing sink; and a ventilated latrine (Procedamo, 2004)

1) If a household has access to a water source in their yard, for example a well with a manual pump attached to it, this is an improved level of service compared to using either a community water source (e.g. a public tap stand or a community well) or an unprotected water source (e.g. a lake or stream). Yet, if the manual pump breaks, there may not be sufficient incentive for the household to repair it in a timely manner (i.e. the household may simply revert to using an alternative water source).

2) If, however, in addition to having access to the water source in their yard, the household is also pumping water through pipe(s) and/or hose(s) to an elevated household tank (so that there is, for example, water readily available at household taps for kitchen tasks, cleaning clothes, taking showers, etc.), the users are going to value the higher level of service, and become significantly more dependent upon the water supply. The appreciation of the service and increased dependence upon the water supply system, caused by its 'added value', makes it more likely that when there are problems with the pump (or other aspects of the system), the household will rectify the issue in a timely manner.

Figure 3-3. Example of EMAS strategy (Buchner, 2011)

For clarity of information dissemination, EMAS makes the comparison to a similar situation with household electricity supply. For instance, when there is electricity power failure in a household that uses the power source only for bulb lighting, the household may be satisfied to use lanterns or candles as alternatives in the short-term. However, when electricity usage also includes powering a television, refrigerator, and/or computer, the household's dependence on electricity is greater, and they thus will be more likely to get the electricity connection repaired promptly in the event of failure. Also, in marketing their technologies, EMAS considers peoples' tendencies to pay attention to what their neighbors have, as if they see value in it, they will likely want to replicate it (Buchner, 2011).

3.7 Results and Discussion

3.7.1 EMAS Pump - Description, Components and Mode of Operation

EMAS manual water pumps are used in many of the EMAS household water supply systems, to lift either groundwater from wells or rainwater from underground storage tanks. The EMAS Pump (also known as the Flexi-Pump, or '*Bomba Flexi'* in Spanish) is a manually-operated pump that can reportedly lift water from depths of more than 30 meters (Buchner, 2006). The simple design of the EMAS Pump, using materials commonly available in developing countries (e.g. PVC pipes, glass play marbles in the pump valves, and rubber cut from a used car tire) and basic tools, allows for the pumps to be fabricated by trained technicians in many developing communities. The ability of the EMAS Pump to lift water from significant depths to heights above the pump head (e.g. for pumping to household tanks, reservoirs at higher elevations, or for installing multiple pumps on wells) adds to the pump's value. It is important to note that the EMAS Pump is designed for use on household systems (up to 5-6 families, or 30 users maximum). The EMAS Pump is not meant to be used as a community pump. Common uses of EMAS Pumps are provided in Figure 3-4.

Pumping from below-ground to surface

- A single EMAS Pump lifting water from a hand-dug well, drilled borehole, or storage tank
- Multiple EMAS Pumps lifting water from a single below-ground water source (hand-dug well, storage tank)
- Pumping to ground level at a distance from an underground water source, through hose(s) and/or pipes attached to the EMAS Pump spout

Pumping from below-ground to an elevated point

- Lifting water from an underground source through the EMAS Pump and directly through hose(s) and/or pipes to an elevated point (a household tank, reservoir on a hillside, or for direct output e.g. for irrigation)

Pumping from near ground-level to an elevated point

- Lifting water from a surface water source (e.g. a lake, river, or storage tank) to an elevated point

Circulating fluid in EMAS manual drilling

- The manual 'mud' pump used to circulate drilling fluid in EMAS percussion-jetting-rotation manual drilling is a modified version of the EMAS Pump

Figure 3-4. Common uses of EMAS Pumps

The EMAS Pump consists of an outer PVC pipe (‘pump cylinder’ - typically of 20-40 mm diameter) with a one-way foot valve on its lower end, and a smaller-diameter inner PVC pipe (‘piston pipe’ – typically of 16mm diameter) with a one-way piston valve on its lower end. A rubber gasket on the outside of the piston valve provides a seal with the pump cylinder. The upper end of the piston pipe attaches to a handle, which is commonly made of galvanized iron. The pump is installed in a well or tank so that the piston valve and foot valve are below water. The pump cylinder remains static, and when the handle (piston pipe) is lifted, suction force causes the foot valve to open (while the piston valve remains closed), and water enters from the well into the pump cylinder. When the handle is then lowered, the foot valve closes and compression pressure causes the piston valve to open, and water flows into the piston pipe. Figure 3-5 shows how the EMAS pump valves function. Continued pumping alternately displaces water from the well into the pump cylinder then into and up the piston pipe, and the water flows out a spout that is located on one side of the pump handle. The EMAS Pump differs from conventional piston pumps in that the water is lifted inside the ‘pump rod’ (piston pipe) rather that outside it, which avoids the problem of sealing the pump rod, and additionally results in the water being delivered to the pump outlet at pressure. Photos of the EMAS Pump in use are shown on the cover of this document (bottom left and bottom right).

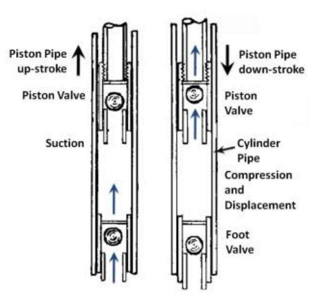

Figure 3-5. Mode of operation of EMAS Pump: Valves function on pump upstroke [left] and down stroke [right] (adapted from Buchner, 2006)

3.7.2 EMAS Pump – Assessment of Cost and Functionality

Analysis of 'snapshot' field data (i.e. data collected one time) found a very high percentage of households in the studied contexts in Bolivia to have functional EMAS Pumps. The cost of a new EMAS Pump, to be installed to 15 meters depth, was reported by local technicians to be US$ 30-45 (for pump material and construction costs only, i.e. not including well drilling). Visits to almost eighty households that use EMAS Pumps in their primary water supply systems (manually drilled wells or RWHS) showed nearly all pumps to be operational (78 out of 79). As shown in Table 3-3 and Figure 3-6, 84% of the EMAS Pumps surveyed were found to be functioning normally (i.e. without significant issues, and with water discharging normally), including 72% of pumps (13 out of 18) that were reported to have been installed 11 or more years ago.

Table 3-3. Reported EMAS Pump age distribution and inspected functionality

EMAS Pump age (years)	**No. of pumps surveyed**	**No. operational w/ no issues**	**Percent operational w/ no issues**	**No. operational w/ issues**	**Percent operational w/ issues**
0-3	20	19	95	1	5
4-10	39	32	82	6	15
11-15	13	11	85	2	15
16-20	4	1	25	3	75
over 20	1	1	100	0	0
unknown	2	2	100	0	0
TOTAL	*79*	*66*	*84*	*12*	*15*

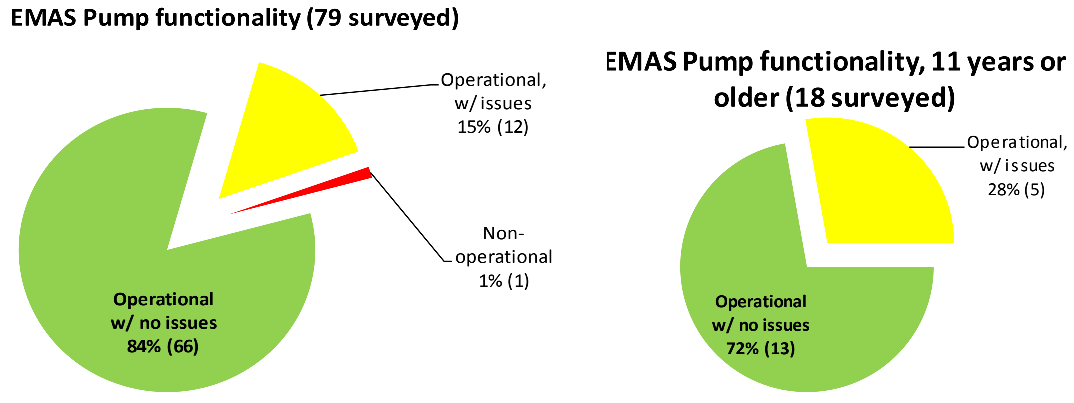

Figure 3-6. (a) Operational state of all EMAS Pumps surveyed [left]; (b) Operational state of sub-set of EMAS Pumps installed 11 or more years ago [right]

Of the surveyed EMAS Pumps that were not operating normally, the issues were determined to be either due to significant leakage from the handle or above-ground pump joint (observed), or below-ground issues such as leakage through the pump pipes or valves (not directly observed, except in one case where a family removed their pump from the well during the household visit). Of the twelve pumps that were functional but not operating normally, three pumps had observable above-ground leakage (including the pump that was removed from the ground during the research visit - this pump was also determined to have a significant leak below-ground, in the pump piston pipe). Two of these pumps were reported to have been first installed 4-10 years ago, and one pump 11-15 years ago.

Of the nine functional pumps determined to have solely below-ground issues, only one pump was reported to have been first installed recently (0-3 years ago), while four were installed 4-10 years ago, and four more at least eleven years ago (including three 16-20 years ago). The considerable age of most of the functional pumps that had below-ground issues suggests that while maintenance/repair should be done on these older pumps it has perhaps been neglected due to the pumps still functioning (although at a reduced level).

In the community of Somopai in the Beni region, there were a few additional instances where non-functional EMAS Pumps were observed at non-surveyed homes. In each of these cases, the pump and borehole had been abandoned, either due to current use of another water system or when a family had moved and also abandoned their house.

Reported EMAS Pump maintenance and repairs consisted primarily of replacing one of the two pump valves and/or replacing the pump handle, and were usually performed by a local technician. The most common repair was replacement of a pump valve, which in Beni and Santa Cruz regions was reported to have been done on 35 of 71 surveyed pumps. The replacement of the pump valve was reported by households to cost an average total of approximately US$ 9 (materials and labor) in the areas where the question was posed (Izozog, Somopai, and Reyes). Technicians capable of performing EMAS Pump repairs were available in all of the research areas. Among surveyed households, 59% (47 out of 79) reported that repairs were done by a local technician, 35% (28/79) by a household member (male or female) and the other respondents (5%, 4/79) either gave no reply or stated that no repairs had been done to that point.

In most of the surveyed areas, the manual pump handles were made out of galvanized iron piping (with pieces either connected with fittings or welded). This type of handle requires minimal maintenance. In one context, in Reyes, PVC handles were almost exclusively used, because users did not want the taste of their water to be affected by the iron pipes of the pump handle. (Local residents of this area are sensitive to iron, as their community water system has issues with high iron levels.) The majority of users throughout the various research sites exhibited a good understanding of how the EMAS Pump works, and were able to talk knowledgably about the main components of the EMAS Pump.

In surveyed areas of both Santa Cruz and Beni regions some users expressed a preference for manual pumps that provide a higher flow rate than the standard EMAS Pump. This preference was not expressed by users in surveyed areas of La Paz region, where other types of manual household pumps were neither observed nor mentioned by participants during the research. In Santa Cruz region, several surveyed households in Izozog expressed plans to replace their EMAS Pump with a 'Baptist Pump', as promoted by the organization Water for All International, due to its higher flow rate.

In the surveyed area of Santa Cruz region, the installed EMAS Pumps used were of a small pump cylinder diameter (20mm). EMAS now also promotes larger pump cylinder diameters (25mm to 40mm) where feasible (depending on water table depth), which allows for higher pumping rates. An experienced EMAS-trained technician in San Julian confirmed that families in that area prefer the Baptist Pump due to its higher-flow rate, and that he and other technicians working in that area using EMAS drilling methods now usually build and install Baptist-type manual pumps.

In Reyes, the standard EMAS Pump piston valve design has been adapted by local technicians to increase the pump flow rate. The adapted design, which is used by many households in the area, significantly increases the pump flow rate, but ends up delivering the water from the pump head at very-low pressure (as does the Baptist Pump). While this low pressure is not a problem when collecting water directly from the pump spout, it eliminates the ability of the pump to deliver water from the pump head to higher elevations (e.g. to an elevated storage tank) via a hose and/or pipes.

In the village of Cachilaya (La Paz region), several surveyed families pump water from underground storage tanks, through their manual EMAS Pump, to a sink, shower tank, and/or solar water heater. The ability of the EMAS Pump to discharge water at pressure from the pump head makes this possible, and is a valuable attribute. However, in the other research sites, pumping to elevations above the pump head was not mentioned by users, nor was it witnessed during the household visits.

In recent years EMAS has been promoting the use of a simple foot-pedal adaptor that connects to the EMAS Pump handle. This ergonomic modification makes pumping of water for long durations with the EMAS Pump considerably easier (as tested by the researchers).

3.7.3 EMAS Manually Drilled Well Systems

In Bolivia, EMAS manually drilled well systems are primarily promoted for domestic water use. EMAS teaches a few different methods for manually drilling wells (Figure 3-7), with the most common (the 'Standard EMAS' method) incorporating percussion, jetting, and rotation drilling techniques. The standard EMAS method is capable of drilling to depths of up to 100m, through sand, clay, and thin layers of soft rock, with a team drilling with a trained technician commonly able to drill 20-30 meters per day (Buchner, 2011). This hybrid percussion-jetting-rotation method consists of a fluid (water mixed with a thickener, usually clay) being pumped down drilling pipe that runs the entire depth of the well, and out through a drill bit attached to the bottom of the pipe. The drilling pipe is alternately raised, dropped, then rotated (usually ¼ to ½ turn, equally in each direction) while fluid is continuously being pumped through the pipe. The earthen material that is broken up (cuttings), primarily by the percussion and rotation actions, rises out the top of the borehole in the circulating fluid. Beside the well, a small dug trench and basin(s) allow for the drilling fluid and cuttings to settle out, and the fluid is then re-circulated back through the drilling system. A support structure with a rope and pulley(s) facilitates raising and dropping of the drilling pipe. Figure 3-8 depicts how a hybrid percussion-jetting-rotation system functions. Figure 3-9 shows this type of EMAS drilling method in practice.

Percussion-Jetting-Rotation ('Standard EMAS' drilling method)

- Drilling is done primarily through percussion (raising and dropping of drilling pipe) and rotation (turning ¼ to ½ turn in each direction). Injection of drilling fluid (water thickened with clay) down the drilling pipe and out the drill bit (jetting) using a pump assists the process, mainly by circulating the earthen cuttings out of the well, as well as by stabilizing the well wall. (Described in Section 7.3, and shown in Figure 5, Figure 6, and the top-left cover photo.)

Percussion-Suction-Rotation

- Similar to the Standard EMAS method, but water circulation is reversed, with drilling fluid and cuttings being sucked up through the drill bit and drilling pipes (Sludging). A one-way valve, placed either at the top of the drilling pipe or between the drill bit and the bottom of the drilling pipe (like in the 'Baptist' manual drilling method), allows for fluid and cuttings to be sucked up the drilling pipe as it is raised and lowered.

  The Percussion-Suction-Rotation drilling method is better suited to drill through thick layers of coarse sand or in the presence of small stones (<2 cm) than the Standard EMAS drilling method. The Percussion-Suction-Rotation method is capable of using thicker drilling fluids and larger pipe diameters to carry the stones up the drilling pipe. The larger pipe diameters limit the feasible drilling depth to approximately 30 meters due to the additional weight of drilling pipe.

Sand Sludging

- Used exclusively in sandy soils and where the water table is shallow. (EMAS has used this method primarily in coastal areas of Sri Lanka.) Consists of telescoping temporary casings into the ground (decreasing pipe diameter every few meters). Drilling within the casings is done by extracting soil with a smaller diameter pipe (above the water table) and suction/Sludging (near, below the water table).

Figure 3-7. Manual drilling techniques developed/promoted by EMAS

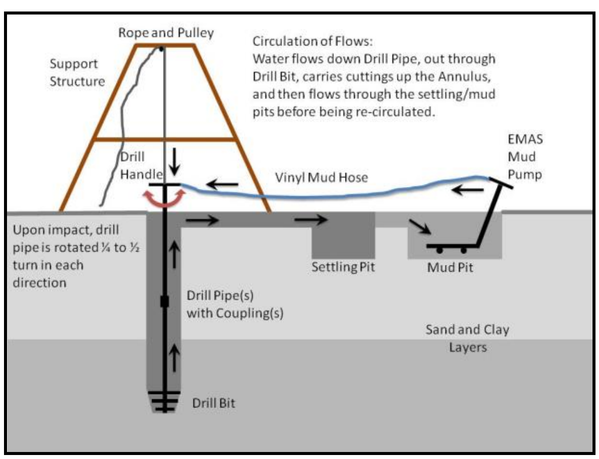

Figure 3-8. Diagram of EMAS hybrid percussion-jetting-rotation ('Standard EMAS' method) manual drilling system

Figure 3-9. EMAS percussion-jetting-rotation manual drilling, Trinidad (Beni region)

EMAS recommends keeping the diameter of the drilled well as small as possible, to minimize the costs of the well casing and the effort needed to drill the well. Well casings of 40mm diameter up to 75mm diameter are common, and sometimes slightly larger diameter pipes are used. PVC well casing is used to line the well, including a well screen made from cutting slots in the pipe with a hack saw. The slotted length of pipe is covered with a polyester sleeve, to prevent fine sand from entering through the screen. Sand is added to the outside of the installed well screen, with the polyester sock minimizing the need for a gravel pack. Well development is done using manual pumping and plunging techniques.

3.7.4 EMAS Manually Drilled Well Systems Assessment

In the research areas of Santa Cruz and Beni regions, it was evident that EMAS manual drilling methods are used widely by small businesses. In Trinidad, there are several technicians previously trained by EMAS that operate their own independent manual drilling businesses. In

Reyes, a rural town context, most of the houses had a borehole in their yard drilled using the EMAS standard manual drilling method. Two technicians that were trained by EMAS around fifteen years ago (in a water and sanitation project that included training of more than 60 technicians in manual drilling throughout Beni region) continued their independent drilling business in Reyes, and several other local technicians that once worked as assistants to EMAS-trained drillers have since started up their own manual drilling businesses. Two independent drilling team leaders in Reyes each reported currently charging families approximately US$ 140 for complete drilling and installation of a 50mm diameter well at a depth of 14-15 meters, with an EMAS or similar-type manual pump installed (pump included in the pricing).

In Somopai, a team of manual drillers reported that they get most of their business from well-off clients, as poor families cannot afford the wells, which the drillers charged about US$ 20 per meter to install (with an EMAS Pump included in the pricing). This price for an installed borehole with pump in Somopai is around double the price of a similar system in Reyes. The higher price in Somopai is likely primarily due to the less-developed market in this area (with the drillers having fewer clients, and no competition). While the inability of poor families in Somopai to afford the wells is likely largely true, it also appears that prior subsidies for household wells and latrines in this area may be encouraging some families to wait for the arrival of another development project, hoping that they can receive subsidies towards their purchase of a household water supply system. Additionally, it was clear that the local drillers in Somopai are flexible with their pricing structure, as during the research visit they were just completing a manually drilled well fitted with an EMAS Pump, for which the client bought the materials himself and exchanged labour (work in the drillers' fields) in place of paying cash for the drillers' services.

EMAS manually drilled well systems in each of the surveyed areas were reported by households to be very reliable. Of 75 household respondents with knowledge of system reliability, 97% (73 out of 75) reported their system to provide water throughout the entire year (i.e. throughout all 12 months). This reliability statistic refers to the manually drilled well producing water, and is independent from pump functionality. Table 3-4 shows the reported reliability of the manually drilled wells surveyed, according to age.

Table 3-4. Reported EMAS manually drilled well age distribution and reliability

EMAS manually drilled wells age (years)	**No. of surveyed wells w/ response**	**No. of wells providing water throughout entire year**	**No. of wells providing water for less than 12 months per year [*and reported months*]**	**Location of wells providing water for less than 12 months/year**
0-3	12	11	1 [*1-3 months*]	Pampa Chililaya
4-10	42	41	1 [*6-9 months*]	Somopai
11-15	12	12	0	
16-20	5	5	0	
over 20	1	1	0	
unknown age	3	3	0	
TOTAL	*75*	*73*	*2*	

As the only two wells that were reported to provide water for less than 12 months out of the year were relatively new (both 10 years old or less), it is possible that other wells that were not supplying water throughout the year had already been abandoned or replaced with a new well. Fourteen surveyed households reported that their previous primary water source was also a manually drilled well (in their yard).

EMAS promotes well head protection with a concrete apron around the top of the manually drilled well (commonly placing an old car tire around the base of the pump at ground level and filling it with concrete). However, inspections of EMAS manually drilled well systems at surveyed households showed that many wells did not have a protective apron.

3.7.5 EMAS Rainwater Harvesting Systems

Rainwater Harvesting refers to the "collection and subsequent storage of water from surfaces on which rain falls" (Mihelcic et al., 2009). RWHS can be appropriate as a primary or secondary (complementary) source of water for use at the household level, depending on the quantity of local rainfall. An EMAS household RWHS consists of a catchment area, which is commonly the roof of a house, to which a gutter/drainage system is attached, which guides the rainwater that falls onto the roof to a simple filter (to catch debris) and onwards to a storage tank. EMAS storage tanks can either be below-ground or above-ground. Where conditions permit, it is generally preferred to construct a below-ground tank, as the material costs are considerably less due to the walls of the underground tank being supported by the surrounding soil. From an underground tank, water can then be pumped to the surface (or above, to household or other elevated tanks) using a manual EMAS Pump. EMAS promotes the construction of underground tanks of various sizes, including up to 7,000 liters (nearly 2,000 gallons) capacity, using a cement and sand mortar as the base and walls, and a reinforced concrete lid. Five to seven 50kg bags of cement are typically used in the construction of a 7,000 liter tank. Above-ground tanks of similar sizes are made using ferrocement (cement and wire mesh) construction, which makes use of wire-reinforced cement mortar. Figure 3-10 shows an underground EMAS tank fitted with an EMAS Pump, and the top-right cover photo shows the same type of tank under construction.

Figure 3-10. Surface view of EMAS underground tank with EMAS Pump

EMAS underground tanks require occasional maintenance to control leakage, sedimentation, and water quality (Buchner, 2006). Tanks can began to leak due to settling and poor waterproofing, with settling being a primary concern shortly after construction. Improper waterproofing of tanks is the most common cause of leaks, with repair requiring a layer of cement (or asphalt) paint to be applied to the interior of the tank. Over time tanks collect sediment near the pump drain, thus requiring cleanout (much of which can be done with the EMAS Pump). If water quality is an issue, chlorination of water can be done within the tank.

3.7.6 EMAS Rainwater Harvesting Systems Assessment

The use of EMAS-style RWHS in Bolivia was very limited at the time of the field research. Although the systems have been promoted in Bolivia through EMAS trainings over the past several years, the only known area where a considerable number of households had implemented these systems was the village of Cachilaya, located one kilometer from EMAS's training center. In Cachilaya, construction of EMAS household RWHS was starting to become more popular after several years of promotion that included training of numerous local residents in RWHS system construction. There were an estimated 25-30 households with EMAS household RWHS that families have mostly financed themselves. Additionally, a project being developed by the local municipality (completely independently of EMAS) planned to subsidize (either partially or fully) the construction of household RWHS.

In Gutierrez (Santa Cruz region), an experienced EMAS-trained independent technician built a demonstration site for EMAS technologies at his home in 2010, including RWHS, with EMAS paying for the cost of construction materials. At the time of the field research, the technician had not built any EMAS RWHS systems in the area for clients, nor had others replicated the systems themselves. It is evident that increased support, at a minimum in the form of promotion of the EMAS RWHS technology, is required in Gutierrez (and other areas of Bolivia) for households to consider uptake of the technology.

In surveyed areas where EMAS-type RWHS are not in existence there was evidence of potential for household RWHS, as it is commonly practiced in very basic form (e.g. catching rainfall off of roofs using buckets or larger containers). Most (80%) of the houses surveyed without EMAS RWHS had either corrugated metal or clay shingle roofing, both of which are very suitable surfaces for rainwater catchment. The average estimated area of these types of roofs among surveyed households is nearly sixty square meters.

3.7.7 Financing of EMAS Water Supply Systems in Bolivia

The majority of EMAS water supply systems surveyed (62%, 53 out of 86) were reported to have been paid for fully by the household, without any subsidy or loan. Loans were reported to have been used to help pay for systems by 5% of households (4/86), with 3 households having received a loan from a bank or official lender, and 1 household having received a loan from a relative. 28% of households reported receiving subsidies to partially fund their EMAS water systems, and 6% reported not knowing specifically how their water system was financed. There were not any households that reported receiving full subsidies for their systems. Table 3-5 shows reported EMAS water supply system financing for each of the research areas.

Table 3-5. Reported financing of EMAS water supply systems in Bolivia

Survey Area	**No. of households**				
	total surveyed	**unsubsidized systems, paid without a loan**	**received loan to help pay for system**	**partially subsidized systems**	**Not known**
Cachilaya	8	6	0	2	0
Pampa Chililaya	7	0	0	7	0
Izozog	36	23	3	9	1
Somopai	9	1	0	6	2
Reyes	26	23	1	0	2
TOTAL	*86*	*53*	*4*	*24*	*5*
Percent of total households		*62*	*5*	*28*	*6*

The types and levels of subsidies received varied between (and within) the surveyed areas, with subsidies reportedly coming from either the implementing agency/project or local government. In Reyes, no households reported receiving subsidies, while in Somopai there was only one household that reported paying for their system in full. In Izozog, the majority of households reported paying for their system in full. In Pampa Chililaya, near the EMAS training center, all of the surveyed households had received labour (well installation services) for free, while paying the full costs of system materials. All of the wells in Pampa Chililaya had been installed by EMAS during training sessions. In Cachilaya, the only area where households with EMAS RWHS systems were surveyed, 75% of respondents said that they had paid for their systems in full, without a loan, while 25% received subsidies in the form of construction materials.

3.8 EMAS Beyond Bolivia

In addition to promoting EMAS technologies in Bolivia, EMAS has also worked in various other countries in South and Central America, as well as in Africa and Asia (where EMAS technology introduction and promotion has been very limited). EMAS's activities outside of Bolivia typically consist of supporting in-country groups/organizations with training and technical support (Buchner, 2011).

Given the low cost of EMAS household water supply systems, and their conduciveness to being built and repaired by local technicians, these technologies offer considerable potential for success in accelerating self-supply in sub-Saharan Africa. The potential includes using the EMAS Pump on existing or new household manually drilled or hand-dug wells (with the possibility of installing multiple pumps on the same hand-dug well), manual drilling of wells using EMAS methods, upgrading of such systems as appropriate/feasible (e.g. pumping through hoses or pipes to a tank/reservoir), and RWHS.

A valid point of comparison in considering the potential of the EMAS Pump for household use in sub-Saharan Africa is the Rope Pump (specifically 'family' models of the Rope Pump, rather than 'community' models). It is estimated that there are over 20,000 Rope Pumps installed in Africa and Asia (Holtslag, 2011). The Rope Pump has some similar attributes to the EMAS Pump, such as a simple concept, relatively low cost, construction from commonly-available materials, and the potential for local production at the small town or village level. A study in Honduras (Brand, 2004) compared the EMAS Pump and the Rope Pump, and found that both types of pumps were appropriate to use in rural water supply in Honduras. While the Rope Pump was found to have a more established market in Honduras at the time, the estimated private market cost of the EMAS Pump was determined to be considerably less than the Rope Pump.

Sutton and Gomme (2009) explored recent experiences and issues of various organizations with introducing the Rope Pump to over a dozen sub-Saharan African countries, where the Rope Pump had to that point had relatively limited market success as a household-level pump. The study found Ethiopia to be the only country to have had a "relatively large-scale development" of Rope Pumps for the household self-supply market. More recent information shows a growing market-based Rope Pump market in Tanzania (Haanen and Kaduma, 2011). In considering the introduction of the EMAS Pump, it may be particularly valuable to further assess specific issues previously encountered in Rope Pump introduction projects (regarding cost, product promotion, project implementation, technical performance, acceptance by users/ governments/ donors, etc.) and to assess how the EMAS Pump may be able to overcome the aforementioned obstacles. With knowledge gained from working in low-cost pump markets, current Rope Pump manufacturers may see value in offering the EMAS Pump, which can likely be manufactured and sold for a considerably lower price, to customers as alternative option to the Rope Pump.

3.9 Conclusion

EMAS manual water pumps are shown to have a high rate of functionality as used at the household level in the studied contexts in Bolivia. The EMAS manually drilled wells surveyed, which were installed by numerous different drilling teams (most of whom are independent of EMAS) were reported to be reliable, with a very high percentage of wells providing water throughout the entire year. These conclusions combine with an evident considerable adoption of the EMAS Pump and manually drilled wells to show that the technologies have had an important impact on increasing access to water supply at the household level in many rural areas of Bolivia. Households are able to maintain low-cost EMAS Pumps, with repairs commonly done by local technicians or household members, and in some cases the same EMAS Pumps have been used for more than a decade.

Manual drilling using the Standard EMAS method is widespread throughout much of the research areas in Bolivia, with evidence of local technicians running small manual drilling businesses. Given the willingness of EMAS water system owners to contribute to the costs of purchasing the systems (and in many cases contributing all of the hardware costs), it is important that the potential of linking low-cost water supply systems with micro-financing loans (which EMAS does not currently get involved in) be explored in Bolivia, to allow for access to the systems by more households.

EMAS household RWHS show potential, based on their success in one of the research areas and the common practice of basic forms of rainwater collection in the other research areas. For the EMAS RWHS technology to have a good chance of broader uptake in other areas of Bolivia, continued training of technicians should be complemented by further support to promote the technology.

The study therefore recommends that further research include:

- An investigation of conditions necessary for successful introduction and further effective scale-up of EMAS household water supply technologies in Bolivia,
- An in-depth comparative analysis of the EMAS Pump and the Rope Pump, exploring the potential for use of the EMAS Pump in household water supply in sub-Saharan Africa (currently taking place by our research group, in Uganda),

- An evaluation of a potential project in Cachilaya (near the EMAS training center) which proposes to provide local households with support to build EMAS household RWHS, and
- A study of the social and economic impact of EMAS technologies in Bolivia, focusing on the results of a previous project that trained over sixty technicians in Beni region in EMAS manual well drilling and pump construction.

3.10 Resources – EMAS Technologies

Over 30 training videos of EMAS technologies (Figure 3-11), including text descriptions in English and Spanish, can be viewed at:

http://vimeo.com/emas and http://blip.tv/mobile-school-for-water-and-sanitation

Additionally, the following websites offer valuable information on EMAS technologies:

- AKVO: http://www.akvo.org/wiki/index.php/EMAS
- EMAS (in Spanish and German; limited English): http://www.emas-international.de/
- RWSN: http://www.rural-water-supply.net/en/implementation/handpump-overview/135-emas-flexi-pump

Water Supply
- Pumps – EMAS Pump construction (standard; high-yield; high-pressure); pipe fittings, air chambers, etc.; pedal-powered EMAS Pump; wind-powered EMAS Pump; hydraulic ram pump
- Manual Drilling – EMAS standard drilling; suction drilling variant; sand sludging;
- RWHS – storage tanks of various sizes (ferrocement; mortar-lined underground tanks)
- Wells – improving existing hand-dug wells, multiple EMAS Pumps on wells
- Spring catchment; irrigation

Other Topics
- EMAS Introduction; EMAS training site
- Household water filter; subsurface wetland water treatment, iron removal;
- EMAS VIP Latrine; water shower; concrete kitchen sink
- Solar water heating, solar room heating

Figure 3-11. EMAS web video topics (Vimeo, 2012; Blip 2012)

CHAPTER 4: A TECHNICAL COMPARISON OF THE EMAS PUMP AND THE ROPE PUMP[3]

4.1 Introduction

This research assesses the potential of the EMAS Pump for use in Self-supply in developing community contexts, with specific focus on use in sub-Saharan Africa. A comparative analysis was carried out in Uganda with the EMAS Pump and another manual water pump, the Rope Pump. The Rope Pump, which has been most successfully marketed as a household-level pump in Nicaragua, was selected for comparison because it is well-known in the international rural water supply sector. It has been introduced in many other developing countries over the past fifteen years, with varying degrees of success (Sutton and Gomme, 2009).

As introduced in *Chapter 1*, Self-supply is based on the idea of users making affordable, incremental improvements to their private family or neighborhood (i.e. small group) water supply systems. While it is not a feasible option in every context, where it is possible implementation of Self-supply can result in "the obstacles to sustainability created by a lack of trust, cohesion, and co-operation within communities" being greatly reduced (Harvey and Reed, 2007). Self-supply projects can be complementary to community water supply systems, and can

[3] This Chapter is part of a study assessing the potential of the EMAS Pump as a low-cost water-lifting option for household water supply systems in sub-Saharan Africa, carried out by the University of South Florida. The chapter author designed the main aspects of the pump comparative analysis, advised on field data collection, and led analysis of pumping rate and material cost data. A fellow University of South Florida graduate student, Jacob D. Carpenter, assisted with design of the pumping rate study, led the design and analysis of heart rate monitoring and energy expenditure, and led all field data collection.

play an important role in helping developing countries to reach the Millennium Development Goal (MDG) target for improved drinking water supply coverage, as conventional community water supplies often bypass the poorest and most remote communities. This potential improved coverage will additionally impact most of the main MDG objectives, including reduction of poverty and child mortality (Sutton, 2010).

In recent years, there has been considerable attention paid to the Rope Pump as a low-cost water supply option for developing communities (e.g. Alberts, 2004; MacCarthy, 2004; Harvey and Drouin, 2006; Sutton and Gomme, 2009). Yet, there has been little published independent documentation related to the manual EMAS Pump and its potential for use in low-cost water supply. A 2004 field note published by the Water and Sanitation Program of the World Bank compares and summarizes experiences with the Rope Pump and the EMAS Pump in Honduras (Brand, 2004). While providing a basic overview and comparison of these two manual pumping technologies, this publication does not present specific scientific data on the technical performance of the EMAS Pump. The article does, however, present a summary table adapted from the Nicaraguan Handpump Evaluation, which compares various attributes of the EMAS Pump and Rope Pump, including initial costs, function and reliability, and overall sustainability.

Chapter 3 (and MacCarthy et al., 2013) showed EMAS Pumps in household water supply systems in Bolivia to have a high rate of functionality, with 99% (78 out of 79) pumps surveyed found to be operational, including 84% (66 out of 79) that were functioning without any apparent problems. A subset of this sample, which consisted of pumps reported to have been installed 11 or more years ago, showed 72% (13 out of 18) to be operational. The results of the study in Bolivia, combined with the results of the comparison of the EMAS Pump and Rope Pump in Honduras, highlight multiple qualities of the EMAS Pump (e.g. low-cost, feasibility of local-manufacture in developing communities, and ability for households to maintain in operation) that lend it to potentially be very suitable as a Self-supply water-lifting option in sub-Saharan Africa.

Harvey and Drouin (2006) performed a field study in northern Ghana comparing the Rope Pump to the Nira Pump, proposing the Rope Pump as an alternative, locally manufactured option to standardized imported handpumps, for community water supplies in sub-Saharan Africa. They found the Rope Pump to outperform the Nira Pump in a number of ways (e.g. low operating and maintenance costs, greater pumping head and flow rate), and found there to be no significant difference between the two pump types in delivered microbiological water quality. The study concluded that the Rope Pump "provides a significant technological opportunity to improve water supply sustainability in Africa".

In a more recent article on the transfer of the Rope Pump technology, Sutton and Gomme (2009) reviewed numerous experiences with the introduction of the Rope Pump in areas of sub-Saharan Africa. That study concluded that the Rope Pump has numerous 'strengths' that make it a good option for use in sub-Saharan African communities, including: (1) its amenability to local manufacture and user-led maintenance; (2) improved quality of water delivered by wells with Rope Pumps, compared to wells that use 'rope and bucket' water-lifting systems, and (3) its affordability, leading to considerable potential for people to use it to help themselves improve their quality of life. Despite these strengths, that study emphasizes issues with the Rope Pump being marketed in sub-Saharan Africa both as a community pump (often perceived "as 'low' technology" – leading to reduced acceptance by various water supply stakeholders) and the likelihood that it may be too expensive to be marketed as an unsubsidized household pump ("Could it be too cheap for donors and too expensive for users?"). The issue of affordability for households in sub-Saharan Africa is an important factor in comparing the EMAS Pump and the Rope Pump.

A 2003 field study in the Maputaland area of northern KwaZulu Natal, South Africa, carried out by the University of Southampton and Partners in Development (and led by the author of this dissertation), considered locally manufactured Rope Pumps as an alternative to "Bucket Pumps" (a bailer and windlass water-lifting system) for use on manually drilled wells (Still et al., 2004; MacCarthy, 2004). That study showed Rope Pumps to have considerably higher water-lifting rates than Bucket Pumps (lifting water from depths of 4 m, 15 m, and 18 m), leading to a significant upgrade in the level of service provided.

As the Honduras Rope Pump and EMAS Pump study does not present specific data on the technical performance of the EMAS Pump, further testing is required. Independently collected pump performance data (e.g. pumping rates from various well water depths) is valuable to allowing researchers and development practitioners to more objectively assess the potential of the EMAS Pump for use at the household level in developing communities. Additionally, an assessment of needs for local construction of the EMAS Pump (e.g. material costs, tools required for construction) in a sub-Saharan African environment is of value in helping to determine the relevance of the EMAS Pump to such contexts. Accordingly, the objective of this study is to analyze (for performance, cost, and construction requirements) the suitability of the EMAS Pump as a locally constructed option for use on household wells in developing community contexts in sub-Saharan Africa, through a technical comparison with the Rope Pump.

The comparative analysis allows researchers and development practitioners to better understand the technical capabilities of the EMAS Pump, as well as socio-economic considerations related to its introduction and use, through comparison with the Rope Pump (and, in turn, with other documented low-cost water-lifting devices) as a Self-supply option for developing communities. Two versions of both the EMAS Pump and the Rope Pump were tested in the field in Uganda (lifting water from various depths to assess flow rates at different depths, and energy expended during pumping).

4.2 Background

4.2.1 EMAS Pump

The EMAS Pump (also known as the EMAS Flexi-pump), as introduced in *Chapter 3*, is a manual low-cost water-lifting device appropriate to use at the household level. Originally developed in the 1980s by Wolfgang Buchner, the EMAS Pump has been marketed extensively for local construction and use at the household level in Bolivia, and to a lesser extent in other developing countries, mostly in South and Central America (Akvo, 2012). The EMAS Pump has also been introduced on a relatively small-scale in several countries in sub-Saharan Africa, including recently in Sierra Leone (Bunduka, 2013). The simple design of the EMAS Pump, using materials that can commonly be found locally in developing countries, allows for the pump to be fabricated in many developing community contexts. The low-cost of the EMAS Pump, combined with its capability of pumping from significant depths to heights above the pump head, adds to its versatility (e.g. for pumping to household tanks, reservoirs at higher elevations, or for installing multiple pumps on a single well).

The EMAS Pump is a type of piston pump. However, it differs from conventional piston pumps in that the water is lifted inside the 'pump rod' (piston pipe) rather that outside it, which avoids the problem of sealing the pump rod, and additionally results in the water being delivered to the pump outlet at pressure. The EMAS Pump can be constructed entirely from materials that are commonly found in developing areas, i.e. PVC and galvanized iron (GI) pipes and fittings, glass play marbles for the pump valves, and rubber cut from an old car tire for a piston valve gasket.

As shown in Figure 4-1, the EMAS Pump consists of an outer PVC pipe with a one-way foot valve on its lower end, and an inner PVC pipe with a one-way piston valve on its lower end. The upper end of the inner pipe attaches to a handle, which is commonly made of galvanized iron (GI). The pump is installed in a well or tank so that the valves of the inner and outer pipes are both below water. The outer pipe remains static, and when the handle (attached to the inner pipe) is lifted, suction force causes the foot valve to open (while the piston valve remains closed), and water enters from the well into the outer pipe. When the handle is alternately lowered, the foot valve on the outer pipe closes and the piston valve on the inner pipe opens, causing water to flow into the inner pipe. Continued pumping alternately displaces water into the outer pipe then into and up the inner pipe, and the water flows out a spout that is located on one side of the pump handle (i.e. at the GI elbow shown in Figure 4-1).

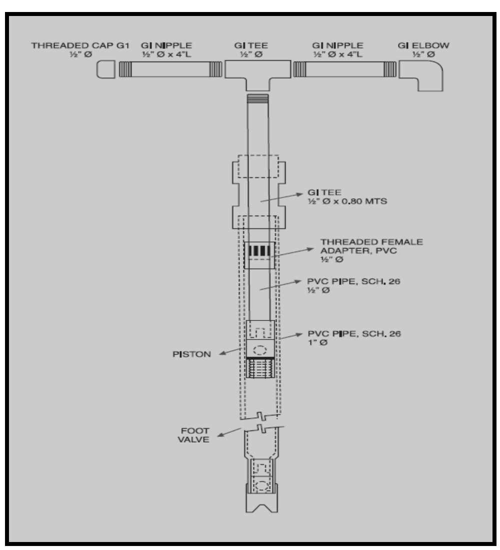

Figure 4-1. EMAS Pump components

A rubber gasket located on the outside of the piston valve forms a seal between the two pipes, and causes the pumped water to flow from the pump spout with considerable pressure. Pumping water at pressure from the pump head is a valuable attribute of the EMAS Pump, as this makes it possible to pump water directly from the well, through the pump head, then through a hose or pipe(s) to an elevated tank (e.g. on a house or a hillside). Figure 4-2 shows (a) an EMAS Pump installed on a drilled well, and (b) an EMAS Pump in use on a hand-dug well upon which several EMAS Pumps are installed.

Figure 4-2. (a) Photo of EMAS Flexi-Pump on manually drilled well [left]; (b) Photo of multiple EMAS Pumps installed on a single hand-dug well [right]

4.2.2 Rope Pump

The Rope Pump has a basic design that consists of five principal components, as shown in Figure 4-3: (1) a pulley wheel attached to supports; (2) a rope with washers attached to it at equally spaced intervals; (3) a top guide, including a spout; (4) a rising main pipe; and (5) a bottom guide (MacCarthy, 2004). The rope with washers forms a loop and runs up the rising main pipe, through the front side of the top guide, around the pulley wheel and back down through the back side of the top guide into the well and through the bottom guide, where it changes direction once again to go up through the rising main. The bottom guide of the Rope Pump is installed under water in a well, and when a handle/crank on the pulley wheel is turned (in the counter-clockwise direction relative to the view in Figure 4-3), the rope and washers move up the rising main pipe, with water from the well being lifted on the washers within the pipe, and being freely discharged through a spout above the top guide.

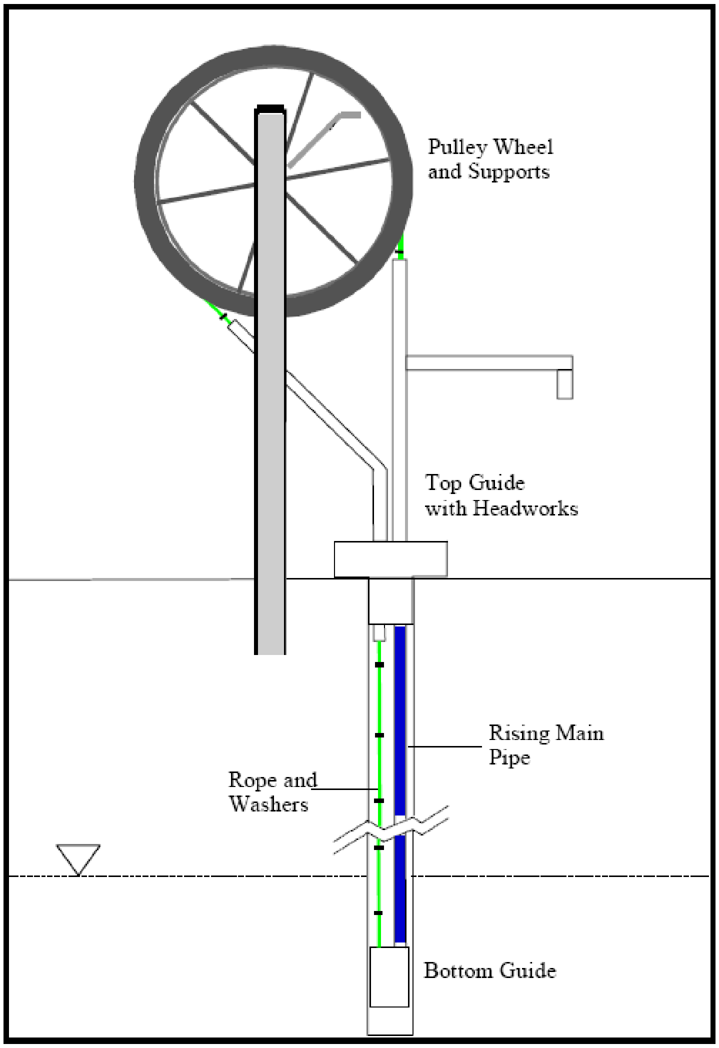

Figure 4-3. Details of Rope Pump installed on a drilled well (MacCarthy, 2004)

Like the EMAS Pump, the Rope Pump can be constructed entirely from materials commonly found in developing areas (e.g. PVC and GI pipes, old car or truck tires, nylon rope, etc.). Figure 4-4 shows (a) a family model Rope Pump installed on a hand-dug well in northern Uganda, and (b) a family model Rope Pump installed on a drilled well in South Africa.

Figure 4-4. (a) Family Rope Pump in use in Gulu, Uganda (photo: J.D. Carpenter); (b) Family Rope Pump in use in South Africa (MacCarthy, 2004)

4.3 Methodology

4.3.1 Introduction

The research considers the potential of EMAS manual pumps (EMAS Pump) for use in Self-supply in developing community contexts, with an emphasis on its potential for use in sub-Saharan Africa. The research builds upon an assessment of EMAS Pumps at the household level in Bolivia (*Chapter 3*) that showed these pumps to have a high rate of functionality in the studied contexts. A comparative analysis was completed of the EMAS Pump and the Rope Pump, considering the technical performance of the two types of pumps, pump material costs, and resources required for local fabrication.

4.3.2 Pumps Examined

Two versions of the EMAS Pump and two versions of the Rope Pump were tested in the field in northern Uganda – a version of each type of pump designed for pumping from depths up to 20 m (using a 25-mm diameter pumping pipe), and a version of each pump designed to pump from deeper depths (30-m-plus; using a 20-mm diameter pumping pipe). Table 4-1 summarizes the details of the two pumps tested in the field. The selection of these pumping pipe sizes was based on Rope Pumps currently promoted in Uganda. Other versions of these pumps, such as the Rope Pump with 32-mm pumping pipe and high-flow EMAS Pump with 16-mm pumping pipe, are less common in household water supply, and were not tested in this study.

Table 4-1. Details of pumps tested

Pump Type	**Recommended Pumping Depth Range (Buchner, 2011; Holtslag, 2013)**	**Pumping Pipe**	**Casing Pipe**
EMAS 'Standard' (20-mm)	30+ m	20-mm PN 16	32-mm PN 10
EMAS 'Quantity' (25-mm)	Up to 20 m	25-mm PN 10	38-mm 'drain' pipe
Rope Pump (20-mm)	30+ m	20-mm PN 16	Not Applicable
Rope Pump (25-mm)	Up to 20 m	25-mm PN 10	Not Applicable

The two versions of the Rope Pump tested consisted of a version with 20-mm pumping (rising main) pipe and pistons and another with 25-mm pumping pipe and pistons; these are referred to as the 20-mm Rope Pump and the 25-mm Rope Pump, respectively. A version of the Rope Pump with 32-mm pumping pipe is recommended for very shallow wells of up to 10 m;

this version was not assessed as it is less common in Uganda, and the 25-mm and 20-mm versions were more comparable to the EMAS Pump variants tested.

The Rope Pump tested in this study corresponds to the low-cost "Family Model" design promoted by the organizations Connect International (http://www.connectinternational.nl/index.html) and SHIPO (http://www.shipo-tz.org/), and manufactured locally by small enterprises in parts of east Africa (Tanzania, Malawi, and Uganda). The EMAS Pump tested is nearly identical to the design recommended by EMAS (http://emas-international.de/index.php?id=32&L=3), with only a slight design variation to the valve construction for the 25-mm "Quantity Pump". This modification was made to allow for simpler construction using the pipes commonly available in Uganda, and is not believed to have made any significant difference in pump operation. In addition, such slight design variation is encouraged by EMAS, depending on the specifications of materials available in a given context. The frame of the Rope Pump tested was modified to mount the community handpump pedestals on the boreholes at the testing sites. The EMAS Pump only required a fabricated mounting plate to be fitted to the standard handpump pedestals and a short hose connected to the spout of the EMAS Pump to ensure that no water was spilled during testing. An alternative version of the EMAS "Quantity" Pump with a 20-mm pumping pipe was not tested in this study. See Carpenter (2014) for more details.

4.3.3 Technical Assessment of Pumping Performance

4.3.3.1 Development of Performance-testing Methodology

The context of performing pumping tests in the field presented numerous challenges, primarily: (1) locating wells of a various range of static water levels (SWLs), (2) determining method to ensure that the pumping rate measurement comparisons between the different pumps tested are valid, and (3) identifying test subjects that were representative of adults that would be using the pumps in Uganda (sub-Saharan Africa).

Two options were initially considered for carrying out the tests: (a) identification of wells with a range of static water levels (with an aim to have several wells in 5 m to 30 m static water level depth) in the same geographic area, so that the studied pumps could be tested on each well, and (b) identification of a deep hand-dug well (of diameter equal or greater than 1.5 m) that could be fitted with a specifically-built testing apparatus (a water container, e.g. a barrel, on a rope and pulley) which would be lowered to incremental levels within the well. An assessment of available groundwater sources in Uganda failed to identify an appropriately deep hand-dug well to carry out the tests, thus option (b) was eliminated. Through collaborators in northern Uganda, numerous possibilities were, however, identified to use community boreholes of various static water levels in Kitgum and Gulu districts, and thus option (a) was pursued.

The distance between the selected well sites (and relative difficulty in accessing them) made it impractical to have more than two test subjects. This necessarily increased the importance of using a reliable method to compare pumping rates. The South Africa Rope Pump study had similarly used two subjects (an adult male and an adolescent female) for all pumping trials, with the subjects being instructed to pump at normal rates (trying to exert the same amount of energy for each test), and with at least half an hour of time between pumping trials to ensure fatigue was not a significant factor in results (MacCarthy, 2004). For the current study, it was determined that this method was not sufficient to ensure reliability of results. Thus, it was decided to additionally monitor the heart rate of the testing subjects during all pumping trials, and to use that to calculate energy expended during pumping. Pumping rates for the EMAS Pump were 'normalized' by adjusting them to reflect the ratio of energy expended for the EMAS

Pump to the energy expended for the corresponding Rope Pump. This methodology is expected to provide sufficient 'internal reliability', i.e. comparing the various pumping rates of a specific testing subject, while not necessarily providing 'external reliability', i.e. comparing the pumping rates of one testing subject to those of another testing subject.

4.3.3.2 Measuring of Pumping Rates

Field data collection consisted of a number of pump tests that were carried out using variants of the EMAS Pump and the Rope Pump detailed in Table 1. These tests included tests on boreholes and wells of various water level depths in Kitgum and Gulu Districts, northern Uganda. Each pump underwent two 40-liter pumping trials by each of two test subjects at five different sites. Testing sites were chosen to represent a range of well depths from approximately 5 to 30 m.

The specifications of the pumps tested are summarized in Table 4-2. The 20-mm variants of both pumps were tested at five wells, with static water levels of 5.1 m, 12.6 m, 18.4 m, 21.1 m, and 28.3 m. Meanwhile, the 25-mm variants of each pump were tested at wells with static water levels of 5.1 m, 12.6 m, and 17.0 m. Each pump was tested for two timed trials for each test subject (male and female) in which 40 liters was pumped.

4.3.3.3 Heart Rate Monitoring

The continuous heart rate (pulse) of the test subjects was measured and recorded during pumping trials with a Polar FT7™ system (Polar Electro, Kempele Finland) that consisted of the H1™ heart rate sensor (chest strap with sensor) and the FT7 training computer (wrist watch with display). The system relies on telemetry signals sent from the chest strap to the wrist-watch computer and was first introduced by Polar in the late 1970's (Shephard & Aoyagi, 2012). Polar still is widely recognized as a leading manufacturer of quality heart rate monitoring hardware and it was noted that Polar devices with chest straps were used in many recent studies focused on energy estimations from heart rate monitoring (Bot & Hollander, 2000). Furthermore, the type of system utilized has been characterized as accurate in relevant literature (Achten & Jeukendrup, 2003). Prior to each round of testing, the chest strap was fitted to the user and the training computer was checked for reliable signal reception. Heart rate was recorded prior to the start of the test and then at each 10-second interval during pumping.

4.3.3.4 Calculation of Energy Expenditure for Pumping

Heart rate was recorded for each 10-second interval during pump testing, so a rate of energy expenditure could be calculated and applied to each interval. When resting energy expenditure is subtracted from the total estimated energy expenditure, an estimation of energy expenditure specifically for pumping can be made. However, this is still a representation of energy rate (energy per unit time, also known as power). The energy expenditure rate for pumping was then applied step-wise to each 10-second interval of the pumping trial in order to determine the total energy spent for each interval. A sum of energy for each of these intervals provides an estimation of total energy for pumping. See Carpenter (2014) for more details on the energy expenditure calculations.

4.3.3.5 Normalization of Pumping Rates

To account for potential differences in energy expended by the pumping subjects when using the different types and variants of pumps, the energy expenditure during each pumping trial was estimated by heart rate monitoring and empirical relationships were used to estimate energy expenditure from heart rate data. It is believed that energy data has significant internal validity for comparisons in this study, however external validity may be limited. Details of the methodology for heart-rate monitoring and estimation of energy, as well as implications of energy expenditure calculations and its limitations are discussed in detail by Carpenter (2014).

4.3.3.6 Selection of Test Users

Two pumping test subjects, one adult female and one adult male, were selected based on several factors. Due to logistical constraints associated with the distance to field sites and the time required for installing and uninstalling pumps, it was only feasible to have two subjects perform testing. Thus, one adult male and one adult female were identified, with their availability for the entire data collection period being a primary concern. The pumping test subjects were a 23-year woman and a 24-year man (unrelated to each other) living in Kitgum Town, each of average build and both accustomed to collecting water from handpumps. Neither subject was previously familiar with the specific pump models tested in this study. The users were paid corresponding to the common local daily wage for skilled labor and provided with water and meals on testing days.

4.3.3.7 Details of Testing Trials

Pumping trials took place at five separate locations in northern Uganda, four in Kitgum District and one in Gulu District, over a one-month period in September-October 2013. Most sites were more than 50 km from the testing base of Kitgum Town and one was more than 100 km away. Throughout each pumping test water levels were measured using a surveying tape measure with a weight attached to the end. One site (Site 3) was visited on two separate occasions (about 30 days apart) for testing of the two different pump sizes (as it was not initially planned to test the 25-mm pumps at this site). The static water level of the Site 3 well had changed during this time. Table 4-2 provides the measured static water levels for each site at the time of testing.

Table 4-2. Static water levels of wells during testing (meters below ground surface)

	Site 1	Site 2	Site 3	Site 4	Site 5
20-mm pumps	5.1 m	12.6 m	18.4 m	21.1 m	28.3 m
25-mm pumps	5.1 m	12.6 m	17.0 m	-	-
**Tests for 20-mm and 25-mm pumps at Site 3 took place at different times because it was not initially planned to test the 25-mm pumps at this site*					

All five sites had existing boreholes (wells) that were fitted with a standard pump pedestal, though only the Site 1 pump was operational. Non-functional handpumps were targeted by the field researchers in order to avoid disturbing operational community water supplies. The one operational pump was located at an unused borehole inside World Vision's compound in the town of Gulu. Local handpump mechanics were hired at each site to assist with removing and reinstalling components of the community handpumps that were installed on the boreholes. Ambient temperature was hot each day during testing, estimated to be around 29° - 35° C (84°-95° F), though the temperature could change rapidly on partially overcast days. The availability of shade was limited at a few of the sites, forcing the test subjects to sit in the vehicle with limited breeze while resting between tests. Two of the sites had large shade trees over the borehole, so test subjects were likely cooler during these trials. In an effort to keep the test subjects properly hydrated, large bottles of water were made available during testing. Each test subject had more than two liters of water available to them and was encouraged to drink plenty of water to prevent dehydration. The water intake for each pump tested was placed approximately 2.5 m below the static water level to eliminate any chance of well drawdown beyond the pump intake. For the Rope Pump, this measurement was made at the bottom of the pumping pipe while for the EMAS Pump it was made at the bottom of the piston valve (in the lowest position).

4.3.3.8 Measurement of Pumping Rates

As the study is assessing pumps for use at the household level, it is expected that the water source will be in close proximity to the household. In such cases, it is common for users to regularly pump water on an 'as needed' basis, rather than pumping larger quantities to store at the household. Twenty liters is the nominal volume of the most common size of water collection container (i.e., the jerrycan) used in Uganda and many other countries in sub-Saharan Africa, and thus for the study was chosen as the standard amount to be compared for calculating pumping rates.

For comparison purposes, it is also of interest to measure pumping rates when pumping two 20-liter buckets consecutively. Thus, the objective of each pumping trial was for the user to pump 40 liters of water at a normal pace, which was explained to the testing subjects as, "a pace that you would pump if you were collecting 40 liters of water on a typical day." Each test was started with the pump primed (ready to immediately discharge water) and time was recorded to the second with a digital stopwatch. All pumped water was collected in containers and each trial was timed to allow for a calculation of average pumping rates. Two marked containers of 20 liters each were used to allow for the "split" time and a comparison of pumping rate for the first 20 liters to second 20 liters of each trial. Marked volume measurements for testing containers were approximated under field conditions by weighing 20 kg of water with a calibrated infant-weighing scale and (assuming a fluid density of 1 kg/liter) marking the 20-liter line with the container on a level surface. Actual measurement during pumping trials was judged by a member of the testing team who took into account the estimated effects of the slope of the ground surface. When the first container reached the 20 liter mark for each trial, it was swiftly exchanged with the second container, and it is believed that no appreciable amount of water was lost. The water level in the well was measured before and after each test and pumped water was poured back into the well to ensure that changes in static water level from pumping did not introduce error to the following pump test.

4.3.4 Material Cost Comparison and Assessment of Pump Construction Needs

The Rope Pump and the EMAS Pump can both be fabricated in Uganda, using local supply chains. Retail costs of materials needed for the pumps were identified by visiting representative manufacturers, importers, and retailers in Kampala, the capital and economic hub of Uganda. Prices of materials in the capital were used in this study because these costs (and particularly percent differences in material costs between the different pump types) are likely to be comparable in other major cities in sub-Saharan Africa. In contrast, price comparisons outside of Kampala may fluctuate more based on local supply chains and other local conditions.

PVC materials are manufactured by two companies in Uganda while most galvanized piping materials are imported. There are some basic differences in skill and resource requirements for the fabrication of the EMAS Pump and the Rope Pump that were included in the assessment. The availability of electricity is a major delineation between areas where the Rope Pump can and cannot be fabricated.

4.4 Results and Discussion

4.4.1 Pumping Performance

4.4.1.1 Pumping Rates from Various Water Depths

Pumping rates were calculated based on the time to pump the first 20 liters of water for each trial and averaged for both users for each pump. Tables 4-3 and 4-4 summarize the pumping rates for the EMAS Pump as a percentage of the Rope Pump for the 20-mm and 25-mm pumps, respectively. The observed pumping rates are presented in Figures 4-5 (average of adult female and adult male), 4-6 (adult female), and 4-7 (adult male).

Table 4-3. EMAS Pump pumping rate as a percentage of 20-mm Rope Pump pumping rate

Pumping Rate Comparison - EMAS Pump to Rope Pump (20mm)			
Static Water Level	**Male**	**Female**	**Combined**
5.1	129%	98%	111%
12.6	114%	95%	103%
18.4	118%	80%	93%
21.1	110%	72%	85%
28.3	62%	64%	63%

Table 4-4. EMAS Pump pumping rate as a percentage of 25-mm Rope Pump pumping rate

Pumping Rate Comparison - EMAS Pump to Rope Pump (25mm)			
Static Water Level	**Male**	**Female**	**Combined**
5.1	86%	73%	79%
12.6	81%	67%	73%
17	109%	81%	93%

Figure 4-5 shows that the 20-mm version of the EMAS Pump had greater average combined pumping rates (adult female and adult male) than the 20-mm Rope Pump at SWL depths of 5.1 m (111%) and 12.6 m (103%), while at deeper depths the average combined pumping rates were lower than for the 20-mm Rope Pump, i.e. at 18.4 m (93%), 21.1 m (85%), and 28.3 m (63%). Combined average pumping rates for the 20-mm EMAS Pump ranged from 5.1 l/m to 17.1 l/m (i.e. 17.1 l/m pumping from 5.1 m SWL, 13.6 l/m from 12.6 m, 9.8 l/m from

18.4 m, 8.0 l/m from 21.1 m, and 5.1 l/m from 28.3). Combined average pumping rates for the 20-mm Rope Pump ranged from 8.0 l/m to 15.5 l/m (i.e. 15.5 l/m pumping from 5.1 m SWL, 13.l/m from 12.6 m, 10.5 l/m from 18.4 m, 9.5 l/m from 21.1 m, and 8.0 l/m from 28.3).

Figure 4-5 also shows that the 25-mm version of the EMAS Pump had average combined pumping rates (adult female and adult male) lower than the 25-mm Rope Pump at all three tested pumping depths (79% the pumping rate of the 25-mm Rope Pump at 5.1 m SWL, 73% at 12.6 m, and 93% at 17.0 m). Combined average pumping rates for the 25-mm EMAS Pump ranged from 20.9 l/m to 29.5 l/m (i.e. 29.5 l/m pumping from 5.1 m SWL, 21.4 l/m from 12.6 m, and 20.9 l/m from 17.0 m). Combined average pumping rates for the 25-mm Rope Pump ranged from 22.4 l/m to 37.2 l/m (i.e. 37.2 l/m pumping from 5.1 m SWL, 29.3 l/m from 12.6 m, 22.4 l/m from 17.0 m).

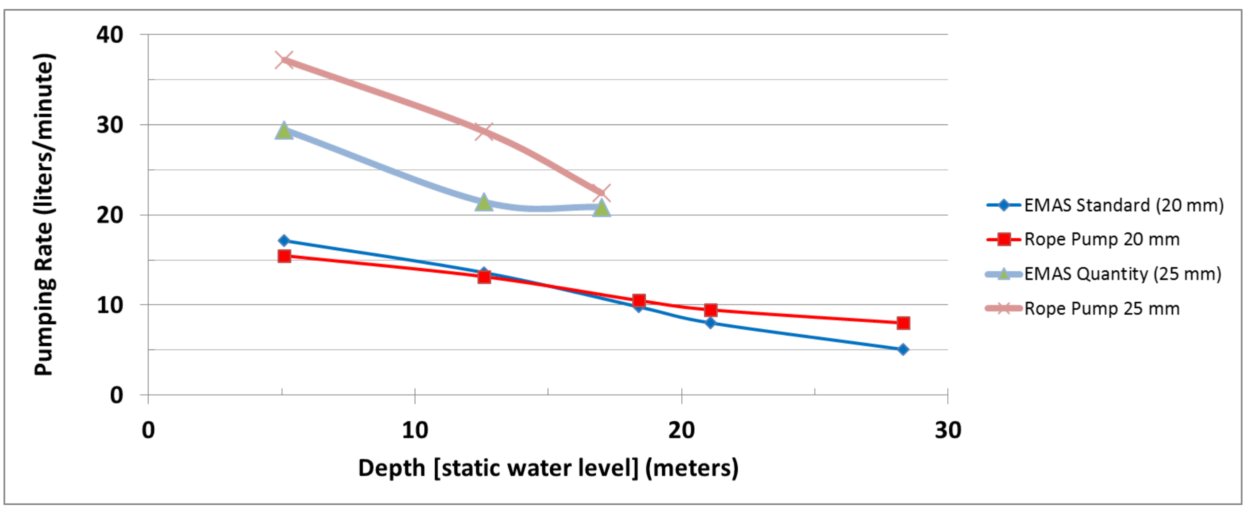

Figure 4-5. Average pumping rates at various depths, combined for adult male and adult female subjects (two trials)

Figure 4-6 shows that the 20-mm version of the EMAS Pump had average pumping rates for the adult female subject that were very similar to those of the 20-mm Rope Pump at SWL depths of 5.1 m (98%; 14.8 l/m vs. 15.1 l/m) and 12.6 m (95%; 12.0 l/m vs. 12.6 l/m). At deeper depths the difference the difference in pumping rates was more pronounced: 18.4 m SWL, 80% (7.5 l/m vs. 9.3 l/m); 21.1 m SWL, 72% (6.1 l/m vs. 8.5 l/m); and 28.3 m SWL, 64% (3.9 l/m vs. 6.1 l/m) (63%). For the 25-m version of the EMAS Pump, the average pumping rate for the adult female subject was 73% that of for the 20-mm Rope Pump at 5.1 m SWL (27.9 l/s vs. 38.1 l/s), 67% at 12.6 m SWL (19.0 l/s vs. 28.2 l/s) and 81% at 17.0 m SWL (18.2 l/s vs. 22.4 l/s).

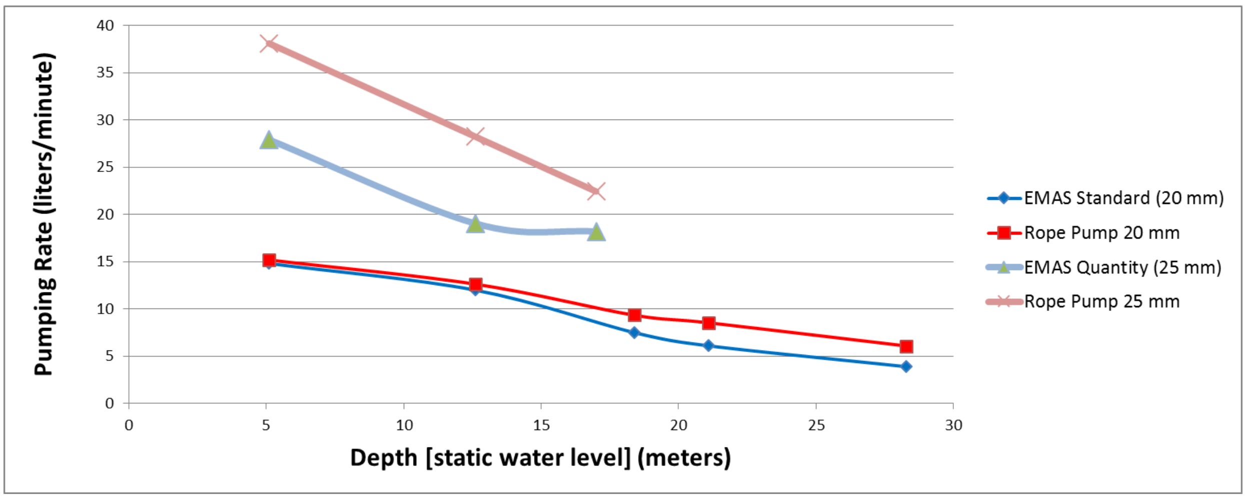

Figure 4-6. Average pumping rate at various depths for adult female user (two trials)

Figure 4-7 shows that the for the adult male subject, the average pumping rate of the 20-mm version of the EMAS Pump was greater than that for the 20-mm Rope Pump at SWL depths of 5.1 m (129%; 20.3 l/m vs. 15.8 l/m), more similar at 12.6 m (114%; 15.7 l/m vs. 13.7 l/m), 18.4 m SWL, (118%; 14.1 l/m vs. 12.0 l/m) and 21.1 m SWL (110%; 11.7 l/m vs. 10.6 l/m), and significantly less at 28.3 m SWL (62%; 7.3 l/m vs. 11.7 l/m). For the 25-m version of the EMAS Pump, the average pumping rate for the adult male subject was 86% that of for the 20-mm Rope Pump at 5.1 m SWL (31.1 l/s vs. 36.3 l/s), 81% at 12.6 m SWL (24.5 l/s vs. 30.4 l/s) and 109% at 17.0 m SWL (24.5 l/s vs. 22.4 l/s).

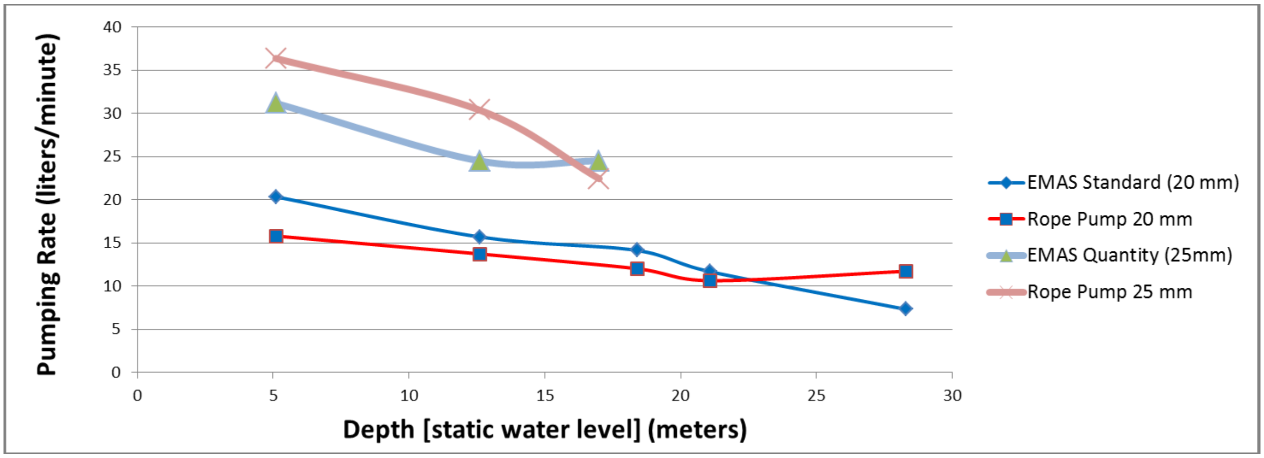

Figure 4-7. Average pumping rate at various depths for adult male user (two trials)

The observed pumping rates for the adult female user were always lower with the EMAS Pump than with the Rope Pump (refer to Figure 4-6, Tables 4-3 and 4-4), while a majority of trials for the male user showed lower pumping rates with the EMAS Pump than the Rope Pump (Figure 4-7, Tables 4-3 and 4-4). It was also observed during the trials that the male subject used longer strokes than the female subject when pumping the EMAS pump, facilitated by his greater height, which would have led to more efficient pumping because less time was spent on changing directions in the pumping cycle. This finding is in-line with the EMAS manual, which indicates that higher pumping rates are common for taller people (Buchner, 2006).

4.4.1.2 Expended Energy and Normalized Pumping Performance

To account for potential differences in energy expended by the pumping subjects when using the different types and variants of pumps, measured pumping rates for the EMAS Pump were ‘normalized’ by adjusting them to reflect the ratio of energy expended for the EMAS Pump to the energy expended for the corresponding Rope Pump. This calculation is an approximation of what the pumping rate would have been for the EMAS Pump if the energy expenditure had been equal to that of the Rope Pump. "Normalization" of the EMAS pumping rate involved the following equation:

$$Pumping\ Rate_{EMAS,normalized} = \frac{EE_{RP}}{EE_{EMAS}} \times Pumping\ Rate_{EMAS,actual} \quad \text{[Eq. 4-1]}$$

where EE_{RP} and EE_{EMAS} are the energy expenditures (in kilojoules) determined for the particular pumping trial for the Rope Pump and EMAS pump, respectively. Details on heart rate monitoring and the calculation of energy expenditures are provided in Carpenter (2014).

The average energy expended to pump 20 liters for each of the pumping trials are displayed in Figures 4-8, 4-9, and 4-10. Figure 4-8 shows the combined average energy expended for the adult female and adult male subjects, at all sites and for all pumps tested. The combined average energy expended for the 20-mm variant of the EMAS Pump was calculated to be 115% that of the 20-mm Rope Pump at 5.1 m SWL; 107% at 12.6 m SWL; 104% at 18.4 m SWL; 117% at 21.1 m SWL; and 135% at 28.3 m SWL. For the 25-mm variant of the EMAS Pump, combined average expended energy was calculated to be 137% that of the 25-mm Rope Pump at 5.1m SWL; 165% at 12.6 m SWL; and 126% at 17.0 m SWL.

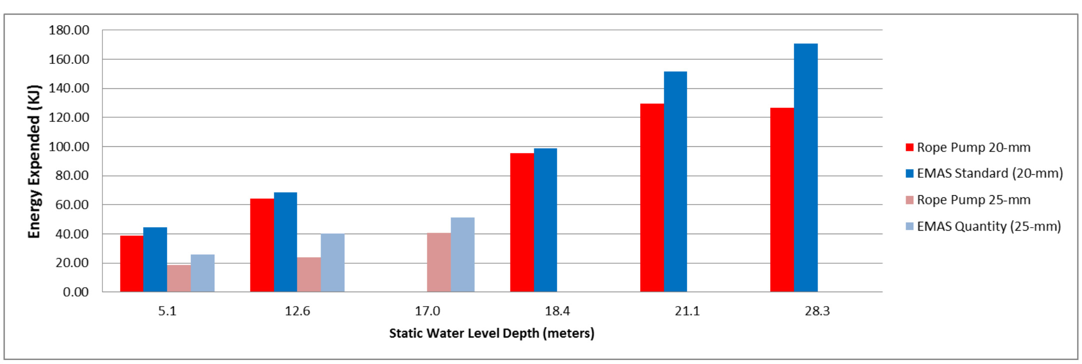

Figure 4-8. Average energy expended by adult female and adult male subjects for EMAS Pump and Rope Pump trials

Figure 4-9 shows the average energy expended for the adult female subject, at all sites and for all pumps tested. The average energy expended for the 20-mm variant of the EMAS Pump was calculated to be 116% that of the 20-mm Rope Pump at 5.1 m SWL; 110% at 12.6 m SWL; 128% at 18.4 m SWL; 130% at 21.1 m SWL; and 133% at 28.3 m SWL. For the 25-mm variant of the EMAS Pump, average expended energy for the female subject was calculated to be 140% that of the 25-mm Rope Pump at 5.1m SWL; 163% at 12.6 m SWL; and 136% at 17.0 m SWL.

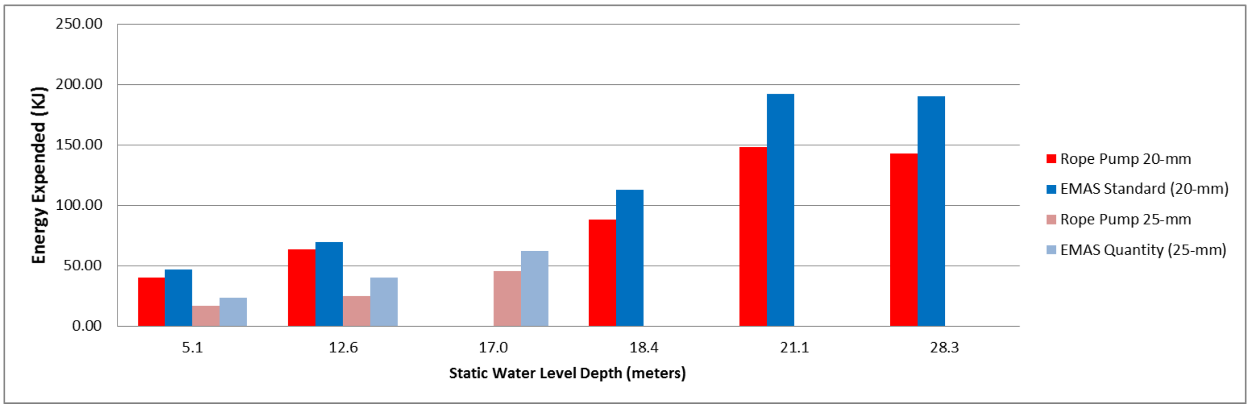

Figure 4-9. Average energy expended by adult female subject for EMAS Pump and Rope Pump trials

Figure 4-10 shows the average energy expended for the adult male subject, at all sites and for all pumps tested. The average energy expended for the 20-mm variant of the EMAS Pump was calculated to be 113% that of the 20-mm Rope Pump at 5.1 m SWL; 104% at 12.6 m SWL; 83% at 18.4 m SWL; equal (100%) at 21.1 m SWL; and 135% at 28.3 m SWL. For the 25-mm variant of the EMAS Pump, average expended energy for the male subject was calculated to be 134% that of the 25-mm Rope Pump at 5.1m SWL; 171% at 12.6 m SWL; and 114% at 17.0 m SWL.

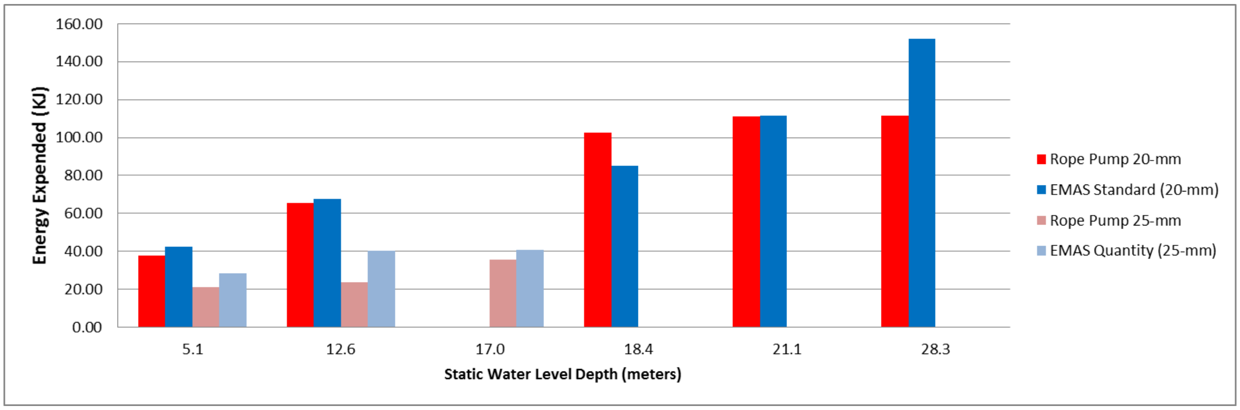

Figure 4-10. Average energy expended by adult male subject for EMAS Pump and Rope Pump trials

The normalized average pumping rates of the EMAS Pumps are presented in Figures 4-11 (average of adult female and adult male), 4-12 (adult female), and 4-13 (adult male) (along with the measured values for the corresponding variants of the Rope Pump, which were used as the baseline).

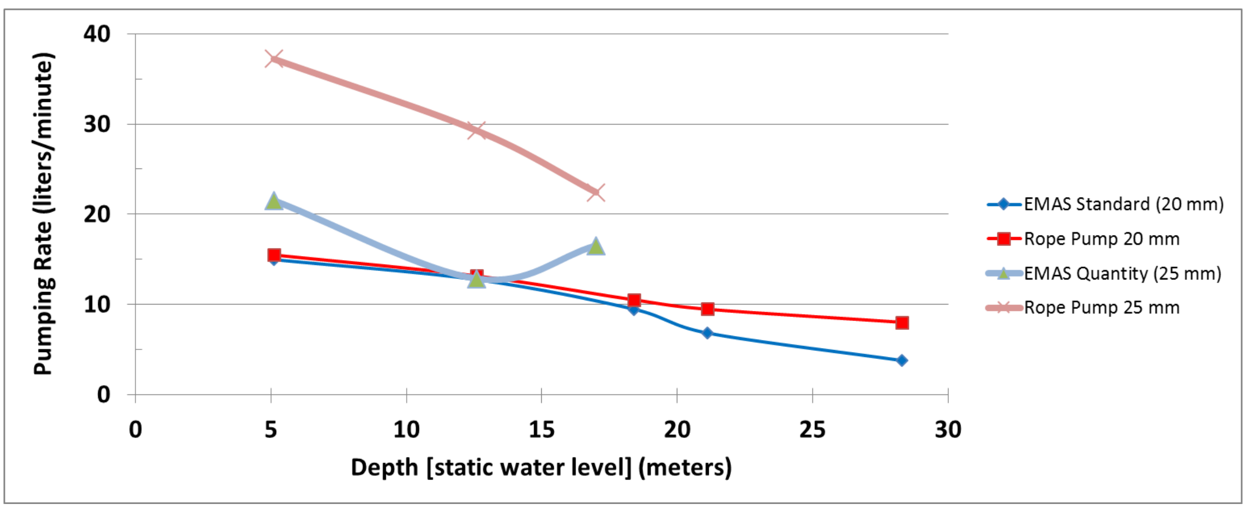

Figure 4-11. Average pumping rates for all trials at various depths with EMAS pumping rates normalized for energy expenditure

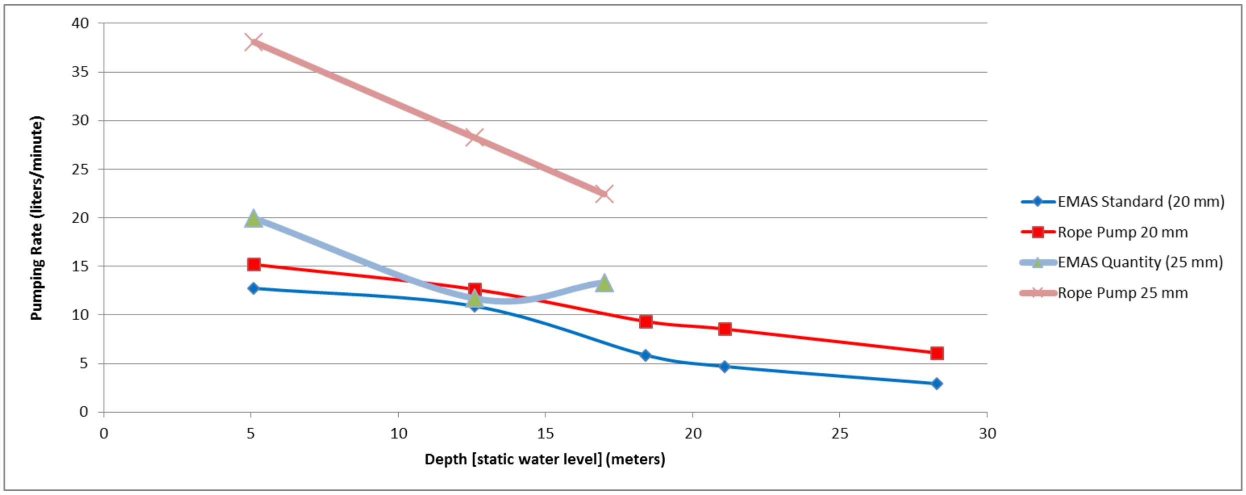

Figure 4-12. Adult female subject: Average pumping rates at various depths with EMAS pumping rates normalized for energy expenditure

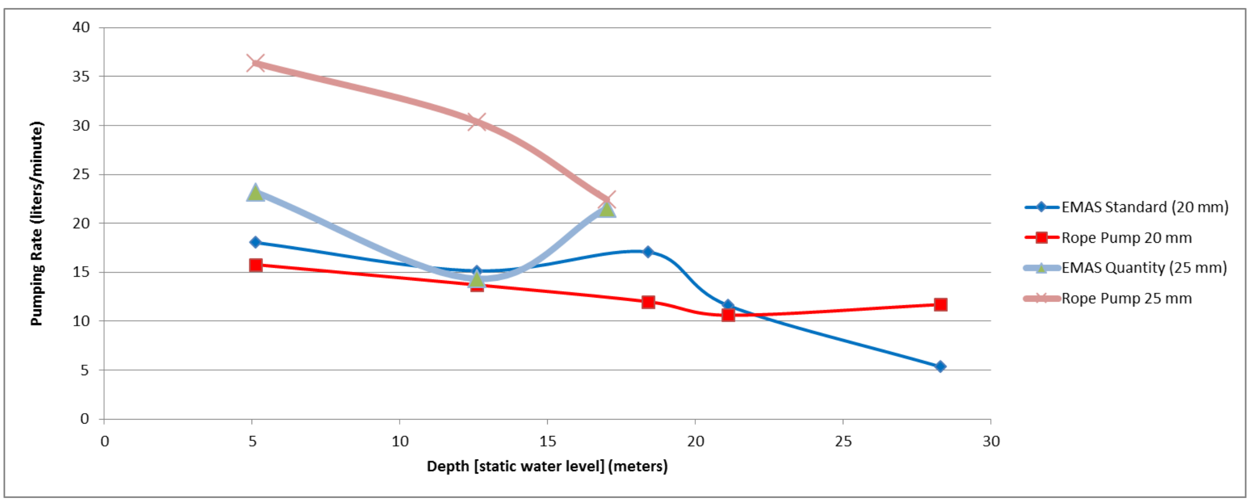

Figure 4-13. Adult male subject: Average pumping rates at various depths with EMAS pumping rates normalized for energy expenditure

The normalized pumping rate calculation provides a more objective comparison between the pumps. In all instances except for the male subject using the 20-mm pump at the 18.4 m deep well, energy expenditure was always greater for the EMAS Pump than the Rope Pump. This means that the effective pumping rates of the EMAS Pump were reduced by normalization in all other instances.

There are some issues that suggest the energy expenditure data calculated from the pumping trials are not reliably accurate in terms of absolute energy expenditure. This relates primarily to resting energy rates and metabolisms in different populations that play a role in how resting energy expenditure is calculated. Additionally, high ambient temperatures in the field could also affect energy expenditure. However, it is believed that the calculated energy data has significant internal validity for comparisons in this study (where comparisons with the same two subjects testing the various pumps in the same field conditions), while external validity (i.e. comparing the results from one testing subject to those from another) may be limited. More details about these concerns can be found in Carpenter (2014). Regardless, the same test subjects underwent the same methodologies for pumping, so it is believed with some confidence that the energy expenditure data has some precision and can be used to indicate relative energy expended for the two pumps. This provides validity to internal comparisons made in this study, but may potentially limit the external comparability of raw energy data. The normalized pumping rate calculations (and results presented in Figures 4-11, 4-12, and 4-13) were made for this reason.

4.4.2 Material Cost Comparison and Assessment of Pump Construction Needs

It was found that the EMAS Pump can be fabricated in Uganda, with locally available materials costing approximately 9 to 32 US dollars (depending on pump length). Currently, the Rope Pump is the most affordable groundwater pump available in Uganda (Carpenter, 2014). The total material costs for both pumps at selected static water levels (i.e., depths) are provided in Table 4-5. This table also indicates the cost of materials for each model/version of pump as well as the cost of the EMAS Pump as a percentage of the corresponding version of the Rope Pump. Full material costs estimates for selected EMAS Pumps and Rope Pumps are provided in Appendix C. All costs are based on retail prices found in Kampala in late-2013.

Table 4-5. Material costs for EMAS Pump compared to the Rope Pump in Uganda (prices from Kampala, Cost % is the ratio of cost of EMAS Pump to Rope Pump)

Static Water Level (m)	EMAS 20-mm	Rope Pump 20-mm	Cost %	EMAS 25-mm	Rope Pump 25-mm	Cost %
5	$9.10	$44.2	21%	$12.5	$44.7	28%
10	$13.6	$46.9	29%	$19.5	$47.9	41%
15	$18.2	$49.7	37%	$26.0	$51.9	50%
20	$22.7	$52.4	43%	$32.8	$54.5	60%
25	$27.2	$55.1	49%	-	-	-
30	$31.8	$57.8	55%	-	-	-

Table 4-5 shows that the EMAS Pump represents the greatest savings over the Rope Pump for shallow wells with depth ranging from 5 to 30 m. For example, material cost for a 25-mm EMAS Pump is 28% that of a 25-mm Rope Pump for a well with 5 m static water level. Though economic savings for the EMAS Pump decrease by approximately 3 US dollars as depth increases by 5 m for the 25-mm pump, and 2 US dollars per 5 m for the 20-mm pump (because the major cost of Rope Pump materials is in the pump head, at an approximate fixed material cost of 42 US dollars, is the same regardless of depth, while the EMAS Pump head is simpler in design), the material cost of EMAS Pump is still only 55% at the deepest recommended depth for the 20-mm pump and 60% that of the Rope Pump at the deepest recommended for the 25-mm pumps.

If costs for pump fabrication were to be assessed and added to pump material costs, it is likely the total difference in costs between the Rope Pump and the EMAS Pump would increase more. This is because the Rope Pump requires extensive welding and cutting that takes time (and more specialized skills, for welding) and incurs electricity costs. In contrast, the EMAS Pump can be constructed with a few simple hand tools such as a hand saw, files, wrenches (spanners), files, and PVC glue. However, the EMAS Pump will also require marginal increased costs associated with the limited use of a heat source such as a gas flame, wood fire, or a charcoal stove.

Based on the differences in fabrication costs, it is not unreasonable to assume that the percentage savings presented in Table 4-5 for the EMAS Pump over the Rope Pump, would translate directly to similar (or greater) savings in regard to the retail price of complete pumps. In other words, this data suggest that the 25-mm EMAS Pump could sell at 28% of the price of the comparable Rope Pump for a 5-m deep well and the 20-mm EMAS Pump could sell at almost on half (49% reported in Table 4-5) of the price of the 20-mm Rope Pump for a 25-m deep well.

Materials required for the fabrication of the EMAS Pump are currently available through existing supply chains in Uganda, though not in all parts of the country. PVC pipes are available in all towns large enough to have a hardware store, though many rural stores may not stock all of the pipes necessary. The lack of metric pipes in some areas is a challenge for the Rope Pump and the EMAS Pump as well as manually drilled boreholes that utilize larger metric pipes for well screens. Marbles are also not readily available upcountry (outside of Kampala), but can be bought at low prices in Kampala (and are known to be common in many other areas of sub-Saharan Africa). Based on current supplies chains and the fact that all materials are readily available in Kampala, it is believed that improvement in the supply of relevant materials in most rural towns is quite feasible. Standard unit pipes, such a Schedule 40 (blue) PVC pressure pipe and standard sanitary drainage pipes are commonly available upcountry because they seem to be the paradigm for plumbing in Uganda.

4.5 Conclusion

This research demonstrated that the EMAS Pump can perform similarly in terms of pumping rate to the Rope Pump at pumping depths that ranged 5 m to 18 m, but less so at deeper depths. Specifically for the 20-mm variants of the EMAS Pump and the Rope Pump, average pumping rates were similar at shallow to medium depths (5.1m SWL to 18.4m SWL), with the average EMAS Pump pumping rate being 10% higher at 5.1 m depth and 6% lower at 18.4 m depth. At the deepest tested depth of 28.3 m, the EMAS Pump pumping rate diverged from the Rope Pump and was 30% lower. The normalized pumping rate (considering energy expended by the user) accentuated the differences between the EMAS and Rope Pump. The small advantages that the EMAS Pump had at shallow depths of 5.1 m and 12.6 m were eliminated (going from 111% of the Rope Pump rate to 97% at 5.1 m, and 103 to 97% at 12.6 m) and the advantage of the Rope Pump at deeper depths was increased (with the EMAS Pump rate dropping from 93 to 90% of the Rope Pump rate at 18.4 m, 85 to 72% at 21.1 m, and 63 to 47% at 28.3 m).

The cost of materials necessary to construct the EMAS Pump were found to be significantly less than those to build the Rope Pump, based on material costs in the Ugandan capital city of Kampala. The material costs for the EMAS Pump were found to range from 21 to 60% of the material costs of the Rope Pump for the tested variants (21 to 55% for the 20-mm version, 28 to 60% for the 25-mm version), considering pumping depths from 5 m to 30 m.

The manufacturing needs for the EMAS Pump were determined to be considerably less than for the Rope Pump, and no electricity is required for manufacturing the EMAS Pump, which may make it much more feasible to construct in rural areas of sub-Saharan Africa.

Based on its relative low-cost, similar technical performance to the Rope Pump when pumping from a range of depths, and the minimal resources needed to construct it, the results of this research show the EMAS Pump has potential for success in household water supply systems in sub-Saharan Africa. Combined with the conclusion from Chapter 4, which showed a high rate of functionality among surveyed household EMAS Pumps in rural areas of Bolivia, it is believed that there is considerable potential to introduce the EMAS Pump as a very low-cost option for Self-supply systems in sub-Saharan Africa.

CHAPTER 5: CONCLUSIONS & FURTHER RESEARCH

5.1 Summary

The below summary aligns the conclusions of the topics studied with the Research Questions from Chapter 1:

1. *What improvements can be made to the Pitcher Pump system used in Madagascar to improve the quality of the product (including reliability, pumping rates, and/or quality of extracted water)?*

The Madagascar research found that Pitcher Pump systems are widely used in the research area of Tamatave and Foulpointe in eastern Madagascar and are shown to provide reliable and convenient access to water at a low cost relative to household connections to the piped water system. The Pitcher Pump market in the research area is unsubsidized, with system owners paying 100% of the initial cost. This market is believed to be the most significant documented example of an unsubsidized household handpump market in sub-Saharan Africa. Owners commonly share maintenance and repair costs with their tenants and/or neighbors. System maintenance is done by local technicians or family members, with more significant repairs undertaken by local technicians or manufacturers.

There are, however, concerns with the quality of water supplied through these systems (i.e. its suitability for drinking), specifically microbiological and lead contamination. Only 55% of wells sampled provided water associated with low-risk of microbial contamination for household systems, and four out of a small sample of ten wells contained lead in excess of safe limits. The market is also unregulated, neglected even, and there are several potential entry points for enhancements to current Pitcher Pump system construction and installation practices that could improve the quality of water delivered.

Results of this study are being shared with USAID and local government officials responsible for urban water supply and public health. Complementary research is ongoing to assess the cause of the lead contamination and make recommendations to mitigate exposure. Follow-up efforts in urban Tamatave seek to support WASH (Water, Sanitation, and Hygiene) sector stakeholders and local government officials to increase regulation of the Self-supply market and address issues of quality of water delivered by Pitcher Pumps, including the important issue of lead contamination. Further research is needed to determine potential improvements to Pitcher Pump systems, to understand how to create synergies between the Pitcher Pump market and community piped water system, as well as to determine the feasibility of household water treatment and rainwater harvesting Self-supply options to improve access to drinking water.

2. *Are low-cost water supply systems that have been developed in Bolivia (EMAS technologies) suitable, affordable options for household water supply (Self-supply) for developing communities in sub-Saharan Africa?*

EMAS manual water pumps (EMAS Pumps) are shown to have a high rate of functionality as used at the household level in the studied contexts in Bolivia. The EMAS manually drilled wells surveyed, which were installed by numerous different drilling teams (most of whom are independent of EMAS) were reported to be reliable, with a very high percentage of wells providing water throughout the entire year. These conclusions combine with an evident considerable adoption of the EMAS Pump and manually drilled wells to show that the technologies have had an important impact on increasing access to water supply at the household level in many rural areas of Bolivia. Households are able to maintain low-cost EMAS Pumps, with repairs commonly done by local technicians or household members, and in some cases the same EMAS Pumps have been used for more than a decade.

Given the low cost of EMAS household water supply systems, and their conduciveness to being built and repaired by local technicians, these technologies offer considerable potential for success in accelerating self-supply in sub-Saharan Africa. The potential includes using the EMAS Pump on existing or new household manually drilled or hand-dug wells (with the possibility of installing multiple pumps on the same hand-dug well), manual drilling of wells using EMAS methods, upgrading of such systems as appropriate/feasible (e.g. pumping through hoses or pipes to a tank/reservoir), and RWHS.

3. *Would EMAS manual water pumps be an effective, less-costly alternative to the Rope Pump, offering a better chance for households or small groups of families in sub-Saharan Africa to improve their private water supplies, while lifting water at an acceptable rate?*

The technical comparison of the EMAS Pump and the Rope Pump concluded that, based on its relative low-cost, similar technical performance to the Rope Pump when pumping from a range of depths, and the minimal resources needed to construct it, the EMAS Pump has potential for success in household water supply systems in sub-Saharan Africa. Combined with the conclusion from *Chapter 4*, which showed a high rate of functionality among surveyed household EMAS Pumps in rural areas of Bolivia, it is believed that there is considerable potential to introduce the EMAS Pump as a very low-cost option for Self-supply systems in sub-Saharan Africa.

4. *Based on the results of Research Questions 1 through 3, what recommendations can be offered to improve sustainable low-cost water supply systems for use at the household level in developing contexts in sub-Saharan Africa?*

Results of the Madagascar Pitcher Pump study are being shared with USAID and local government officials responsible for urban water supply and public health. Follow-up efforts in urban Tamatave seek to support WASH (Water, Sanitation, and Hygiene) sector stakeholders and local government officials to increase regulation of the Self-supply market and address issues of quality of water delivered by Pitcher Pumps, including the important issue of lead contamination.

Further research is needed to determine potential improvements to Pitcher Pump systems, to understand how to create synergies between the Pitcher Pump market and community piped water system, as well as to determine the feasibility of household water treatment and rainwater harvesting Self-supply options to improve access to drinking water. Topics of ongoing and potential further research are described in the following subsection.

5.2 Further Research

Ongoing and potential future related research has been developed from this dissertation work are discussed, focusing on accelerating Self-supply in Madagascar, and include: technical improvements to the Pitcher Pump technology; formative research in Social Marketing; and Development of the Self-Supply Market in Madagascar beyond Pitcher Pump systems

1. Technical Improvements to the Pitcher Pump system

   (a) The identification of lead (Pb) contamination in Pitcher Pump systems in this study has been followed up in a more in-depth study, which confirmed Pb contamination to be an issue in Pitcher Pump systems, and identified the major source of this contamination as the Pb valve weights used by most system manufacturers (Akers, 2014)[4].

(b) A second follow-up study investigated fecal contamination in Pitcher Pump systems in Tamatave, Madagascar (Wahlstrom-Ramler, 2014)[5]. This study did not find any link between Pitcher Pump system well depth and level of contamination (which was a suggested possibility from *Chapter 2* data analysis). However, the fecal contamination study found that Pitcher Pump priming was significant factor in microbiological water quality in these systems.

(c) An continuing manual drilling study in eastern Madagascar is exploring: (i) ways of improving water quality through use of alternative well-lining materials and drilling methods that reduce/eliminate the use of Pb-containing components in the well screen drilling; and (ii) expanding the household groundwater supply market to areas with more diverse hydrogeological conditions (i.e. deeper water tables, harder soils) through the use of alternative manual well drilling and water pumping technologies.

2. Formative Research in Social Marketing

Ongoing Social Marketing research led by the author of this dissertation is focusing on the following topics:

(a) Identification of factors that Picher Pump users find important about Pitcher Pump systems (i.e. why do consumers continue to buy, use them).

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[4] This research was led by University of South Florida Peace Corps Master's International student D. Brad Akers. The dissertation author provided research support and mentorship on Self-supply and the water supply context in Tamatave, Madagascar.

[5] This research was led by University of South Florida Peace Corps Master's International student Meghan Wahlstrom-Ramler. The dissertation author provided research support and mentorship on Self-supply and the water supply context in eastern Madagascar.

(b) Identification of factors that Pitcher Pump manufacturers appreciate about Pitcher Pump systems (i.e. why do they keep making, selling them).

These studies are being carried out through in-depth interviews with Pitcher Pump system manufacturers and owners-users in Tamatave. Interviews of manufacturers are in the process of being analyzed. Future research involves combining this with the results of the Pitcher Pump market and technology assessment, and using a Social Marketing framework to design and propose improvements to the Pitcher Pump market in eastern Madagascar. A Social Marketing framework is distinguished from other social change planning approaches by its careful segmentation of target markets, reliance on research to generate insights into consumers' needs, desires, and preferences and use of consumer insights to create an integrated strategic plan based on marketing's conceptual framework known as the 'Four Ps' of marketing (Product, Price, Place, Promotion) (Grier and Bryant, 2005).

A Social Marketing framework can be used to guide the assessment/evaluation of current Self Supply markets and practices, particularly when aiming to make improvements. The use of such a framework provides a structure for the collection and analysis of data that assists in assessing how the project adheres to Social Marketing principles. Importantly, even when Social Marketing has not previously been considered in the design of an existing market, assessing it using a Social Marketing framework can be done through interpretation of a Social Marketing purpose and focus for the existing market and constructing the framework from that base with further information gathered during the formative research process. This assessment is valuable towards designing improvements to the existing market that can achieve determined Social Marketing objectives.

3. Development of the Self-Supply Market in Madagascar beyond Pitcher Pump systems

Ongoing research led by the author of this dissertation is focusing on assessing other traditional Self-supply practices in areas of Madagascar (e.g. hand-dug wells in the south-central highlands, rainwater harvesting systems in the south of the country, etc.). Field data has been collected during four field "rapid assessments", and will contribute to a future field note publication on 'The Potential for Accelerating Self-Supply in Madagascar", aimed at disseminating the acquired knowledge from to local actors in Madagascar (and beyond).

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APPENDICES

Appendix A Madagascar Field Data Collection Guide and Raw Data

A.1 Survey Form

Date:
ID:
Interviewer:
Interviewee: Male
Female

Madagascar Self-Supply: Assessing Access to Household Water and Sanitation with Pitcher Pump systems in eastern Madagascar

Household Survey

Demographic Information

1. What is your age?
   a. 18-35
   b. 36-50
   c. 50-65
   d. Over 65

2. How many persons live in your household? __________

3. How many are adults aged 18 and above? ____________

4. How many children aged 5 – 17? _______________

5. How many children under 5 years? ____________

6. What is the occupation of male head of household? ___________

7. What is the occupation of female head of household? ___________

Water and Sanitation Infrastructure Systems in Household

8. What type of household water source does your family have? (If two or more, circle all that are relevant, but consider Pump Tany as primary, and for responding to following questions)
   a. Hand-dug well
   b. Manually drilled Well
   c. Rainwater Harvesting System
   d. Piped water from community system
   e. Other ___________________________

9. What is the age of the household water source?

a. 0-3 years
b. 4-10 years
c. 11-15 years
d. 16-20 years
e. Older than 20 years

10. Where did you get your water before you had the current system?
    a. Hand-dug well
    b. Manually drilled Well
    c. Rainwater Harvesting System
    d. Piped water from community system
    e. Other ___________________________

11. How many months per year does this source provide water?
    a. 1-3 months per year
    b. 4-6 months per year
    c. 6-9 months per year
    d. 10-11 months per year
    e. Other ___________________________

12. Who is responsible for maintaining the water source?
    a. Female head of household
    b. Male head of household
    c. Other female adult in household
    d. Other male adult in household
    e. Female child
    f. Male child
    g. Other ___________________________

13. What do you use to lift water from the water source?
    a. Rope and Bucket
    b. Manual pump
    c. Fuel-powered pump
    d. Motorized pump
    e. Other ___________________________

14. What is the age of the household water-lifting device?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years

15. Who is responsible for repair and maintenance of the water-lifting device?
    a. Female head of household
    b. Male head of household
    c. Other female adult in household
    d. Other male adult in household

e. Female child
f. Male child
g. Other ___________________________

16. What repairs have you made to the water-lifting device? ______________________________

17. How much did these repairs cost? Materials ______ Labor________ TOTAL

18. Does your family get any water for the household from another source? YES or NO
If YES, what type of source is this secondary source?
a. Hand-dug well
b. Manually drilled Well
c. Rainwater Harvesting System
d. Piped water from community system
e. Other ___________________________

Water and Sanitation System Construction

19. Who built/installed your household water supply system (circle all that apply)?
a. Self (anyone in family)
b. Friend
c. Local Technician(s)
d. Other ___________________________________

20. How much did your household water supply system cost? Materials_______ Labor_______ TOTAL _______

21. Did you receive subsidies to pay for your household water and sanitation system? YES or NO
If YES, where did the subsidies come from?
a. Local municipality (specify name _______________)
b. Local or national NGO (specify name ____________)
c. International NGO (specify name ________________)
d. Other ___________________________________

22. If YES to QUESTION 21, how much did you receive in subsidies? _________

23. Did you receive a loan to pay for your household water and sanitation system? YES or NO
If YES, where did the subsidies come from?
a. Local municipality (specify name _______________)
b. Local or national NGO (specify name ____________)
c. International NGO (specify name ________________)
d. Other ___________________________________

24. If YES to QUESTION 23, how much did you receive as a loan? _________

25. Do you have any plans to upgrade your household water system within the next year?

YES or NO

If YES, what upgrade(s) do you plan on making?

a. Replace pump (specify type of new pump _____)
b. Add tank
c. Add piping to house
d. New well
e. Other ___________________________________

Household Water Practices & Use

26. Is the water from the Pump Tany system used for drinking water?
    a. Yes
    b. No

27. If no, what is the source for drinking water? __________________________

28. What is the water from the Pump Tany system used for? (circle all that apply)
    a. Drinking (Note: Already answered in Question #21)
    b. Washing food/cooking
    c. Hand washing
    d. Bathing
    e. Brushing teeth
    f. Clothes washing
    g. Irrigation (flowers, crops, etc.)
    h. Other _____________

29. What methods do you use to treat your water before use?
    a. Storage tank disinfection (What kind of disinfection? ____________________________)
    b. Point of use disinfection (What kind of disinfection? ______________________________)
    c. Boiling
    d. Filter (what type? ____________)
    e. Other ___________
    f. None

30. Is water treated for all uses or only for drinking?
    a. Yes
    b. No
    c. Treated for drinking and _________________

31. Does someone disinfect the water in the storage tank? (If answer is NO, skip to Question 34)
    a. Yes
    b. No

32. If yes to disinfection, how frequently is the water disinfected?
    a. Daily

b. Weekly
c. Monthly
d. Every 6 months
e. Annually
f. Rarely
g. Other _____________

33. If yes to disinfection, when was the last time of disinfection?
    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year

34. If you disinfect your water, how long after disinfection do you use it?
    a. Immediately

    b. 1-5 minutes

    c. 5-10 minutes

    d. 15-30 minutes

    e. 30 minutes or more

35. If you disinfect your water, do you feel your health is better, worse, or the same as a result of this (for example, you have seen a decrease in diarrheal episodes)?

    a. Better

    b. Worse

    c. The same

<u>Household Sanitation</u>

36. What type of sanitation system do you have in your household?
    a. None
    b. Pit Latrine
    c. VIP Latrine
    d. EcoSan Latrine
    e. Pour-flush latrine
    f. Septic System
    g. Other __________

36. What is the age of the household sanitation system?
    a. 0-3 years
    b. 4-10 years

c. 11-15 years
d. 16-20 years
e. Older than 20 years

37. What type of household sanitation system did you have before you had the current system?

a. None
b. Pit Latrine
c. VIP Latrine
d. EcoSan Latrine
e. Pour-flush latrine
f. Septic System
g. Other __________

Household Hygiene

39. Prior to getting water from the point source (well, spigot, river, etc.), do you wash your hands (with soap)?

a. yes

b. no

c. sometimes

40. Generally, during what times do you wash your hands (circle all that apply)?

a. After going to the toilet

b. After changing child diapers or washing baby's bottom

c. Before preparing food

d. Before eating

e. Before giving food to others (including the child

f. Never or do not know

Thank you for your time. The survey is now complete.

A.2 Observation/Inspection Sheet

Date:
ID:
Observer:

Self-Supply: Assessing Access to Household Water and Sanitation In Madagascar
Inspection Sheet

House (building) Observations

1. How many levels does the house have?
   a. One b. Two
2. Approximately how many rooms are in the house?
   a. 1-3
   b. 4-6
   c. 7-9
   d. 10 or more
3. Is there a separate room for the kitchen?
   Yes No
4. What type of toilet do the household members use? (Confirm – also asked in survey)
   a. None
   b. Pit Latrine
   c. VIP Latrine
   d. EcoSan Latrine
   e. Pour-flush latrine
   f. Septic System
   g. Other __________

5. Estimate the area (in sq. meters) of the roof (i.e. area that can be used to capture rain)

6. General observations (roof and housing materials, fresh paint, general condition of the house, etc.)

____
____

Water System Inspection

7. What is the type of water source? (Confirm – also asked in survey)
   a. Hand-dug well
   b. Manually drilled Well
   c. Rainwater Harvesting System
   d. Piped water from community system
   e. Other __________________________

8. Is there a water storage tank.

   YES NO

9. If YES to Question 8, What is the approximate tank capacity in liters? ___________ (diam_____ , depth____)

10. Where is the tank located?
    a. Roof top
    b. On top of other elevated structure
    c. Above ground, not elevated
    d. Below ground
    e. Other _____________

11. What is the tank made of?
    a. Reinforced concrete
    b. Unreinforced concrete
    c. Ferrocement
    d. Plastic
    e. Metal
    f. Other _____________

12. Does the tank have a cover or lid? Yes No

13. If yes to Question 12, what is the cover or lid made of? ____________

14. Is a manual pump used?

    YES NO

15. If YES to Question 14, is the manual pump functional?

    YES NO NA

16. If YES to Question 15, what is the measured flow rate from the manual pump?

    ________ time to pump 20 liters (trial 1) _________ time to pump 20 liters (trial 2) _____ average

17. General observations (conditions of well, pump, tank, RWH gutters, etc.)

____

Sanitation System Inspection

18. If no to Question 18, what is the latrine made of? (circle all that apply, and take photos)
    a. Reinforced concrete
    b. Unreinforced concrete
    c. Ferrocement
    d. Plastic

e. Metal (e.g. currogated iron/zinc)
f. Other _____________

19. Does the latrine appear to be used on a regular basis?

    YES NO

20. Are there hand-washing facilities within 5 meters of the latrine?

    YES No

21. Describe the general condition of the sanitation infrastructure:

22. ______ # of housholds use the household water source.

23. _____ meter(s), latrine to water source.

24. _____ meter(s), reported wellpoint depth.

A.3 Focus Group Script

Focus Group Script – Pitcher Pump (Pump Tany) Systems

Note: Expected total time of Focus Group is 2 hours. Estimated time of Questions is 1 hour 40 minutes. Expected Focus Group size is 8-10 participants.

Introduction: Good day, and welcome. Thank you for agreeing to participate in our discussion of household water supply systems. My name is Mike MacCarthy, and I represent the University of South Florida in the Unites States. My project colleague(s), __________________, will be assisting. We are attempting to gather information on low-cost water supply systems used at the family/household level in Madagascar. We have invited people from several different areas around the city of Tamatave (eastern Madagascar) to share their experiences and ideas.

You have been selected because you are each users of "Pump Tany" water supply systems (locally made pump and drilled well lining). More specifically, you are each the head females in households which use these water supply systems.

Today we will be discussing your experiences with the Pump Tany systems. This will include how long you have been using the technology, where you first learned of it, how and from whom you came to purchase it, and your experiences with its use, maintenance, and repair. Please tell us about both positive and negative aspects of the systems. Different points of view are welcome, and there are no correct or in-correct answers.

I'd like to inform you of a few basic ground rules before we start. Please only speak one person at a time. We are taping your comments on an audio recorder, to insure that we properly record everyone's comments. If multiple people are talking at the same time, the audio becomes difficult to understand. We can all call each other by our first names during our discussion. Your names will not be attached to the comments in the report.

Our discussion will last for about an hour, with no planned breaks. Name cards have been placed on the table to help us remember each other's names. To get to know each other, we'll now go around the table and give each person a chance to introduce themselves. Please tell us your name and the village/neighborhood where you live.

Questions:

Opening:	1. Tell us your name (first name and family name) and the name of the village/neighborhood where you live. (5 minutes)
Introductory:	2. How did you learn about Pump Tany household water supply systems? (5 minutes)
Transition:	3. When you first saw a Pump Tany system working, what were your first impressions? (5 minutes)
	4. How (and when) did you obtain a Pump Tany system for your family/household? (5 minutes)
Key Questions:	5. What do you like about your Pump Tany system? (10 minutes)
	6. Prior to obtaining a Pump Tany system, how did you get water for your household? (5 minutes)
	7. How has the Pump Tany system changed the uses for water within your household? (5 minutes)
	8. Is your household any different because you now have a Pump Tany household water supply system? If so, how? (10 minutes)
	9. What do you (or a member of your household) do to keep the Pump Tany system operating? (15 minutes)
	10. What specific issues have you had with breakdown of the Pump Tany system, and how have these issues been resolved? (10 minutes)
	11. How are costs for maintaining and repairing your Pump Tany system paid ? (5 minutes)

Ending Questions: 12. If you could offer improvements to the Pump Tany system, what would you recommend? (10 minutes)

13. We would like for you to help us to evaluate the Pump Tany technology and how it is used by local communities. We want to know how the service that it provides can be improved. Is there anything that we have not spoken about that you would like to add about the Pump Tany systems and your experiences with household water supply? (10 minutes)

A.4 Madagascar Household Surveys – Raw Data

Survey No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
	Age (years)	# in hh	Adults	kids 5-17	kids lt 5	Male Job	Fem Job	Type, Water Source
1	18-35	3	2	0	1	driver	homemaker	manually-drilled well; faucet
2	50-65	4	2	2	0	instituteur	homemaker	manually-drilled well
3	36-50	6	4	1	1	shopkeeper	accountant	manually-drilled well
4	18-35	2	2	0	0	painter	student	manually-drilled well
5	50-65	4	3	0	1	mechanic	homemaker	manually-drilled well

6	18-35	7	2	4	1	technician (welding, roofing)	salesperson	manually-drilled well
7	18-35	5	2	3	0	independent work	homemaker	manually-drilled well
8	18-35	4	3	0	1	student	X	manually-drilled well
9	18-35	4	4	0	0	salesperson	homemaker	manually-drilled well
10	18-35	5	2	3	0	driver	homemaker	manually-drilled well
11	18-35	3	2	1	0	officework	institutrice	manually-drilled well
12	18-35	4	2	1	1	driver	salesperson	manually-drilled well
13	50-65	15	7	5	3	work at garage	institutrice	manually-drilled well; faucet
14	50-65	8	4	3	1	nurse	homemaker	manually-drilled well

15	36-50	7	6	1	0	independent work	homemaker	manually-drilled well; faucet
16	NR	7	2	5	0	independent work	farmer	manually-drilled well
17	36-50	4	3	1	0	NR	craftmaker	manually-drilled well
18	50-65	7	4	3	0	state nurse	animatrice	manually-drilled well
19	36-50	6	3	3	0	salesperson	auditor	manually-drilled well
20	18-35	3	3	0	0	electrician	homemaker	manually-drilled well
21	18-35	3	2	1	0	barber	homemaker	manually-drilled well
22	50-65	6	4	2	0	retired	salesperson	manually-drilled well
23	18-35	4	2	0	2	pousse driver	homemaker	manually-drilled well
24	36-50	6	4	1	1	military	homemaker	manually-drilled well

25	36-50	2	1	1	0	X	homemaker	manually-drilled well
26	36-50	5	2	2	1	military	homemaker	manually-drilled well
27	65+	2	1	1	0	X	homemaker	manually-drilled well; faucet
28	18-35	2	1	0	1	X	salesperson	manually-drilled well
29	18-35	3	2	0	1	work at garage	secretary	manually-drilled well
30	65+	6	4	2	0	retired	retired	manually-drilled well; faucet
31	36-50	6	4	1	1	machinist / woodworker	homemaker	manually-drilled well
32	18-35	4	2	2	0	X	cashier	manually-drilled well
33	36-50	4	4	0	0	boat worker	salesperson	manually-drilled well

34	18-35	7	4	2	1	secretary	homemaker	manually-drilled well
35	36-50	6	4	2	0	driver	tailor	manually-drilled well
36	36-50	4	4	0	0	machine driver	animatrice	manually-drilled well
37	50-65	2	2	0	0	retired	X	manually-drilled well
38	36-50	2	2	0	0	X	homemaker	manually-drilled well
39	18-35	8	4	3	1	technician	salesperson	manually-drilled well
40	36-50	5	2	2	0	agent - JIRAMA!	homemaker	manually-drilled well
41	18-35	3	2	1	0	security	homemaker	manually-drilled well
42	18-35	5	2	3	0	fisherman	homemaker	manually-drilled well

43	50-65	10	5	4	1	state nurse	salesperson	manually-drilled well
44	50-65	3	3	0	0	retired	homemaker	manually-drilled well
45	36-50	6	2	3	1	daily worker at port	salesperson	manually-drilled well
46	18-35	8	2	3	3	salesperson	homemaker	manually-drilled well
47	36-50	5	3	2	0	salesperson	salesperson	manually-drilled well
48	36-50	6	2	3	1	driver	homemaker	manually-drilled well
49	36-50	7	4	2	1	storekeeper	salesperson	manually-drilled well
50	18-35	2	2	0	0	mason	homemaker	manually-drilled well
51	18-35	5	4	1	0	independent work	salesperson	manually-drilled well
52	18-35	6	3	2	1	mason	doctor	manually-drilled well
53	36-50	7	2	4	1	driver	homemaker	manually-drilled well

Survey No.	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
	Age, Water Source (years)	**Previous Source**	**Months of year gives water**	**Responsible, Maintenance of Water Point**	**Water Lifting Device**	**Age, Water Lifting Device (years)**	**Responsible, Mainten / Repair, WL Dev**	**WL Dev Repairs Done**
1	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
2	0-3	faucet	12	local technician	manual pump	NR	local technician	replace leather
3	more than 20	manually drilled well	12	local technician	manual pump	NR	local technician	add 3m piping (9 to 12): replace leather
4	0-3	faucet	12	local technician	manual pump	NR	local technician	replace leather
5	0-3	manually drilled well	12	local technician	manual pump	NR	other male adult in house	weld handle connection
6	4-10	faucet	12	male head of household	manual pump	NR	male head of household	"plomb"
7	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather

8	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, piston
9	0-3	household faucet	12	local technician	manual pump	NR	local technician	replace leather
10	4-10	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather
11	4-10	faucet	12	local technician	manual pump	NR	local technician	bolt
12	16-20	manually drilled well	12	local technician	manual pump	NR	local technician	leather, bolt
13	20+	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
14	20+	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, pump head
15	20+	manually drilled well	12	boy in household	manual pump	NR	boy in household	replace leather

16	20+	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather (top and bottom)
17	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	pump head
18	11-15	faucet	12	local technician	manual pump	NR	local technician	replace leather
19	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
20	11-15	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather
21	11-15	manually drilled well	12	boy in household	manual pump	NR	boy in household	replace pump head, wellscreen , leather
22	4-10	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather
23	11-15	manually drilled well	12	boy in household	manual pump	NR	boy in household	replace leather
24	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace head of pump and pipes
25	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, pipes

26	4-10	faucet	10-11	local technician	manual pump	NR	local technician	replace leather
27	0-3	household faucet	12	local technician	manual pump	NR	local technician	replace wellscreen , pipes
28	11-15	faucet	12	local technician	manual pump	NR	local technician	replace leather
29	20+	manually drilled well	12	male head of household	manual pump	NR	male head of household	leather, pump arm/handl e
30	20+	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
31	20+	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
32	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
33	20+	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, wellscreen , bolts

34	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace bolt(s)
35	11-15	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, wellscreen , pipes
36	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
37	4-10	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather, piston
38	0-3	manually drilled well	12	local technician	manual pump	NR	boy in household	replace bolt
39	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
40	4-10	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather
41	0-3	traditional well	12	local technician	manual pump	NR	male head of household	replace bolt
42	0-3	traditional well	12	local technician	manual pump	NR	local technician	replace leather, wood support, bolt

43	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, wellscreen , bolt(s)
44	4-10	manually drilled well	12	local technician	manual pump	NR	boy in household	replace leather
45	0-3	manually drilled well	10-11	boy in household	manual pump	NR	boy in household	replace leather
46	20+	manually drilled well	10-11	boy in household	manual pump	NR	boy in household	replace leather, piston
47	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace pipes
48	4-10	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather, wellscreen , bolt(s)
49	11-15	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather (top and bottom)
50	0-3	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
51	16-20	manually drilled well	12	local technician	manual pump	NR	local technician	replace wellscreen
52	11-15	manually drilled well	12	local technician	manual pump	NR	local technician	replace leather
53	11-15	manually drilled well	12	male head of household	manual pump	NR	male head of household	replace leather

Survey No.	Q17a	Q17b	Q17c	Q18	Q19	Q20a	Q20b	Q20c
	WL D Repair Cost - Materials	**WL D Repair Cost - Labor**	**WL D Repair Cost - Total**	**Other Water Source??**	**Who built / installed water system?**	**Cost of System - Materials**	**Cost of System - Labor**	**Total Cost of System**
1	8000	4000	12000	faucet	local technician	160000	16000	176000
2	5000	1000	6000	faucet	local technician	120000	20000	140000
3	40000	0	40000	faucet	local technician	X	X	Don't Know
4	5000	2000	7000	faucet	local technician	160000	20000	180000
5	X	X	Don't Know	faucet	local technician	X	X	Don't Know
6	X	X	Don't Know	faucet	someone in the household	X	X	Don't Know
7	5000	5000	10000	faucet	local technician	50000	50000	100000
8	10000	4000	14000	faucet	local technician	50000	0	50000

9	3000	3000	6000	NO	local technician	70000	0	70000
10	7000	0	7000	faucet	local technician	X	X	Don't Know
11	X	X	Don't Know	faucet	local technician	X	X	Don't Know
12	15000	0	15000	NO	local technician	X	X	Don't Know
13	6000	6000	12000	faucet	local technician	160000	30000	190000
14	37000	0	37000	NO	local technician	30000	0	30000
15	3500	0	3500	faucet	someone in the household	X	X	Don't Know
16	9000	0	9000	NO	local technician	20000	0	20000

17	50000	16000	66000	NO	local technician	X	X	Don't Know
18	7000	1000	8000	faucet	local technician	X	X	Don't Know
19	3000	2000	5000	faucet	local technician	X	X	Don't Know
20	3500	0	3500	faucet	local technician	140000	0	140000
21	80000	0	80000	NO	someone in the household	X	X	Don't Know
22	3000	0	3000	NO	local technician	30000	0	30000
23	7000	0	7000	NO	local technician	100000	20000	120000
24	100000	0	100000	faucet	local technician	140000	20000	160000
25	20000	10000	30000	faucet	local technician	60000	0	60000

26	3000	2000	5000	faucet	local technician	100000	20000	120000
27	30000	0	30000	household faucet	local technician	140000	10000	150000
28	3000	1000	4000	faucet	local technician	140000	20000	160000
29	40000	0	40000	faucet	local technician	X	X	Don't Know
30	4000	2000	6000	faucet	local technician	X	X	Don't Know
31	6400	0	6400	faucet	local technician	X	X	Don't Know
32	4000	2000	6000	faucet	local technician	120000	20000	140000
33	56000	0	56000	NO	local technician	60000	0	60000

34	2000	0	2000	faucet	local technicia n	100000	20000	120000
35	40000	0	40000	faucet	local technicia n	90000	0	90000
36	3000	0	3000	faucet	local technicia n	100000	20000	120000
37	13000	0	13000	NO	someone in the househol d	95000	0	95000
38	1000	0	1000	NO	local technicia n	135000	0	135000
39	8000	3000	11000	NO	local technicia n	140000	0	140000
40	7000	0	7000	Water from San Gabriel system*	local technicia n	110000	20000	130000
41	X	X	X	NO	local technicia n	200000	0	200000
42	20000	0	20000	NO	local technicia n	160000	60000	220000

43	12000	0	12000	NO	local technician	100000	0	100000
44	4500	0	4500	faucet	local technician	X	X	Don't Know
45	4000	0	4000	NO	someone in the household	120000	0	120000
46	12000	0	12000	other manually drilled well	someone in the household	X	X	Don't Know
47	30000	0	30000	faucet	local technician	X	X	Don't Know
48	30000	0	30000	faucet	local technician	X	X	Don't Know
49	7000	2000	9000	faucet	local technician	80000	0	80000
50	5000	0	5000	faucet	local technician	120000	25000	145000
51	8000	4000	12000	faucet	local technician	45000	0	45000
52	5000	0	5000	NO	local technician	X	X	Don't Know
53	15000	0	15000	NO	local technician	120000	0	120000

Survey No.	Q21/22	Q23/24	Q25	XX	YY	ZZ	Q26/27
	Subsidy, Amount	Loan, Amount	Improvement Plans in next year?	Current Daily Water Usage (liters)	Daily Water Usage MORE, LESS, or Equal previously?	Previous Daily Water Usage (liters)	Drink water from primary source? If not, where?
1	NONE	NONE	new borehole	-	-	-	YES
2	NONE	NONE	replace leather	-	-	-	YES
3	NONE	NONE	new borehole	-	-	-	YES
4	NONE	NONE	add 3m of pipe	-	-	-	YES
5	NONE	NONE	NONE	-	-	-	YES
6	NONE	NONE	replace wellscreen, pipes	-	-	-	YES
7	NONE	NONE	replace pump head	-	-	-	YES
8	NONE	NONE	replace handle	-	-	-	YES

9	NONE	NONE	NONE	300	more	200	YES
10	NONE	NONE	replace wellscreen	250	more	150	NO, from community tap
11	NONE	NONE	replace parts	150	same	150	NO, from community tap
12	NONE	NONE	NONE	100	same	100	YES
13	NONE	NONE	NONE	800	more	600	NO, from household connection to community system
14	NONE	NONE	NONE	500	more	400	YES
15	NONE	NONE	replace pipes, wellscreen	250	more	200	YES
16	NONE	NONE	new borehole	300	more	200	YES

17	NONE	NONE	replace pipes	120	more	80	YES
18	NONE	NONE	new borehole	150	more	100	YES
19	NONE	NONE	new borehole	300	more	260	NO, from community tap
20	NONE	NONE	new borehole	150	more	80	NO, from community tap
21	NONE	NONE	household connection to community water system	300	more	200	YES
22	NONE	NONE	new borehole	800	more	500	YES
23	NONE	NONE	new pump head	200	more	140	YES
24	NONE	NONE	household connection to community water system	200	more	100	YES
25	NONE	NONE	NONE	80	more	60	YES

26	NONE	NONE	replace pipes, wellscreen (i.e. new well, same pump)	130	more	100	faucet
27	NONE	NONE	NONE	50	less	160	household faucet
28	NONE	NONE	new borehole	300	more	200	faucet
29	NONE	NONE	new borehole	200	more	160	YES
30	NONE	NONE	replace wellscreen, leather	200	less	300	household faucet
31	NONE	NONE	NONE	360	more	300	YES
32	NONE	NONE	household connection to community water system	250	more	200	YES
33	NONE	NONE	NONE	300	more	200	YES

34	NONE	NONE	NONE	450	more	300	faucet
35	NONE	NONE	household connection to community water system	400	more	300	YES
36	NONE	NONE	NONE	150	more	120	faucet
37	NONE	NONE	new borehole	120	more	100	YES
38	NONE	NONE	NONE	200	less	250	YES
39	NONE	NONE	NONE	600	more	400	YES
40	NONE	NONE	NONE	300	more	250	ONG San Gabriel system
41	NONE	NONE	NONE	150	more	100	YES
42	NONE	NONE	add concrete around pump	300	more	200	YES

43	NONE	NONE	NONE	400	more	330	YES
44	NONE	NONE	NONE	100	less	200	faucet
45	NONE	NONE	NONE	250	more	230	YES
46	NONE	NONE	new borehole	300	more	260	YES
47	NONE	NONE	NONE	300	more	220	YES
48	NONE	NONE	replace leather	200	more	160	YES
49	NONE	NONE	new borehole	320	more	280	YES
50	NONE	NONE	NONE	75	more	100	YES
51	NONE	NONE	new borehole	100	less	150	YES
52	NONE	NONE	replace wellscreen, leather	320	less	400	YES
53	NONE	NONE	replace leather	400	more	370	YES

							40 out of 53 households reported drinking from Pump Tany well

Appendix B Bolivia Field Data Collection Guide and Raw Data

B.1 Survey Form

Date:
ID:
Interviewer:
Interviewee: Male   Female

Bolivia Self-supply: Assessing Access to Household Water and Sanitation with EMAS Technologies in Rural Areas of Bolivia

Household Survey

<u>Demographic Information</u>

1. What is your age?
    a. 18-35
    b. 36-50
    c. 50-65
    d. Over 65

2. How many persons live in your household? __________

3. How many are adults aged 18 and above? ____________

4. How many children aged 5 – 17? _______________

5. How many children under 5 years? ____________

6. What is the occupation of male head of household? ___________

7. What is the occupation of female head of household? ___________

<u>Water and Sanitation Infrastructure Systems in Household</u>

8. What type of household water source does your family have?
    a. Hand-dug well
    b. Manually drilled Well
    c. Rainwater Harvesting System
    d. Piped water from community system
    e. Other ___________________________

9. What is the age of the household water source?
    a. 0-3 years

b. 4-10 years
c. 11-15 years
d. 16-20 years
e. Older than 20 years

10. Where did you get your water before you had the current system?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years

11. How many months per year does this source provide water?
    a. 1-3 months per year
    b. 4-6 months per year
    c. 6-9 months per year
    d. 10-11 months per year
    e. Other ___________________________

12. Who is responsible for maintaining the water source?
    a. Female head of household
    b. Male head of household
    c. Other female adult in household
    d. Other male adult in household
    e. Female child
    f. Male child
    g. Other ___________________________

13. What do you use to lift water from the water source?
    a. Rope and Bucket
    b. Manual pump
    c. Fuel-powered pump
    d. Motorized pump
    e. Other ___________________________

14. What is the age of the household water-lifting device?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years

15. Who is responsible for repair and maintenance of the water-lifting device?
    a. Female head of household
    b. Male head of household
    c. Other female adult in household

d. Other male adult in household
e. Female child
f. Male child
g. Other ___________________________

16. Does your family get any water for the household from another source? YES or NO

If YES, what type of source is this secondary source?

a. Hand-dug well
b. Manually drilled Well
c. Rainwater Harvesting System
d. Piped water from community system
e. Other ___________________________

Water and Sanitation System Construction

17. Who built/installed your household water and sanitation systems (circle all that apply)?

a. Self (anyone in family)
b. Friend
c. Local Technician(s)
d. Other ____________________________________

18. Did you receive subsidies to pay for your household water and sanitation system? YES or NO

If YES, where did the subsidies come from?

a. Local municipality (specify name _______________)
b. Local or national NGO (specify name ____________)
c. International NGO (specify name ________________)
d. Other ____________________________________

19. Did you receive subsidies a loan to pay for your household water and sanitation system? YES or NO

If YES, where did the subsidies come from?

a. Local municipality (specify name _______________)
b. Local or national NGO (specify name ____________)
c. International NGO (specify name ________________)
d. Other ____________________________________

20. Do you have any plans to upgrade your household water and sanitation system within the next year?

YES or NO

If YES, what upgrade(s) do you plan on making?

a. Replace pump (specify type of new pump _____)
b. Add tank
c. Add piping to house

d. New well
e. Other ___________________________________

Household Water Practices & Use

21. Is the water from the EMAS system used for drinking water?
    a. Yes
    b. No

22. If no, what is the source for drinking water? __________________________

23. What is the water from the EMAS system used for? (circle all that apply)
    a. Drinking (Note: Already answered in Question #21)
    b. Washing food/cooking
    c. Hand washing
    d. Bathing
    e. Brushing teeth
    f. Clothes washing
    g. Irrigation (flowers, crops, etc.)
    h. Other _____________

24. What methods do you use to treat your water before use?
    a. Storage tank disinfection (What kind of disinfection? ____________________________)
    b. Point of use disinfection (What kind of disinfection? _____________________________)
    c. Boiling
    d. Filter (what type? ____________)
    e. Other ___________
    f. None

25. Is water treated for all uses or only for drinking?
    a. Yes
    b. No
    c. Treated for drinking and _________________

26. Does someone disinfect the water in the storage tank? (If answer is NO, skip to Question 29)
    a. Yes
    b. No

27. If yes to disinfection, how frequently is the water disinfected?
    a. Daily
    b. Weekly
    c. Monthly
    d. Every 6 months
    e. Annually
    f. Rarely
    g. Other _____________

28. If yes to disinfection, when was the last time of disinfection?
    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year

Household Sanitation

29. What type of sanitation system do you have in your household?
    a. None
    b. Pit Latrine
    c. VIP Latrine
    d. EcoSan Latrine
    e. Pour-flush latrine
    f. Septic System
    g. Other __________

30. What is the age of the household sanitation system?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years

31. Where did you get your water before you had the current system?
    a. None
    b. Pit Latrine
    c. VIP Latrine
    d. EcoSan Latrine
    e. Pour-flush latrine
    f. Septic System
    g. Other __________

Thank you for your time. The survey is now complete.

B.2 Observation/Inspection Sheet

Date:
ID:
Observer:

Factors Bolivia Self-Supply: Assessing Access to Household Water and Sanitation

with EMAS Technologies in Rural Areas of Bolivia

Inspection Sheet

House (building) Observations

1. How many levels does the house have?
   a. One b. Two
2. Approximately how many rooms are in the house?
   a. 1-3
   b. 4-6
   c. 7-9
   d. 10 or more
3. Is there a separate room for the kitchen?
   Yes No
4. What type of toilet do the household members use? (Confirm – also asked in survey)
   a. None
   b. Pit Latrine
   c. VIP Latrine
   d. EcoSan Latrine
   e. Pour-flush latrine
   f. Septic System
   g. Other ___________
5. Estimate the area (in sq. meters) of the roof (i.e. area that can be used to capture rain)

6. General observations (roof and housing materials, fresh paint, furniture, general condition of the house, etc.)

____

Water System Inspection

7. What is the EMAS-type water source? (Confirm – also asked in survey)
   a. Hand-dug well

b. Manually drilled Well
c. Rainwater Harvesting System
d. Piped water from community system
e. Other ___________________________

8. Is there a water storage tank.

YES NO

9. If YES to Question 8, What is the approximate tank capacity in liters? ___________ (diam_____ , depth____)
10. Where is the tank located?
    a. Roof top
    b. On top of other elevated structure
    c. Above ground, not elevated
    d. Below ground
    e. Other _____________
11. What is the tank made of?
    a. Reinforced concrete
    b. Unreinforced concrete
    c. Ferrocement
    d. Plastic
    e. Metal
    f. Other _____________
12. Does the tank have a cover or lid?

Yes No

13. If yes to Question 12, what is the cover or lid made of? ____________

14. Is a manual pump used?

YES NO

15. If YES to Question 14, is the manual pump functional?

YES NO NA

16. If YES to Question 15, what is the measured flow rate from the manual pump?

________ time to pump 20 liters (trial 1) _________ time to pump 20 liters (trial 2) _____ average

17. General observations (conditions of well, pump, tank, RWH gutters, etc.)

____

Sanitation System Inspection

18. Does the latrine appear to be a standard EMAS latrine?

YES NO

19. If no to Question 18, what is the latrine made of? (circle all that apply, and take photos)
    a. Reinforced concrete
    b. Unreinforced concrete
    c. Ferrocement
    d. Plastic
    e. Metal (e.g. currogated iron/zinc)
    f. Other _____________
20. Does the latrine appear to be used on a regular basis?

    YES NO
21. Are there hand-washing facilities within 5 meters of the latrine?

    YES No
22. Describe the general condition of the sanitation infrastructure:

B.3 Semi-structured Interview Script

Bolivia Self-Supply Study

Semi-Structured Interview Script: Water/Sanitation Technicians

Purpose: to help determine the experiences that technicians have had with implementing EMAS household water and sanitation technologies in rural areas of Bolivia.

Introduction

Good morning/afternoon, and welcome. Thank you for agreeing to participate in our discussion of household water supply systems. My name is Michael MacCarthy, and I represent the University of South Florida in the Unites States. My project colleague(s) (_____________ and _______________ , will be assisting. We are attempting to gather information on EMAS low-cost water supply systems used at the family/household level in Bolivia. We have invited several other people to share their experiences and ideas.

Questioning Route (time estimates in parentheses are for Focus Groups)

Opening:	1. Tell us your name (first name and family name) and the name of the village/region in which you work.
Introductory:	2. How did you learn about EMAS household water and sanitation systems?

Transition: 3. When you first saw an EMAS manual water pump working, what were your first impressions?

4. When you first saw an EMAS water well being drilled, what were your first impressions?

5. How (and when) did receive training in EMAS technologies?

Key Questions: 6. What do you like about EMAS systems?

7. In your experience, what specific problems do users of EMAS systems most often have?

8. What do users tell you that they like about EMAS systems?

9. What percentage of your monthly income comes from building, installing or servicing EMAS systems?

10. In managing your project/business, what aspect do you find the most difficult?

11. Who do you get help from when you have questions about EMAS technologies or running your project/business?

12. Is the help that you get from others about EMAS technologies or running your project/business sufficient? What additional support do you feel would be of benefit to you in managing your project/business?

Ending Questions: 13. We would like for you to help us to evaluate the EMAS systems and your experiences implementing projects using these systems. We want to know how the service these systems provide can be improved. Is there anything that we have not spoken about that you would like to add about the EMAS systems and your experiences with household water supply

B.4 Bolivia Household Surveys – Raw Data

Table B1. Cachilaya survey data

Subject	Department	Village			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14		
			Survey No.	Respondant (M/F)	Age (years)	# in hh	Adults	kids 5-17	kids lt5	Head of household 1	Head of household 2	Type, Water Source	Age, Water Source (years)	Previous Source	Months of year gives water	Responsible, Maintenance of Water Point	Water Lifting Device	Age, Water Lifting Device (years)	Pump functional?	State of functionality
RWHS	La Paz	Cachilaya	1	Male	b	20	18	2	0	portero	comercio	RWHS	4-10	community well	12	male head of household	manual pump	4-10	YES	Normal
			2	Male	a	7	3	3	1	albanil	X	RWHS	0-3	community well	6-9	male head of household	manual pump	0-3	YES	Normal
			3	Male	c	4	2	2	0	agricultor, albanil	X	RWHS	4-10	community well	10-11	male head of household	rope and bucket	0-3	NA - No pump	NA
			4	Male	a	5	3	2	0	agricultura, ganadaria	X	RWHS	0-3	hand-dug well	NR	male head of household	manual pump	0-3	YES	Normal
			5	Female	b	4	2	2	0	pescador	X	RWHS	0-3	hand-dug well	12	male head of household	manual pump	0-3	YES	Normal
			6	Male	b	5	2	3	0	pescador	X	RWHS	0-3	hand-dug well	12	male head of household	manual pump	0-3	YES	Normal
			7	Male	b	9	5	3	1	pescador	comercio	RWHS	4-10	community well	12	male head of household	manual pump	#1 - 0-3; #2 - 4-10	YES	Normal
			8	Male	c	8	6	2	0	albanil	comercio	RWHS	0-3	community well	10-11	male head of household	rope and bucket	0-3	NA - No Pump	
																			6 out of 6 manual pumps working	6 out of 6 manual pumps functio

Table B2. Pampa Chililaya survey data

Subject	Departme nt	Village			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14			
			Survey No.	Respondant (M/F)	Age (years)	# in hh	Adults	kids 5-17	kids lt 5	Head of household 1	Head of household 2	Type, Water Source	Age, Water Source (years)	Previous Source	Months of year gives water	Responsible, Maintenance of Q12 Water Point	Water Lifting Device	Age, Water Lifting Device (years)	Pump functional?	State of functionality	problem with pump
Pumps/Wells - Rural Villages	La Paz	Pampa Chililaya	1	Male	over 65	1	1	0	0	agricultur	X	manually-drilled well	0-3	hand-dug well	12	male head of household	manual pump	0-3	YES	Normal	
			2	Fem ale	over 65	1	1	0	0	ganaderia	X	manually-drilled well	4-10	river or stream	12	female head of household	manual pump	4-10	YES	Normal	
			3	Male	b	5	3	2	0	forragero ?	ganaderia y comercio	manually-drilled well	4-10	hand-dug well	12	male head of household	manual pump	4-10	YES	Normal	
			4	Male	c	3	2	1	0	agricultur a	ganaderia	manually-drilled well	0-3	hand-dug well	12	male head of household	manual pump	0-3	YES	Normal	
			5	Male	c	4	3	1	0	agricultur a y ganadaria	X	manually-drilled well	16-20	hand-dug well	12	male head of household	manual pump	0-3	YES	Not functioni ng normally	low flow
			6	Male	b	7	6	1	0	pescador, agricultur a	X	manually-drilled well	0-3	hand-dug well	1-3???	other adult male in the household	manual pump	0-3	YES	Normal	
			7	Male	c	3	1	2	0	ganaderia	X	manually-drilled well	0-3	hand-dug well	??? (ojo)	female head of household	manual pump	0-3	YES	Normal	
															5 out of 7 provide water 12 months / yr				**7 out of 7 manu al pump s worki**	6 out of 7 manual pumps functioni ng normally	

Table B3. Izozog survey data

Subject	Department	Village			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14					
			Survey No.	Respondant (M/F)	Age (years)	# in hh	Adults	kids 5-17	kids lt 5	Head of household 1	Head of household 2	Type, Water Source	Age, Water Source (years)	Previous Source	Months of year gives water	Responsible, Maintenance of Q12 Water Point	Water Lifting Device	Age, Water Lifting Device (years)	Pump functional?	State of functionality	Comments		
Pumps/Wells - Rural Villages	Santa Cruz	Izozog	1	Female	b	10	2	7	1	guardaparques	X	manually-drilled well	4-10	manually-drilled well	12	female head of household	manual pump	4-10	YES	Normal			
			2	Female	c	6	4	2	0	agricultor	X	manually-drilled well	16-20	community well	12	female head of household	manual pump	16-20	YES	Very Poor	long time to prime, and very little water		
			3	Female	c	6	5	0	1	agricultor	X	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal			
			4	Male	a	7	2	0	5	agricultor	X	manually-drilled well	11-15	community well	12	female head of household	manual pump	11-15	YES	Very Good	Pumps very well, high pressure		
			5	Male	c	10	4	5	1	agricultor y ganaderia	X	manually-drilled well	4-10	manually-drilled well	12	male head of household	manual pump	4-10	YES	Normal			
			6	Male	a	6	2	1	3	ganaderia	X	manually-drilled well	0-3	neighbor's manually-drilled well	12	male head of household	manual pump	0-3	YES	Normal			
			7	Male	a	7	3	0	4	agricultor	X	manually-drilled well	4-10	No sabe	12	female head of household	manual pump	4-10	YES	Poor	takes a long time to prime, not much water per		
			8	Female	b	4	4	0	0	tejido/telares	X	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Very Good	very effective pump, no priming needed, good flow rate		
			9	Male	a	15	13	1	1	agricultor	X	manually-drilled well	11-15	manually-drilled well	12	male head of household	manual pump	11-15	YES	Good			
			10	Male	c	7	3	4	0	agricultor	X	manually-drilled well	over 20	community well	12	male head of household	manual pump	over 20	YES	Normal			
			11	Male	a	8	2	5	1	agricultor	agricultora	manually-drilled well	11-15	community well	12	other adult male in the household	manual pump	11-15	YES	Normal			
			12	Female	c	7	4	3	0	agricultor	tejido / telar	manually-drilled well	4-10	river or stream	12	female head of household	manual pump	4-10	YES	Normal			
			13	Male	c	10	5	5	0	agricultor	X	manually-drilled well	4-10	manually-drilled well, tap from communit	12	male head of household	manual pump	4-10	YES	Normal			
			14	Female	b	8	3	5	0	agricultora	X	manually-drilled well	4-10	brother's manually-drilled well	12	female head of household	manual pump	4-10	YES	Poor			
			15	Male	a	4	2	0	2	agricultor	X	manually-drilled well	4-10	manually-drilled well	12	male head of household	manual pump	4-10	YES	Normal			
			16	Female	c	15	6	6	3	agricultor	X	manually-drilled well	11-15	community well	12	female head of household	manual pump	11-15	YES	Normal			
			17	Female	c	6	4	0	2	agricultor	tejido / telar	manually-drilled well	4-10	manually-drilled well	12	female head of household	manual pump	4-10	YES	Normal			
			18	Female	c	7	5	0	2	agricultor	X	manually-drilled well	11-15	manually-drilled well	12	female head of household	manual pump	11-15	YES	Not very good	leak in handle, and pump rising pipe		
			19	Male	b	7	2	4	1	agricultora	X	manually-drilled well	4-10	community well	12	male head of household	manual pump	4-10	YES	Normal			
			20	Female	a	9	4	4	1	agricultor	X	manually-drilled well	4-10	manually-drilled well	12	male head of household	manual pump	4-10	YES	Normal	additional old well that no longer has a pump		
			21	Female	a	6	2	3	1	sector publica	X	manually-drilled well	4-10	manually-drilled well	12	male head of household	manual pump	4-10	YES	Not very good	leak at connection of spout and handle		
			22	Male	b	7	4	2	1	agricultor	tejido / telar	manually-drilled well	11-15	community well	12	male head of household	manual pump	11-15	YES	Not very good	pump takes a while to prime, pumps a bit slowly	owner took pump out - there was a piercing just above the valve where water was leaking	
			23	Female	b	2	2	0	0	agricultor	X	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	good			
			24	Female	a	2	2	0	0	tecnico	X	manually-drilled well	4-10	brother's manually-drilled well	12	female head of household	manual pump	4-10	YES	Not very good			
			25	Female	a	8	3	3	2	agricultor	X	manually-drilled well	11-15	community well	12	female head of household	manual pump	11-15	YES	Normal			
			26	Female	a	15	4	10	3	tejido/telares	X	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal			
			27	Female	d	8	6	1	1	agricultor	artesania	manually-drilled well	4-10	community well	12	male head of household	manual pump	4-10	YES	Normal			
			28	Female	c	7	7	0	0	agricultor	tejido	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal			
			29	Male	c	6	3	3	0	agricultor	tejido/telares	manually-drilled well	4-10	community well	12	male head of household	manual pump	4-10	YES	Normal			
			30	Male	b	6	3	3	0	agricultor	X	manually-drilled well	4-10	community well	12	male head of household	manual pump	4-10	NO	Pump reported to be broken for a week	Pump not in well - has been pulled out	owner says bottom valve is the problem (has no rubber ring)	outer pump tubing fell down the borehole
			31	Male	b	8	5	3	0	agricultor	X	manually-drilled well	11-15	community well	12	male head of household	manual pump	11-15	YES	Normal			
			32	Male	c	3	2	1	0	agricultor	X	manually-drilled well	11-15	manually-drilled well	12	male head of household	manual pump	11-15	YES	Normal		also an old well - kids had taken pump out and filled in with sand	
			33	Female	d	6	5	1	0	agricultor	X	manually-drilled well	16-20	community well	12	female head of household	manual pump	16-20	YES	Normal			
			34	Female	b	10	5	2	3	agricultor	agricultora	manually-drilled well	11-15	community well	12	female head of household	manual pump	11-15	YES	Normal			
			35	Female	b	10	6	0	4	agricultor	tejido	manually-drilled well	16-20	community well	12	female head of household	manual pump	16-20	YES	Not very good	low flow from pump		
			36	Female	c	8	7	0	1	agricultor	artesana	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Very Good			
															36 out of 36 provide water 12 months per year			10 out of 14 pumps installed over 10 yrs ago functioning normally	**35 out of 36 pumps working**	*27 out of 35 functioning pumps operate normally*			

Table B4. Somopai survey data

Subject	Department	Village			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14			
			Survey No.	Respondant (M/F)	Age (years)	# in hh	Adults	kids 5-17	kids lt 5	Head of household 1	Head of household 2	Type, Water Source	Age, Water Source (years)	Previous Source	Months of year gives water	Responsible, Maintenance of Water Point	Water Lifting Device	Age, Water Lifting Device (years)	Pump functional?	State of functionality	
Pumps/Wells - Rural Villages	Beni	Somopay	1	Female	50-65	4	1	3	0	dentista	X	manually-drilled well	No sabe	community well	12	female head of household	manual pump	No sabe	YES	Normal	
			2	Female	36-50	8	6	2	0	maestro	maestra	manually-drilled well	4-10	community well	6-9	female head of household	manual pump	4-10	YES	Normal	
			3	Male	36-50	4	4	0	0	maestro	X	manually-drilled well	4-10	community well	12	"all"	manual pump	4-10	YES	Normal	
			4	Male	18-35	5	2	2	1	ganaderia	X	manually-drilled	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal	
			5	Female	36-50	5	2	2	1	agricultor	panaderia	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal	
			6	Female	18-35	4	2	0	2	contratista	X	manually-drilled	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal	
			7	Female	18-35	4	2	0	2	agricultor	X	manually-drilled	No sabe	community well	12	female head of household	manual pump	4-10	YES	Normal	Salty water taste
			8	Male	36-50	5	2	2	1	agricultor	agricultora	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal	
			9	Female	36-50	4	2	1	1	comercio	X	manually-drilled well	4-10	community well	12	female head of household	manual pump	4-10	YES	Normal	
															8 out of 9 provide water 12 months /yr				9 out of 9 manual pumps working	9 out of 9 manual pumps functioning normally	

Table B5. Reyes survey data

Subject	Department	Village			Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14		
			Survey No.	Respondant (M/F)	Age (years)	# in hh	Adults	kids 5-17	kids lt 5	Head of household 1	Head of household 2	Type, Water Source	Age, Water Source (years)	Previous Source	Months of year gives water	Responsible, Maintenance of Water Point	Water Lifting Device	Age, Water Lifting Device (years)	Manual Pump functional?	State of functionality
Pumps/Wells - Rural Town		Reyes	1	Female	36-50	7	1	5	1	logger and driller	X	manually-drilled well	0-3	neighbor's manually-drilled well	NR	female head of household	manual pump	0-3	YES	Normal
			2	Male	50-65	5	5	0	0	farmer	X	manually-drilled well	4-10	family well (hand dug)	12	male head of household	manual pump	4-10	YES	Normal
			3	Male	50-65	6	3	2	1	farmer	X	manually-drilled well	0-3	family well (hand dug)	12	male head of household	manual pump	0-3	YES	Normal
			4	Female	36-50	7	2	3	2	chapista	X	manually-drilled well	No sabe	No sabe	12	female head of household	electric pump	No sabe	NA - Electric Pump	NA
			5	Female	36-50	2	1	1	0	homemaker	X	manually-drilled well	No sabe	No sabe	12	female head of household	manual pump	No sabe	YES	Normal
			6	Female	36-50	8	5	3	0	ganadero	comercio	manually-drilled well	4-10	family well (hand dug)	12	female head of household	manual pump	4-10	YES	Normal
			7	Male	over 65	3	3	0	0	jubilado	X	manually-drilled well	4-10	tap from community system, manually-drilled well	12	male head of household	electric pump	0-3	NA - Electric Pump	NA
			8	Female	18-35	4	2	0	2	asesor de credito	docente	manually-drilled well	0-3	manually-drilled well	12	female head of household	electric pump	0-3	NA - Electric Pump	NA
			9	Female	36-50	11	6	4	1	ganadero	homemaker	manually-drilled well	4-10	family well (hand dug)	12	female head of household	electric pump	0-3	NA - Electric Pump	NA
			10	Female	36-50	6	3	3	0	madarero	X	manually-drilled well	16-20	neighbor's hand-dug well	12	female head of household	manual pump	16-20	YES	Not very good (very slow pumping)
			11	Female	18-35	10	5	3	2	cerrajeria	X	manually-drilled well	4-10	tap from community system, manually-drilled well	12	female head of household	manual pump	4-10	YES	Not very good
			12	Female	over 65	6	4	1	1	???	X	manually-drilled well	4-10	tap from community system, hand dug well	12	female head of household	manual pump	4-10	YES	Not great
			13	Female	18-35	9	2	3	4	logger	X	manually-drilled well	11-15	family well (hand dug), community water system	12	male head of household	manual pump	11-15	YES	Normal
			14	Female	36-59	4	2	2	0	panaderia	X	manually-drilled well	4-10	family well (hand dug), community water system	12	female head of household	manual pump	11-15	YES	Normal
			15	Male	50-65	1	1	0	0	transporte	X	manually-drilled well	4-10	manually-drilled well	12	male head of household	manual pump	0-3	YES	Normal
			16	Female	50-65	7	5	2	0	jornalero	lavandera	manually-drilled well	0-3	neighbor's hand-dug well	12	female head of household	manual pump	0-3	YES	Normal
			17	Male	18-35	4	2	2	0	mecanico	X	manually-drilled well	0-3	family well (hand dug)	12	female head of household	manual pump	0-3	YES	Normal
			18	Female	18-35	4	2	1	1	carpinteria	X	manually-drilled well	4-10	family well (hand dug)	12	female head of household	electric pump	4-10	NA - Electric Pump	NA
			19	Male	18-35	8	4	3	1	artesano	artesana	manually-drilled well	0-3	No sabe	NR	male head of household	manual pump	0-3	YES	Normal
			20	Male	36-50	10	5	4	1	ganaderia, motosier	homemaker	manually-drilled well	0-3	manually-drilled well	12	other adult male in the household	manual pump	0-3	YES	Normal
			21	Male	36-50	5	4	1	0	caminos (ABC transpor	artesania	manually-drilled well	0-3	hand-dug well	12	female head of household	manual pump	0-3	YES	Normal
			22	Female	18-35	5	3	1	1	veterinario	profesora	manually-drilled well	4-10	hand-dug well	12	female head of household	manual pump	4-10	YES	Normal
			23	Female	over 65	6	3	3	0	albanil	X	manually-drilled well	4-10	arroyo???	12	female head of household	manual pump	4-10	YES	Normal
			24	Male	50-65	12	8	2	2	armero	comercio	manually-drilled well	4-10	hand-dug well	12	male head of household	manual pump	4-10	YES	Normal
			25	Male	18-35	6	3	2	1	agricultor	mecanico	manually-drilled well	11-15	hand-dug well	12	other adult male in the household	manual pump	11-15	YES	Normal
			26	Female	50-65	7	3	2	2	jornalero	secretaria	manually-drilled well	0-3	manually-drilled well	12	female head of household	manual pump	0-3	YES	Normal
															24 out of 24 (with 2 no replies) provide water 12months out of the year			3 out of 4 pumps installed over 10 yrs ago functioning normally	**21 out of 21 manual pumps working**	18 out of 21 pumps function normally

Appendix C Uganda Field Data

C.1 Uganda Field Data - Additional Charts from Pumping Tests

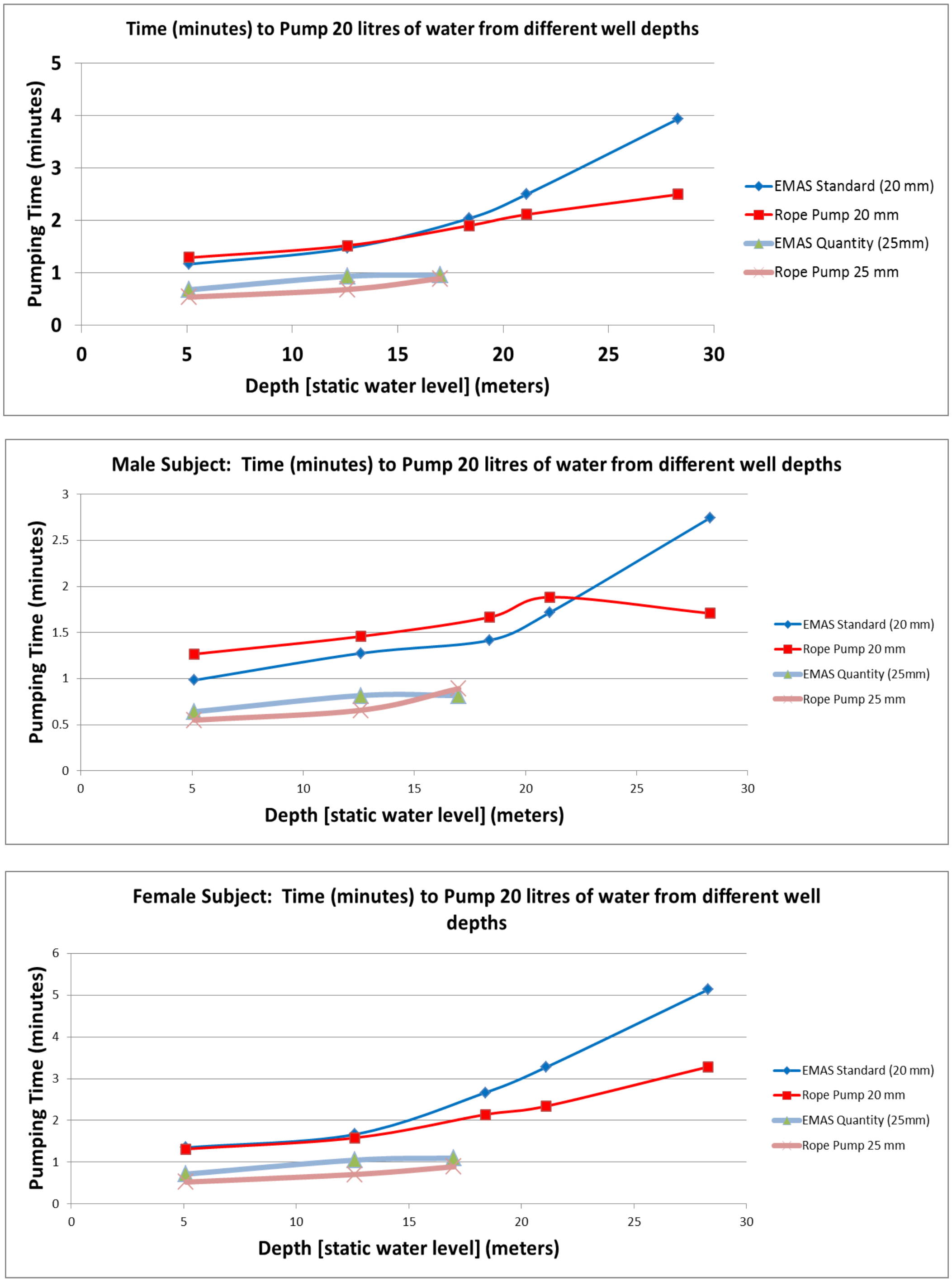

Figure C1. Graphs indicating average time to pump 20 liters at various depths

C.2 Material Costs for EMAS Pumps and Rope Pumps (Kampala)

Table C1. Material costs for 20-mm Rope Pump – 10 m depth

Family Model Rope Pump (20mm riser pipe)					Depth =	10					
Material	Size	Type	Misc	Use	Unit	Quantity	Unit Sold		Unit Price 1	Total Price	USD $
GI	1/2"	STD pipe	2.2mm wall	pump frame / guide box	m	5.75	6	m	UGX 28,000	UGX 26,833	$10.73
GI	3/4"	STD pipe		pump frame / guide box	m	1	6	m	UGX 35,000	UGX 5,833	$2.33
GI	1"	STD pipe		pump frame / guide box	m	0.3	6	m	UGX 68,000	UGX 3,400	$1.36
PVC	20mm	PN 16	(~1/2")	riser pipe	m	10.75	6	m	UGX 5,500	UGX 9,854	$3.94
PVC	25mm	PN10	(~3/4")	handle grip	m	0.1	6	m	UGX 6,800	UGX 113	$0.05
PVC	32mm	PN 10	(~1")	guide pipes	m	1.5	6	m	UGX 10,800	UGX 2,700	$1.08
PVC	50mm	PN 6	(~1.5")	pump spout	m	1	6	m	UGX 17,000	UGX 2,833	$1.13
PVC	50mm	Tee	fitting	spout connection	EACH	2	6	m	UGX 4,800	UGX 1,600	$0.64
PVC	50mm>32mm	Bushing	fitting	riser > spout adaptor	EACH	4	1	EACH	UGX 1,500	UGX 6,000	$2.40
PVC	32mm>25mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
PVC	32mm>20mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
polyrope	4mm		100m roll	rope	EACH	23	100	m roll	UGX 22,000	UGX 5,060	$2.02
Used Car Tire	14"	No Steel!!	whole tire	washers /wheel	EACH	1	1	EACH	UGX 10,000	UGX 10,000	$4.00
Iron round bar	8mm			rebar for install	m	2	12	m	UGX 20,000	UGX 3,333	$1.33
Paint	Rex Oxide			prevents rust	Small can	1	1	EACH	UGX 6,000	UGX 6,000	$2.40
Spray Paint	Any Color			coating	Can	1	1	EACH	UGX 15,000	UGX 15,000	$6.00
Welding Rods	2.5mm			welding	EACH	12	1	EACH	UGX 200	UGX 2,400	$0.96
Grinding Discs				cutting / grinding	EACH	1	1	EACH	UGX 14,000	UGX 14,000	$5.60
										UGX 117,361	**$46.94**

Table C2. Material costs for 20-mm Rope Pump – 25 m depth

Family Model Rope Pump (20mm riser pipe)					Depth =	25					
Material	Size	Type	Misc	Use	Unit	Quantity	Unit Sold		Unit Price 1	Total Price	USD $
GI	1/2"	STD pipe	2.2mm wall	pump frame / guide box	m	5.75	6	m	UGX 28,000	UGX 26,833	$10.73
GI	3/4"	STD pipe		pump frame / guide box	m	1	6	m	UGX 35,000	UGX 5,833	$2.33
GI	1"	STD pipe		pump frame / guide box	m	0.3	6	m	UGX 68,000	UGX 3,400	$1.36
PVC	20mm	PN 16	(~1/2")	riser pipe	m	25.75	6	m	UGX 5,500	UGX 23,604	$9.44
PVC	25mm	PN10	(~3/4")	handle grip	m	0.1	6	m	UGX 6,800	UGX 113	$0.05
PVC	32mm	PN 10	(~1")	guide pipes	m	1.5	6	m	UGX 10,800	UGX 2,700	$1.08
PVC	50mm	PN 6	(~1.5")	pump spout	m	1	6	m	UGX 17,000	UGX 2,833	$1.13
PVC	50mm	Tee	fitting	spout connection	EACH	2	6	m	UGX 4,800	UGX 1,600	$0.64
PVC	50mm>32mm	Bushing	fitting	riser > spout adaptor	EACH	4	1	EACH	UGX 1,500	UGX 6,000	$2.40
PVC	32mm>25mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
PVC	32mm>20mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
polyrope	4mm		100m roll	rope	EACH	53	100	m roll	UGX 22,000	UGX 11,660	$4.66
Used Car Tire	14"	No Steel!!	whole tire	washers /wheel	EACH	1	1	EACH	UGX 10,000	UGX 10,000	$4.00
Iron round bar	8mm			rebar for install	m	2	12	m	UGX 20,000	UGX 3,333	$1.33
Paint	Rex Oxide			prevents rust	Small can	1	1	EACH	UGX 6,000	UGX 6,000	$2.40
Spray Paint	Any Color			coating	Can	1	1	EACH	UGX 15,000	UGX 15,000	$6.00
Welding Rods	2.5mm			welding	EACH	12	1	EACH	UGX 200	UGX 2,400	$0.96
Grinding Discs				cutting / grinding	EACH	1	1	EACH	UGX 14,000	UGX 14,000	$5.60
										UGX 137,711	**$55.08**

Table C3. Material costs for 20-mm EMAS Pump – 10 m depth

EMAS "Standard" Pump	20mm pumping pipe			Depth of pump=	10						
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**	**Unit Sold**		**Unit Price 1**	**Total Price**	**USD $**
GI	1/2"	Std Pipe		Handle	m	1.3	6	m	UGX 28,000	UGX 6,067	$2.43
GI	1/2"	Tee		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
GI	1/2"	Elbow		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
GI	1/2"	Cap		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
PVC	20mm	PN 16	grey pressure pipe	Pumping Pipe	m	9.5	6	m	UGX 5,500	UGX 8,708	$3.48
PVC	32mm	PN 10	grey pressure pipe	Pump Casing	m	7.5	6	m	UGX 10,800	UGX 13,500	$5.40
PVC	25mm	PN 16	grey pressure pipe	Valve Component	m	0.3	6	m	UGX 8,700	UGX 435	$0.17
PVC	1/2"	Sch 40	blue pressure pipe	Valve Component	m	0.3	6	m	UGX 10,700	UGX 535	$0.21
Used Car Tire	small	sidewall		gasket	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
marble	small			valves	EACH	2	12	bag	UGX 5,000	UGX 833	$0.33
										UGX 34,078	**$13.63**

Table C4. Material costs for 20-mm EMAS Pump – 25 m depth

EMAS "Standard" Pump	20mm pumping pipe			Depth of pump=	25						
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**	**Unit Sold**		**Unit Price 1**	**Total Price**	**USD $**
GI	1/2"	Std Pipe		Handle	m	1.3	6	m	UGX 28,000	UGX 6,067	$2.43
GI	1/2"	Tee		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
GI	1/2"	Elbow		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
GI	1/2"	Cap		Handle	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
PVC	20mm	PN 16	grey pressure pipe	Pumping Pipe	m	24.5	6	m	UGX 5,500	UGX 22,458	$8.98
PVC	32mm	PN 10	grey pressure pipe	Pump Casing	m	18.75	6	m	UGX 10,800	UGX 33,750	$13.50
PVC	25mm	PN 16	grey pressure pipe	Valve Component	m	0.3	6	m	UGX 8,700	UGX 435	$0.17
PVC	1/2"	Sch 40	blue pressure pipe	Valve Component	m	0.3	6	m	UGX 10,700	UGX 535	$0.21
Used Car Tire	small	sidewall		gasket	EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
marble	small			valves	EACH	2	12	bag	UGX 5,000	UGX 833	$0.33
										UGX 68,078	**$27.23**

Table C5. Material costs for 25-mm Rope Pump – 5 m depth

Family Model Rope Pump (25mm riser pipe)					Depth =	5					
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**			**Unit Price 1**	**Total Price**	**USD $**
GI	1/2"		2.2mm wall	pump frame	m	5.75	6	m	UGX 28,000	UGX 26,833	$10.73
GI	3/4"			pump frame	m	1	6	m	UGX 35,000	UGX 5,833	$2.33
GI	1"			pump frame	m	0.25	6	m	UGX 68,000	UGX 2,833	$1.13
PVC	25mm	PN10	(~3/4")	riser pipe / handle grip	m	5.85	6	m	UGX 6,800	UGX 6,630	$2.65
PVC	32mm	PN 6	(~1")	guide pipes	m	1.5	6	m	UGX 10,800	UGX 2,700	$1.08
PVC	50mm	PN 6	(~1.5")	pump spout	m	1	6	m	UGX 17,000	UGX 2,833	$1.13
PVC	50mm	Tee	fitting	spout connection	EACH	2	6	m	UGX 4,800	UGX 1,600	$0.64
PVC	50mm>32mm	Bushing	fitting	riser > spout adaptor	EACH	4	1	EACH	UGX 1,500	UGX 6,000	$2.40
PVC	32mm>25mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
PVC	32mm>20mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
polyrope	6mm		100m roll	rope	EACH	13	100	m roll	UGX 25,000	UGX 3,250	$1.30
Used Car Tire	14"	No Steel!!	whole tire	washers / plungers	EACH	1	1	EACH	UGX 10,000	UGX 10,000	$4.00
Iron round bar	10mm			rebar for install	m	2	12	m	UGX 20,000	UGX 3,333	$1.33
Paint	Rex Oxide			prevents rust	Small can	1	1	EACH	UGX 6,000	UGX 6,000	$2.40
Spray Paint	Any Color			coating	Can	1	1	EACH	UGX 15,000	UGX 15,000	$6.00
Welding Rods	2.5mm			welding	EACH	12	1	EACH	UGX 200	UGX 2,400	$0.96
Grinding Disc				cutting /grinding	EACH	1	1	EACH	UGX 14,000	UGX 14,000	$5.60
										UGX 111,647	**$44.66**

Table C6: Material costs for 25-mm Rope Pump – 15 m depth

Family Model Rope Pump (25mm riser pipe)					Depth =	15					
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**			**Unit Price 1**	**Total Price**	**USD $**
GI	1/2"		2.2mm wall	pump frame	m	5.75	6	m	UGX 28,000	UGX 26,833	$10.73
GI	3/4"			pump frame	m	1	6	m	UGX 35,000	UGX 5,833	$2.33
GI	1"			pump frame	m	0.25	6	m	UGX 68,000	UGX 2,833	$1.13
PVC	25mm	PN10	(~3/4")	riser pipe / handle grip	m	15.85	6	m	UGX 6,800	UGX 17,963	$7.19
PVC	32mm	PN 6	(~1")	guide pipes	m	1.5	6	m	UGX 10,800	UGX 2,700	$1.08
PVC	50mm	PN 6	(~1.5")	pump spout	m	1	6	m	UGX 17,000	UGX 2,833	$1.13
PVC	50mm	Tee	fitting	spout connection	EACH	2	6	m	UGX 4,800	UGX 1,600	$0.64
PVC	50mm>32mm	Bushing	fitting	riser > spout adaptor	EACH	4	1	EACH	UGX 1,500	UGX 6,000	$2.40
PVC	32mm>25mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
PVC	32mm>20mm	Bushing	fitting	riser > spout adaptor	EACH	2	1	EACH	UGX 600	UGX 1,200	$0.48
polyrope	6mm		100m roll	rope	EACH	33	100	m roll	UGX 25,000	UGX 8,250	$3.30
Used Car Tire	14"	No Steel!!	whole tire	washers / plungers	EACH	1	1	EACH	UGX 10,000	UGX 10,000	$4.00
Iron round bar	10mm			rebar for install	m	2	12	m	UGX 20,000	UGX 3,333	$1.33
Paint	Rex Oxide			prevents rust	Small can	1	1	EACH	UGX 6,000	UGX 6,000	$2.40
Spray Paint	Any Color			coating	Can	1	1	EACH	UGX 15,000	UGX 15,000	$6.00
Welding Rods	2.5mm			welding	EACH	12	1	EACH	UGX 200	UGX 2,400	$0.96
Grinding Disc				cutting /grinding	EACH	1	1	EACH	UGX 14,000	UGX 14,000	$5.60
										UGX 127,980	**$51.19**

Table C7. Material costs for 25-mm EMAS Pump – 5 m depth

EMAS "Quantity" Pump (Uganda Version) 25mm pumping pipe				Depth of pump=	5						
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**	**Unit Sold**		**Unit Price 1**	**Total Price**	**USD $**
GI	3/4"	Std Pipe		Handle	m	1.3	6	m	UGX 35,000	UGX 7,583	$3.03
GI	3/4"	Tee		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
GI	3/4"	Elbow		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
GI	3/4"	Cap		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
PVC	1 1/2"	Pipe	gray drain pipe	Pump Casing	m	4.5	6	m	UGX 13,500	UGX 10,125	$4.05
PVC	25mm	PN 10	gray pressure pipe	Pumping Pipe	m	4.25	6	m	UGX 6,800	UGX 4,817	$1.93
PVC	1 1/4"	drain pipe	gray drain pipe	Valve Component	m	0.2	6	m	UGX 11,500	UGX 383	$0.15
PVC	3/4"	sch 40	blue pressure pipe	Valve Component	m	0.2	6	m	UGX 14,200	UGX 473	$0.19
PVC	1"	sch 40	blue pressure pipe	Valve Component	m	0.2	6	m	UGX 20,200	UGX 673	$0.27
Used Car Tire	small	piece			EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
marble	small			valves	EACH	2	6	bag	UGX 5,000	UGX 1,667	$0.67
										UGX 31,222	**$12.49**

Table C8: Material costs for 25-mm EMAS Pump – 15 m depth

EMAS "Quantity" Pump (Uganda Version) 25mm pumping pipe				Depth of pump=	15						
Material	**Size**	**Type**	**Misc**	**Use**	**Unit**	**Quantity**	**Unit Sold**		**Unit Price 1**	**Total Price**	**USD $**
GI	3/4"	Std Pipe		Handle	m	1.3	6	m	UGX 35,000	UGX 7,583	$3.03
GI	3/4"	Tee		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
GI	3/4"	Elbow		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
GI	3/4"	Cap		Handle	EACH	1	1	EACH	UGX 1,500	UGX 1,500	$0.60
PVC	1 1/2"	Pipe	gray drain pipe	Pump Casing	m	14.5	6	m	UGX 13,500	UGX 32,625	$13.05
PVC	25mm	PN 10	gray pressure pipe	Pumping Pipe	m	14.25	6	m	UGX 6,800	UGX 16,150	$6.46
PVC	1 1/4"	drain pipe	gray drain pipe	Valve Component	m	0.2	6	m	UGX 11,500	UGX 383	$0.15
PVC	3/4"	sch 40	blue pressure pipe	Valve Component	m	0.2	6	m	UGX 14,200	UGX 473	$0.19
PVC	1"	sch 40	blue pressure pipe	Valve Component	m	0.2	6	m	UGX 20,200	UGX 673	$0.27
Used Car Tire	small	piece			EACH	1	1	EACH	UGX 1,000	UGX 1,000	$0.40
marble	small			valves	EACH	2	6	bag	UGX 5,000	UGX 1,667	$0.67
										UGX 65,055	**$26.02**

C.3 Raw Data from Pumping Trials

Table C9. Raw data summary for 20 mm EMAS Pump

Static Water Level (meters)		EMAS Pump Standard													
		Male							Female						
	Trial	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note
5.1	1	40.86	59	60.58	61	101.44	120		46.27	83	65.88	93	112.15	176	
5.1	2	44.26	59	68.55	63	112.81	122		46.50	79	60.61	79	107.11	158	
5.1	**AVG**	**42.56**	**59.0**	**64.57**	**62.0**	**107.12**	**121.0**		**46.38**	**81.0**	**63.25**	**86.0**	**109.63**	**167.0**	
12.6	1	67.61	81	98.88	89	166.49	170		68.05	106	79.77	99	147.82	205	
12.6	2	67.65	72	101.49	86	169.14	158		70.93	94	70.58	92	141.51	186	
12.6	**AVG**	**67.63**	**76.5**	**100.19**	**87.5**	**167.81**	**164.0**		**69.49**	**100.0**	**75.17**	**95.5**	**144.66**	**195.5**	
17.0	1														
17.0	2														
17.0	**AVG**														
18.4	1	81.64	85	134.36	105	216.00	190		110.55	160	142.57	176	253.12	336	
18.4	2	88.42	85	137.29	105	225.70	190		114.28	160	144.47	176	258.74	336	
18.4	**AVG**	**85.03**	**85.0**	**135.82**	**105.0**	**220.85**	**190.0**		**112.41**	**160.0**	**143.52**	**176.0**	**255.93**	**336.0**	
21.1	1	94.81	98.0	146.67	117.0	241.49	215		189.41	198.0					
21.1	2	127.96	108.0	174.68	130.0	302.64	238		194.71	195.0					
21.1	**AVG**	**111.39**	**103.0**	**160.67**	**123.5**	**272.06**	**226.5**		**192.06**	**196.5**					
28.3	1	145.38	160	196.20	185	341.58	345		189.07	321					
28.3	2	158.83	169	205.16	193	363.99	362		190.60	295					
28.3	**AVG**	**152.11**	**164.5**	**200.68**	**189.0**	**352.79**	**353.5**		**189.84**	**308**					

Table C10. Raw data summary for 20 mm Rope Pump

Static Water Level (meters)		Rope Pump 20mm													
		Male							Female						
	Trial	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note
5.1	1	36.79	77	53.46	78	90.25	155		39.14	78	67.28	90	106.42	168	
5.1	2	38.74	75	52.45	78	91.20	153		40.63	80	61.81	79	102.43	159	
5.1	**AVG**	**37.77**	**76**	**52.96**	**78**	**90.72**	**154.0**		**39.88**	**79.0**	**64.54**	**84.5**	**104.43**	**163.5**	
12.6	1	62.57	94	85.39	82	147.96	176		56.23	94	76.03	91	132.26	185	
12.6	2	68.05	81	92.19	84	160.24	165		70.03	96	80.76	96	150.79	192	
12.6	**AVG**	**65.31**	**88**	**88.79**	**83**	**154.10**	**170.5**		**63.13**	**95.0**	**78.40**	**93.5**	**141.53**	**188.5**	
17.0	1														
17.0	2														
17.0	**AVG**														
18.4	1	103.91	100	146.86	120	250.78	220		93.65	140	116.12	143	209.77	283	
18.4	2	101.60	100	147.79	123	249.39	223		82.29	117	123.67	145	205.96	262	
18.4	**AVG**	**102.76**	**100**	**147.33**	**122**	**250.08**	**221.5**		**87.97**	**128.5**	**119.90**	**144.0**	**207.87**	**272.5**	
21.1	1	97.71	100	152.27	108	249.98	208		149.66	146.0					
21.1	2	124.39	126	169.12	130	293.51	256		145.76	135.0					
21.1	**AVG**	**111.05**	**113**	**160.70**	**119**	**271.75**	**232.0**		**147.71**	**140.5**					
28.3	1	103.55	96	197.05	157	300.60	253		152.64	208					
28.3	2	119.29	109	211.02	170	330.31	279		132.16	186					
28.3	**AVG**	**111.42**	**103**	**204.03**	**164**	**315.45**	**266.0**		**142.40**	**197.0**					

Table C11. Raw data summary for 25 mm Rope Pump

Static Water Level (meters)		Rope Pump 25mm													
		Male							Female						
	Trial	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note
5.1	1	19.02	33	29.09	34	48.11	67		15.33	30	22.66	33	37.99	63	
5.1	2	23.12	33	28.62	32	51.75	65		18.08	33	23.45	34	41.53	67	
5.1	**AVG**	**21.07**	**33.0**	**28.86**	**33.0**	**49.93**	**66.0**		**16.70**	**31.5**	**23.06**	**33.5**	**39.76**	**65.0**	
12.6	1	24.35	38	38.30	42	62.65	80		23.81	45	34.30	48	58.11	93	
12.6	2	22.87	41	38.62	42	61.48	83		25.01	40	32.91	40	57.92	80	
12.6	**AVG**	**23.61**	**39.5**	**38.46**	**42.0**	**62.07**	**81.5**		**24.41**	**42.5**	**33.60**	**44.0**	**58.02**	**86.5**	
17.0	1	33.46	44.0	71.58	42.0	105.04	86		43.06	57.0					
17.0	2	38.09	63.0	93.52	75.0	131.61	138		48.32	50.0					
17.0	**AVG**	**35.77**	**53.5**	**82.55**	**58.5**	**118.33**	**112.0**		**45.69**	**53.5**					

Table C12. Raw data summary for 25 mm EMAS Pump

Static Water Level (meters)		EMAS Pump Quantity													
		Male							Female						
	Trial	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note	1st 20L (KJ)	Time (sec)	2nd 20L (KJ)	Time (sec)	Total (40L) (KJ)	Time (sec)	Note
5.1	1	27.08	38	42.25	41	69.33	79		23.03	41	34.04	45	57.07	86	
5.1	2	29.54	39	42.25	40	71.79	79		23.70	45	37.34	48	61.04	93	
5.1	**AVG**	**28.31**	**38.5**	**42.25**	**40.5**	**70.56**	**79.0**		**23.36**	**43.0**	**35.69**	**46.5**	**59.05**	**89.5**	
12.6	1	34.64	48	56.65	52	91.30	100		43.75	68	50.55	61	94.31	129	
12.6	2	46.02	50	69.08	55	115.10	105		35.74	58	51.96	60	87.70	118	
12.6	**AVG**	**40.33**	**49.0**	**62.87**	**53.5**	**103.20**	**102.5**		**39.75**	**63.0**	**51.26**	**60.5**	**91.00**	**123.5**	
17.0	1	39.16	53.0	78.40	64.0	117.57	117		61.91	71.0	89.35	99.0	151.26	170	
17.0	2	42.13	45.0	71.30	60.0	113.43	105		62.66	61.0	64.29	69.0	126.95	130	
17.0	**AVG**	**40.64**	**49.0**	**74.85**	**62.0**	**115.50**	**111.0**		**62.29**	**66.0**	**76.82**	**84.0**	**139.10**	**150.0**	

Table C13. Raw data from Site 1

Location	**WV Gulu**	Site 1								
Static Water Level =	**5.1m**									
Pump Depth =	**7.8m**									
Rope Pump	**20mm PN 16 pumping pipe - guide box installed at 7.8m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	71		71		Resting HR:	85		85	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	78	one hand (right)	76	pump primed	**0**	87	pump primed	103	pump primed
	10	96		97	one hand	**10**	104	one hand	111	one hand R
	20	109		102		**20**	118		118	
	30	108		111		**30**	127		127	
	40	115		118		**40**	136		135	
	50	112		128		**50**	144		140	
	60	116		128		**60**	147		145	
	70	123	**1:17 - 20 L full**	128	**1:15- 20L full**	**70**	148	**1:18 - 20L full**	150	
	80	127	two hands	122	switch hands - L	**80**	146	switch hands	148	**1:20 - 20L full**
	90	115	one hand (left)	124		**90**	145		145	switch hands L
	100	118		122		**100**	151		147	switch hands R
	110	125		122		**110**	150		150	
	120	128		126		**120**	152		157	
	130	128		130		**130**	157		154	
	140	130		135		**140**	158	switch hands	152	
	150	134	**2:35 - 40L full**	136	**2:33 - 40L full**	**150**	155		155	**2:39 - 40L full**
						160	153	**2:48 - 40L full**		
EMAS Pump	**20mm PN 16 pumping pipe, 32mm PN 10 cylinder pipe - piston valve installed at 7.8m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	80		80		Resting HR:	90		9190	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	83	pump primed	93	pump primed	**0**	98	pump primed	91	pump primed
	10	107	long strokes	110		**10**	112		98	
	20	123		130		**20**	132		135	
	30	129		136		**30**	137	slow pumping	145	slow pumping
	40	137		140		**40**	137		153	
	50	150	**0:59 - 20L full**	156	**0:59 - 20L full**	**50**	137		156	
	60	155		162		**60**	155		158	
	70	157		166		**70**	157		159	**1:19 - 20L full**
	80	160		170		**80**	156	**1:23 - 20L full**	160	
	90	160		171		**90**	155		163	
	100	159		172		**100**	159		168	
	110	165		173		**110**	159		168	
	120	170	**2:00 - 40L full**	173	**2:02 - 40L full**	**120**	161		170	
	130					**130**	161		171	
						140	163		170	
					(46 strokes on 2nd 20L)	**150**	165		172	**2:38 - 40L full**
						160	163			
						170	162	**2:56 - 40L full**		(64 strokes on 2nd 40L)
Rope Pump	**25mm PN 10 pumping pipe - guide box installed at 7.8m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	80		82		Resting HR:	97		93	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	83	one hand (right)	89	pump primed	**0**	98	pump primed	108	pump primed
	10	113		120	one hand	**10**	115	one hand R	128	one hand R
	20	116		136		**20**	135		139	
	30	131	**0:33 - 20 L full**	143	**0:33 - 20 L full**	**30**	154	**0:30 - 20 L full**	149	**0:33 - 20 L full**
	40	143		150		**40**	150	one hand L	149	two hands
	50	152		153		**50**	159		158	
	60	149	**1:07 - 40L full**	153	**1:05 - 40L full**	**60**	164	**1:03 - 40L full**	163	**1:07 - 40L full**
EMAS Pump	**25mm PN 10 pumping pipe, 1.5" "drain" cylinder pipe - piston valve installed at 7.8m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	79		81		Resting HR:	87		89	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	87	pump primed	96	pump primed	**0**	101	pump primed	99	pump primed
	10	115	long strokes	123		**10**	121		102	
	20	138		141		**20**	139		132	
	30	141	**0:38 - 20 L full**	147	**0:39 - 20 L full**	**30**	146	slow pumping	149	slow pumping
	40	149		152		**40**	158	**0:41 - 20 L full**	153	**0:45 - 20 L full**
	50	156		160		**50**	160		159	
	60	165		167		**60**	166		164	
	70	172	**1:19 - 40L full**	173	**1:19 - 40L full**	**70**	169		172	**1:19 - 20L full**
					(21 strokes on 2nd 20L)	**80**	172	**1:26 - 20L full**	174	
						90			176	**1:33 - 20L full**

Table C14. Raw data from Site 2 for 20 mm Pumps

Location	**Muchwini Central**			Site 2						
Static Water Level =	**12.6m**									
Pump Depth =	**15.1m**									
Rope Pump	**20mm PN 16 pumping pipe**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	76	pump primed	79	pump primed	**0**	108	pump primed	121	pump primed
	10	95	two hands	103		**10**	126	two hands	142	one hand
	20	109	one hand	127		**20**	140	one hand	150	
	30	112	switch hands	140		**30**	152	switch hands	159	two hands
	40	120		143		**40**	155		163	
	50	137		157		**50**	160		168	one hand
	60	135		163		**60**	164		172	
	70	144		170		**70**	169		173	two hands
	80	156	one hand - support	172	**1:21 - 20L full**	**80**	172	one hand - support	172	
	90	159	**1:34 - 20L**	171		**90**	175	**1:34 - 20L**	172	**1:36 - 20L full**
	100	151	two hands	171	two hands	**100**	172	two hands	172	one hand
	110	148	one hand supprt	171		**110**	175	one hand supprt	175	two hands
	120	150	switch hands	170		**120**	179	switch hands	177	
	130	155		172		**130**	178		179	**one hand**
	140	158	two hands	173		**140**	178	two hands	179	
	150	160	**switch hands**	173		**150**	178	**switch hands**	180	two hands
	160	163		172	**2:45 - 40L full**	**160**	178		180	
	170	163	faster			**170**	181	faster	180	one hand
	180		**2.56 - 40L full**			**180**	181	**3.05 - 40L full**	181	
						190			182	**3:12 - 40L full**
EMAS Pump	**20mm PN 16 piston pipe**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	85		84		**0**	88		85	
	10	114		121		**10**	120		118	
	20	136		151		**20**	130		138	
	30	146		159		**30**	139		145	
	40	148		163		**40**	150		155	
	50	150		167		**50**	156		162	
	60	156		170		**60**	157		167	
	70	159		173	**1:12 - 20L full**	**70**	159		169	
	80	162	**1:21 - 20L full**	170		**80**	164		171	
	90	169		179		**90**	168		175	
	100	173		178		**100**	170	**1:46 - 20L full**	172	**1:34 - 20L full**
	110	169		179		**110**	168		168	
	120	171		180		**120**	167		171	
	130	172		183		**130**	171		177	
	140	173		183		**140**	173		180	
	150	175		181	**2:38 - 40L full**	**150**	174		182	
	160	177				**160**	174		174	
	170	177	**2:50 - 40L full**			**170**	176		174	
	180					**180**	176		173	
	190					**190**	178		173	**3:11 - 40L full**
	200					**200**	179	**3:25 - 40L full**		
	210					**210**				
	220					**0**				
	User didn't stand on tire			user stood on tire						

Table C15. Raw data from Site 2 for 25 mm Pumps

Location	**Muchwini Central**			Site 2						
Static Water Level =	**12.6m**									
Pump Depth =	**15.1m**									
Rope Pump	**25mm PN 10 pumping pipe**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	75	Pump primed	75	Pump primed	**0**	90	Pump primed	102	Pump primed
	10	106		112		**10**	118	one hand	130	one hand
	20	127		118		**20**	131	two hands	150	
	30	139	**0:38 - 20L full**	118		**30**	140		156	
	40	144		130	**0:41 - 20L full**	**40**	150	**0:45 - 20L full**	164	**0:40 - 20L full**
	50	150		153		**50**	156	slower	170	two hands
	60	153		154		**60**	157	faster	176	faster
	70	153		154		**70**	163	faster	180	
	80	162	**1:20 - 40L full**	157	**1:23 - 40L full**	**80**	165	one hand	180	**1:20 - 40L full**
	90					**90**	165	**1:33 - 40L full**		
	Like this pum very much. Feels little difference from other RP but much more flow						Says this pump is the easiest and likes that it is so fasr			
Qty EMAS Pump	**25mm PN 16 piston pipe**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	65	Pump primed	70	Pump primed	**0**	101	Pump primed	101	Pump primed
	10	120		107		**10**	125		121	
	20	125		150		**20**	137		138	
	30	135		161		**30**	150		141	
	40	146	**0:48 - 20L full**	174		**40**	159		162	
	50	158		182	**0:50 - 20L full**	**50**	163		165	**0:58 - 20L full**
	60	162		183		**60**	165	**1:08 - 20L full**	170	
	70	170		186		**70**	172		174	
	80	172		186		**80**	175		187	
	90	175		187		**90**	178		180	
	100	178	**1:40 - 40L full**	190	**1:45 - 40Lfull**	**100**	177		184	
	110					**110**	177		186	**1:58 - 40 L full**
						120	179	**2:09 - 40L full**		
	Prefers lighter emas pump									
						prefers lighter emas pump. Says that 25mm rope pump is the best				

Table C16. Raw data from Site 3 for 25 mm Pumps

Location	**Wangowet**	(Amida)	Site 3*							
Static Water Level =	**17**		*25 mm Pumps							
Pump Depth =	**19.5**									
Rope Pump	**25mm PN 10 pumping pipe - guide box installed at 19.5m from top of pedestal**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Resting HR:	71		71		Resting HR:	91		91	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	92	OHR	95	pump primed	**0**	99	TH	104	TH
	10	107		124	OHR	**10**	124		122	
	20	138		150		**20**	140		139	
	30	147		162		**30**	153		151	
	40	159	**0:44 - 20 L full**	173	**0:42 - 20 L full**	**40**	159		158	
	50	158	TH	179	TH	**50**	161	:57 - stopped at 20L	168	:50 - 20L full
	60	170		176					171	
	70	170		174	OHR				174	1:15 stopped
	80	170		180						aprox 28 L
	90	171		186	TH					
	100	169	**1:47 - 40L full**	179						
	110			183	**1:57 - 40L full**					
EMAS Pump	**25mm PN 10 pumping pipe, 1.5" "drain" cylinder pipe - piston valve installed at 19.5m from top of pedestal**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Resting HR:	84		93		Resting HR:	87		90	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	85	pump primed	106	pump primed	**0**	91	pump primed	120	pump primed
	10	104		112		**10**	117		146	
	20	130		138		**20**	135		153	
	30	136		159		**30**	145		162	
	40	147		164	**0:45- 20 L full**	**40**	153		169	
	50	161	**0:53 - 40L full**	164		**50**	158		173	
	60	170		180		**60**	163		175	**1:01 - 20L full**
	70	173		183		**70**	166	**1:11 - 20L full**	179	
	80	173		185		**80**	168		180	
	90	175		186		**90**	170		183	
	100	180		185	**1:45 - 40L full**	**100**	172		184	
	110	183	**1:57 - 40 L Full**			**110**	173		185	
						120	174		186	**2:10 - 40L Full**
						130	175			
						140	175			
						150	177	2:50 - 40 L Full		
					Clair stated afterward that she prefers the EMAS pump to the RP for this applications.					
					Says that it is easier to pump and she doesn't get so tired.					

Table C17. Raw data from Site 3 for 20 mm Pumps

Location	**Wageowet**		Site 3*							
Static Water Level =	**18.4**		*20 mm pumps							
Pump Depth =	**20.9**									
Rope Pump	**20mm PN 16 pumping pipe - guide box installed at 20.95m from top of pedestal**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	80	pump primed	83	pump primed	**0**	87	pump primed	105	pump primed
	10	127	two hands	116	two hands	**10**	120	one hand	130	
	20	161		152		**20**	135	two hand	145	
	30	166		164		**30**	143		152	one hand / sideways
	40	167		165		**40**	150	one hand / sideways	160	
	50	167		167		**50**	153	two hand / sideways	165	two hand / sideways
	60	170		170		**60**	156	two hand	170	
	70	170		172		**70**	159	one hand	170	
	80	177		176		**80**	162	two hand	173	
	90	177		177		**90**	164		176	
	100	179	**1:40 - 20L full**	180	**1:40 - 20L full**	**100**	165		178	
	110	180		179		**110**	168		179	**1:57 - 20L full**
	120	181		170		**120**	169		177	two hand / sideways
	130	184		171		**130**	169		179	
	140	181		178		**140**	169	**2:20 - 20L full**	177	
	150	181		182		**150**	170		180	
	160	181		182		**160**	170	faster	180	
	170	186		182		**170**	175		180	
	180	185		185	semi-sideways	**180**	175		180	
	190	185		185		**190**	177		179	
	200	185		185		**200**	177		179	two hands
	210	187		187		**210**	177	faster	179	
	220	188	**3:40 - 40L full**	190	**3:43 - 40L full**	**220**	172	twohand / sideways	181	
						230	174	faster	182	
						240	175	one hand / sideways	184	two hand / sideways
						250	175	two hand / sideways	184	
						260	177		184	**4:22 - 40L full**
						270	178			
						280	178	**4:43 - 40L full**		
EMAS Pump	**20mm PN 16 pumping pipe, 32mm PN 10 cylinder pipe - piston valve installed at 20.95m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	86	pump primed	84	pump primed	**0**	100	pump primed	98	pump primed
	10	111		123		**10**	124		120	
	20	137		135		**20**	140		137	
	30	139		152		**30**	140		139	
	40	157		159		**40**	140		154	
	50	164		174		**50**	154		159	
	60	176		184		**60**	156		161	
	70	176		186		**70**	160		170	
	80	179	**1:25 - 20L full**	188	**1:25 - 20L full**	**80**	166		171	
	90	181		190		**90**	168		171	
	100	181		191		**100**	169		172	
	110	182		189		**110**	171		173	
	120	181		188		**120**	171		174	
	130	179		190		**130**	171		173	
	140	180		190		**140**	170		173	
	150	181		191		**150**	170		173	
	160	181		194		**160**	171	**2:40 - 20L full**	171	**2:40 - 20L full**
	170	180		194		**170**	169		168	
	180	183		195		**180**	169		169	
	190	184	**3:10 - 40L full**	195	**3:10 - 40L full**	**190**	171		172	
						200	171		174	
						210	172		176	
						220	174		176	
						230	175		176	
						240	175		178	
						250	175		179	
						260	174		178	
						270	175		178	
						280	175		178	
	User says that he prefers the EMAS pump to the rope pump at this depth					**290**	177		178	
						300	179		178	
						310	180		178	
						320	179		181	
						330	179	**5:36 - 40L full**	178	**5:36 - 40L full**
						User says that she prefers the rope pump to the EMAS pump at this depth				

Table C18. Raw data from Site 4

Location	**Yepa**	Mucwini	Site 4							
Static Water Level =	**21.05**									
Pump Depth =	**23.55**									
Rope Pump	**20mm PN 16 pumping pipe - guide box installed at 23.55m from top of pedestal**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Resting HR:	88		103		Resting HR:	107		107	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	93	OHR	103	TH	**0**	107	OHR	110	TH
	10	121		127		**10**	126	TH	125	
	20	141		148		**20**	141		146	
	30	150	TH	155		**30**	151		156	
	40	163		159		**40**	156		166	
	50	170		170		**50**	161	Speed up	170	
	60	170		172		**60**	166		172	
	70	168		175		**70**	170		175	
	80	171		180		**80**	171		178	**Sideways**
	90	173		182		**90**	173		179	
	100	175	**1:40 - split**	183		**100**	174		180	
	110	178		182	1:48 - Split	**110**	173		180	
	120	178	OHR	181		**120**	172		178	
	130	179	TH	181		**130**	172		177	**2:15 - 20L full**
	140	180		180		**140**	171	**2:26 - 20L full**		Stop
	150	180		181				**Stop**		
	160	180		183						
	170	182		185						
	180	184		185						
	190	185		185						
	200	186	OHR	185						
	210	183		185						
	220	183	**3:46 - 40L Full**	186						
				187	**3:58 - 40L Full**					
EMAS Pump	**20mm PN 16 pumping pipe, 32mm PN 10 cylinder pipe - piston valve installed at 23.55m from top of pedestal**									
		Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2	
	Resting HR:	79		79		Resting HR:	86		86	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	93	pump primed	94	pump primed	**0**	95	pump primed	100	pump primed
	10	121	long strokes	131		**10**	99		115	
	20	134		158		**20**	130		137	
	30	138		166		**30**	132	slow pumping	141	slow pumping
	40	157		176		**40**	140		150	
	50	165		184		**50**	151		154	
	60	170		188		**60**	156		162	
	70	174		189		**70**	159		162	
	80	178		190		**80**	160		159	
	90	180	1:38 Split	192		**90**	160		166	
	100	180		191	1:48 Split	**100**	160		169	
	110	180		191		**110**	163		168	
	120	183		192		**120**	168		168	
	130	181		190		**130**	169		170	
	140	185		192		**140**	170		171	
	150	187		193		**150**	169		172	
	160	186		192		**160**	170		172	
	170	186		193		**170**	170		170	
	180	188		194		**180**	168		166	
	190	190		196		**190**	168	**3:18 - 20L full**	165	**3:15 - 20L full**
	200	192		197						
	210	192	3:35 - 40L Full	198						
	220			198						
	230			198	**3:58 - 40L full**					

Table C19. Raw data for Site 5

Location	**Akara P/S**	Muchwini	Site 5							
Static Water Level =	**28.3**									
Pump Depth =	**30.4**									
Rope Pump	**20mm PN 16 pumping pipe - guide box installed at 30.4m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	67		67		Resting HR:	84		84	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	82	pump primed	83	pump primed	**0**	89	pump primed	85	pump primed
	10	118	one hand (fast)	123	one hand (fast)	**10**	120	two hands	126	two hands
	20	150		156	two hands	**20**	135		143	
	30	165		170		**30**	148	sideways	157	
	40	173		173	using body a lot	**40**	156		162	
	50	177		176		**50**	162		167	
	60	181		179		**60**	166		172	
	70	183		178		**70**	168		175	
	80	185	slower	178		**80**	168	slower	177	
	90	187	**1:36 - 20 L full**	188		**90**	169		178	
	100	186		183	**1:49 - 20L full**	**100**	169		180	
	110	186		182		**110**	170		180	sideways
	120	186	slower	183	slower	**120**	173		180	slower
	130	186	using body a lot	183		**130**	173		180	
	140	185		183		**140**	174		180	
	150	185	slower	182		**150**	174		180	
	160	186		184		**160**	174		180	
	170	186		185		**170**	174		180	
	180	187		186	semi-sideways	**180**	173	slower	179	**3:06 - 20L full**
	190	187		186		**190**	171			stopped at 20L
	200	188		187		**200**	170	**3:28 - 20L full**		
	210	188		186	slower (seems tired)			Stopped at 20L		
	220	188		185						
	230	188		186						
	240	188		187						
	250	186	**4:13 - 40L full**	187						
	260			187						
	4:30			187	**4:39 - 40L full**					
	4:40									
EMAS Pump	**20mm PN 16 pumping pipe, 32mm PN 10 cylinder pipe - piston valve installed at 30.4m from top of pedestal**									
			Sam - Test 1		Sam - Test 2			Clair - Test 1		Clair - Test 2
	Resting HR:	75		75		Resting HR:	83		83	
	Time	Heartrate	Note	Heartrate	Note	**Time**	Heartrate	Note	Heartrate	Note
	0	79	pump primed	80	pump primed	**0**	93	pump primed	101	pump primed
	10	130		114	long strokes	**10**	109		115	
	20	137		143		**20**	116		120	
	30	137	long strokes	149		**30**	122	slow pumping	131	slow pumping
	40	144		150		**40**	134		141	
	50	152		157		**50**	138		149	
	60	158		165	steady pumping	**60**	142		154	
	70	163		162		**70**	145		158	
	80	162	steady pumping	159		**80**	148		159	
	90	163		155		**90**	148		159	
	100	159		159		**100**	147		160	
	110	156		166		**110**	146		161	
	120	159		167		**120**	149		158	
	130	160		164		**130**	145		157	
	140	158		164		**140**	146		155	
	150	161		163		**150**	150		154	
	160	160	**2:40 - 20L full**	162	**2:49- 20L full**	**160**	150		156	
	170	159		165		**170**	148		155	
	180	161		167		**180**	150		154	
	190	165		165		**190**	149		155	
	200	165		162		**200**	153		154	
	210	167		165		**210**	154		156	
	220	167		170		**220**	153		158	
	230	167		173	change grip	**230**	151		159	
	240	167		171		**240**	151		159	
	250	170		171		**250**	150		158	
	260	169		168		**260**	149		160	
	270	171		171		**270**	149		159	
	280	169		170		**280**	150		158	
	290	169		167		**290**	152		157	**4:55** - 20L full
	300	170		163		**300**	152			Stopped at 20L
	310	172		165		**310**	149			
	320	172		170		**320**	149	**5:21** - 20L full		
	330	171		169		**330**		Stopped at 20L		
	340	173	**5:45 - 40L full**	171						
	350			171						
	360			170	**6:02- 40L full**					

Appendix D USF Institutional Review Board (IRB) Correspondence

D.1 IRB Correspondence – EMAS Technologies Research

Activity Details | UNIVERSITY OF SOUTH FLORIDA | arc | Michael MacCarthy | My Home

Home | IRB Studies | IACUC | COI | NetID Announcement

IRB Studies > Bolivia Self Supply Study

1 / 10 Next >

Activity Details (Study that has never been approved is Closed)

Author:	Cheryl Byers (Research Integrity & Compliance)
Logged For (Study):	Bolivia Self Supply Study
Activity Date:	6/12/2011 12:02 PM

Activity Form | Property Changes | Documents | Notifications

Comments:
This study has been withdrawn from review as it does not meet the definition of human subjects research requiring review and approval by the USF IRB. This project will explore experiences with household water supply and sanitation systems, and specifically with EMAS technologies and does not collect information about individuals. If you have any questions or concerns, please feel free to contact me at 813-974-3234.

Add Documents:

Name	Description
There are no items to display	

D.2 IRB Correspondence – Hand Pump Research

Inquiry regarding IRB review

Byers, Cheryl <cbyers1@usf.edu> Wed, Jul 27, 2011 at 10:58 AM
To: "Maccarthy, Michael" <mmaccarthy@mail.usf.edu>
Cc: "Hart, Olivia" <olivia@usf.edu>

Hi Mike,
Thank you for the additional information. Like your other research project, I do not believe this is human subjects research under the purview of the IRB. As you are not collecting information "about" individuals and are collecting information about a water supply system, this does not meet the definition of human subjects research as outlined by the federal regulations. Therefore, you are not required to submit an application to the USF IRB for review and approval.

Thank you for your inquiry, good luck with your project.
Cheryl

From: "Maccarthy, Michael" <mmaccarthy@mail.usf.edu<mailto:mmaccarthy@mail.usf.edu>>
Date: Tue, 26 Jul 2011 08:48:30 -0400
To: Cheryl Byers <cbyers1@usf.edu<mailto:cbyers1@usf.edu>>
Subject: Re: Inquiry regarding IRB review

Dear Cheryl,

Thanks very much for your reply, and apologies for the delay in getting back to you. I was away for a long weekend.

The water supply system study in Madagascar is very similar to the Bolivia study. We will be analyzing household water and sanitation systems (primarily water systems).

The research objective is: To evaluate the effectiveness of a project in a developing community context in sub-Saharan Africa (Madagascar) in which low-cost household groundwater supply systems have proven to be sustainable

Appendix E Permissions

Below are permissions to use published manuscripts in Chapter 2 and Chapter 3.

request for permission to use WaA article

francois.molle@ird.fr <francois.molle@ird.fr> Thu, Jul 10, 2014 at 2:25 AM
To: Mike MacCarthy <mmaccarthy@mail.usf.edu>

Dear Michael

When publishing in Water Alternatives you remain the right holder of your publication. You are therefore welcome to reuse your paper for your PhD.

Kind regards

François

François Molle
IRD, France; and International Water Management Institute (IWMI)

Mail address
c/o ICARDA, P.O. Box 2416, Cairo, Egypt

Mobile in Cairo: (002)01010078921

Office : (00202)35724358 ext. 122

Water Alternatives www.water-alternatives.org

request for permission to use 2013 EMAS Field Note (MacCarthy et al.)

Kerstin Danert <Kerstin.Danert@skat.ch> Thu, Jul 10, 2014 at 4:03 AM
To: Mike MacCarthy <mmaccarthy@mail.usf.edu>, Sean Furey <Sean.Furey@skat.ch>

Dear Mike,

This is no problem at all!!!

Good luck,

Smiles,

Kerstin

From: Mike MacCarthy [mailto:mmaccarthy@mail.usf.edu]
Sent: Donnerstag, 10. Juli 2014 06:04
To: Kerstin Danert; Sean Furey
Subject: request for permission to use 2013 EMAS Field Note (MacCarthy et al.)

Dear Kerstin and Sean,

I hope that all is well with both of you.

I'm currently in the process of finalizing my dissertation, part of which consists of my research on EMAS Water Supply Technologies in Bolivia. I would thus like to request permission from RWSN to allow me to use the 2013 Field Note that I was lead author on, "EMAS Household Water Supply Technologies in Bolivia: Increasing Access to Low-Cost Water Supplies in Rural Areas" as a chapter in my dissertation. The version that would appear in full in my dissertation would be only slightly modified from the peer-reviewed field note (mainly formatting).

Please let me know if you require any additional information. I look forward to hearing back from you.

Kind Regards,