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Long Paper

Household Water Supply Technologies for Increasing Access to Domestic Water Supplies in Rural Bolivia

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Abstract/Summary

EMAS household water technologies have been developed in Bolivia, South America over the past three decades, and consist primarily of manual water pumps made from materials commonly available in developing countries, hybrid percussion-jetting manual drilling techniques, and rainwater harvesting systems that often use underground storage tanks. This research is believed to be the first independent field assessment that considers EMAS manual water supply technologies as well as users' perceptions of these systems and technicians' experiences with system implementation in Bolivia. Research methods consist of semi-structured interviews with technicians and other stakeholders involved in implementation of EMAS technologies, combined with household visits that include surveying and observation/inspection. Results of the investigation show use of EMAS drilling techniques to be widespread in parts of Bolivia, and prove the EMAS Pump to be an effective, low-cost/maintenance household pump.

Introduction

Bolivia is a landlocked country located on the continent of South America, with an estimated population of just over ten million people (CIA, 2011). Bolivia ranks 95th out of 169 countries included in the Human Development Index (HDI) of the 2010 Human Development Report, commissioned by the United Nations Development Program (UNDP, 2010). Within South America, Bolivia currently has the 3rd-lowest HDI ranking, just above Paraguay (96) and Guyana (104).

According to the Joint Monitoring Program for Water Supply and Sanitation (JMP), a program of the United Nations that reports progress towards the Millennium Development Goal (MDG) target for drinking water, the 2008 estimate shows that 67% of the rural population of Bolivia use 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 42%. However, rural drinking water coverage is still drastically less than the urban coverage for Bolivia, as the same report estimated that 96% of the urban population uses improved drinking water sources (JMP, 2010). Table 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 Systems. By the JMP definition, all of the household water supply systems considered in this study are improved drinking water sources.

Table 1: Categories of Improved and Unimproved Water Sources (JMP, 2011), and EMAS Household Water Supply Systems Considered in the Presented Research

Improved drinking water sources	**Unimproved drinking water sources**	**EMAS household water supply systems studied**
- Piped water into dwelling, plot or yard - Piped water into neighbour's plot - Public tap/standpipe - Tubewell/borehole - Protected dug well - Protected spring - Rainwater	- Unprotected dug well - Unprotected spring - Small cart with tank/drum - Tanker truck - Surface water (river, dam, lake, pond, stream, channel, irrigation channel) - Bottled water	- Manually-drilled wells fitted with manual pump - Rainwater Harvesting Systems (including manual pump)

SENASBA (National Service for Sustainable Sanitation Services) 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. It has as its mission to help 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, 2011). 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 more 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 NGOs, the Catholic University system, the Water and Sanitation Program of the World Bank (WSP), and the Inter-American Development Bank (IADB).

EMAS (a Spanish acronym for Mobile Water and Sanitation school – Escuela Mobil de Agua y Sanimiento) was founded by Wolfgang Buchner in Bolivia in the early 1980's. With a goal of making adequate water supply and sanitation infrastructure available to households in rural areas of Bolivia, throughout its history EMAS has focused on the development and implementation of various low-cost water and sanitation technologies. EMAS aims for their technologies to be adequately strong for use at the household level, while keeping technology costs low by making best use of locally-available materials and labour. In addition to promoting their technologies in Bolivia, EMAS has promoted and implemented their technologies (largely through on-site trainings) in various other countries throughout Latin America, and to a much lesser extent in Africa and Asia.

<u>EMAS Approaches to Improving Water Supply</u>

EMAS's strategy for encouraging families to use EMAS water and sanitation technologies, and to incrementally improve their household infrastructure, focuses on the 'added value' of EMAS technologies towards improving household living conditions and lifestyles. This strategy is implemented largely through the training of local technicians from various parts of Bolivia (subsidized by EMAS), as well as through disseminating training videos via Bolivian television and the internet. Figure 1 illustrates several EMAS household water and sanitation components, which include a rainwater harvesting system with an underground storage tank and manual pump, a shower with a small elevated tank and washing facilities, and a ventilated latrine.

<u>Figure 1: Promotional material for EMAS showing basic household water and sanitation technologies (Rainwater harvesting system with underground water storage tank; manual pump to lift water to small elevated tank for shower and washing clothes; ventilated latrine) (Procedamo, 2004)</u>

EMAS's 'added value' strategy can be illustrated through the following example (Buchner, 2011):

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 tapstand or a community well) or an unprotected water source (e.g., a lake or stream). Yet, if the 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 a water source in their yard, the household is also pumping this water through pipes and/or hoses 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 become significantly more dependent upon the water supply. The 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.

For clarity, EMAS makes the comparison to a similar situation with household electricity. If a household has electricity that they use for lighting, and it ceases to function, they may be satisfied to use lanterns or candles in the short-term. However, if they also use the electricity for other things, such as powering a television, refrigerator, or computer, their dependence on the electricity is much greater, and they will thus be more likely to get their electricity connection repaired promptly when it fails. In marketing their technologies, EMAS also considers peoples’ tendencies to pay attention to what their neighbour’s have, as if they see value in it, they will likely want to replicate it (Buchner, 2011).

EMAS Water Supply Technologies

Manual Water Pumps

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) is a manually-operated pump that can reportedly lift water from depths of more than 30 meters (EMAS, 2006). The simple design of these pumps, using materials commonly available in developing countries (e.g., PVC pipes for the pump chassis and glass play marbles for the pump valves) allow for them to be fabricated in many developing community contexts. The low-cost of the 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 wells). Figure 2 shows an EMAS Pump installed on a manually-drilled well.

Figure 2: (a) Photo of EMAS Pump installed on a manually-drilled well [left]; (b) Photo of EMAS Pump in operation [right] (EMAS)

Manual Drilling Techniques

Many thousands of wells have been installed in households throughout Bolivia using manual drilling techniques developed by EMAS (Danert, 2009). EMAS teaches several techniques for manually drilling wells, with the most common incorporating two drilling methods – percussion and jetting. This hybrid percussion-jetting method consists of a fluid (water mixed with a thickener) being pumped down drilling pipe that runs the entire depth of the well, and out through a drill bit attached to the bottom pipe. The drilling pipe is alternately raised, dropped, then rotated (usually ¼ to ½ turn in each direction) while water is continuously being pumped through the pipe. The earthen material that is broken up, primarily by the percussion action, rises to the top of the well in the drilling fluid. Beside the well, a small dug trench and basin(s) allow for the drilling fluid and cuttings to settle out, and for the drilling fluid to then be re-circulated back through the drilling system. A support structure with a rope and pulley facilitates raising and dropping of the drill pipes. Figure 3 is a diagram of how a hybrid percussion-jetting system functions. Figure 4 shows an EMAS percussion-jetting set-up as used in Bolivia, and a similar percussion-jetting set-up that has been tested at the University of South Florida (Tampa) since Fall 2010.

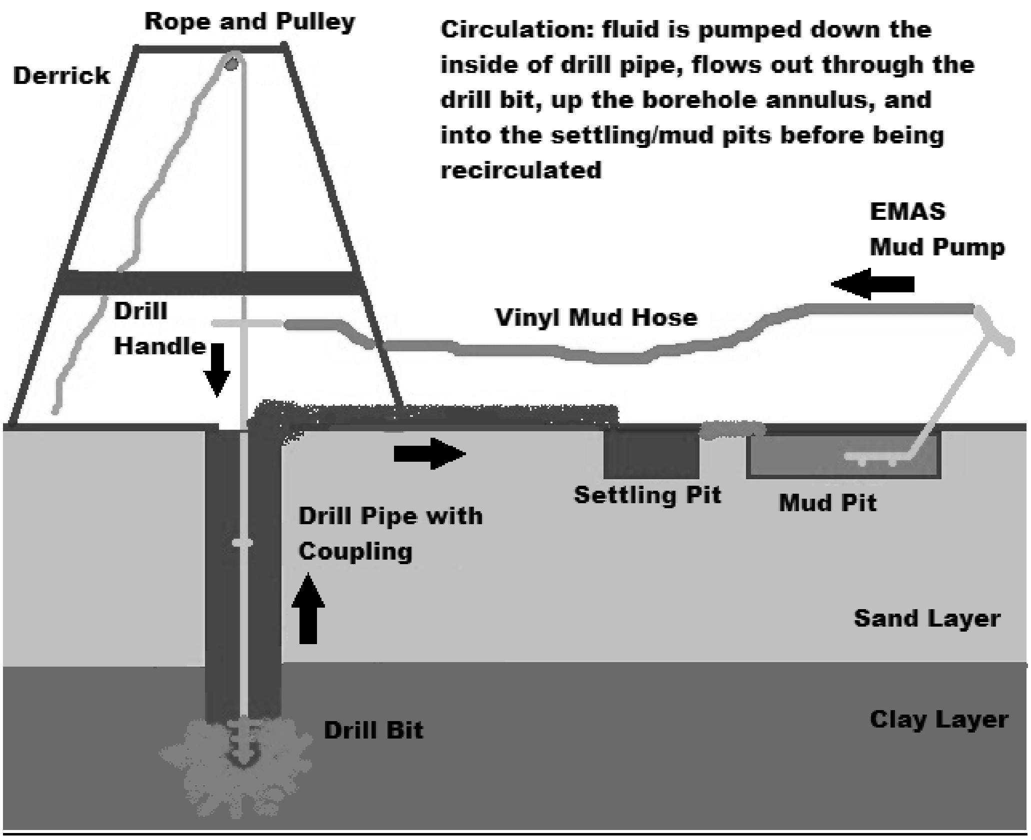

Figure 3: Diagram of EMAS hybrid percussion-jetting system (credit D. Bales, 2011)

Figure 4: (a) EMAS percussion-jetting set-up, Bolivia [left]; (b) Test-drilling using percussion-jetting at the University of South Florida GeoPark [right] (M. MacCarthy)

Rainwater Harvesting Systems

Rainwater Harvesting refers to the "collection and subsequent storage of water from surfaces on which rain falls" (Mihelcic et al., 2009). Rainwater Harvesting systems (RWHS) can be appropriate as primary or secondary (complementary) sources of water for use at the household level, depending on the quantity of local rainfall. EMAS household rainwater harvesting systems consist 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 storage tank. These 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 litres (nearly 2,000 gallons), using a cement and sand mortar as the base and walls, with a reinforced concrete lid. Above-ground tanks of similar sizes are made using ferrocement construction, which makes use of wire-reinforced cement mortar. Figure 5 shows several EMAS storage tanks.

Figure 5: EMAS water storage tanks used in RWHS, (a) underground tank, in construction [top left]; (b) completed underground tank with manual pump [bottom left]; (c) aboveground ferrocement tank, in construction [middle]; (d) ferrocement tank elevated on a hillside [right] (M. MacCarthy)

Description of the Case Study – Approach or technology

Assessing low-cost water supply technologies in developing world contexts in which they have been sustainable over a significant time period can provide valuable insight into the potential for use of these types of technologies in similar contexts. Such an assessment can also act as a baseline for improving and/or expanding implementation of these technologies in the studied context. While known previous studies have focused specifically on the technological aspects of EMAS water and sanitation systems (Tapia-Reed, 2008), this study is believed to be the first independent field assessment that considers the EMAS manual water supply technologies as well as users' perceptions of these systems and technicians' experiences with system implementation in Bolivia.

The assessment was carried out as part of a larger study that aims to assess low-cost household water supply technologies that have been developed and used in Bolivia, for impact and feasibility of technology transfer to developing community contexts in Sub-Saharan Africa, as well as for scale-up potential of these technologies within Bolivia.

Research Methodology

The research consists of an assessment of EMAS low-cost water supply technologies in Bolivia, South America, and provides an independent assessment of select EMAS water supply technologies in specific contexts in which they have been implemented at the household level in rural areas of Bolivia. Field data for the research was gathered during two trips to Bolivia, in March-April 2011 and June-July 2011.

EMAS facilitated the carrying out of the assessment through sharing of information on EMAS-developed water and sanitation technologies, project implementation areas, and key stakeholders, as well as providing assistance with some logistics in La Paz department. As part of the information-gathering process for the assessment, the primary researcher participated in a month-long (300-hour) EMAS-sponsored training workshop on low-cost water supply and sanitation technologies, from mid-March to mid-April 2011, at EMAS's training centre in Puerto Perez, Bolivia.

The field research makes use of mixed-methods for gathering of qualitative data, including surveys and semi-structured interviews. Quantitative data was also gathered through household surveys and inspections of household water and sanitation infrastructure. Field research was approved by the Institutional Review Board of the University of South Florida. Table 2 shows the quantities of household visits and semi-structured interviews done in each region.

Table 2: Summary of number of household visits and interviews by department

Department	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*	*12*

Research Methods

Surveys

Surveys at the household level of users of EMAS water supply technologies were used as a primary data gathering tool. Survey questions focused on the following aspects of household water supply: water and sanitation infrastructure/technologies used by the household; water usage; user's appreciation of EMAS technologies; and performance issues associated with the household water systems.

Semi-structured Interviews

Semi-structured interviews were used as a primary data gathering tool. These interviews were done with rural water supply technicians, and organisations involved in the promotion, construction, installation, and/or repair of EMAS household water supply systems.

Visual and Physical Inspection of Infrastructure

Household water and sanitation infrastructure was inspected for all surveyed households. Installed manual pumps were tested to determine their level of functionality.

Research Sites

Research was carried out in three regions of Bolivia: Santa Cruz, Beni, and La Paz departments. Figure 6 shows the locations of the research sites. In Santa Cruz, research was primarily done in Izozog, an indigenous area located over 200 km southeast of the city of Santa Cruz. Additionally, 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, primarily to interview experienced EMAS-trained technicians.

In Beni department, 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 an organization and technicians involved in the promotion of EMAS water supply technologies, and additionally installation of a borehole using EMAS standard drilling techniques was observed. In Somopai, household visits were conducted, and initial installation of an EMAS manual pump on a new manually-drilled well was observed. In the rural town of Reyes, household visits were done with families with boreholes that were manually-drilled using EMAS methods, and which were either fitted with EMAS Pumps (with locally-adapted pump valve designs, in some cases), or with small electric pumps. Manual drilling of an EMAS well in Reyes was also observed.

In the Lake Titicaca area of La Paz department, several communities near the EMAS training centre were included in the research. In Cachilaya community, EMAS rainwater harvesting systems using underground storage tanks and EMAS manual pumps were assessed. Cachilaya was chosen to assess household RWHS as this village provides the most significant example (and currently one of the only examples) of these EMAS systems being implemented in Bolivia. Additionally, household visits were done in Pampa Chililaya community, where EMAS manually-drilled borehole and pump systems are used by many families. In Huarina and Taquina villages, interviews were done with technicians who have recently participated in EMAS trainings.

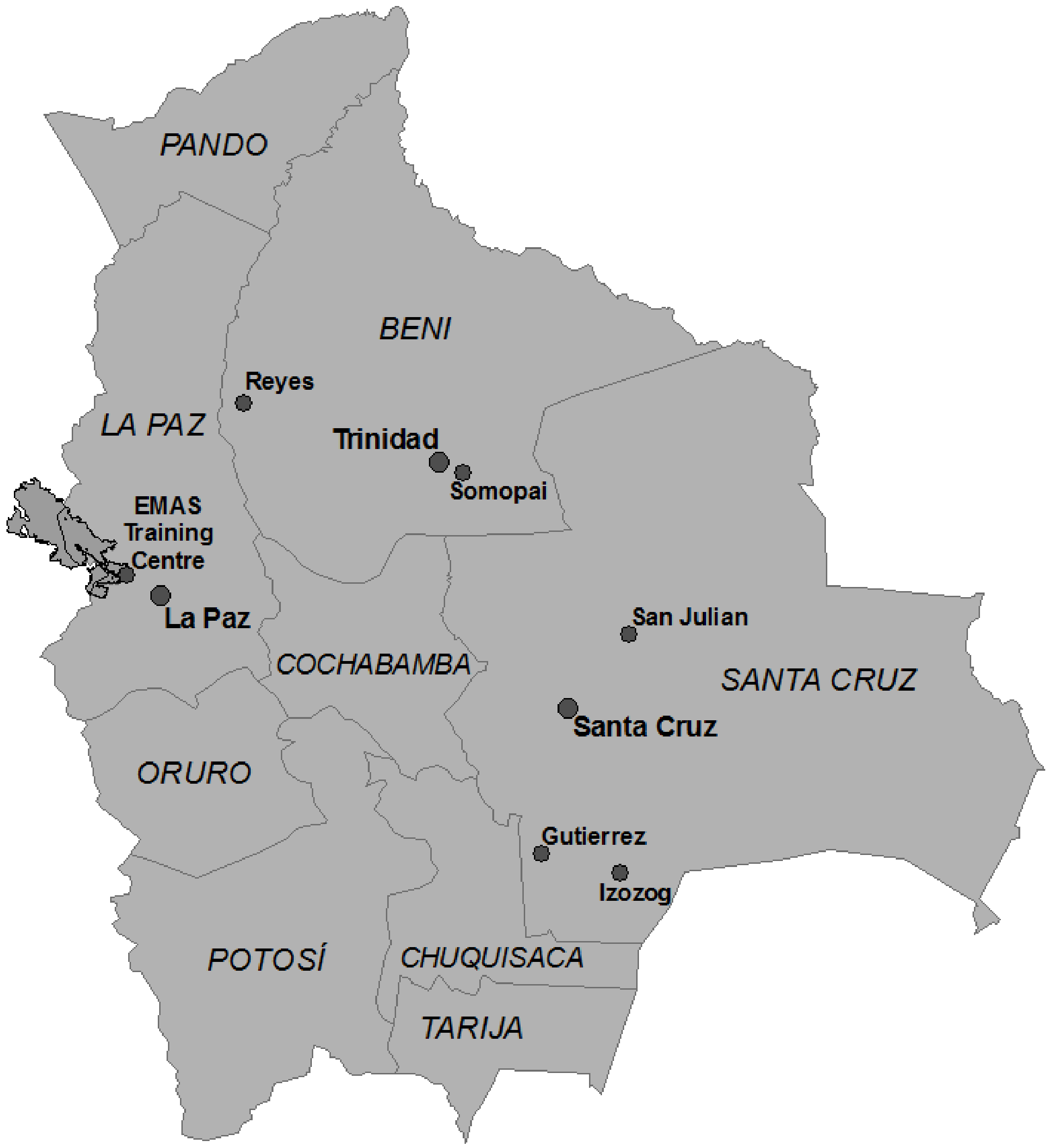

Figure 6: Map of Bolivia showing geographic departments and research site locations

Main results and lessons learnt

Analysis of collected field data shows EMAS low-cost water supply technologies, specifically manual water pumps and manual well drilling techniques, to have had a significant impact on improving access to water supply at the household level in rural areas of Bolivia. Interviews with manual well drilling technicians in various parts of the country confirmed that small businesses are successfully implementing manually-drilled borehole systems fitted with EMAS or similar types of low-cost manual pumps. Surveys and inspections performed during household visits show that families are using EMAS wells and pumps as primary household water sources in situations in which they are the only water system available at the household level, as well as when other water supply systems exist. EMAS manual water pumps are shown to be a low-cost household-level water lifting option with low maintenance and repair costs. EMAS rainwater harvesting systems, while showing much potential, have to this point been implemented in Bolivia on a relatively small-scale.

<u>EMAS Manual Pumps</u>

Preliminary analysis of field data shows EMAS manual pumps to be a sustainable water-lifting option for household water supply in the studied contexts in Bolivia. Visits to over eighty households that use EMAS manual pumps in their primary water supply systems (wells or RWHS) showed nearly all pumps (78 out of 79) to be operational. Of these operational pumps, 85% (66 out of 78 pumps) were found to be functioning normally (i.e. without significant issues, and water discharging normally), including 72 % of pumps (13 out of 18) that were reported to have been installed over ten years ago.

Of the EMAS Pumps that were not operating normally, the issues were determined to be either due to significant leakage from the handle or above-ground well-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).

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

Reported 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 departments was reported to have been done on 35 of 71 pumps surveyed. The replacement of the pump valve was reported by households to cost an average total of approximately US$ 9 (materials and labour) in the areas where this question was posed (Izozog, Somopai, and Reyes). The cost of a new EMAS Pump, to be installed to 15 metres depth, was reported by local technicians to be US$ 30-45 (pump material and construction costs only, i.e. not including well drilling).

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

In surveyed areas of both Santa Cruz and Beni departments, some users expressed a preference for manual pumps that provide a higher flow rate than the standard EMAS manual pump. This was not expressed by users in surveyed areas of La Paz department, where other types of manual household pumps were neither observed nor mentioned by participants during the research. In Santa Cruz department, several surveyed households in Izozog expressed plans to replace their EMAS Pump with a higher-flow “Baptist Pump”, as promoted by Water For All International, who developed Baptist manual drilling in Bolivia. [*Note*: In this area, the installed EMAS Pumps used were of a small pump-cylinder diameter (3/4”). EMAS now also promotes larger pump-cylinder diameters (1-inch to 1 ½ inch) where feasible, which allows for higher pumping rates.] An experienced EMAS-trained technician in San Julian confirmed that families in that area prefer the higher-flow Baptist Pump, and that he and other technicians working in the 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. This 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 is not a problem when collecting water directly from the pump spout, the low pressure 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, several surveyed families pump water from underground storage tanks, through their manual pump, and on to a sink, shower tank, and/or solar hot water heater. The ability of the EMAS Pump to discharge water at pressure from the pump head is seen as an important attribute. However, in the other research sites, pumping to elevations above the pump-head was not mentioned by households, nor was it witnessed during observation/inspection.

EMAS Manual Drilling Methods

In the research areas of Santa Cruz and Beni departments, it was evident that EMAS manual drilling techniques are used widely by small businesses. In Reyes, a rural town context, most of the houses in the town had a borehole in their yard drilled using EMAS techniques. Two technicians that were trained by EMAS about fifteen years ago (in a water and sanitation project that included training of more than 60 technicians in manual drilling throughout Beni department) continued their drilling business, 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 2-inch diameter well at a depth of 14-15 metres, including an EMAS or similar-type manual pump.

In Somopai, a team of manual drillers reported that they get most of their business from well-off clients, as poorer families cannot afford the wells (which the drillers charged about US$ 20 per metre to install, including a manual pump). While the ability of poorer families 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 project, which could potentially subsidize their purchase of a household well 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, where the client paid for the materials and exchanged labour (work in drillers' fields) in place of paying cash.

EMAS Rainwater Harvesting Systems

The use of EMAS-style rainwater harvesting systems in Bolivia is very limited at this point. Despite these systems being promoted in Bolivia through EMAS trainings over the past several years, the only known area where a significant number of households have implemented these systems is in Cachilaya, the small community one kilometre from where EMAS's training centre is located.

In Cachilaya, construction of EMAS Household Rainwater Harvesting systems is starting to catch on after several years of promotion, including training of several local residents in system construction. There are currently an estimated 25-30 families in Cachilaya with EMAS household RWHS that they have financed on their own. Additionally, a project being developed by the local municipality (completely independently of EMAS) would subsidize (either partially or fully) the construction of household RWHS.

In Gutierrez, an EMAS-trained technician built a demonstration site for EMAS technologies at his home in 2010, including RWHS, with EMAS paying for the cost of the materials. To this point, the EMAS RWHS has yet to be replicated by others in the area. It is evident that significant support, at a minimum in the form of promotion of the household RWHS technology, is needed in this area for others to consider uptake of the technology.

Financing of EMAS Water Supply Systems

In the studied areas, various subsidy levels were reported, from no subsidies, to partial subsidies that covered some material costs, and in other cases covered all labour costs. In the Rural town of Reyes, of 26 households surveyed, no households reported to have received subsidies for their well and pump systems. In Somopai and Izozog, household well and pump systems have often been partly subsidized by development projects.

In the area around Lake Titicaca in La Paz, near the EMAS training centre, many of the manually-drilled wells fitted with EMAS Pumps have been partially subsidized by EMAS, with labour being provided by EMAS training participants, and households being responsible for all material costs and feeding the drilling team. In Cachilaya, 6 out of 8 households with RWHS reported not receiving any subsidies, with one household receiving subsidies for materials, and another being financed by the government (for teaching housing).

Throughout the study area, a total of six families (7%) reported having received a loan for purchase of their household water supply system. Given the willingness of families in the research areas to invest in household water supply systems, possibilities for linking microfinance loans to household water supply should be explored.

Conclusions and Recommendations

EMAS manual water pumps and manual drilling techniques are shown to be a sustainable household water supply option, and to have had a significant impact on improving access to water supply at the household level in the studied rural areas of Bolivia. Households are able to maintain low-cost EMAS Pumps, which have in some cases been used for more than 10 years. These pump systems can be installed and repaired by local technicians, and numerous examples have been seen of small groups of local technicians running small businesses installing and repairing such systems.

Given the willingness of EMAS water system owners to pay a significant percentage of the costs for purchasing their systems (and in many cases all of the costs), it is important that the potential of linking low-cost water supply systems with microfinancing loans be explored in Bolivia, to allow for access to these systems by more households.

EMAS rainwater harvesting systems show potential, based on their success in Cachilaya. For the technology to have a good chance at broader uptake in other areas of Bolivia, continued training of technicians should be complemented by further support to promote the technology.

Recommendations for further research include:

- A study of how to effectively scale-up the implementation of low-cost EMAS household water supply technologies within Bolivia (planned),
- A comparative analysis of EMAS manual pumps with other types of low-cost manual pumps commonly used at the household level in developing countries, as well as with the Rope Pump (planned),
- An evaluation of a potential project in Cachilaya (near EMAS Training Centre) which proposes to provide local households with support to build EMAS household RWHS.
- An in-depth study of the impact of a previous project that trained over sixty technicians in Beni department in EMAS manually drilling and pump construction.

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