

Increasing Access to Low-Cost Water Supplies in Rural Areas:

# EMAS Household Water Supply Technologies in Bolivia



## 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 consisted of household visits that included 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 these systems. While EMAS rainwater harvesting systems (RWHS) exhibit potential to provide adequate household water 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.

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, a 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.

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).

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## Abbreviations

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

## 1. 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 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.

## 2. Context

### 2.1 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 108<sup>th</sup> 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).

## 2.2 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 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.

Improved drinking water sources	Unimproved drinking water sources	EMAS household water supply systems studied
<ul style="list-style-type: none"> <li>■ Piped water into dwelling</li> <li>■ Piped water to yard/plot</li> <li>■ Public tap or standpipe</li> <li>■ Tubewell or borehole</li> <li>■ Protected dug well</li> <li>■ Protected spring</li> <li>■ Rainwater</li> </ul>	<ul style="list-style-type: none"> <li>■ Unprotected spring</li> <li>■ Unprotected dug well</li> <li>■ Cart with small tank/drum</li> <li>■ Tanker truck</li> <li>■ Surface water</li> <li>■ Bottled water</li> </ul>	<ul style="list-style-type: none"> <li>■ Manually-drilled wells (i.e. tubewell or borehole) fitted with manual pump</li> <li>■ Rainwater Harvesting Systems (including manual pump)</li> </ul>

**Table 1: Categories of Improved and Unimproved Water Sources (JMP, 2013), and EMAS Household Water Supply Systems Considered in the Research**

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 organisations, 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.

## 2.3 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. Research 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 centre 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 2 shows the numbers of household visits and semi-structured interviews done in each region of Bolivia.

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
<b>TOTAL</b>		<b>86</b>	<b>15</b>

**Table 2: Summary of number of household visits and interviews by region**



## 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.

## Semi-Structured Interviews

Semi-structured interviews were conducted with rural water supply technicians and organisations 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.

## 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.

## Research Locations

Research was carried out in three regions of Bolivia: Santa Cruz, Beni, and La Paz (Figure 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 organisation 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 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 organisation 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 centre 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.

## 4. 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 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 Box 1. In their work outside of Bolivia, EMAS typically partners with other organisations and local/national governments for implementation, and promotes the same strategy through trainings and assessment trips.

- 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.

**Box 1: Example of EMAS strategy (Buchner, 2011)**



**Figure 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)

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 neighbours have, as if they see value in it, they will likely want to replicate it (Buchner, 2011).

## 5. Results and Discussion

### 5.1 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 metres (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 Box 2.

#### Pumping from below-ground to surface

- A single EMAS Pump lifting water from a hand dug well, drilled bore-hole, 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

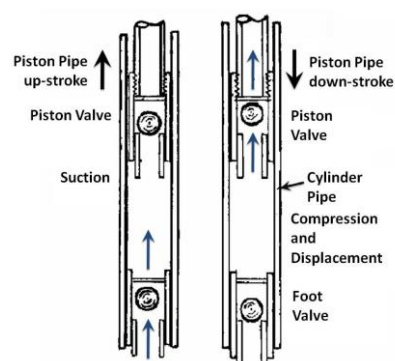
- Lifting water from a surface water source (e.g. a lake, river, or storage tank) to an elevated point

#### 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

#### Box 2: Common uses of EMAS Pumps

The EMAS Pump consists of an outer PVC pipe ('pump cylinder' - typically of 20-40mm 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 shows how the EMAS pump valves function.



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

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 than 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).

## 5.2 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 metres 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 and Figure 4, 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.

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
<b>TOTAL</b>	<b>79</b>	<b>66</b>	<b>84</b>	<b>12</b>	<b>15</b>

**Table 3: Reported EMAS Pump age distribution and inspected functionality**

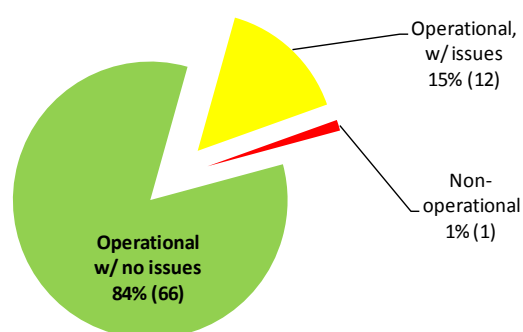
Of the surveyed EMAS Pumps that were not operating normally, the issues were determined to be either due to significant leakage from the handle or above-ground pump joint (observed), or below-ground issues such as leakage through the pump pipes or valves (not directly observed, except in one case where 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).

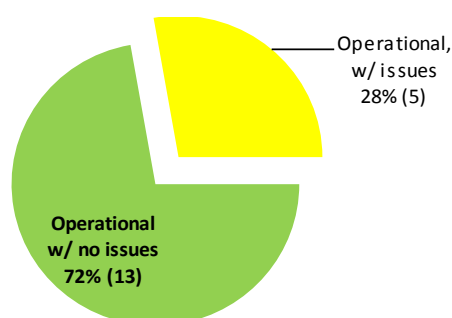
In the community of Somopai in the Beni region, there were a few additional instances where non-functional EMAS Pumps were observed at non-surveyed homes. In each of these cases, the pump and borehole had been abandoned, either due to current use of another water system or when a family had moved and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

**EMAS Pump functionality (79 surveyed)**



**EMAS Pump functionality, 11 years or older (18 surveyed)**



**Figure 4: (a) Operational state of all EMAS Pumps surveyed [top]; (b) Operational state of sub-set of EMAS Pumps installed 11 or more years ago [bottom]**

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 knowledgeably 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 organisation 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).

### 5.3 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 (Box 3), 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 metres 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  $\frac{1}{4}$  to  $\frac{1}{2}$  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 5 depicts how a hybrid percussion-jetting-rotation system functions. Figure 6 and the top-left cover photo of this document show 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  $\frac{1}{4}$  to  $\frac{1}{2}$  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 stabilising 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.

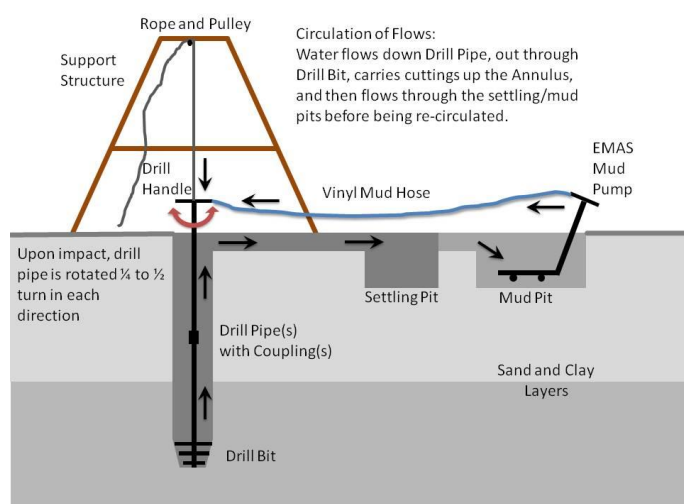
The Percussion-Suction-Rotation drilling method is better suited to drill through thick layers of coarse sand or in the presence of small stones (<2 cm) than the Standard EMAS drilling method. The Percussion-Suction-Rotation method is capable of using thicker drilling fluids and larger pipe diameters 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 metres). 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).

#### Box 3: Manual drilling techniques developed/promoted by EMAS





**Figure 5: Diagram of EMAS hybrid Percussion-Jetting-Rotation ('Standard EMAS' method) manual drilling system**



**Figure 6: 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/sock 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 an artificial gravel pack. Well development is done using manual pumping and plunging techniques.

## 5.4 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 busi-

nesses. 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 metres, 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 metre 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 4 shows the reported reliability of the manually-drilled wells surveyed, according to age.

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	
<b>TOTAL</b>	<b>75</b>	<b>73</b>	<b>2</b>	

**Table 4: Reported EMAS manually-drilled well age distribution and reliability**



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.

## 5.5 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 litres (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 litre tank. Above-ground tanks of similar sizes are made using ferrocement construction, which makes use of wire-reinforced cement mortar. Figure 7 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 7: 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 begin 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.

## 5.6 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 kilometre from EMAS's training centre. 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 metres.

## 5.7 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 5 shows reported EMAS water supply system financing for each of the research areas.

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
<b>TOTAL</b>	<b>86</b>	<b>53</b>	<b>4</b>	<b>24</b>	<b>5</b>
<i>Percent of total households</i>		62	5	28	6

**Table 5: Reported Financing of EMAS Water Supply Systems in Bolivia**

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 centre, 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.

## 6. 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 (WSP, 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 organisations 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.

## 7. 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 paper 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 centre) 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.

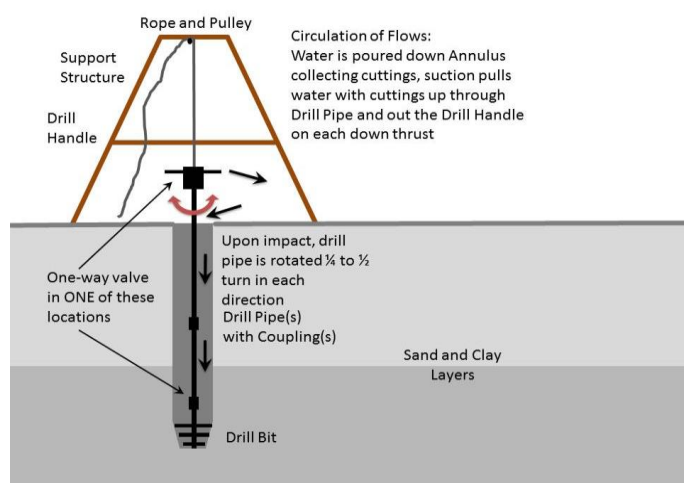


Figure 8: Suction Drilling

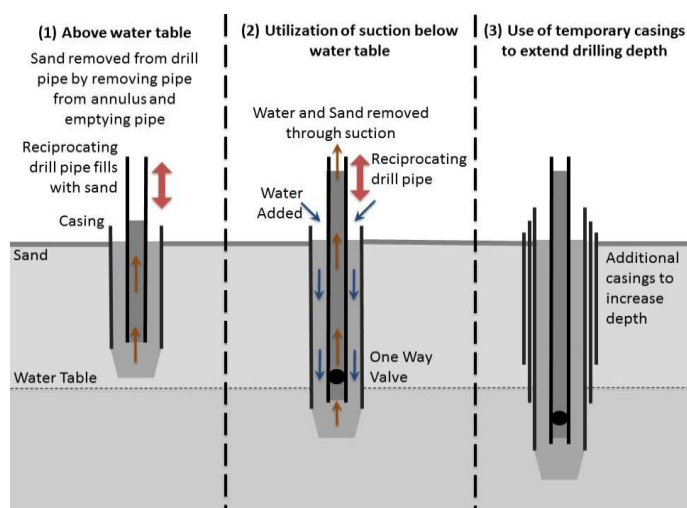


Figure 9: Sand Sludging Drilling

## 8. Resources – EMAS Technologies

Over 30 training videos of EMAS technologies (Box 4), 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

Box 4: EMAS Web Video Topics (Vimeo, 2012; Blip 2012)

## Contacts

Queries related specifically to this publication:

Michael F. MacCarthy [mmacCarthy@mail.usf.edu](mailto:mmacCarthy@mail.usf.edu)

Queries related to EMAS technologies:

Wolfgang Eloy Buchner, EMAS [emasinternational@yahoo.es](mailto:emasinternational@yahoo.es)



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## About the Authors

Michael F. MacCarthy is a rural water supply and sanitation specialist, with interests in accelerating self supply, low-cost technologies, social marketing, and entrepreneurship. He is currently a doctoral candidate in the Department of Civil & Environmental Engineering at the University of South Florida (Tampa).

James W. Buckingham recently graduated from the University of South Florida with a Master of Civil Engineering degree (Water Resources specialty).

James R. Mihelcic has expertise in sustainable development and education, research, and implementation of international water and sanitation systems. He is a Professor of Civil & Environmental Engineering and State of Florida 21st Century World Class Scholar at the University of South Florida (Tampa). He also directs the University of South Florida's Peace Corps Master's International Program in Civil & Environmental Engineering.

## Contact



RWSN Secretariat  
SKAT Foundation  
Vadianstrasse 42  
CH-9000 St.Gallen  
Switzerland

The Rural Water supply Network (RWSN) is a global knowledge network for promoting sound practices in rural water supply.

Phone: +41 71 228 54 54  
Fax: +41 71 228 54 55  
Email: [ruralwater@skat.ch](mailto:ruralwater@skat.ch)  
Web: [www.rural-water-supply.net](http://www.rural-water-supply.net)

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