UNIVERSITY OF TWENTE

Safe drinking water for men and animals

A report for the Bachelor-thesis of Civil Engineering (& Management)

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“Safe drinking water for men and animals”

A report for the Bachelor-thesis of Civil Engineering (& Management), University of Twente, The Netherlands.

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ABSTRACT

Students of different disciplines are often send abroad to do small scale development projects. This report is part of a project (Save Drinking Water for Men and Animals) that sends a technical student with a veterinarian student abroad who have the common goal to improve hygiene and health in an underdeveloped village. Target of this research is installing water supplies with clear, potable water in a safe and hygienic environment. Therefore a literature study is done to all facets, difficulties and problems regarding the realization of water supplies in development countries.

The approach used in this research is largely based on the method Water Safety Plans of the World Health Organization (Davidson et al., 2005). The Water Safety Plans, in turn, is part of the Guidelines for Save Drinking Water (Abbaszedegan et al., 2004). However this method does not deal with practical designs and therefore directives of the Bolivian government are added to design water supplies (Norma Boliviana, 2006 and 1995). Finally for Operation & Maintenance important directives of Davis & Brikké (1995) have been used.

After doing research to geo- and hydrological properties of the area, site investigation and hazard assessment (Water Safety Plans), a flat area within the agricultural area (the pampa) has been chosen to construct a water supply with respect to the Water Safety Plans and Bolivian directives. The best way to realize a water supply in this area within the framework of the project Save Drinking Water for Men and Animals is creating a water tank just below the ground surface. This water tank will be automatically filled with water from a 50 meters deep confined aquifer, containing clear and potable water. The water tank will be filled automatically due to a constant hydrostatic pressure which is present throughout the year. On top of a water tank a pump will to be installed. Research and practical experiences showed that Bolivian pumps need to be long-lasting; the importance of the pump being long-lasting is inferior to the pump having sufficient capacity since time is no issue on the Bolivian highlands. The area around the pump should be kept as hygienic as possible in order to secure the quality of the water for the future. Therefore a concrete slab should be constructed around any water supply. Furthermore a ditch and a fence should be included in order to keep the pump area clean and hygienic.

To ensure the continuity of the water supplies is guaranteed, operation & maintenance plays a crucial role. For this type of water supply, only a selection of the directions of Davis & Brikké (1995) is necessary to ensure the continuity of this type water supply. Responsibilities are given to those who meet the criteria (Davis & Brikké, 1995).

Other technical solutions are a rope-pump, springwater catchment, rainwater catchment or PVC-pumps. All of these could be applicable, but within their own conditions and budgets.

PREFACE

This report is primarily written for the final bachelor assignment for the study Civil Engineering & management at the University of Twente. Besides this, the report is also meant for all participants on the project 'Save Drinking Water for Men and Animals' (SDWMA). The SDWMA-project made it possible to do the final bachelor assignment in Bolivia from May to September 2007. This report will be used during the evaluation off the project results.

This SDWMA-project is the first of its kind and therefore has been set up to test a manual written for small scale development projects by students of different disciplines, an initiative of prof. Frans van Knapen (University of Utrecht) and some Dutch rotary clubs who have shown their interest in this kind of projects. When this test-project turns out to be a success, rotary clubs will organize more projects in this set-up.

For this test-project a veterinarian student and a student Civil Engineering are being send abroad to Bolivia, supported by the Dutch-Bolivian NGO AIPUR. Target of the technical student is the realization of water supplies for poor people; in this case the target village is Cohana. Therefore literature and local research should be done to determine the best solutions involving water supplies in the regent. Target of the veterinarian student is testing water and informing people concerning hygiene and health by setting up a hygiene program in close cooperation with the NGO.

I would like to thank all people involved in this report and the project SDWMA. Special thanks go to Sara Kuijer, German Aramayo, Agnes Krijnen, prof. Frans van Knapen, Koen Tjoa, Kin Sun Lam, Frans Cox and Mariska Leeflang for their contributions to the project. Furthermore I´d like to thank Richard Beckett, Wolfgang Buchner, Hans Zandvliet, Hans Geerse, Marcelino Lima-Mendosa for their contributions and help in Bolivia. Finally I'd like to thank Ellen van Oosterzee-Nootenboom and Denie Augustijn for their advises regarding the Bachelor-thesis.

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M.M. Vierstra

1. INTRODUCTION

Since NGO AIPUR (Acción Integral Participativa Urbana Rural) started up in 2003 there has been hope for a better future for the people in and around the village Cohana situated near the lake Titicaca. The people living here are poor, do not have sanitary facilities nor safe drinking water nor knowledge about hygiene and health. Members of AIPUR in Bolivia are working on two frontiers at the same time. First target is to improve hygiene and health in the village Cohana by supplying safe drinking water and inform the villagers about aspects related to hygiene, health and how to deal with safe drinking water. The second goal is laying hands on the source of all problems. AIPUR is trying to make the river Katari (which flows via Cohana to the lake Titicaca) a healthier river by reducing the immense contamination in the cities El Alto and Viacha.

The project Safe Drinking Water for Men and Animals (SDWMA) has chosen NGO AIPUR for executing the pilot project to test the manual. Significant parts of the manual are subtracted from the WHO documents of Abbaszadegan (2004) and Davidson (2005) who developed Safety Plans and Guidelines for Save Drinking Water. Because the manual is not completed at the start of the project, some parts of the project have to be improvised. An SDWMA-project sends to students of different disciplines abroad who have the common goal to improve hygiene and health in an underdeveloped village. In earlier projects student have been send abroad with the goal only to provide clean water or only perform hygiene education. The idea is that this does not lead to satisfying health improvement. Founders of the SDWMA-project think that the combined effect is significant bigger then the sum of both aspects individually. The first student is veterinarian student, who will be responsible for informing and educating people about hygiene & health and testing water with a testing kit. The second student is a technical student who is responsible for the provision of clean drinking water.

In the first part of this report inventarizations, research and situation descriptions are given. These form the basis for the Water Safety Plans in chapter 4. Based on the outcome of previous chapters, a program of requirements for the water supply is made at the end of this chapter. The next chapter (5) shows the design, characteristics and requirements of the proposed water supply. Subsequently the last part deals with implementation, operation & maintenance and verification. Finally some practical experiences are listed.

2. BACKGROUND

2.1. GENERAL

Cohana is an underdeveloped village with approximately 1485 residents and is located on the Bolivian altiplano adjoining the lake Titicaca, 3815 meters above sea level (figure 1). There are no accurate population numbers available since people tend not to register themselves when for example moving to the city (rural communities receive money for every resident, so people are encouraged to indicate they still live in the village). Live standards of the villagers are very poor, although the influence of western products is quite largely visible. People ride on mountain bikes and have thermos flasks while still having no showers nor access to sanitary. In general, people in Cohana are working in the agricultural sector, with cultivations of potatoes, barley, grain and cheese. Since the agricultural revolution in 1952 all children are going to school till the age of 17. All households have access to electricity, but only a few houses have access to basic sanitary, which is nothing more then a hole in the ground surrounded by walls. The yearly rainfall in Cohana is 515 mm/year. Most of the rain comes in the raining season December – April (appendix A). The dry season runs from May till November. The climate in Cohana is described as cold; frost is very usual in Cohana throughout the year.

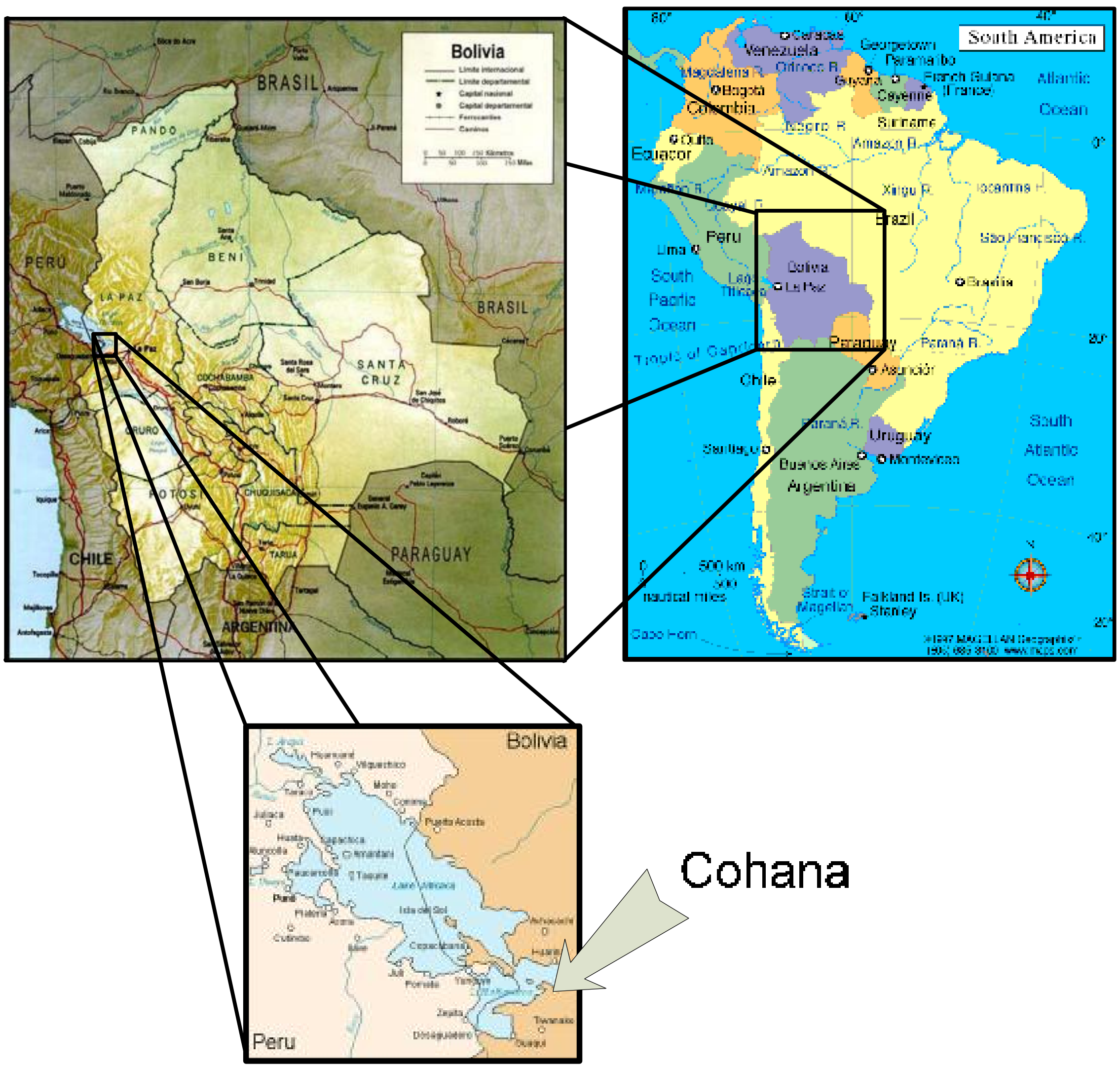

FIGURE 1, LOCATION OF TARGET AREA COHANA, BOLIVIA.

2.2. HYDROLOGICAL PROPERTIES AND SOURCES

There are many methods of exploring shallow groundwater, although they vary widely in investment, costs, difficulty of interpretation, skilled manpower requirements and effectiveness. Test drilling and pumping is the preferred method for detailed groundwater surveys for hand drilled tube wells. This method can provide absolute certainty about quantity and quality and is very cheap when carried out with hand operated equipment. But no survey should be undertaken without the prior planning and study of the available documents relating to the area (Blankwaardt, 1984).

2.2.1. GEOLOGY, THE ALTIPLANO

Cohana is located on the altiplano, between two main mountain rigs of the Andes (figure 2). The pampa of Cohana is flat and marks the beginning of the altiplano, which stretches from the Titicaca lake to the salt plateau (Salar Uyuni) in the south of Bolivia. The altiplano near Cohana is formed by the glacier Milluni million years ago. When the glacier started to melt down and drawback, it's melting water disposed sand, rocks and clay, which nowadays form the lower layers of the altiplano. The upper layers of the altiplano are alternately very small clay layers (up to 1 cm) and large layers of sand. The clay layers are deposits of floodings from the lake Titicaca; the sand layers are created after periods of heavy rainfall whereby sand is eroded from the hills in the area. In figure 3 a sectional plane of the altiplano and the nearby range of hills is shown. This situation reflects the situation in Cohana, which is located a bit uphill. Groundwater in the hills streams down over the impermeable layers of the Andes. A well in Cohana visualizes this constant flow of water because it always contains fresh groundwater throughout the year on a constant level.
The first water is found on 2,80 meters and is very salty; also underlying layers contain salt as well. This are the remains of what was once the largest sea in the world. A sandy earth layer with high hydrostatic pressure between 47 and 58 meters contains fresh water. The hydrostatic pressure in the 50 meter deep earth layer is caused by the groundwater flowing down hills, 8 kilometers away all the under the pampa (figure 3figure 3). All over the pampa this Layer is found between 47 and 58 meters of depth.

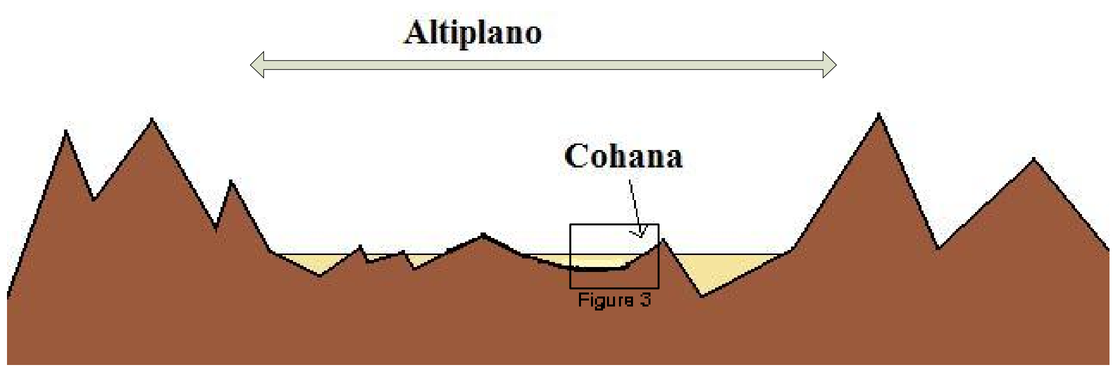

FIGURE 2, SCHEMATIC SKETCH OF CROSS SECTION OF THE ANDES SOUTH-WEST OF THE LAKE TITICACA WITH ALTIPLANO AND LOCATION OF COHANA

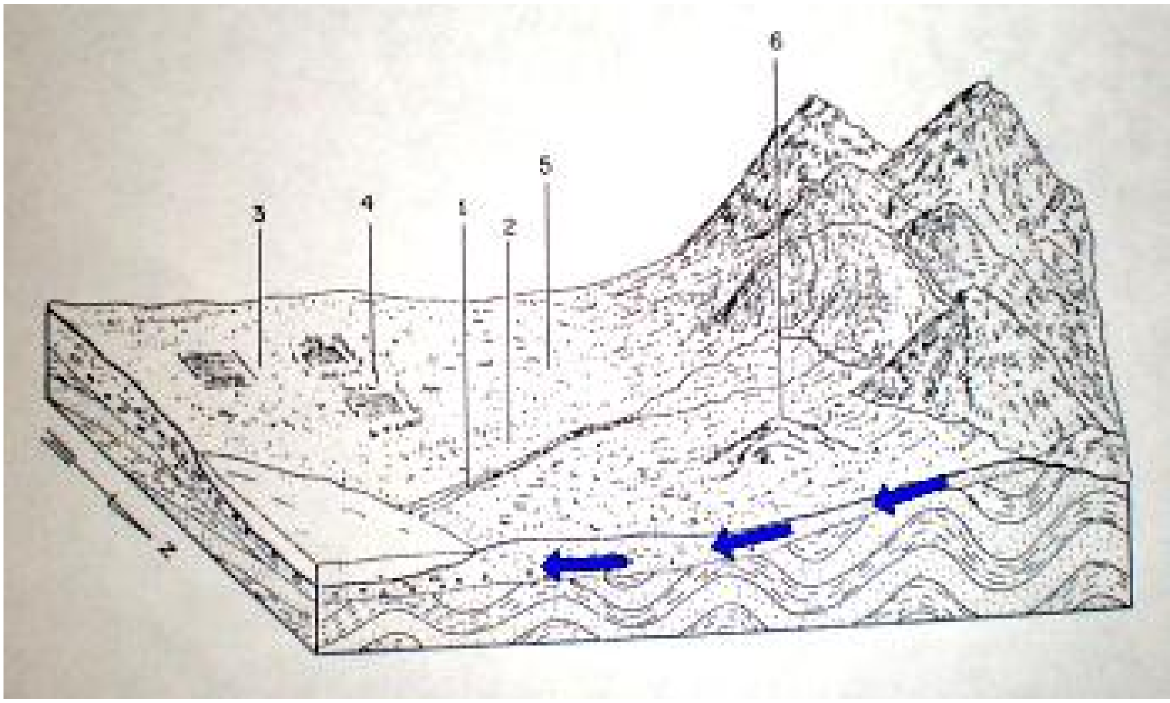

FIGURE 3, SKETCH OF THE EARTH LAYERS AND FRESH WATER STREAM IN PUCARANI, DISTRICT OF COHANA.

3. PROBLEM ANALYSIS

Cohana

At the end of the dry season (October/November) the problems caused by shortage of clean drinking water are considerably. There are some natural sources which provide clear (not potable, Appendix G) water, but the availability is limited. Since 2003 the government has installed water taps in or close to every house in the community. These water taps are connected to a water tank on a hill 5 kilometers away. Old water tanks constructed before 2003 by NGO Suma Yayma and by engineer Richard Becket have fallen into disrepair. Water is flowing out of these sources and evaporating or disappearing into the ground. Generally the water that is available is used for washing, cleaning and cooking. People in Cohana don't drink potable water even if it is available; they tend to drink soda's all day long. Because of this, nowadays bottled drinking water is not longer available in the town. Along the village flows the river Katari, which is heavily polluted by the cities El Alto and Viacha. Formerly people used to use this water for bathing and as drinking water for the animals. Nowadays bathing is impossible, because the skin of the people gets irritated from bathing and the water is very bad for the production, growth and health of animals. The river forms an obstacle between the village and the large agricultural area belonging to Cohana: the pampa. There's no bridge available since a flood in 1984 destroyed the bridge and the government has failed to reconstruct the bridge ever since.

Pampa

The pampa is an extensive area with a lot of animals and agricultural activities, located on the other side of the river Katari. In the dry season there's no potable water available on the pampa. However there is water, like the water from the swamp or the river; as said this water is highly contaminated. Furthermore there are some hand dug open wells (private) on the pampa, but these wells do not contain potable water; these wells are very salty and most of them vulnerable for flooding or contain oil and garbage. There are no public water supplies available on the pampa, while there are approximately 3.900 cows, 15.000 sheep's, 1.500 pigs and some donkeys situated in this area. Furthermore, people work on the pampa during the day and need water for different purposes. Most of the people have a house on the pampa as well, but they normally don't sleep here, they use it as a place for cooking and storage of agricultural products. Along an old riverbed there's a close density of houses. People build their houses here, because this place is relative close to Cohana and safe from flooding since it's a little bit higher than the rest of the pampa (Appendix E).

Quantitative and qualitative needs

In Appendix B an overview is given of the drinking water needs in Cohana before the startup of the project. There is about 150.000 liters per day needed in the village and an additional 250.000 liters a day on the pampa. These numbers are excluded from irrigation needs; people in Cohana don't use water for irrigation, first because there is no water available for irrigation (except for water in the river which is not only polluted but mostly also to far away), second there are no materials available for irrigation and third, because they most probably wouldn't irrigate when problems one and two are dissolved because of their behavior, lack of knowledge and culture. However, investigation on this topic is not part of this project.

Definition of the problem

Large drinking water shortages exist within the area of Cohana in winter times. The biggest concern comprehends the shortages on the pampa, where little to no drinking water is available. A structured approach to this problem should lead to a solution and application of the solution that is practical, effective, hygienic, easy maintainable and low budget.

3.1. Operational limits and Health-based targets

Operational limits

Goal is the realization of one or more water supplies for the benefit of Cohana. The following list shows the operational limits where within the technical student has to work.

- The budget available for civil technical installations is 675 USD (€ 500,-).
- The design of water supplies will have to meet WHO-criteria.
- The design of water supplies need to be sustainable and long lasting: over 15 years.
- The design should be easy so local people can operate and maintain the water supply themselves.

Health-based targets

Targets are set according to set-ups of the Guidelines for Safe Drinking Water (Abbaszadegan et al, 2004). The purpose of setting targets is to mark out milestones to guide and chart progress towards a predetermined health and/or water safety goal. To ensure effective health protection and improvement, targets need to be realistic and relevant to local conditions and financial, technical and institutional resources.

TABLE 1, HEALTH-BASED TARGETS FOR SAFE DRINKING WATER IN COHANA

target	- provide the community of Cohana safe drinking water
Health outcome	- reduction in disease incidence or prevalence
Water quality targets	- No or limited presence of harmful chemicals - No or limited presence of harmful pathogens and bacteria's
Performance targets	- provision of sufficient potable water for people and animals within range of water supply system - no faecal contamination through application of the water supply system
Specified technology targets	- protecting the well head against filtration of any possible source of contamination - protecting the surrounding ground from infiltration of access water of the pump - only desirable visiting of the pump by humans - protection against animals - no undesirable activities uphill or close to water source

4. WATER SAFETY PLAN COHANA

4.1. SITE INVESTIGATION

Cohana

In Cohana are different water sources available. First of all there are the water taps which provide clear, but not potable water according to the analysis of the hygiene student. The water contains Escherichia coli (E. coli, indicates the presence of feacal contamination), enterococci (more than directive of University of Utrecht) and other biogenic contamination (Appendix G). A water tank of 20 m^3 (see chapter 3, problem analysis) provides the water for these taps and is being filled by a natural source which provides 0.18 l/sec at the end of the dry season, which means a daily supply of 15.7 m^3 liters per day; the buffering water tank does have a capacity of 20m^3.
Secondly, there are some small natural water sources (Appendix C) which are no more then a very little stream of water flowing out of the Cohana hills; these are used by surrounding houses; people get their water from these sources by buckets. The remains of old water supply systems are visible, but these systems have fallen into disrepair. Because these are open aquifers accessed by human every day, these are microbiologic contaminated (Davidson, et al., 2005). However, usage of these sources is limited to none. Furthermore there exist two unused springs in the east of Cohana, these provide 0.20 and 0.40 l/sec (Ambiente, 2006). The local government (Pucarani) has the intention to install 2 standard water tanks (20m^3) connected to these springs including a water pump. After completion of the government plans a total provision of 0.18 + 0.20 + 0.40 = 0.78 l/sec is realized. The human consumption of Cohana for 2026 is determined at 0,71 l/sec, so after completion of the government plans, there should be sufficient water at least till 2026 (ambiente, 2006). It should be noticed that the local government does not take care of water for animals; this is not their priority and they assume this water is provided by the river.
When people are asked where the water needs and problems caused by shortage of (drinking) water are the biggest, they always refer to the pampa and indicate most problems exist there.

The pampa

Most of the people of Cohana work on the pampa during daytime; their work includes production of their own food and food for their animals. There's little chance in selling agricultural products; only some cheese is sold by a select group of people. The pampa is an area of 5*4 square kilometers and owned by farmers of different surrounding villages like Lacalle, Quercoha, Aygachi and Cohana. The part of the pampa belonging to Cohana geographical is 1,5 * 3 square kilometers, but a lot of people of Cohana use land of surrounding pampas like the pampa of Quercoha. All the land on the pampa theoretically is divided in hectares and most families own 2-4 hectares. In wintertimes (April till November) there is no drinking water available on the pampa while approximately 250.000 liters per day are needed (table 7). In the past there have been some efforts by local people to try to acquire drinking water on the pampa, like hand dug wells and EMAS-drilled holes with a simple piston. Both solutions nowadays are unsatisfactionary. First, the water in the hand dug wells is salt and contains microbiological contamination, because it's an open aquifer and it's accessed with buckets (Davidson, et al., 2005). One still functions and has not collapsed so far. This hand dug well has been created close to a dry riverbed (this river only contains water in the raining season). The depth of the well is 3,50 meters and the water table is 2,80 meters below surface (June, 2007). The locations of present water sources are shown in figure 7. Second, there exist some EMAS-drilled holes. These are hand drilled holes fitted with 1,5 inch PVC tubes which reach to a sandy earth layer with depths between 47 and 58 meters (Buchner, 2007). The water in this earth layer is potable according the analysis of the hygiene student (see appendix G). The hydrostatic water pressure in this earth layer is very high: the water tables in the tubes reach from 20 cm below surface to 50 cm above surface and are constant throughout the year. There are no other layers with fresh water at higher depts. Layers between 3 and 47 meters contain too much salt or insufficient water. In the near future, a water supply system of the Bolivian Government will be installed on the Quercoha pampa, but considering the corruption this system will never be completed.

Selection of wells locations

The major shortage of clean water is abundantly clear on the pampa. This is mainly a shortage of water for animals. Reasons for locating a public water supply on the pampa and not in the community are:

- All houses in the community have a private water tap (since 2003), therefore people are not interested in public (drinking) water which is not located in their backyard, even if there is no water available temporary in their own tap. (Buchner, 2007)
- The village is very elongated, so only a very small part will be covered by one water supply (Blankwaardt, 1984).
- An available public well containing clean water is not used by villagers.
- Villagers indicate their greatest concerns about water exist on the pampa.
- Cattle in Cohana can drink water from the closely located, but very polluted river; the same goes for animals on the pampa, but there are far more animals located on the pampa and the people need to walk great distances with the cattle to reach the river.
- The houses on the pampa do not have access to any water.
- Regarding the polluted water of the river, relatively clean water is available in the community; this does not count for the pampa.

According to (Blankwaardt, 1984) locations should meet the following criteria:
- Located within a distance of 400 m of those parts of the pampa for which the well is meant to serve
- It must be safe from flooding
- It must meet environmental criteria; i.e. at least 50 meters from pit latrines, etc.
- It should be located in such a way spill water and rainwater can be drained away from the well.

Furthermore, concerning the hydrological criteria's quantity and quality, any location on the pampa can be chosen, since the pampa is a quite flat area with the 50m deep fresh water layer available anyplace on the pampa (paragraph 4.1 Site Investigation). The proposed well locations are presented to the village chiefs (Mallku's) and people who will be responsible for maintaining the water supply systems of Cohana as recommended by Sawyer et al. (1998). The village chiefs did choose a location that very well statisfied most criteria; it only didn't meet the criteria 'safe from flooding', because it was located in an old riverbed. However, considering the whole pampa the locations are actually quite good, because most of the cattle is situated near this dry riverbed or could quite easy reach this place by walking the riverbed; nowadays the riverbed is like a big road; a lot of houses are situated along this riverbed also (people work around here, but don't use these houses for living). This place is a little bit higher than the other parts of the pampa and safe from flooding. Because the site proposed by the village chiefs only didn't satisfy the criteria involving safety from flooding, an alternative is proposed 25 meters away from the riverbed, close to the riverbed on an old bank were all the houses are situated (see Appendix D and E for respectively a map and a schematic cross section of the chosen locations for the first two water supplies).

4.2. POSSIBLE SOLUTIONS

While making the water safety plan for Cohana, different options for the water supply system have been considered. These are shown below (summed up if more then one); an argumentation is given for these alternatives being dropped out. No multicriteria analysis is made, since most options turned out to be unrealistic for this project or are not long lasting on the within the circumstances of the Bolivian altiplano; only two options are determined realistic, both include a hand drilled EMAS-tube: an automatic filling water tank with a rope pump and an automatic filling water tank with a local made, long lasting hand pump.

Borehole by machine
A borehole drilled by a machine of the Bolivian government costs € 4.400,-. This price makes the application of this option impossible within the framework of this project. However, also when sufficient financials are available, this option is not worth the costs, because of the limited range of a single point water supply (Blankwaardt, 1984). When combined with a distribution network, this could be a realistic option, but therefore further investigation is necessary.

Hand dug well with cement rings
All layers till a depth of 40m contain salt (paragraph 4.1) and therefore do not provide satisfactionary drinking water. Hand dug wells are limited to a depth of 10-15 meters depending on circumstances and therefore no option within the framework of this project (NWP, 2006).

Purifying water of the river.

This alternative is being dropped out because:
(1) Inappropriate for large quantities of water. Solutions concerning purifying water in development countries is limited to small quantities, because purifying is done in bottles or jerricans (Buchner, 2007 and NWP, 2006).
(2) to expensive
(3) intended supply areas are located to far from the river.

Gravity feeded water supply system
Dropped out because:
(1) Hills are located to far away from intended supply area
(2) the river Katari forms a barrier between the hills and the pampa, hills on the other side are located to far away
(3) to expensive

Alternatives regarding the option cheap hand drilled boreholes: 1,5” EMAS-boreholes (NWP, 2006)

Solar energy pumps fitted on borehole
Dropped out because:
(1) Too expensive (even after 40% reduction because of good connections in La Paz)
(2) not maintainable by locals
(3) minimum diameter of borehole: 4 inch or more (Lorenz price list 2007)

EMAS PVC-pump fitted on borehole
Dropped out because:
(1) Very little access water, because designed for private use
(2) very fragile, short lifespan

Rope pump with water tank as buffer (a technical design for a rope pump with water tank can be found in Appendix M)
An extra tube needs to be installed next to the water tank, because a minimum of 0,80 meter water level is required. Rope pumps require regular maintenance and contain fragile parts. The rope pump is easy to maintain, but several volunteers, NGO’s and other people found out that a rope pump in Bolivia just doesn’t work, even if people are instructed properly. People do not execute reparations even if they do know how to how to perform. Therefore the rope pump is not built anymore in Bolivia since 1995 (Suma Jayma, 2007).

Local made long lasting hand pump
Nowadays materials and designs have become available and affordable for long lasting hand pumps. These pumps do provide a little bit less water (depending on water depth), but time is no issue on the altiplano; on the other hand, repairing and maintaining is an issue, especially regarding public supplies. Constructors and designers claim the pump lasts for more than 15 years without any maintenance. The pump provides less water than a rope pump, but adds great advantage through an enormous reduction of operation and maintenance. Improved design by Richard Beckett and Wolfgang Buchner (2007), produced by the Bolivian NGO Suma Jayma in Viacha. Versions installed 15 years in neighboring towns of Cohana are still functioning without any maintenance. A guarantee is given on these pumps as well: in case of a broken pump, the manufacturer can be called (even poor people in Bolivia do have a cellular) for repairing the pump. Based on above statements, this design is being drawn up further in Chapter 5.

4.3. Hazard assessment and control measures

In order to establish what requires to provide safe drinking-water a hazard assessment will be performed. Hazards are identified by analyzing a flow diagram of the water safety plan for Cohana. In appendix H the flow diagram for water supplies in Cohana is shown. The identified possible hazards are shown in column 1 of table 2. After assessing the hazards all significant hazards in the water supply process, identified during the hazard analysis need to be identified as being controlled, or potentially controlled, by some mitigating process. Therefore control measures are determined (column 3). Control measures directly effect water quality and collectivily ensure that water consistently meets health based targets (paragraph 3.1). These are actions, activities and processes applied to prevent or minimise hazards occurring. Considered are direct and indirect hazardous events and activities that can migrate the risks from those events (Davidson et al, 2005). Furthermore responsibilities for monitoring are shown in column 4. Column 5 contains the actions that should be executed to control the hazard. Based on likelyhood and consequence (column 6) a risk rating has been made, indicating the importance of controlling the potential hazard. The risk ratings are determined by using the Quantitative risk analysis matrix, table 5.2 of the Water Safety Plans (Davidson, et al., 2005). The hazard assessment has been performed in close cooperation with the hygiene student (See appendix I).

TABLE 2, HAZARD ASSESSMENT AND CONTROL MEASURES

*RISKS RATED HIGH OR EXTREME HIGH ARE CONSIDERED TO BE SIGNIFICANT

Hazard	Cause	Control measure	monitoring	Corrective action	Likelihood / consequence	Risk rating
Ingress of contaminants due to poor construction or damage to the lining	Poorly maintained wellhead completion	Proper wellhead completion	As need arises, community operator	Insert seal around annulus, replace worn and corroded rising mains.	Moderate / major (WHO code: C4)	Extreme risk*
Ingress of contaminated water directly into the borehole	Poor wellhead completion	1 m concrete apron around wellhead; lining extends 30 cm above the apron; drainage ditches in place	Monthly, community operator	Extend lining, Repair apron, Clean and repair drainage ditches	Unlikely / major (WHO code: D4)	High risk*
Borehole area is inundated with contaminated surface water	Lack of diversion ditches	Good drainage around wellhead; situating the water supply system on a higher plateau	In the raining season, community operator	Repair and clean ditch, increasing size of ditch	Unlikely / major (WHO code: D4)	High risk*
Leaching of microbial contamination in aquifer	Leaching of feacal material from sanitation, animals, solid waste or drains	Provide adequate setback distances	Before construction, water development agency	Use alternative source	Moderate / moderate (WHO code: C3)	High risk*
Water tank contains too many deposits	Deposition of fine materials	Filtering of water	2 times a year	Clean the water tank	Almost certain / minor	High risk*
Contamination introduced as hand pump requires priming	Priming water contaminated	no priming when hand pump is in place	Annual, community operator	Refresh source water	Unlikely / minor (WHO code: E2)	Low risk
Contaminated shallow water drawn into aquifer	Hydraulic connection exists between shallow and deeper aquifer	Pumping regimes do not induce leaching	-	-	rare / minor (WHO code: E2)	Low risk
Leaching of chemicals into groundwater	Leaching of chemicals from landfills, waste dumps, discharges to ground	Provide adequate setbacks distances defined on travel time	Monthly, community operator	Move pollutant sources, improve pollution containment	unlikely / minor (WHO code: D2)	Low risk

4.4. PROGRAM OF REQUIREMENTS

As result of the outcome of the hazard assessment and determined control measures, specifications for the intended water supply system can be given; this will provide the basis for the design in chapter 6. For specifications of numbers see Appendix L (indicated with a *).

a. Wellhead and metal parts of hand pump need to have a life span of at least 15 years.
b. Parts underground need to have a life cycle of at least 30 years.
c. The used materials should meet Bolivians standards for water supply systems: NB-689.
d. Quality of water from water supply system should at least meet Bolivian standards: NB-512.
e. The system should have a minimum capacity of 6,2 m^3 per day (based on covering distance (Blankwaardt, 1984) in combination with total amount of water needed in the pampa: table 7). *
f. The water supply should be repairable by local people.
g. People responsible for maintenance should be able to purchase spare parts for an acceptable price within acceptable range (see Spare Part Requirements; paragraph 8.4)
h. The system should control or potential control all possible hazards considered significant (table 2).
i. All parts that possibly can contain water need to be accessible to be cleaned from deposits.
j. A water tank should have a minimum capacity of 3000 liters based on usage during peak hours. *

In the future, NGO AIPUR will work with a standard concept for cheap water supply systems on the pampa based on this research.

5. DESIGN & CONSTRUCTION

Below is a design of the water supply based on the chapters 2 to 4. The design encompasses a large water tank in the ground which will be automaticly filled with an adjoining EMAS-drilled hole. The tank is closed with a concrete cover, with on top a a robust metal water pump. The possibility of hazards occurring is reduced to a minimum. An alternative design with a rope pump and plastic water tank can be found in appendix M; this design has a greater flow rate (up to 60l/min). However this design is by far less reliable, because of vulnerability to hazards or breakdown. Table 3 gives an overview of all components of this design, the dimensions and their individual live span.

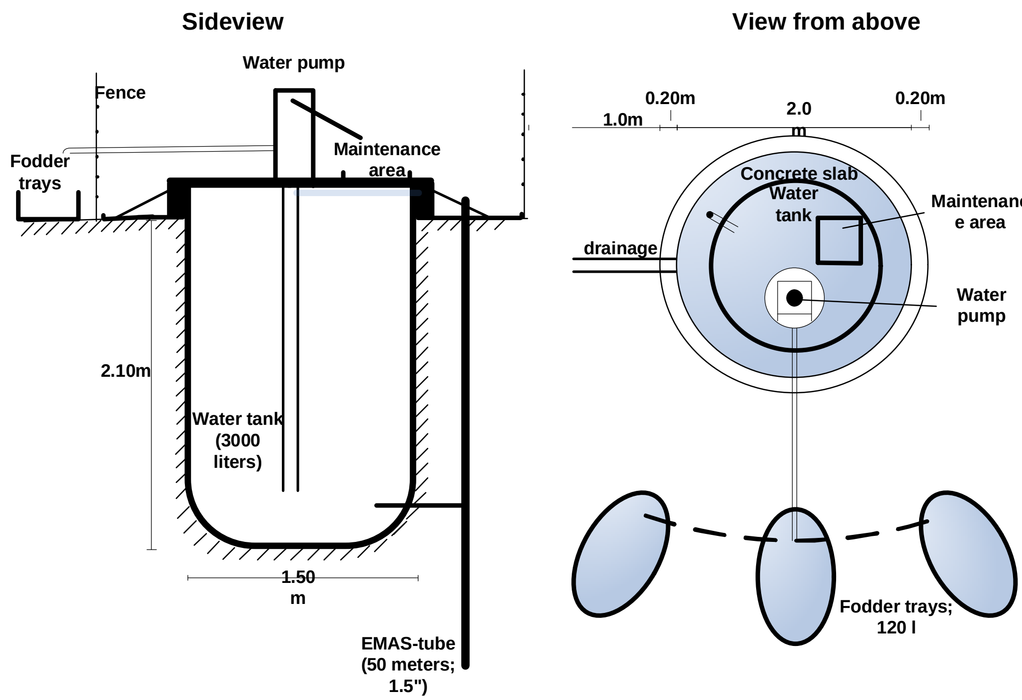

FIGURE 4, DESIGN OF WATER SUPPLY SYSTEM

TABLE 3, MATERIALS FOR ONE WATER SUPPLY SYSTEM ACCORDING TO BOLIVIAN STANDARDS (NB-689)
* ESTIMATED VALUES, SINCE NO INFORMATION IS AVAILABLE BY SALESMEN
** DEPENDING ON INTENSITY OF USAGE

Part	Description	Dimensions / amounts (m)	Life span (years)
Fence	Iron wire Wire netting Wooden post	18m 18m # 8	5 - 10*
Concrete for slab	- Portland cement; normas bolmanas (N.B. 2.1 -001 till N.B. 2.1 -014 and NB 001) - Sand. 0.02 – 7 mm - Gravel. 7 – 30 mm	Cement: 200kg Sand:0,28 m^3 Gravel: 0,4m^3	20 - 40*
Ferro cement tank	- Portland cement; normas bolmanas (N.B. 2.1 -001 till N.B. 2.1 -014 and NB 001) - Sand. 0.02 – 7 mm	Cement: 250kg Sand: 0,5 m^3	20 - 40*
Concrete fodder trays	Composition as concrete slab	# 3	20 - 40*
Reinforcement	Construction steel	45 m, 3/8"	-
Bricks	- upper part of the water tank - Rim of plateau	# 144 # 60	-
Water tank	3500l (3000 according to theory)	# 1	35
PVC tubes	- 1m 1.5" thick PVC; - T(tee) 1.5" thick - plug 1.5"	# 1 # 2 # 1	35
hand pump	Iron pump, according to most recent insights	# 1	15 - 30*
Clean water	From the EMAS-tube	-	-

Below a description is given to the 5 main components of the design.

EMAS-tube

The EMAS-tube will enter the ferro cement tank on the bottom and will at least last as long as the tank lasts, because this is a PVC-tube in the earth and not accessible. It could be possible that after time the EMAS-tube gets tapped with sand; for the continuity of the water supply it should be possible to clean the EMAS-tube when necessary. The tube will be extended to the surface, reinforced with cement. The upper part of the tube is extended with a iron tube of the same size; even a cow can stand on these above ground parts while still not damaging it.

Water tank

The water tank is made of concrete; no reinforcement steel is necessary since the earth surrounding the tank will provide the necessary pressure from outside. For construction, the surrounding earth is used as a mould. The water tank will be accessible for people to be cleaned from deposits. A volume ratio cement : sand of 1 : 3 is used. No gravel will be used since the wall will only be 3 centimeters thick and little rocks will form weak spots in the wall. The bottom of the tank is made round, since corners and a flat bottom will form weak spots also.

Water pump

The water pump is a standard produced robust pump constructed in different parts of Bolivia, including El Alto (La Paz) and Viacha. Advantage of this pump is that it requires no maintenance by the users of the pump, which is crucial for functioning of water supply systems Bolivia (see chapter 8, Verification). Previous versions of these pumps installed 15 years ago are still functioning without any maintenance. However, pistons rods may wear out through time causing a reduction of the pumps yield, but do not cause malfunctioning. Although not absolutely necessary, it may be worth the effort to change a piston after 3-10 years, depending on the usage.

Concrete slab

A concrete slab surrounding the well is installed in order to guide spill water away from the pump. A volume ratio cement : sand : gravel of 1 : 2 : 3,5 is used. The slab will be strengthened with reinforcement steel to prevent cracking of the concrete when loaded with weight.

Fodder trays
Fodder trays can contain 120 liters. A mould of Richard Beckett, a civil technical engineer living in La Paz, is used for the construction of these trays. These trays are large enough for a cow with horns to enter and low enough for a small sheep to drink. Iron and plastic versions are also available, but experiences on the altiplano proved that these don't last.

5.1. COSTS

The sum of all costs regarding one water supply is an important key factor to the success of future pumps . A lot of alternatives have been dropped out, because of their high costs. A new water supply (including pump and fodder trays) costs around € 325,- (Appendix K). However it is possible due to local circumstances to make these types of water supplies cheaper.

5.2. DURABILITY

Maintenance is reduced to the minimum. The water supply in its entirety will have a life span of over 15 years. Critical parts are those of the water pump. The constructors of the pump claim that the pump will function at least 15 years without maintenance. To ratify their claim, a guarantee is given by the constructors: when the pump does not work (properly) anymore, people can call and the pump will be repaired. In the past 10 years, only one broken pump was reported; the pump appeared to be struck by lightning. Experiences in Bolivia show operation and maintenance by locals does not function as it should, even if people are instructed properly. People tend not to repair public facilities; however they will give a call if that's the only thing they have to do to get their water supply working again.
Furthermore, all other parts above ground level are made of solid materials like bricks, concrete and iron, which should last for at least 30 years. Parts below ground are also made of bricks/concrete or PVC-tubes, which are protected by soil or concrete.

6. IMPLEMENTATION

This chapter shows the organization of the construction works for one water supply (as in figure 5). Bolivian people tend to postpone anything they need to do; numbers are according to observations in Bolivia. The planning is organized according to WHO-standards (Davidson, 2005). It is the task of the student to coordinate purchasing of materials, logistics and construction works. Information of local people can be a very useful contribution to purchasing and logistics, because they know their own environment better then anybody else.

6.1. PLANNING

The implementation traject of a water supply system on the Bolivian altiplano takes about 23 days in total. Especially getting to learn a local active EMAS-driller and having him doing preparations, takes most of the time.

Constructing a water supply system on the pampa starts with contacting an EMAS-driller as soon as possible. There are not many people with an official certificate who can use equipment for drilling boreholes to depts up to 90 meters by hand. When having found an EMAS-driller make appointments about drilling works as soon as possible. They tend to postpone their activities; the typical Bolivian mentality. Drilling works should normally take three days including installing the PVC-tube. After this, local people should be charged to do digging works of a hole for a water tank. In the meanwhile, materials can be purchased. Sand, gravel, stones and even cement can be purchased closer then the big city (El Alto, La Paz). Ask local people where they purchase these materials; they should know very well and are able to purchase it as well. Organizing this by locals takes some time so this should be prioritized. Remaining, more specialized materials, are purchased in El Alto (La Paz) and can be transported easily on top of passenger busses that travel every day to the altiplano areas (chapter 6.3, logistics). After having all materials available on the construction site, construction of the water tank should be performed. This is done in three days (when using three layers of cement, which should normally do). During the construction works, people who will be responsible for operation and maintenance should be involved so they know how the system is build. After this, continue with operation and maintenance training (chapter 7). At the same time give orders to do the completion works like constructing the slab, a fence around the whole system, fodder trays and distribution pipes to the fodder trays. On the 20th day the hand pump will be installed; this normally should not take longer than half an hour, but cannot be performed until the concrete has reached sufficient strength.

6.2. ORGANIZATION OF THE CONSTRUCTION WORKS

EMAS-drilling works:

EMAS-drilling works are performed by an EMAS-driller. Since these people have achieved proper training and do have a lot of experience, the organization and completion of the EMAS-tube (1.5”) is completely done by the EMAS-driller and his teammates. It should be noticed that about 1 in 10 EMAS-drillings fails and does not provide (sufficient) water. This could be caused by prehistoric geographical features, like an old riverbed.

Unskilled works:

After the installation of an EMAS-tube most off the unskilled work is done, like digging works, getting all materials on location and preparations to the construction site. The village should agree to carry out all the unskilled work for the construction of the wells on a self-help basis. At this stage operation & maintenance workers should be trained and digging works are done together by the intended users (Blankwaardt, 1984).

Installation works:

Installation works are done by the technical student in close cooperation with 6 people including those who will be responsible for operation & maintenance (chapter 7).

6.3. LOGISTICS

Transporting materials bought in El Alto (La Paz) can be done by two routes:

1) to Cohana by bus. Further transport needs to be done by locals by using wheelbarrows, boats and donkey’s.

2) To Lacalle by bus. Further transport will be done by tractor, since the pampa can be accessed from Lacalle without first crossing a river, which is the problem in Cohana.

Some materials can be purchased cheaper or easier in the neighborhood. These materials include:
- clean white sand; this can be purchased in Batallas 10 kilometers from Cohana. For a fair price the salesmen brings the sand on location as well.
- rocks; the whole village is full of rocks. With the help of locals these can be gathered and transported on location. (no rocks are found on the pampa)
- wooden posts; the hills of Cohana contain some trees. People of Cohana cut these trees for several purposes. Some of these could be used for constructing a fence around the water supply system.

7. OPERATION & MAINTENANCE

The operation and maintenance of water supply systems of small communities have been neglected in the past in a great number of underdevelloped countries. According to the World Health Organization, it is estimated that 30 to 60 percent of existing water supply systems are not operational, which has an important impact on the wellbeing of concerned populations (Davis & Brikké, 1995).

7.1. OPERATION

Operation refers to the everyday running and handling of a water supply. This includes the correct handling of facilities by users to ensure long component live and operations required to convey safe drinking water to the users. The proper operation of a supply results in its optimum use and contributes to a reduction in breakdowns and maintenance needs (Davis & Brikké, 1995).

7.2. MAINTENANCE

Maintenance refers to the activities required to sustain the water supply in a proper working condition, which include preventive maintenance, corrective maintenance and crisis maintenance. People who will be responsible for maintaining the water supply system meet the following criteria:

- Good motivation
- Authority and respect to control use of facilities
- Able to carry out maintenance and small repairs after training
- Good communication with women and men about water use and hygiene
- Living near the water facility
- Seldom absent for long periods
- Likely to remain in the community
- Completes training successfully
- Able to keep records - not always a requirement but level of literacy to be stipulated if necessary.

Individual responsibilities need to be clearly defined and understood. Responsibilities of maintaining the water supply are given to Rosendo Mendosa. This is a man, which has been village chief for many years, is much known in the town, was involved closely in the activities since the beginning of the project, very motivated and always in town. His sons have been closely involved also; they did a lot of work and are able to assist Rosendo with his maintenance works. With his influence on the meetings with all the village chiefs he will be able to collect the necessary money for maintenance.

7.3. Technical requirements

Appropriate operation and maintenance for a particular supply depends on a range of O&M factors. In table 4 the O&M factors for a water supply with borehole are shown; the second column contains the requirements of belonging to every factor. The last column contains the practical realization concerning this project.

TABLE 4, O&M FACTORS, REQUIRENTS AND REALIZATION

O&M Factors	O&M requirements	O&M realization
Technology	Training of local caretakers/mechanics. Availability of spares locally. Back-up support for major repairs. Women tend to be more conscientious in doing preventive maintenance and small repairs than men.	Training of Rosendo Mendosa. Spares available, responsible: Marcelino Mendosa-Lima. Major repairs by Rosendo Mendosa and Felipe Copaja. Women are not involved, since they should only do domestic work according to religion and habits.
Demography	Adjust maintenance schedule to hand pump usage which depends on the population served	Maintenance schedule based on 30 users (families). (paragraph 8.5)
Environment	Cylinder setting depth may need to be lowered by adding rising main pipes. Suction pumps may need to be replaced by medium lift pumps.	O&M factor does not apply to this situation. Water tables of used layer are constant throughout the year.
Flooding	Raise or site pumps above the flood line	Already fulfilled after fulfilling of program of requirements.
Accessibility	Communities which are difficult to reach or have poor access to spares and repair expertise need special consideration	O&M factor does not apply to this situation, since accessibility is good and spare parts can be persuaded easily.
Cost	Communities need to budget for ongoing maintenance and keep a reserve of funds for irregular expenditure. Training, appropriate financing, financial management and stock control is necessary.	The Mallku's (village chiefs) will be responsible for the collection of money. Rosendo Mendosa will, with his influence, continually point out the importance of continuating the payments.
Management	Define the hand pump user group (whole village, section of village) and who takes the management decisions - men, women or a sharing of decision making?	30 families in a circle 400m around the water supply are defined as the user group. Management decisions by Mallku's (village chiefs). Responsible for mentioning at general meeting: Mallku of the Cohana pampa: Guan.
General economy and level of development	Spare parts: price stability and reliable delivery system.	Parts are produced in El Alto and Viacha for more than 15 years, prices are still dropping because of refining and mass production. Furthermore economy depending on stability of important economies of south-America and the United States.
Government policy and legal framework	Clarification of who owns the hand pump and therefore who has responsibility for O&M.	No owners of water supply since this is a public supply; responsibilities have been chosen.

Concerning the design and O&M factors above a practical quantitative and qualitative description of activities can be made. A maintenance schedule is shown below in table 5. This is a list of tasks that should be executed to operate and maintain the water supply to an optimum according to theory (Davis & Brikké, 1995). Practical experiences in Bolivia show that maintenance should be reduced to a minimum in order to even have chance of being performed. Therefore the prioritizing table of Davis & Brikké (1995) is used (Appendix N). The final selection of tasks can be found in Appendix O.

TABLE 5, TASK SCHEDULE ACCORDING TO THEORY
**APPLIED BECAUSE ESSENTIAL FOR SUSTAINABILITY (SEE APPENDIX N)

frequency	activity
Daily	- Carry out an early morning test to check if the foot valve holds water in the rising main overnight. - Check whether the pump delivery is normal or low. - Check if the hand pump is firmly fixed in place. - Check for loose nuts and bolts on the hand pump. ** -> weekly - Clean the platform and drain. ** -> monthly - Check the fence is in sound condition and the gate will close. ** ->monthly
weekly	- Carry out daily checks and in addition - Tighten all the above-ground nuts and bolts with a spanner. - Clean the accessible moving parts. ** -> monthly
monthly	- Carry out the weekly checks. - Collect and record contributions to the water committee. ** -> yearly
yearly	- Dismantle the pump head parts. - Remove the connecting rods, piston assembly and foot valve. - Inspect all the parts. - Replace worn or defective parts. - Replace piston seals.** - Straighten bent connecting rods, or replace. ** - Replace rods with badly corroded threads. ** - Replace corroded or missing connecting rod lock nuts. - If connecting rods show severe corrosion, remove the rising main. - Check the rising main and replace badly corroded pipes - check the threads in particular. - Clean pipe threads and install the rising main. - Re-assemble and replace the below-ground parts. - Assemble the pump head. - Check the pump operation and pump until the water delivered is clean. - Record all significant actions.
irregular	- Repair cracks with cement mortar in the pump platform and drain. ** - If pump mounting bolts become loose in the concrete platform, remove pump, breakout old bolts, and remount in fresh concrete.** - Arrange to clean the borehole if the pump delivers cloudy water with silt. **

7.4. SPARE PARTS REQUIREMENTS

The lack of spare parts has been a major constraint in the sustainability of water supplies. In some cases it has led to the complete abandonment of schemes. The problem is in large part due to the policies pursued by donors. Some donors have attempted to overcome the problem by supplying a stock of spares at the time of installation. But this is only a short term remedy. Stocks do not get replenished due to the lack of a supply system and a lack of foreign exchange.
Spare parts are all those materials and goods that are necessary for the efficient and sustainable operation of the technical components of a water supply. This is a broad definition and does not alone include mechanical parts, but also lubricants, chemicals and tools (Davis & Brikké, 1995). The spare parts and their costs can be found in Appendix P.

7.5. COST RECOVERY

It has been said that people should not have to pay more than 3 to 5% of their income for water and sanitation services. They may be ready to financially support O&M but they may also be keen to keep payment to a minimum, or even avoid payment. However users should pay for operation and maintenance, nomather how small the amount is; paying for the water supply will result in more involvement and awareness (Davis & Brikké, 1995). When a water supply is properly maintained, provides clean water water and users are satisfied with it, they are willing to pay. If not, this leads to a vicious circle of under defined and poorly maintained water supplies (figure 5).

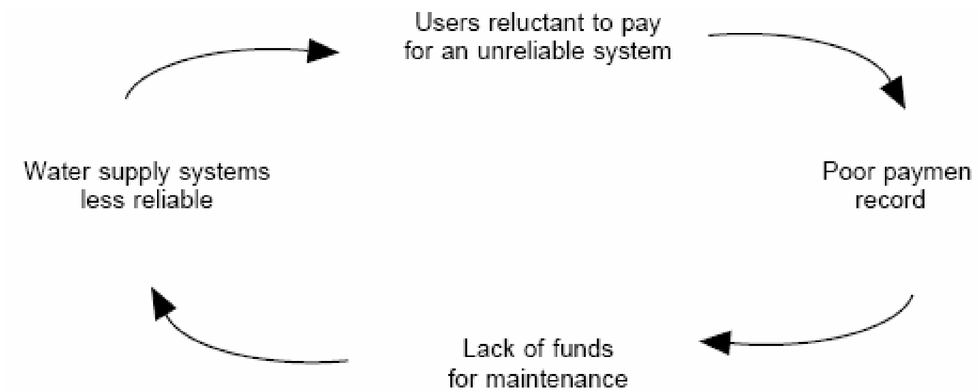

FIGURE 5, THE VICIOUS CIRCLE OF UNDERFUNDED AND POORLY MAINTAINED WATER SUPPLIES.

A total amount of 52 Bs per year plus some money for hazard recovery needs to be collected in order to keep the water supply working properly in the future. Since a total number of 30 families will be using this water supply, not more than 3 Bs (0,30 EUR) per family will be charged. This is easy affordable for people in Cohana, because a healthy cow wages about 2000 Bs, while the healthiness of a cow strongly depends on access to drinking water.

8. RESULTS AND REFLECTION

8.1. RESULTS

Finally 2 water supplies have actually been realized on the pampa of Cohana. These are a 6000 and 2300 liters variant to the design as in chapter 5. That both not have been constructed in the intended 3000 liters is the result of local circumstances: people did have their own thoughts about the execution and executed according to these thoughts. The tank of 6000 liters could easily handle the local water demands, but it is unknown if the 2300 liters tank has enough capacity, because the official opening of this water supply was on the day of departure. Also the fodder trays are constructed different as intended, because a mould that should have been used, was unavailable. Finally this resulted in larger and even better trays. The people of Cohana have shown their happiness and gratitude to the results. However, these 2 water supplies only serve a fraction of the total number of citizen of Cohana. Several people have come to ask for more water supplies after seeing the results of the first water supply. However, time and money were limited and realizing more water supplies would create conflicts with the goal of the SDWMA project.

8.2. REFLECTION ON COMMUNITY AND AIPUR

Works by community

People of Cohana tend to work only in the afternoon and furthermore they tend only to work when the instructor/student is present at the location. It is very hard to get people to work when they have not seen any result of what they are trying to construct. Within their culture there are 2 different words for indicating that they understand what someone is saying: 1) they understand it, because they understand what you are saying and 2) they understand it, because they have seen it once with their own eyes. This is a crucial fact for development workers who are working in the Aymarian regions.

AIPUR

NGO AIPUR is a young Dutch-Bolivian organization established by Ing. German Aramayo. He is born and grown up in Bolivia and has great development aid plans. He has some volunteers in Bolivia as well. Furthermore there are volunteers from The Netherlands who are setting up the Dutch part of AIPUR concerning an official foundation to collect money for projects in Bolivia. Nowadays AIPUR is depending on students from The Netherlands who are doing small projects from time to time. Of course students will help a little bit to improvement of the situation, but when considering the goals of Ing. G. Aramayo, these works are just a drop in the ocean. For example, when having set a goal about cleaning the river of a city with a population of 750.000 habitants by preventing them to throw their garbage in the river, cannot be solved by students who are doing small projects of 3 to 6 months. This is rather a governmental issue who does not have a service of collecting refuse and who failed to set guidelines for drains onto the river.

9. FUTURE PROJECTS

9.1. APPROACH

Installing water supplies in a SDWMA project should be done by taking the following procedure.

Before being send abroad, one should collect all possible geo- and hydrologic information about the area and in addition some population facts as well. After arrival in the country of destination, it is important to visit the target area as soon as possible. This is important for a better insight in the situation and the people of the target village will get the chance to know what will be going on in their village the next months which will create more involvement.
Then locally should be searched for geo- and hydrological documents on the area of interest. These, if they exist, are mostly the property of the (local) government and probably hard to acquire. It is also possible that a tax is wagered to access these documents. Note that local mining industry could probably also deliver some information about earth layers in the area.
After having studied the geo- and hydrological information a site investigation will be done where the gathered information is merged with observational information and population facts. Subsequently a hazard analysis will be performed where all possible hazards are being considered together with their possibility of occurring. Finally all research can be put together resulting in a program of requirements. With the program of requirements a design can be drawn. It is recommended to find some national directives and/or regulations on constructing water supplies. Discuss the design with local experts if possible; they know better then anybody else what to do and what not to do. Subsequently make a planning for all works; ask local people where materials can be purchased easy and cheap. There is a good chance that some materials can be purchased closer (and cheaper) then the big city.
The last and probably most important stage is planning of operation & maintenance. Davis & Brikké (1995) provide very good directives and tips to perform this stage as good as possible. Spend some time to find the right person for this job. With a good motivated person as maintainer, the life span of the water supply will increase significantly. Finally write all your experiences and recommendations in a report as a contribution for future projects in the SDWMA setup.

9.2. WATER SUPPLY OPTIONS FOR DIFFERENT SCENARIOS

The circumstances in Cohana turned out to be very helpful in realizing a large capacity water supply with safe and clean drinking water. It's important to realize that every situation has its own characteristics, problems and solutions. In every situation the best solution has to be figured out again. In this chapter the most common solutions and their applying conditions are shortly reviewed.

The rope pump

The rope-pump is a very cheap and simple pump. It has been said that if introduced properly 90% remains in operation in Africa. Rope pumps can be maintained by the users because of its simplicity. Rope-pumps are limited to a depth of 35m and borehole diameters of minimal 4 inch. Problems are caused by the water containing parts of the rope through wearing out, dirt entering via the rope/pistons and, above all, the need of regular maintenance (WOT, 2007; NWP, 2006).

Spring water catchment

Small discharges of water flowing out of hills or mountains can be turned into a significant water supply (system) when collecting this water into large catchments. Because of the large numbers of small sources in Bolivia, the Bolivian government did do a lot of specialization into the constructing of these water supply systems. In their official document NB-689 about water supply (systems) an extensive design with all needed details for construction can be found. Problems with these water supply (systems) arise with shortcomings in the biological water quality (not potable according to analysis of hygiene student, Appendix G) and insufficient protection to negative effects of freezing. Furthermore are these systems expensive, because pipelines need to be constructed from the source to the village.

Rainwater catchment

As the EMAS-drilling, cheap rainwater catchment is also invented by Wolfgang Buchner (director of EMAS). Large quantities of water can easily be stored underground for the cost of only one bag of cement per cubic meter. This can be applied in areas were raining and dry seasons alternate with each other. Water stored in the rainy season can be used in the dry season. The water is originated from the roof of houses and needs to be filtered before entering the underground tanks (Buchner, 2007; NWP, 2006).

PVC-pumps

PVC-pumps are cheap pumps that can not only pump water from great depths (up to 90 meters); they can also pump water as high as 30 meters above stationed level. This adds great advantage with respect to other cheap pumps. However, the use is limited to domestic use, since the discharge of these pumps is very small (Buchner, 2007; NWP, 2006).

Solar pumps

In development areas with a shortage of drinking water, there is normally no shortage of sunlight. Pumps driven by solar do have the advantage that they can pump all day long; with batteries even all day. However, this option is more expensive then solutions like the rope- or PVC-pump and requires specialized maintenance. The cheapest solar pump is about 700 USD (Lorentz price list, 2007). Furthermore the minimum diameter for pumps with solar energy is 4 inch.

10. CONCLUSIONS

Large shortages of clean drinking water have been noticed within the area of Cohana, Bolivia. A lack of natural sources and extreme pollution of the River Katari are the main causes of these shortages. Drinking water shortages influence the quality of life for men and animals. The objective of this research is to design a plan for a water supply in the community of Cohana by doing research to constructing and installing a local producible, maintainable, repairable, durable and social accepted water supply system for clean and safe drinking water, but within the boundaries of the project 'Save Drinking Water for Men and Animals' (SDWMA).

The goal of the first research question was to determine the locations that are suitable to construct water supplies given (geo)hydrological properties of the area. These locations have been determined to be on the pampa where rocks are absent and where clean and safe drinking water is found at 50 meters depth with high hydrostatic pressure causing the water to rise until the surface.

The goal of the second research question was to determine all the potential hazards that could harm the success of a drinking water supply in Cohana. The hazards considered significant are: ingress of contaminants into the borehole, borehole area is inundated with contaminated surface water, leaching of microbial contamination in aquifer and water tank contains too many deposits. These potential hazards are cleared away with appropriate measures (research question 3) which are shown in the design of the water supply (Davidson et al., 2005).

Subsequently the way of implementing the water supplies (there have been installed 2 water supplies) is determined. This stage of the research depends substantially on local circumstances. It should be noticed that very useful information can be obtained from local people and experts e.g. locations to purchase materials, means of transportation and local (natural) available materials (sand, rocks, wood, etc.).

Finally the goal of the fifth research question was to set up a maintenance and monitoring program. The number of tasks for the local people has been limited to those tasks that are determined significantly important. Important for the continuity of the water supplies is a self serving cost recovery, because poor payment will lead to the vicious circle of underfunded and poorly maintained water supplies (Davis & Brikké, 1995).

The answers to the research questions have led to a solution for the drinking water shortages in Cohana. A below ground level water tank filled by an EMAS-tube to 50m depth is the best solution within the boundaries of the SDWMA-project on the Bolivian Altiplano in the canton Pucarani. On top of the water tank a local made hand pump will to be installed. Research and practical experiences showed that Bolivian pumps need to be long-lasting; the importance of the pump being long-lasting is inferior to the pump having sufficient capacity since time is no issue on the Bolivian highlands. The area around the pump should be kept as hygienic as possible in order to secure the quality of the water for the future. Therefore a concrete slab should be constructed around any water supply. Furthermore a ditch and a fence should be included in order to keep the pump area clean and hygienic. Other solutions are dropped out because they are not applicable in the target area or do not comply within the framework of the SDWMA-project. These solutions include a rope-pump, springwater catchment, rainwater catchment and PVC-pumps. All of these could be applicable within this type projects, but in within their own conditions and financial limits.

The procedure to come to the method applied in this research should be based on the manual for the SDWMA-project, but as it is at this moment, the manual is not completed nor yet usable. The SDWMA-project has shown that the set-up for this type of projects worked out very well and therefore the manual, once completed, could have potential. Since also the technical part is not completed yet, an initial scheme for the technical part has been used as the framework for this report and turned out to be very reasonable for projects in this set-up. As the job for the technical student is installing water supplies, WHO documents of Abbaszadegan (2004) and Davidson (2005) are important guidelines in making the water supplies hygienic, safe and effective. Davis & Brikké (1995) provide useful methods and directives for operation & maintenance, which is neglected too much in the past. However, participants to these projects should not refrain from logical reasoning, valuing the usability of local information, valuing experiences and adapt design and planning to materials locally available.

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Due to circumstances information about some references is lost. Among other things these include reports and documents as described below:

Report of the local government (Alcaldia) of Pucarani, province of Cohana. Contents: information about current situation of the village.

Report of local government about realizing water pumps in the area. Contents: some hydrological information about the area and a solution regarding the water problems that are the best according to them (note that local governments in Bolivia are corrupt). Original reference in report: (Ambiente, 2006).

Information sources

Google earth (2007). http://maps.google.com

Lorentz price list (2007)

Netherlands Water Partnership (NWP) , (2006). Smart water solutions, Examples of innovative, low-cost technologies for wells, pumps, storage, irrigation and water treatment.

Suma Jayma (2007) http://www.sumajayma.org/en/inicio/.

Wikipedia, economy of Bolivia (2007) retrieved on 16 July 2007 from: http://en.wikipedia.org/wiki/Economy_of_Bolivia#_note-locpro106

Wolfgang Buchner, (2007). EMAS: http://www.emas-international.de

Workshop storten betonplaat waterput, Ingenieurs zonder grenzen (2006). Civiel Ingenieur, Kivi Niria, Werkgroep Ontwikkelings Technieken.

Werkgroep Ontwikkelings Technieken (WOT) (2007). Manual on rope-pumps. Enschede, The Netherlands

APPENDICES

CONTENTS

APPENDIX A CLIMATE FACTS COHANA

TABLE 6, CLIMATE FACTS OF CANTON COHANA (AMBIENTE, 2006)

variable	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Monthly rain	128	90.6	72.6	41.5	6.02	5.04	2.94	11.4	27.9	29.5	50.8	48.5
Min temp	1,9	2,2	1,6	-2,5	-7,6	-10	-8	-7,9	-5,9	-2,3	-1,7	2,2
Max temp	18,4	18	18,2	18	17,8	16,8	16,6	17,6	18,3	19,3	19,7	19,7

APPENDIX B OVERVIEW OF DRINKING WATER NEEDS

TABLE 7, DRINKING WATER NEEDS IN COHANA AND ON THE PAMPA (LITERS) (BLANKWAARDT, 1984).

Overview of drinking water needs in Cohana in liters per day							
Cohana				Pampa			
consumer	number	consumption	total	consumer	number	consumption	total
men	1485	30	44500				
cow	2400	45	108000	cow	3900	45	175500
sheep	0	4	0	sheep	15000	4	60000
donkey	450	20	9000	donkey	0	20	0
pig	300	7	2100	pig	1500	7	10500
		total:	163600			total:	246000

Appendix C Overview of water sources and present persons and animals

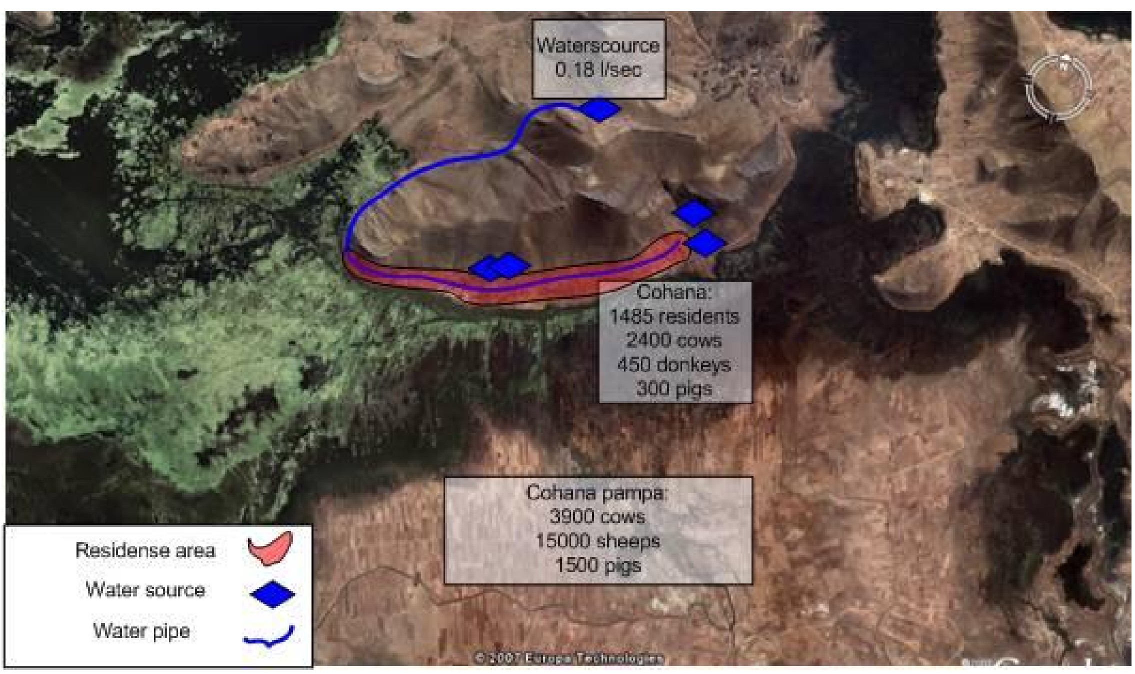


FIGURE 6, OVERVIEW OF WATER SOURCES AND PRESENT PERSONS AND ANIMALS

Appendix D Siting on the pampa

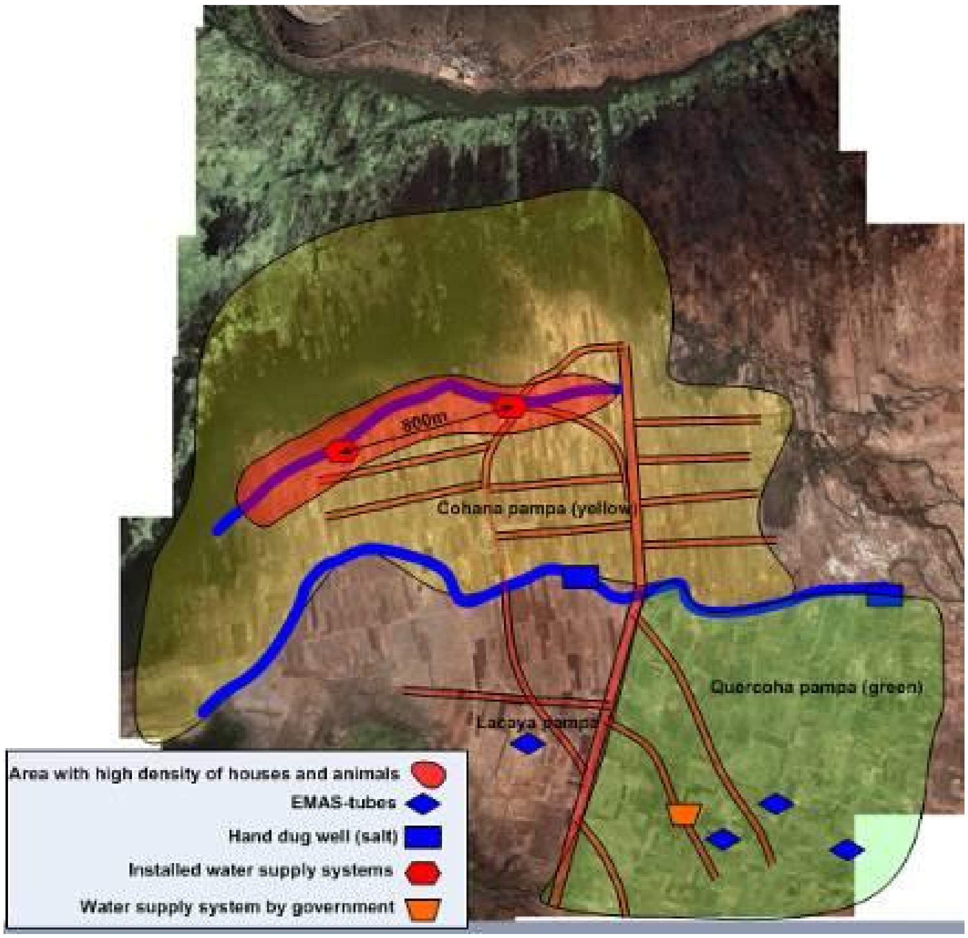


FIGURE 7, SITING ON THE PAMPA OF WATER SUPPLIES

Appendix E Schematic cross section of Cohana pampa

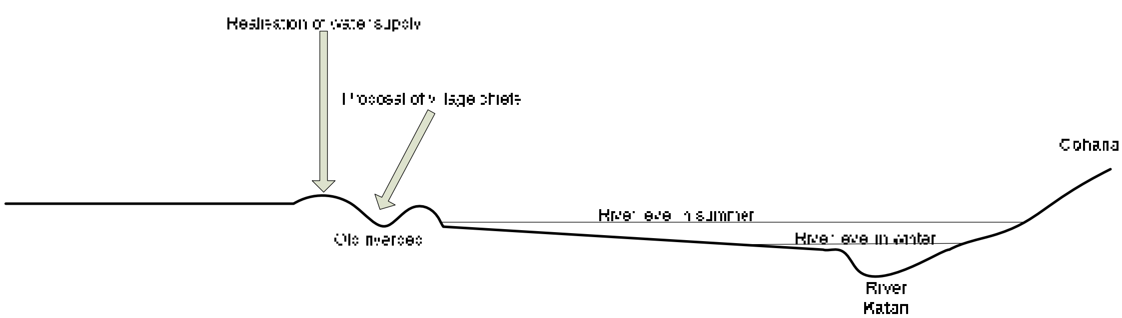


FIGURE 8, SCHEMATIC CROSS SECTION OF COHANA PAMPA

Appendix G Water tests (by hygiene student)

<u>Introduction</u>

The following analyses have 2 goals. The first is analyzing the water in and around Cohana. A small village in Bolivia near the Titicaca lake. The second is to validate the testing kit used for these analyses. It is called TRAWAS portable testing kit fabricated by Sandberg and Schneidewind when the validation is positive, the testing kit will be used more in the same kind of small projects.

<u>Analysis 1:</u>
<u>Bolivia, pampa Quercoha (next to pampa Cohana)</u>

Source

Private. Open pipe from where the water slowly flows by hydrostatic pressure. Depth of the source is 53 m. There is no protection against (wild)animals

Method of working

- Taken and filled 3 “Nasco whirlpak”.
- Analysed ± 19 hours later (in between stored in coolbox of the testkit, because of the cold at night)
- Bottled water sterilized with minisartfilter (0,20μm). This water has been used for the Nutrient Pads, rinsing and negative controls.
- “Filterpump set” disinfected with alcohol and fire (filter + funnel). Hereafter rinsed 1 time with the sterile water.
- Filtrated 7 samples and 3 negative controls. From the sourcewater, 10ml and 100ml for Azide, Caso and Endo and from every type 1 negative control, in addition 100ml bottled water on Caso. Rinsed only between the different types of water (sourcewater – bottled water – negative controls).
- Before taking a Nitrate filter, used tweezers always disinfected by keeping it in ethanol and thereafter through a flame.
- The Nitrate filters layed directly on the Nutrient Pads after filtrating.
- Afterwards the filterpump set has been disinfected again.
- Placed Nutrient Pads in incubator in coolbox (24h, 36,5°C)

- Arsenic, pH and phosphate in the source tested according to instructions.
- In addition Arsenic, pH and phosphate of the source of the host family on the pampa has been tested. (water still comes out of this source, but it is defect)

Comments:

- 1 Nitrate filter has possibly been infected, this is written on the petridish.
- Used volumes are 10ml and 100ml, 10ml volumes are not very precise.
- After about 2 hours there was a power failure, hereafter the incubator went of automatically, after starting it again it did not continue automatically with the right temperatures, after adjusting again (2 hours later) it started again.

Results

	Azide Nutrient Pads Enterococci	Endo Nutrient Pads Escherichia coli	Caso Nutrient Pads Total count
	44 h		44 h
10 ml source water	1	0	37
100 ml source water	7	0	155
Negative control	0	0	9
100ml bottled water			12

	Arsenic (ppb)	pH	Phosphate (ppb)
Bron	175 (0,175 mg/l)	7,0-7,5	±30
Familiebron	75-175 (0,075-0,175 mg/l)	7,0	15-30

Guideline values WHO (Guidelines for drinking water quality 2004) :
Arsenicum:
Provisional guideline value: 0,01mg/l (=10μg/l)
Levels in natural waters generally range between 1 and 2 μg/l, although concentrations may be elevated (up to 12mg/l) in areas containing natural sources.

pH: 6,5-9,5 pH less or greater then these markedly impair the potability of the water. (No direct impact)

Conclusion/discussion
The tested water is probably drinkable, but there is faecal contamination. This contamination is limited (3 enterococs/100ml) and a longer time ago (no e.coli was found). De tested source is just a tube sticking about 30cm out of the ground from where the water flows continually but slowly (100ml/24sec). There is no fence to keep (wild) animals away from the source and hygiene standards are very poor. This means there is a great probability there is regular contamination, but not very often.
It is advisable not letting young children drink from this water, unfortunately cleaner sources will not be available at the moment.

Analysis 2:
Bolivia, Tap of the family Mendoza

Source
The tap is private but the source is used by more people in the village who have as well a private tap or who use a public tap. The source is situated higher in the hill behind Cohana. The water comes naturally up from deeper grounds.

Method of working
Like first sample, with differences:

- Used 2 "Nasco whirlpaks" to fill a number of times, because the tested source was near the testing equipment.
- Water taken after about 3 sec. flowing.
- Analysed immediately.
- Filtrated 9 samples: 10 ml and 2 times 100 ml for every type of Nutrient Pad.
- Arsenic and pH in the source tested according to instructions.

Results

	Endo Nutrient Pads Escherichia coli	Azide Nutrient Pads Enterococci	Caso Nutrient Pads Total count
	24 h	44 h	44 h
10 ml source water	0	11	177
100 ml source water	3 + 4 other coliforms*	101#	-
100 ml source water	0 + 2 other coliforms	140#	-

* Colonies e.coli are typical but smaller than in the lab. Other coliforms are red coloured, also typical, but smaller.
# 1 bigger colony in these petridishes, all colonies are typical.

Arsenic: 0 ppb
pH: 7

Conclusion/discussion

It is recommended not to drink the tested water. There is definitely faecal contamination. Not many e.coli have been found (only 3), but this is still enough to be able to say there is faecal contamination. In addition many enterococci have been found, which says something about faecal contamination on longer term. Total count is also high, so other sources than faecal contamination also are probable.
The source of contamination is not clear. It is very probable there is contamination at the tap, because hygiene standards are very low. Higher sources at other taps are also probable (same hygiene standards) and contamination at the source itself could also be possible because part of the source is open and could get contaminated by every human or animal.

Analysis 6:
Bolivia, borehole 2 on pampa Cohana

Source

The source is the second borehole made on pampa Cohana for this project. At the moment the water was taken, the source was only an open pipe from the ground. In the future there will be a closed tank and a pump to take the water. The system will be closed then.

Method of working

See earlier analyses. The water was taken with a cleaned mineral (ethanol and boiled water) water bottle.

Results

	Endo Nutrient Pads Escherichia Coli (24h ± 2)	Azide Nutrient Pads Enterococci (48h ±4)	Caso Nutrient Pads Total count (48h ± 4)
10 ml	-	-	3
10 ml	0 e.coli/17 other coliforms	0	5
100 ml	0 e.coli/63 other coliforms	1	80
100 ml	0 e.coli/64 other coliforms	3	uncountable

pH: 7,0
Arsenic: 500-1500 ppb (0,5-1,5 mg/l)

Conclusion/discussion

Microbiologically the tested water seems suitable to drink. No E.coli and hardly no Enterococci have been found, which means there will hardly be faecal contamination. A bit strange is the number of coliforms found. The number is about the same as the number of total bacteria. This number can not be explained.
The level of arsenic is far too high according to the guideline of the WHO (0,01 mg/l). Although there are many scientific uncertainties, for humans this water would not be suitable to drink, only in minimal quantities. For animals this would not be a problem.

Microbiological Waterquality: most important bacteria to analyse with minor facilities

Parameter	cfu/100ml	Faecal contamination				Suitable for consumption?
		-	±	+	++	
E. coli /Thermotolerant coliforms	0		±			Yes
	1-10			+		For adults, children untill an age of 6 rather not.
	10-100				++	No, cook or treat first
Enterococci	0		±			Yes
	1-10			+		Contamination longer ago, drinkable, but not ideal.
	10-100				++	No, cook or treat first
Total count	<100/ml		±			Says something about bacterial contamination in general, not about faecal contamination
	100-10000/ml		±			,, ,,
	>10000/ml		±			,, ,,

Tabel is partly based on WHO norms(Guidelines for drinking water quality) en the Dutch "Waterleiding besluit".

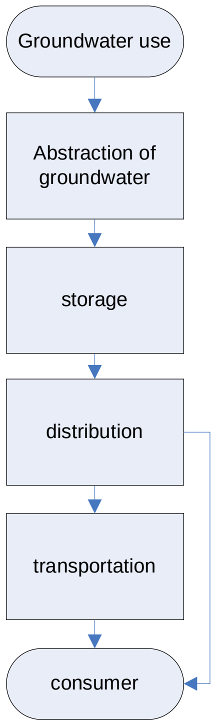
- These measurements are random indications, when the water is probably clean, measurements to keep it clean are still necessary.
- Every parameter is just an indicator, they will give the probability of contamination, but it will never be 100% certain whether or not there is contamination. (this is also the reason none of the parameters has an – in the table.)
- When every parameter is ++, there is almost an 100% certainty of contamination and it will be very unwise to drink this water.
- When every source has traces of faecal contamination, it is best to use the less contaminated. Possibly there can be looked at ways to make this water cleaner.

General comments (6-6-2007)

- On pampa Cohana almost every area is private. This means it will be hard to find a place to set a pump for public use which will also be in reach for everyone.
- Hygiene behaviour is in general very poor. People do not use soap, there are no sanitation facilities, no showers or hot water and people are handling animals (alive and dead) every day. Taking this in consideration, even then it is worth to provide the people with a source of cleaner water. People now drink very less, they are often whole days on the pampa without drinking more than half a liter (approximately).
- At the moment people do not use water to drink. They drink sodas and often for lunch and supper soup. Water is used to make this, tea and coffee. This fact makes very clean water less important, because the water used for consumption is always cooked.
- People in Cohana really want a source for drinking water and they see it themselves as a great problem that there are no sources or whatsoever on the pampa, where they are during the day. They say it is also very important for their animals, because the surfacewaters are salted or heavily polluted.
- Testing the water is useful, but taking the costs of the testing kit in consideration, I don't think it is worth it. The microbiological quality of the water can be well predicted with all the "checkpoints" (hazards, risk, etc.). In contrary, chemical quality (like arsenicum) is not very well predicted and I think, testing this will be more useful. Also for the price of the testing kit, you can make 3 or 4 more pumps for the community. Providing pumps, sanitation facilities and hygiene education (not in this form, but on longer term) are higher in priority than testing the water microbiologically.

APPENDIX H FLOW DIAGRAM

Analyzing every arrow of a flow diagram of a water supply (system) on possible hazards, prevents possible hazards to be forgotten. Below is the (rather simple) flow diagram for the situation on the pampa of Cohana.



APPENDIX I, HAZARD ASSESSMENT – HYGIENE ASPECTS BY HYGIENE STUDENT

Cohana pampa

- Hazardous event: Direct ingression of faecal material of humans, domesticated animals and wild animals along the pipe → Faecal material can be found everywhere, including that of humans. There are no sanitation facilities on the pampa so people may defecate wherever they want.
  - Probability and risk: Intermediate. Pampa Cohana has a huge surface. Probability of ingression of animal faecal material is a bit higher, because there are more animals than humans on pampa Cohana. However the risk will be less because people will get ill faster of human faecal material than animal faecal material than. The probability of ingression of human faecal material is less. Only with construction this could be a small risk because before construction the place of the pump was just a regular place like all others. Once the pump is in place, human faecal material will not be a big risk anymore because, logically, people will not defecate near a "crowded" water pump.
    - Prevention: Preventing animals from defecating near the pump can easily be done by placing a fence around the pump. However, preventing wild birds and small animals from approaching the pump and defecating near the pump cannot be prevented in this way. Proper closure of the lining of the pipe may prevent this.

- Hazardous event: Direct ingression of faecal material because of rain.
    - Prevention: Placing the pump on a higher plateau and proper closurer can easily prevent this.

- Hazardous event: Indirect ingression of faecal material through touching the rope of the pump or touching the tap.
    - Probability and risk: There is a high probability most people in Cohana will have faecal material on their hands, as hygiene standards are low and most do not wash their hands after defecating. Because the rope needs maintenance and the pump is handled by people the probability of ingression of faecal viruses, bacteria and parasites in this manner is very high. However, the risk will be low in this case. One, because the water will be used mainly for animals and two, people use their ´dirty´ hands also for eating. As long as hygiene standards are low, risk or impact will stay low, contamination of the water in this matter will not add much risk to the already existing risks, because of the low hygiene standards. Whithout proper protection, ingression through animal touching the pump could also occur, as with humans, the risk will be very low.
        - Prevention: A fence around the source can prevent domesticated animals from touching the source. Again however, wild small animals and birds cannot be prevented from touching. This will not be a huge problem, because ingression in this manner will be minor and the water is mainly for animals. Protection of the rope and ´high´ setting of the tap could prevent touching by small animals and birds (protection of the rope). People could be asked not to touch the rope (for example on a notice board next to the pump) and the one who is responsible for the maintenance could be asked to wash his hands before doing so. Unfortunately, these interventions will not secure that the source will not get contaminated.

- Hazardous event: Ingression of contaminants through the ground when the source is situated near a river or lake.
    - Probability and risk: Probability is probably low but insecure because the exact composition of the ground is not known. Risk is also probably low.

APPENDIX K COMPOSITION OF THE COSTS OF A WATER SUPPLY

TABLE 8, ALL PRICES ARE INCLUDING POSSIBLE TRANSPORTATION COSTS AND LABOUR

Part	costs
EMAS-tube (materials and construction)	€ 88,-
Water tank	€ 50,-
Hand pump	€ 112,-
slab	€ 40,-
3 fodder trays	€ 36,-
Total	€ 326,-

APPENDIX L ADDITIONAL INFORMATION PROGRAM OF REQUIREMENTS

Some numbers in the program of requirements need some explanation. These are worked out below; the letter refers to the letter in the text.

e. Assuming that all animals are spread out evenly though the pampa, one water supply system should provide 6,2 m^3:
Covering distance for a water supply system: 400m (Blankwaardt, 1984).
Total surface area of the pampa: 20km^2 (Google Earth, 2007).
Total amount of water needed on the pampa: 245.000 l/day (table 7).

$$W = \frac{(\pi \cdot 0{,}400^2)}{20} \cdot 245.000 = 6150 = 6{,}2m^3$$

j. peak hours: water is commonly collected during two peak periods, namely from 6.00 to 9.00 in the morning and from 3.00 to 6.00 in the afternoon, making a total of 6 hours. (Blankwaardt, 1984).
Water input through EMAS-tube: 27 sec/2liters (10 measurements) = 4,44l/min = 6400 m^3/day
Water usage per peak: 3,1m^3
Water input during peak: 4,44 * 60 * 3 = 800l = 0,8 m^3
Water buffer for a peak: 3,1 – 0,8 = 2,3 m^3
Water input between peak hours: 4,44 * 60 * 6 = 800l = 1,6 m^3
Total buffer capacity needed: (2 * 3,1) – (1,6 + 2 * 0,8) = 3,0 m^3

APPENDIX M DESIGN OF WATER SUPPLY SYSTEM WITH ROPE PUMP.

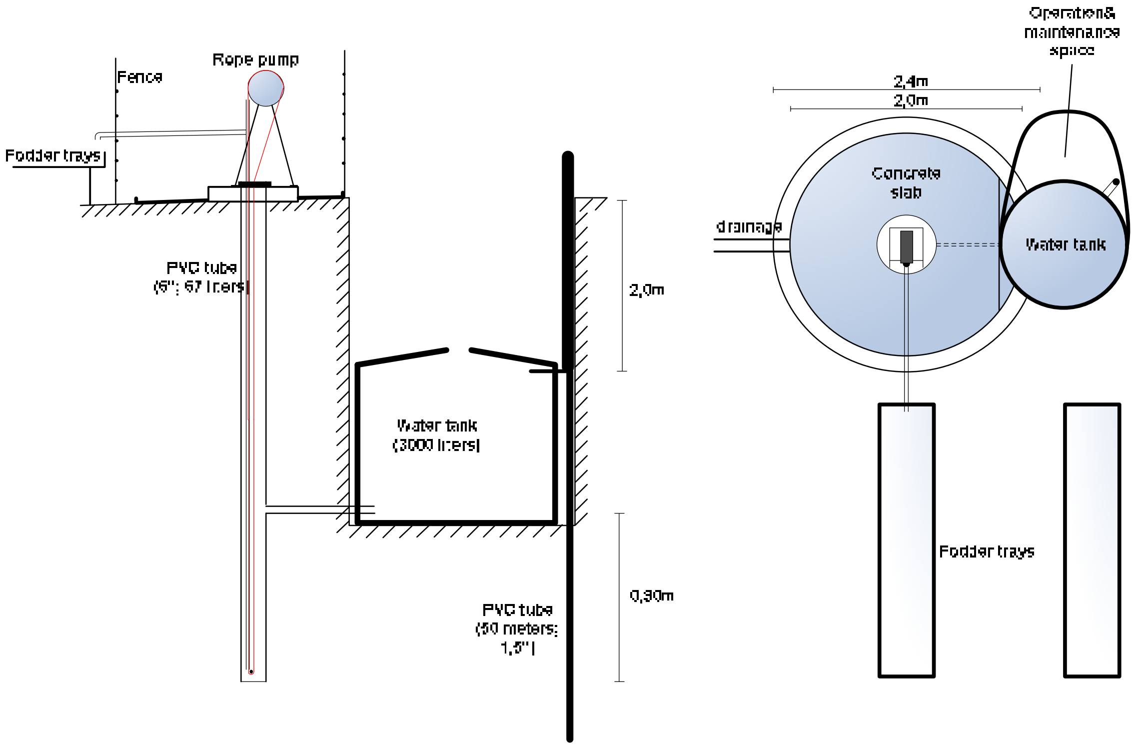


FIGURE 9, DESIGN OF WATER SUPPLY WITH ROPE PUMP

Appendix N Task prioritizing matrix of Davis & Brikké (1995)

O&M tasks / components	Supervising & monitoring	operation	Preventive maintenance	Minor repairs	Major repairs
borehole	*	--	--	--	**
Rising main	*	--	*	**	--
Hand pump	*	**	**	**	**
platform	*	--	*	*	*
fence	*	--	*	--	--

TABLE 9, MAINTENANCE TASKS

**ESSENTIAL FOR SUSTAINABILITY

* PREFERABLE FOR SUSTAINABILITY

-- NOT RELEVANT

APPENDIX O MAINTENANCE SCHEDULE WATER SUPPLY COHANA PAMPA

Frequency	activity
Weekly	- Check for loose nuts and bolts on the hand pump.
Monthly	- Clean the platform and drain. - Clean the accessible moving parts.
Yearly	- Collect and record contributions to the water committee. - Replace piston seals. - Straighten bent connecting rods, or replace. - Clean the water tank from deposits.*
Irregular	- Repair cracks with cement mortar in the pump platform and drain. - If pump mounting bolts become loose in the concrete platform, remove pump, breakout old bolts, and remount in fresh concrete. - Clean EMAS-tube when producing significantly less water.

TABLE 10, MAINTENANCE SCHEDULE WATER SUPPLY COHANA PAMPA

* ACTIVITY NOT MENTIONED IN DAVIS & BRIKKÉ (1995)

APPENDIX P SPARE PARTS AND COSTS

Spare part	Purchasing place	Price in Bs (10 Bs = 1,35 USD = 1EUR)	Life cycle of spare part	Cost per year
Pump parts	El Alto (La Paz), Viacha	50	3 - 10	10
Thick PVC-tube 10”	El Alto	65 (4m)	2**	33
Wooden post	Hills in the neighborhood	-	2**	-
Iron wire	El Alto	12 (50m)	10*	2
Lubricants & chemicals				
paint	El Alto	30	5*	6
tools				
Paint brush	El Alto	3	5	1
Metal saw	Always available in town	-	-	-
Water stop	El Alto	2	-	-
total				52

* ESTIMATED VALUE’S, SINCE NO INFORMATION IS AVAILABLE BY SALESMEN

** ESTIMATED TIME BEFORE BREAK DOWN DUE TO MEN AND ANIMAL ACTIVITIES