Examensarbete
TVVR 07/5017

Water utilization in a river basin in the Lake Poopó region of Bolivia: problems and conflicts.

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Avdelningen för Teknisk Vattenresurslära
ISRN LUTVDG/TVVR-07/5017 58
ISSN-1101-9824

Water utilization in a river basin in the Lake Poopó region of Bolivia: problems and conflicts

-A Minor Field Study-

Anna Ekdahl

Abstract

The main objective of this thesis is to investigate the distribution of hydrological resources over time and space in two sub basins of the Lake Poopó area in Bolivia. This investigation is made in order to evaluate how supply and demand can be balanced and what effect the insufficiency of hydrological resources has on the socio economic situation. The two main problems in the area regarding water resources, are the variations over time and space and the contamination. A long history of mining industry without environmental regulations has lead to contamination of water and soil. The precipitation varies both seasonally within the year and also from year to year. In order to evaluate the situation, the water supply and demand was estimated. The total water resources in the study area would not have to be insufficient if quality and distribution over time and space could be improved and controlled. Water storage and support to the small mining industry could accomplish this. The main hindrances for improvement are the poverty and general low level of education. If water quality of and accessability to the water does not improve, leading to additional income sources, the area will depopulate, become entirely dependent on the mining industry and completely die out if or when the mineral deposits dry out.

Acknowledgements

I would like to thank my supervisor Professor Lars Bengtsson at the Department for Water Resources Engineering, Lund University.

I would like to show my appreciation to the employees at the Instituto de Hidrología e Hidraúlica at Universidad Mayor de San Andrés, La Paz, Bolivia for helping me. Especially, Engineer Andrés Calizaya Terceros, coordinator of the SIDA-UMSA project and Maria Eugenia Garcia for lending me a pH-meter and a thermometer.

I would also like to show my sincere gratitude to the employees at the office of APEMIN II, Oruro, Bolivia, in particular my adoptive supervisors Dr. Sohrab Tawackoli and Eng. Tarik Kubach and my friend and collegue Eng. Mario Veizaga. Their help was most valuable for the work of this master thesis and their support and kindness invaluable for me personally when I was sick and alone.

I would also like to express my thanks to the Head of the European Commission Delegation, La Paz, Oruro, Mr. Andrew Standley for putting me in contact with APEMIN II.

For the financial support I would like to thank the Swedish International Development Cooperation Agency (SIDA) and the Department for Studies of Social Change and Culture, (ISAK), Linköpings University for granting me an MFS scholarship.

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1 Introduction

The main objective of this thesis is to investigate the distribution of hydrological resources over time and space in two sub basins of the Lake Poopó area in Bolivia. This investigation is made in order to evaluate how supply and demand can be balanced and what effect the insufficiency of hydrological resources has on the socio economic situation. Lake Poopó is one of the two major lakes in the Bolivian high plateau, an arid to semi arid area. There is a direct relationship between the abundance of water, population density, and quality of life and the scarcity of water in the area marks and defines certain aspects of the lifestyle and population. The study area is one of the poorest in Bolivia with mining industry as the overall important economic activity since colonial times, with additional income sources from agriculture and livestock.

A long history of mining industry without environmental regulations has lead to contamination of water resources and soil, manifested primarily through piles of mining residue and sludge along with low pH and dissolved heavy metals in the water systems. In addition to this, some parts of the basins suffer natural contamination, foremost from salt. Over the last decade the mining industry has been declining in significance. With growing interest in alternative income sources, the conflicts over water resources have become more frequent and severe.

To evaluate the situation, the water supply and the demand must first be estimated. In addition to the limitation of water supply, the two main problems in the area are the variation over time and space and the contamination. The local precipitation varies greatly over the seasons, as well as the years. Almost all precipitation is concentrated to the few months of rainy season, from November to March, and sometimes the yearly precipitation deviates due to the effect of El Niño, manifested in droughts. This variation strongly affects the productivity of agriculture and the life quality, but also both the concentration and the nature of the contamination.

The main water rights demands come from the mining industry and agriculture but the water must also be sufficient for household uses and keeping of livestock. In the area, tin, zinc, silver and lead is exploited in underground mines. The mining industry does not have much use for water but rather pump it out in order to prevent the mines from being flooded. The consequent problems consist of acid mine drainage, improperly discarded residues and dissolved heavy metals, but also a scarcity of groundwater caused by the extraction in the mines. The environmental laws controlling the mining industry are getting stricter and the situation is slowly improving, but it is stalled by old residue still lixiviating acid and the precarious situation, in which many of the villages in the area finds themselves. Due to the contamination of soil and water, there is in many cases no optional income source such as agriculture and when mines close down the families are forced to work the mines illegally. This not only leads to further contamination but also to extreme danger to the personal health and security.

This paper is outlined so as to first give an introduction to the area, its geographical characteristics as well as the socioeconomic situation and its conflicts. Following, a presentation is given of the hydrological resources in the area, quantification, variation over time and space and description of the sources. The next chapter is dedicated to the water demand, uses are quantified and their inevitable subsequent contamination is considered. A short description of previous water quality studies follows, substantiating the prior statements of contamination in the area, given the contaminations importance to the uses of hydrological resources and its limiting character. An account of a future project planned in the area is given and its estimated benefits to the socioeconomic situation presented. After the quantification of supply and demand, the consideration of limiting factors, such as contamination and poverty, and the presentation of benefits from a planned project, the analysis section considers the connections between and consequences of the different factors. Potential solutions are presented and finally there is a conclusion.
The information on which this paper is based was obtained through literature studies but more importantly through interviews, forms and workshops during a field study, see section 3.2.1. This approach was essential for the purpose of understanding the situation. Cultural, historical and economical differences would have conditioned misinterpretation and miscalculation of the situation if information was only interpreted from a distance. Although lessened by the field trip, these differences are an important feature of this paper. They are not only limiting but should be taken into account when reading the paper.

2 Introduction to the area

2.1 Location

Bolivia is located in the centre of the South American continent. Bolivia consists of a mountainous region, about one third of its area, and a region with tropical rainforest, the remaining two thirds of the area. The southwest part of the country is situated in the mountain range the Andes and the eastern to northern part in the Amazon. In Bolivia the mountain range Andes, which runs through the entire South American continent, divides into two main chains called the Occidental and the Oriental chain. Between the two chains the Bolivian high plateau is found, an extensive and desert like plain, stretching from Peru in the north to Chile in the south. There are two major lakes in the high plateau, the Lake Titicaca, partly situated in Peru, and the smaller Lake Poopó.

Figure 1 shows where in Bolivia the study area is situated.

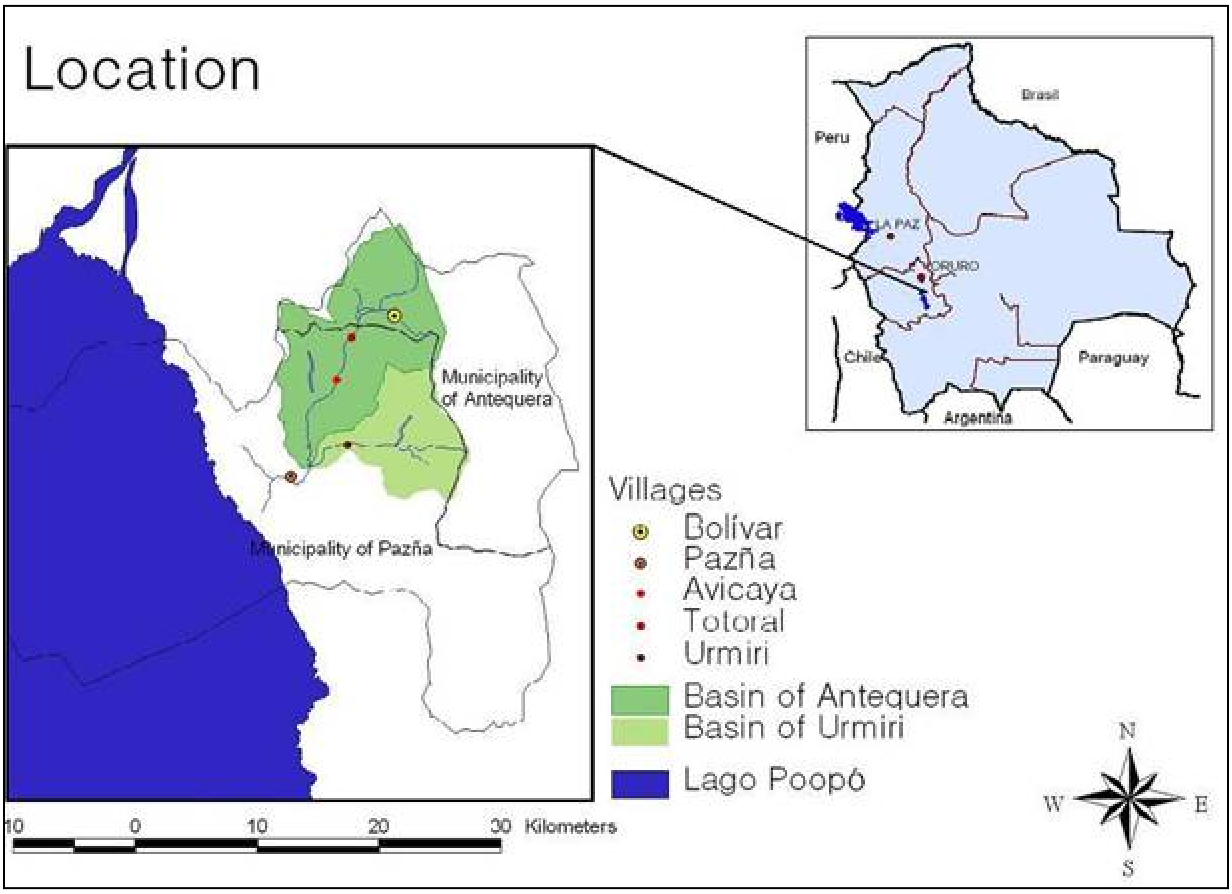

Figure 1. The municipalities and the basins of the study and their location in Bolivia

The study area is situated in the Bolivian high plateau, in the Lake Poopó region, at an average altitude of 3 800 meters above sea level, with the lowest point at 3 700 and the highest at 4780 m.a.s.l. The catchments area is located between 18.25 and 18.37 º S and

66.55 and 66.46 ºW and consists of two basins; the upper basin of river Antequera (downstream called river Pazña) with an area of 150 km^2 and the basin of river Urmiri, a southern tributary to river Pazña, with an area of 76 km^2, see Figure 1.

The rivers are formed in the mountainous parts of the basins, belonging to the Oriental chain of the Bolivian Andes, and reaches the plain areas where they confluence and the catchments area has its perimeter. As can be seen in Figure 1, the river passes Pazña and is dispersed over the plain next to Lake Poopó rather than have a surface discharge to the lake. This is due to the high permeability of the soil in the high plateau, allowing infiltration of the surface water. In the municipality of Antequera the river is called river Antequera to further downstream change name to river Pazña. River Pazña merges with river Urmiri, with its origin in the basin of Urmiri, further downstream but keeps the name river Pazña after the confluence.

Politically the basins belong to the department of Oruro and they constitute a big part of the municipalities of Pazña and Antequera, see Figure 1. Both municipality capitals, Pazña and Bolívar, are situated in the basin of Antequera, see Figure 2.

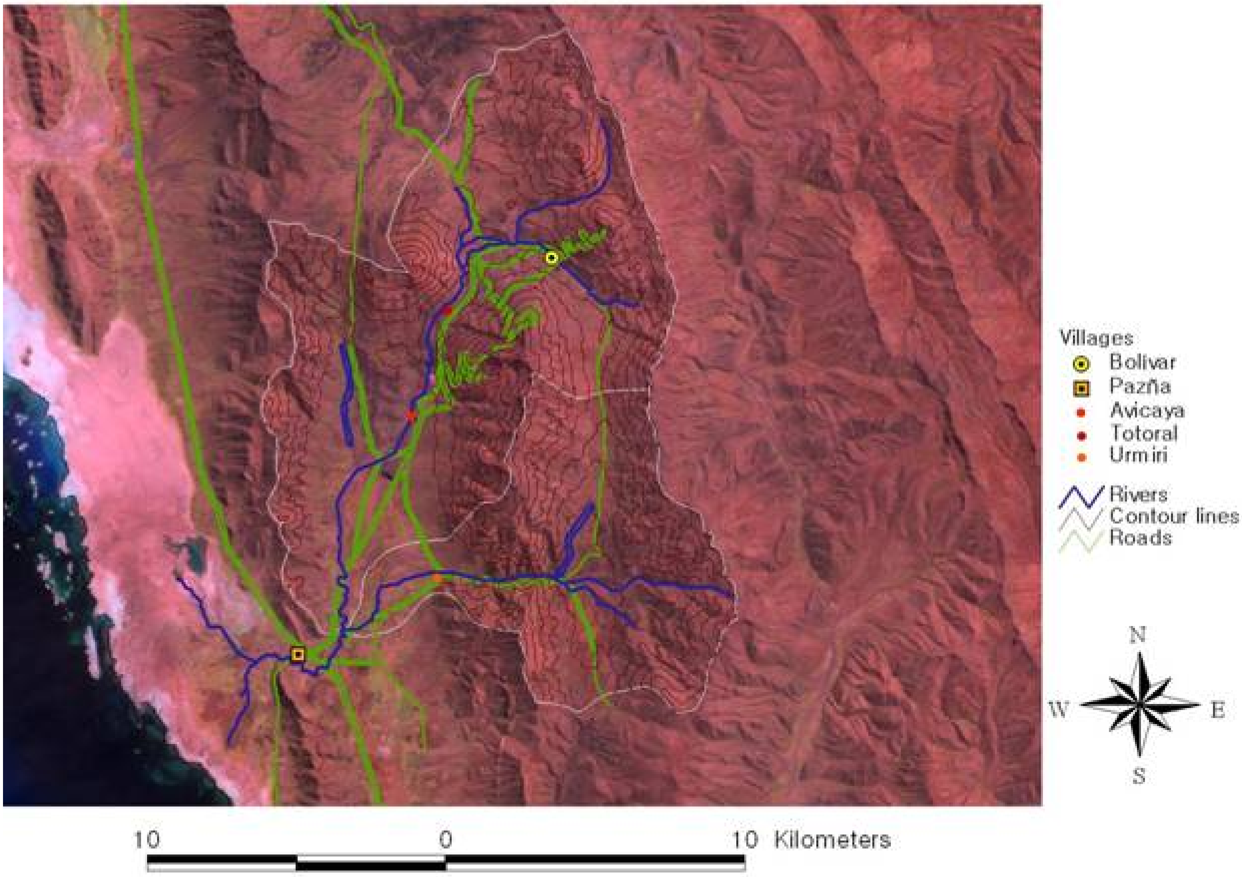

Figure 2. Satellite image of the two study basins with contour lines, roads, rivers and village

2.2 Climate

The climate in the region is strongly marked by its geographical setting. Being situated at a high altitude the temperature is low considering the proximity to the equator.

The air and ground heat up during the day with the energy of the sun and cools down rapidly when the sun sets. It is not uncommon for the difference between night and day temperatures to exceed 25 ºC. The nearby Lake Poopó has a variable area with an upper limit of approximately 3 191 km^2, (the area varies over the seasons and over the years). Although it is extensive it is shallow, with a maximum depth of around 2 m., and has little thermo-regulatory effect, unlike Lake Titicaca. According to data presented by A.L.T. (1993), Pazña has a mean temperature of 8.5 ºC. The temperature varies over the year with around 12 ºC in the summer (November to March) and 4 ºC in winter (May to August). Every month of the year has days with temperatures below 0 as can be seen in Table 1.

Table 1. Hydrological data for Pazña

Pazña	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Year**
Precipitation (mm)	110	96	66	22	4	4	5	9	21	22	34	58	**451**
Temperature (ºC)	12.2	11.8	11.2	9	5.2	3.1	3.3	5.5	8	9.5	11.4	12.1	**8.5**
PET (mm)	164	148	148	128	107	93	99	127	146	172	185	154	**1671**
Days with Tº below 0	3.1	1.9	8.8	23.1	30.4	30	30.6	30.8	25.7	23.7	15.5	7	**230.4**
Frec. Drought (%)	30	40	50	90	100	100	100	100	90	100	100	40	

Source: A.L.T. (1993) and SGAB (1996)

The region has an arid to semiarid climate. Precipitation in Pazña has been measured by SGAB. The measurements started year 1975 and was presented in PPO (1996). The average yearly precipitation was found to be 451 mm, but the precipitation varies strongly over the seasons and the years. The year is divided into one wet season (October to March), with about 95 % of the total rainfall and one dry season (April to September) with 5 % of the precipitation. The precipitation is of torrential character with short and intensive rainfalls. Sometimes the precipitation falls in form of snow but the snow never stays longer than a few days. The area is affected by regular draughts and the climatological phenomenons of El Niño and La Niña, sometimes bringing unusually heavy draughts and at times uncommonly long wet seasons.

Being close to the equator as well as at a high altitude the solar radiation is strong and the evaporation is intensive. Average potential evaporation in Pazña is about 1 700 mm/year, PPO (1996).

2.3 Geology

The studied basins are situated in the western part of the mountain range of Azanaques. Azanaques is a part of the Oriental chain of the Bolivian Andes, a mountain range formed of sedimentary rocks from the Palaeozoic era intruded by granitic plutons, Clapperton et al. (1997).

The mountain range was created through tectonical movements caused by the subduction of the Nazca plate beneath the South American plate, uplifting, folding and comprising sedimentary layers. Tectonic forces result in earthquakes and volcanic eruptions and as Colquehuanca Matias (2006) describes is his study, the volcanic activity is the origin of the mineralization of the Azanaques range. Anticlines and synclines are numerous in the area with a general direction of NNW to SSE, Salinas Revollo (2005). Most rivers follow the mountain range in a N – S direction and the rivers that cross the mountain range transversally follows geological faults. This is the case of river Urmiri where thermal waters are also found, see Figure 3.

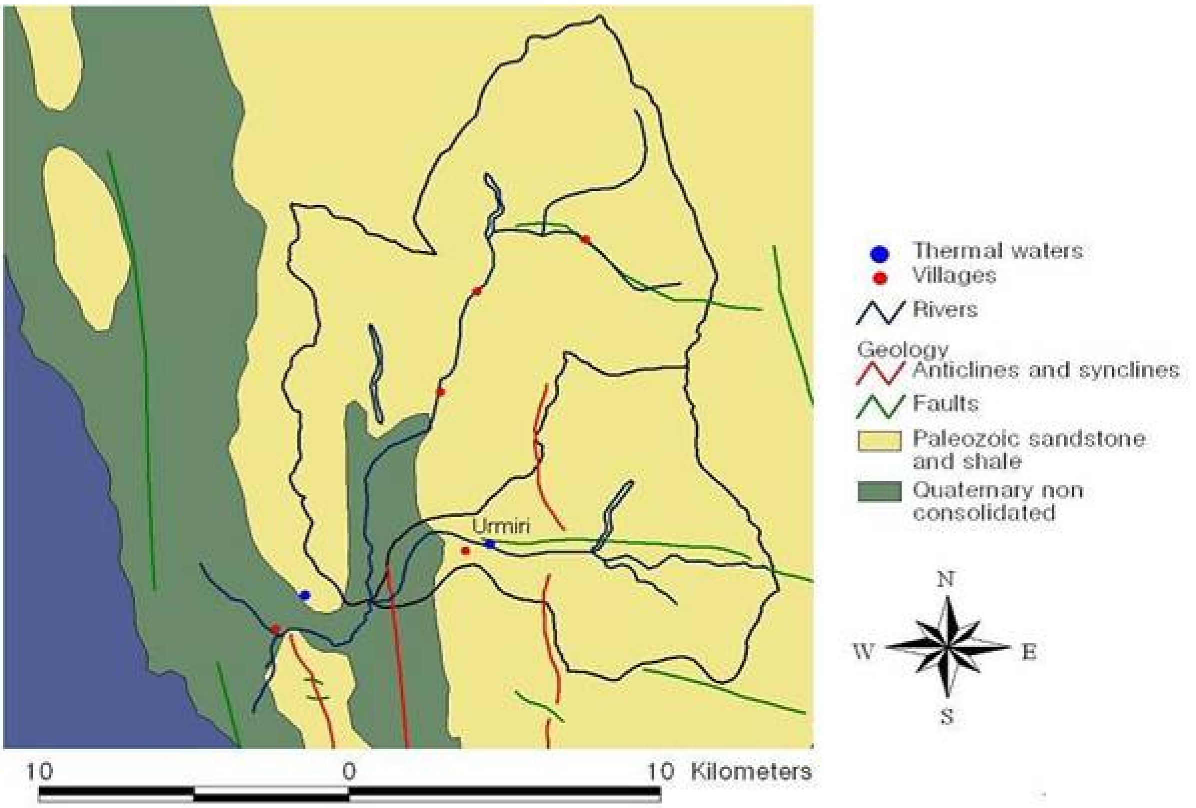

Figure 3. Geological formations

Source: Salinas Revollo, (2005)

The rocks in the basins are from the Silurian era, composed by quartzite, shale and sandstone, and Quaternary era mostly of gravel, sand and clay formed through alluvial deposits, Salinas Revollo (2005). The permeability varies depending on the use of, the nature of and the geological composition of the earth. As described by Salinas Revollo (2005) the mountainous part of the basins is the area of high potential recharge of aquifers whilst the low or plane areas are those of high aquifer storage, having higher permeability.

2.4 Vegetation

The information about the vegetation in the area has its origin in personal observations and interviews. The vegetation is typical for that of arid to semi arid areas with small bushes, grass and cactuses. Among the most important ones are the bush Thola (various species of the family Asteraceae) used for combustion, the grass paja brava (Poaceae family), see Figure 4, used for forage for llamas, sheep and donkeys and the gramíneas (Fabaceae, Rosaceae, etc.), Montaño (2002).The column cactuses growing in the area are of small species (Lobivio sp, Opuntyia floccose, Cajophora sp), see Figure 5. The vegetation is sparse and many of the plants present in the area are known to support uncommonly high contents of salts, so called halófitas (Frankeniaceae, Chenopodiaceae, Poaceae etc.) reflecting the location of salt contamination of the soil, Salinas Revollo (2005).

Figure 4. Photo of farmer harvesting alfalfa with paja brava in the background

Figure 5. Column cactus, poplar and pine trees in the central plaza of Pazña

There are occasional trees in protected locations such as village plazas, see Figure 5. Some species of trees can survive and thrive in the area but similar to the situation for the Thola today, trees have been cut down and used for combustion. Among the most common species are eucalyptuses (Eucalyptus globulus), poplar (Populus Deltoides) and pine trees (Cupresus macrocarpa, Pinus radiata).

2.5 Population

According to Censo Nacional de Población y Vivienda 2001, the national registrations compilation of national statistics, the municipality of Antequera had 3 352 inhabitants with a growth rate of -0.41 % and the municipality of Pazña 5 469 with a growth rate of -4.20 %. The entire population of the two municipalities does not live within the study area and the population within the study basins is approximated to 4 300. The growth rate of the population is -2 % and they live in 1 300 houses with 3-4 persons in every household. By evaluating information obtained through interviews, the number of inhabitants in the major villages was estimated to the number specified in Table 2.

Table 2. Distribution of the population in the study area

Village	Bolívar	Pazña	Totoral	Avicaya	Urmiri	Rural	Total
Nº of inhabitants	2 000	1 300	500	100	50	350	4 300

The farms are few and scattered on the hill sides. The farmers living outside villages are estimated to 350 persons.

The migration is a problem in the area mostly due to the decreasing mining activity and a lack of alternative income sources. When field lie fallow most farmers leave temporarily for cities in search of an additional earnings. Many young people leave for bigger cities during their studies and many never return.

2.6 Socio-economic situation

According to the Instituto Nacional de Estadística, the national statistics institute, the area of the project is considered a poor area in the department of Oruro, the poorest department in the country. The infant mortality rate (IMR) in the rural area of Oruro is 12.3 % and the rate of illiteracy, for people over 15 years of age, is 15.4 %, Montaño (2006). These numbers can be compared to the national values of 5.4 % for IMR and 13.1 % of illiteracy, UNESCO (2004). Further comparisons give that South Africa has similar values to Bolivia while Sierra Leone has the worlds worst IMR, see Table 3.

Table 3. Values of IMR and illiteracy rate in some of the worlds' countries in 2004

Parameter	Rural Oruro	Bolivia	South Africa	Sweden	Sierra Leone
IMR	12.3	5.4	5.4	0.3	16.5
Illiteracy	15.4	13.1	17.5	No data	64.55

Source: UNESCO (2004)

The major sources of income supporting over 90 % of the population in the area are the mining industry, agriculture and livestock.

2.6.1 Mining activity

Underground mining started in small scale in the study area at colonial times. At the time there were no regulations controlling the environmental effect of the mining activity resulting in the accumulation of large quantity of piles of mining residue and sludge in the area. Since then, exploitation of minerals has been the most important economic activity in the area, declining in importance over the last decade but gaining in importance again over the last two years due to better exportation conditions.

There are three, presently active, major mines in the Antequera basin; Bolívar, Totoral and Avicaya, see Figure 6. In the mines silver, led, tin and zinc are exploited.

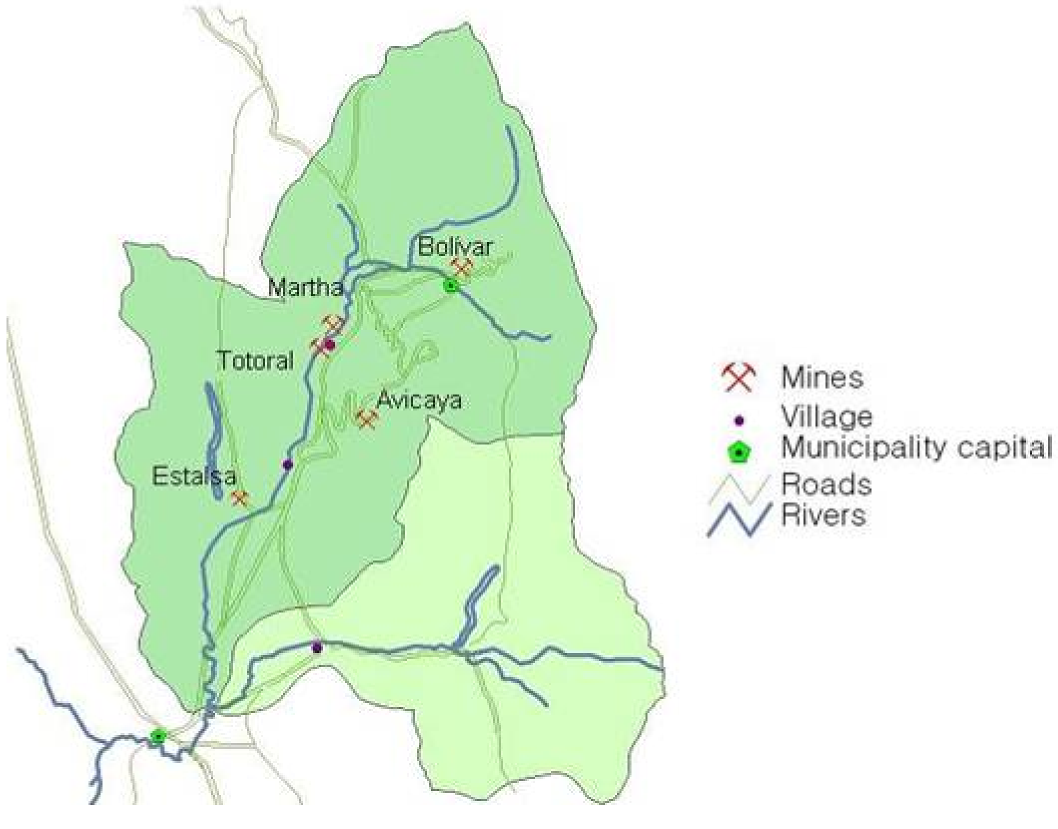

Figure 6. Location of mines

Apart from these mines there are also several small and illegally working mines in the area, for instance around Bolívar. Miners often create small cooperatives which together sell minerals to buyers in the cities. The cooperatives sometimes re-open closed mines, working under appalling and dangerous conditions with undeveloped, outdated tools. Minerals are also collected on hill slopes and by washing old mining residues, see Figure 7. Women are traditionally, because of local beliefs, not to enter the mines but child labour occurs both in the mines and in associated work. The small mining industry is well described at the homepage of MEDMIN (2007) - Medio Ambiente Minería e Industria.

Figure 7. Piles of old mining residues being searched through again, close to Totoral

The mine of Bolívar is owned by the multinational Swiss owned company Sinchi Wayra whilst the mine in Avicaya is owned by a small company, Minera Avicaya S.A., and a cooperative is working the mine of Totoral.

The mine Martha is also owned by Sinchi Wayra but currently not active. The company ESTALSA stopped working in 1996, Ríos (2002). ESTALSA exploited tin from the glacial-fluvial deposits open air, through dredging the fluvial gravel south of Avicaya.

An estimation of the deposits of mining residue and sludge, in the Antequera basin was made in PPO (1996) and is presented in Table 4.

Table 4. Mining residue in the river valley Antequera

River valley	Volume (m^3)	Weight (ton)	Area (m^2)
Antequera	599 000	940 000	392 000

Source: PPO (1996)

In the basin of Urmiri there exists no evidence of present or previous exploitation of minerals.

2.6.2 Agriculture

The production of agriculture is the responsibility of all family members. Barley grains, potatoes, onion and carrots are sold locally and cultivated in limited areas. The cultivation of forages such as alfalfa and barley is of major importance. 80-90 % of the total production is sold to the interior of the country either by the producer or through a middle hand active in the area.

Rotation of the plants grown is practiced in the area. Rotation is known to maintain the fertility of the soil. Most activities are performed by hand though many use rented tractors for the preparation of the soil and sowing of forages. Very little herb- and pesticides are used.

Factors strongly limiting the agricultural production are the frequent droughts, freezes and hail in January and February but also the lack of possibility to invest in the technical and qualitative improvements. With irrigation not only does the area of productivity expand, but the cultivable season prolongs and the productivity per hectare increases. An estimation of the increase of productivity is, for alfalfa, from 6.9 to 8.5, for broad bean, from 3.8 to 4.8, and for potatoes, from 5.5 to 7 tons per hectare, H.A.M. de Pazña, (2006).

The main problems, as a consequence of irrigation in the world are water logging and salinization. Water logging should not be a problem for the area but salinization certainly could be. The soil and water quality must be investigated properly before implementing irrigation system.

2.6.3 Livestock

The most important livestock are cows and sheep but llamas are also bred in some parts of the basins, see Figures 8 and 9. The stock-farming is secondary and complementary to the agriculture. The number of livestock is relative to the area with cultivations of forages. This activity has a fundamental importance as an economic reserve to be used for eventualities. However, the keeping of livestock also contributes with an extra income from cheese and milk production. 90-95 % of the meat, cheese and wool produced are sold and the rest consumed in the family.

Experiences from the workshops about stock-farming show that the animals suffer severely from intestinal parasites as well as consequences from the contaminated water. According to the stock-farmers, livestock, which drink water from the river, suffers from diarrhoea, inflamed livers and lungs. The livestock farmers first priority for a project to improve their situation is access to good quality water, see Appendix 2. These problems are known effects from contamination of sulphates and iron. For further details, see chapter 6.2 “Effects of water contamination”.

Figure 8. Sheep

Figure 9. Llamas

2.6.4 Thermal waters

There are two thermal bath facilities in the basins both of which a small entrance fee is demanded, Bs 2-3 per 30 min (0.19-0.29 €). In the two facilities a total of three employees work. There is possibility for further tourist exploitation of the thermal waters.

2.7 Current situation (problems and conflicts)

The life in and the productivity of Lake Poopó area is in many ways limited by the water shortage, both due to the temporal variations and a lack of total water resources. Over the last decades many mines have shut down and in search of additional income sources, arises new demands and uses for water. There is nothing to regulate the rights of the water use and the conflicts over water are getting more serious and numerous as the water demand and use increases. The sectors with major water rights claims are the mining activity, irrigation and fishing. Due to the lack of regulation, in most cases, water is simply used without consideration given to the users further downstream. This means that the final users suffer the severest consequences, in this case, the lake and the fishing industry.

In some places there is a lack of groundwater for irrigation because of the use in the mining industry. The village of Totoral is experiencing unusually long periods with dry wells, which they claim to be caused by the groundwater use in the mine of Bolívar. Because of the water uses for irrigation and in the mines less water is reaching the lake, something which is already for environmental reasons a problem. The lake volume fluctuates naturally with varying precipitation and dries out almost entirely some years. The lake dried out in the early 1940's, the early 1970's and remained dry from 1994 to 1997, Pillco Zolá & Bengtsson (2006). Due to this and contamination the fishing industry is severely affected. The native fish species have died out because of the lake volume reduction and the production of the fishing industry has decreased to almost nothing, affecting over 4000 people, Pillco Zolá & Bengtsson (2002).

Lake Poopó is a terminal lake most years and therefore sensitive to variations in inflow. Contaminations accumulate and concentrations increases with decreasing lake volume. The salinity and some of the heavy metal contamination is natural though most originates from the mining activity. In addition to this contamination there is also pollution from human activities and agriculture. There exist no waste water treatment in the whole department and only in Oruro are solid residues treated, though not all covering. People in Oruro have not yet developed a sense of responsibility and importance regarding the solid residues and paper are thrown without further consideration onto the streets, see Figure 10.

Figure 10. A desolate site in Oruro

Loss of vegetal cover due to overgrazing exposes the soil to wind and water erosion as well as compacting the soil leading to reduction of the permeability and thereby the infiltration of rainwater.

2.8 Organisations working in the region

Apart from the work of the local authorities, the prefecture and the mayors' office and the universities from Oruro, Potosí and La Paz there are several other organisations working in the area with the issue of water contamination and resources.

The SIDA, SAREC – UMSA cooperation program, studying the basin of Lake Poopó and Uru Uru from a technical point of view but also historical and anthropological.

The Japan – Bolivia cooperation program, JICA, which since year 2000 have been drilling wells in the villages around Lake Poopó. By 2007 almost 90 wells had been drilled, of which around 30 is currently working.

The European commission – Bolivia cooperation program APEMIN II working to support the sustainable economic development in the occidental part of Bolivia, focused on small mining activity but also supporting projects in agriculture, handicraft, fishing and livestock.

CIPRODEC - A partner to the NGO International Land Coalition, supporting the agricultural and livestock production as well as offer small credits in the departments of Oruro and Cochabamba. Working with an emphasis on secured alimentation and economic promotion, contributing to the improvement of the life quality.

3 Methodology

The work behind this thesis can be divided into three distinctive stages. It started with literature study and project planning, followed by a three month field study and data acquisition in Bolivia, and concluded with synthesis and analysis.

3.1 Literature study

The initial stage consisted solely of inductive data acquisition (little of the situation was known beforehand) of secondary data. A first project plan was made with the restricted access to relevant information. This inadequacy was a limit both for the comprehension of the situation and the critical analysis and comparison of data.

3.2 Field study

The field study in Bolivia started with further literature study and learning of ArcGIS, a group of geographic information system software including, amongst others, ArcView, which allows one to view spatial data, at the Universidad Mayor de San Andrés in La Paz. A first recognition trip was made to the study area. The following weeks were used to find further information at the university, UMSA, at the European commission – Bolivia cooperation program APEMIN II, in Oruro and in the study area.

During the first stage of the field study a deductive approach was applied for the acquirement of data, given the existing project plan and the previous information of the situation. As the work progressed, understanding differing viewpoints, hearing contradictory statements and being made aware of underlying interests, the approach changed to inductive. This change of strategy was made, to a large extent, because of the difficulty to realise the first project plan, due to the lack of tangible data.

The secondary data consist of relevant literature, thesis and reports, hydrological and chemical data and basic maps and satellite images processed in ArcView.

The primary data was obtained both through qualitative and quantitative approach. Qualitative data acquisition was used, so as not to draw a general conclusion but to generate a hypothesis, through participative observation such as interviews, forms and involvement in workshops about agriculture and keeping of livestock. The quantitative data consisted of information about location, for the maps, specified with a GPS of type GARMIN GPSMAP 76CS, and pH measured with a pH meter of type sension 156 Hach.

3.2.1 Interviews, forms and workshops

Interviews were made with officials, professionals and locals. As the work progressed a clearer picture of all the actors present in the study area was acquired. Given that specific pieces of information were sought and not personal opinions or analysis, no explicit thought was given to the approach. The interviews were held freely and only short notes were taken.

Among the professionals interviewed are; the superintendent of environment of Sinchi Wayra and the responsible for international technical assistance, APEMIN II as well as several engineers at JICA, the prefecture of Oruro and the mayor's offices in Pazña and Bolívar. The officials interviewed are the mayors and sub-mayors of the study area, they were also asked to fill in a form with details and numbers of water use, sources and treatment in their village, see Appendix 2. Locals were interviewed during the visits to the study area but much information was also obtained through the workshops.

The workshops had been planned by engineer Mario Veizaga from APEMIN II, assisted by Anna Ekdahl with the objective to understand the needs and demands of the locals and thereby get ideas to new projects as well as inform about the work of APEMIN II. The three workshops were divided into the categories livestock, agriculture and fishing. Participants were first urged to describe the different difficulties they have with their respective income source. When a list of defined problems had been put together a discussion was held to come up with ideas for solutions and projects. The priority of each project was then decided. Lists of the prioritised projects can be found in Appendix 2. Other topics such as private economy, additional income sources and distribution of time and occupation were also discussed.

3.2.2 Limitations

The major difficulty during the field study in Bolivia was to find relevant information. There are several organisations working in the area with water issues and many studies have been conducted. There is very little intercommunication between the different organisations, sometimes they are not aware of each others presence in the area, some companies conduct their own studies and the prefecture does for instance not work with the mayors' office and vice versa. This leads to that the information is very disperse and also that many studies give contradictory information.

A minor obstacle in the work was the fact that some people, in particular the women, in the area do not speak Spanish, but only Quechua and in some cases Aymara. However, this was not a major problem since there was always someone nearby who spoke Spanish.

3.2.3 Reliability

Much of the information obtained through the qualitative approach does not seem probable. In many cases a feeling of misinterpretation appeared, the people in the area seemed to have difficulties relating to the interviewer and the questions, which resulted in answers not always in coherence with the question or with the situation. All information from interviews and workshops, included in this thesis has had support from various sources.

3.3 Synthesis and analysis

After the return to Sweden a synthesis was made from all the data collected. Information was completed from and support for theories searched for in specialist literature. With this additional information, quantifications of access and consumption could be made and compared. Maps were refined and adjusted in ArcView. An analysis of the situation was done and conclusions drawn.

4 Water supply and sources

The study area has an arid to semi-arid climate and water resources are naturally scanty over some periods. The scarcity limits the economical development and defining the supply and resources available are fundamental for the analysis of possible improvements.

4.1 Precipitation

Precipitation in the Lake Poopó area has been measured by SENAMHI, the national service of meteorology and hydrology, since 1975 at various stations around the lake. There is one meteorological station in Pazña, originally measuring only precipitation, see Figure 11, but later completed with instruments measuring, for example, temperature and relative humidity.

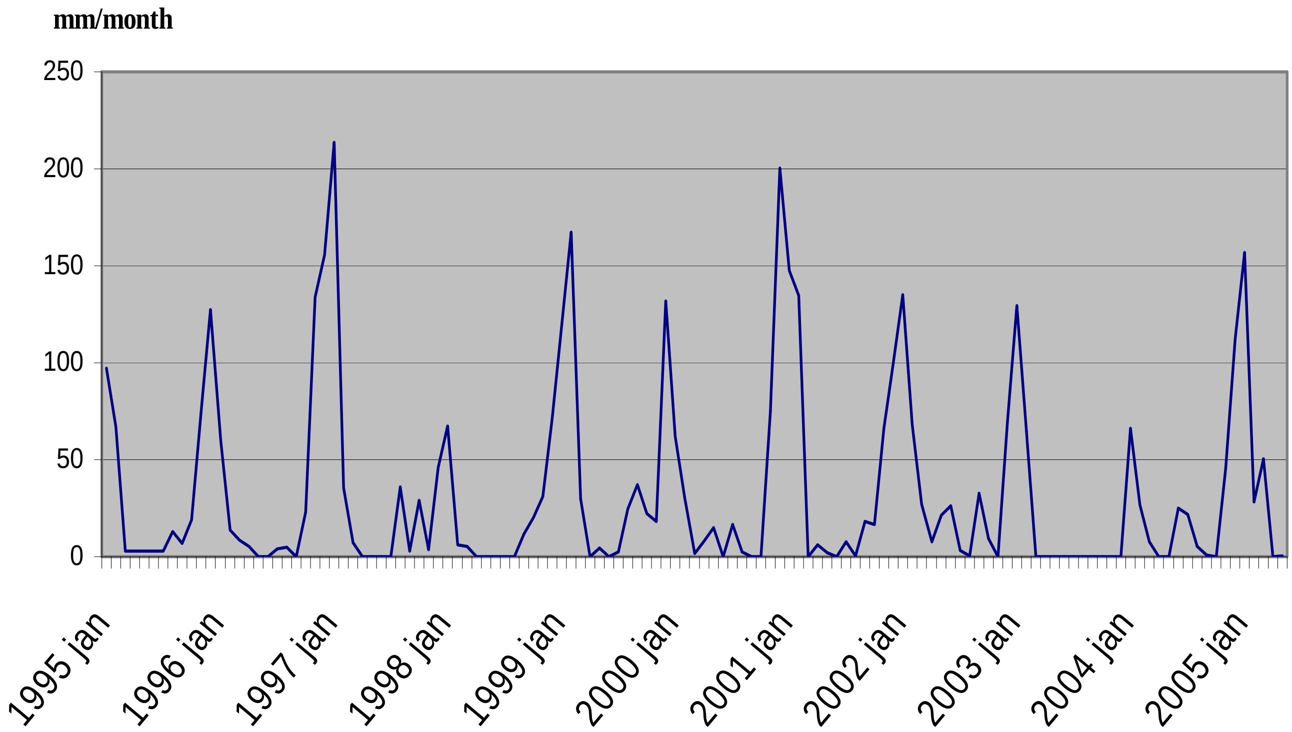

Figure 11. Precipitation in Pazña 1995 - 2005

As can be seen in Figure 11, almost the entire yearly precipitation falls during the few months of rainy season. These variations are highly predictable. Less predictable are the climatic variations due to the effect of El Niño and La Niña. Comparing the pattern in Figure 11 with the information about the climatic changes caused by the El Niño Southern Oscillation (ENSO) events in Table 5, one can clearly see a connection. There is a strong El Niño effect in late 1997 to early 1998. The effect is a strongly reduced precipitation in the following rainy season (1998). The effect is repeated in late 2003 to 2004 with reduced precipitation in 2004, but not as strong.

In Table 5 the numbers are marked with blue colour for cold and red colour for warm when difference exceed +/- 0.5 ºC for the Oceanic Niño Index (ONI)[1] for a minimum of 5 consecutive over-lapping seasons. The El Niño effect is correlated to warmer periods and the La Niña effect to colder. Further details can be found on the NOAA homepage www.

Table 5. Table of sea surface temperature variations in the tropical Pacific 1995-2005

	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1995	1.2	0.9	0.7	0.4	0.2	0.1	0.0	-0.3	-0.5	-0.6	-0.7	-0.8
1996	-0.8	-0.7	-0.5	-0.3	-0.2	-0.2	-0.1	-0.2	-0.2	-0.2	-0.3	-0.4
1997	-0.4	-0.3	0.0	0.4	0.9	1.4	1.7	2.0	2.3	2.4	2.5	2.5
1998	2.4	2.0	1.4	1.1	0.4	-0.1	-0.8	-1.0	-1.1	-1.1	-1.3	-1.5
1999	-1.6	-1.2	-0.9	-0.7	-0.8	-0.8	-0.9	-0.9	-1.0	-1.2	-1.4	-1.6
2000	-1.6	-1.5	-1.1	-0.9	-0.7	-0.6	-0.4	-0.3	-0.4	-0.5	-0.7	-0.7
2001	-0.7	-0.5	-0.4	-0.2	-0.1	0.1	0.2	0.1	0.0	-0.1	-0.2	-0.2
2002	-0.1	0.1	0.3	0.4	0.7	0.8	0.9	0.9	1.1	1.3	1.5	1.3
2003	1.1	0.8	0.6	0.1	-0.1	0.0	0.3	0.4	0.5	0.5	0.6	0.5
2004	0.4	0.2	0.2	0.2	0.3	0.4	0.7	0.8	0.9	0.9	0.9	0.8
2005	0.6	0.5	0.3	0.4	0.5	0.3	0.2	0.0	0.0	-0.2	-0.4	-0.7

Source: NOAA (2007)

4.2 Evapotranspiration

The evaporation depends on factors such as the solar radiation, the wind, the temperature but also on how much water that is available to be evaporated. This, in turn, is dependent on the type of soil and soil use, i.e. if water is easily filtered through. Transpiration depends on the type of vegetation and wind speed.

The potential evapotranspiration (PET) is a representation of the environmental demand for evapotranspiration and it reflects the energy available to evaporate water. The PET at the station of Pazña has been calculated in the study for which Pillco Zolá (2002) was responsible comparing the equation of Penman and the equation of Ivanov and concluded that both equations are applicable to the area. For the values presented in Figure 12 the formula of Ivanov (1) has been used to calculate the daily evapotranspiration.

[1] The Oceanic Niño Index (ONI) is the standard that NOAA uses for identifying climatologic events in the tropical Pacific. It is the running 3-month mean sea surface temperature anomaly for the Nino 3.4 region (5oN-5oS, 120o-170oW).

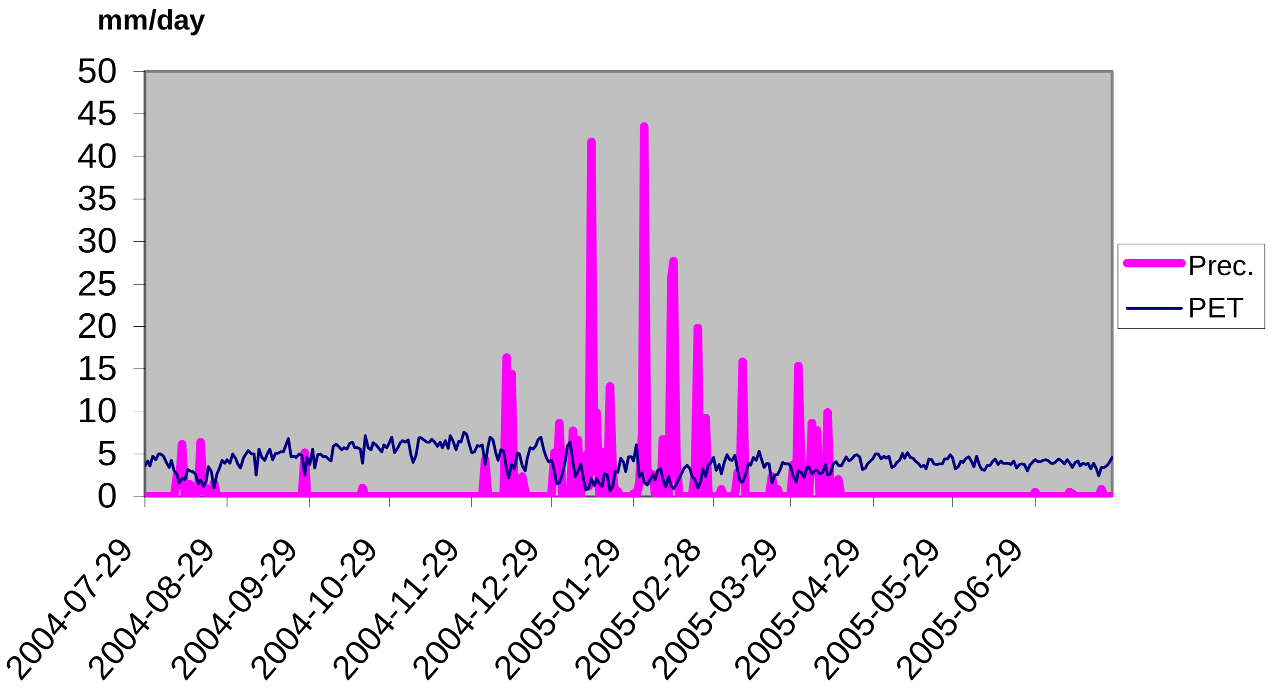

Figure 12. PET and precipitation in Pazña

Values for year 2004-2005 were chosen because data exist about relative humidity during this period and the year had precipitation (423 mm/year) close to the average year and a representative seasonal distribution.

As can be concluded from Figure 12, the PET exceeds the precipitation during the whole year, except a few days during the rainy season. The total yearly PET is 3.5 times higher the yearly precipitation.

4.3 River flow

The flow in river Pazña has been calculated from 1960 until 2002, Pillco Zolá (2002). Some data exist about the water level and flow in the river after year 2002 but the data is not complete and not always reliable. In the study by Pillco Zolá the program Qbox was used to compute the flow and these numbers have been used to plot the distribution over the year, see Figure 13. As can be seen in Figure 13, the river has practically no flow during dry season.

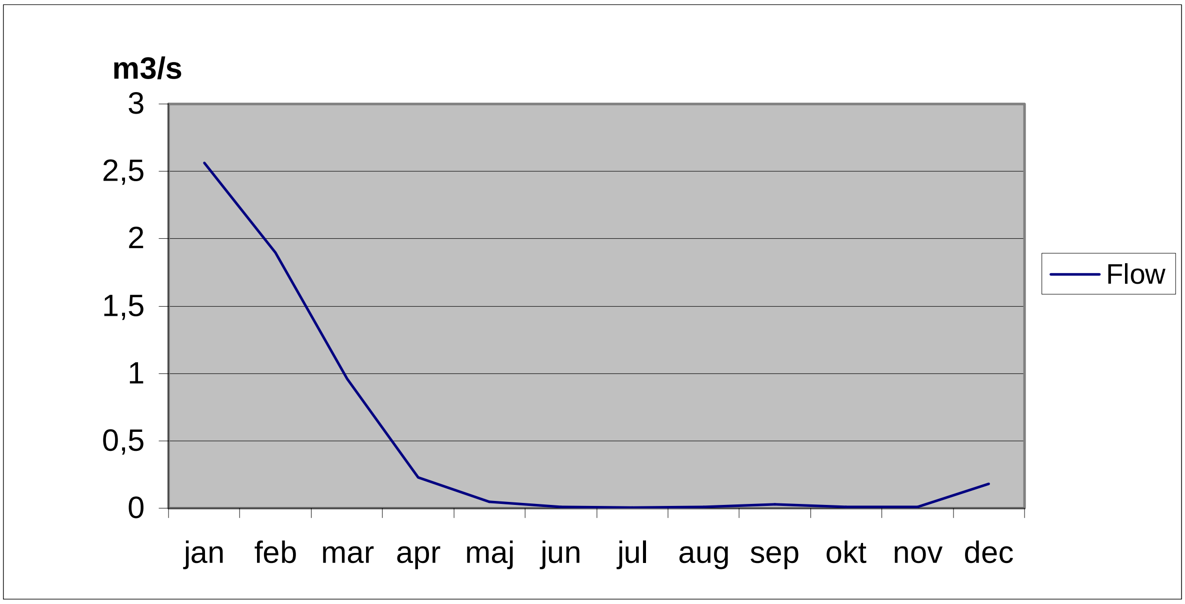

Figure 13. The average flow between 1960-2002 in River Pazña and its distribution over the year. The flow has been modelled from known levels of precipitation.
Source: Pillco Zolá (2002)

The yearly average flow was calculated to be 0.495 m^3/s which equals an accumulated flow of 15 610 000 m^3/year. It is also important to mention that the yearly flow varies strongly. Some years the flow is as high as 1.83 m^3/s (1985 and 2001) while in some year it drops to almost zero (1989-0.0075 m^3/s and 1998-0.037 m^3/s).

4.4 Groundwater

Groundwater is the water under which level the soil is saturated. Generally groundwater moves slowly and therefore acts as solvents rather than being erosive. Groundwater can have its origin in meteoric-, magmatic- or seawater, (water trapped in the pores of marine sediments). Due to the temporal variations of the water level in the springs and wells in the area as well as the mineral content of the water it can be concluded that the groundwater in the area has meteoric origin, Salinas Revollo (2005).

An aquifer is an underground geologic formation that has the capacity to store and transmit water, Fetter (2001). It is a permeable layer on top of a confining one and can transmit water to wells in an economic fashion as a result of its porosity. There are three types of aquifers. An unconfined aquifer is when the water level has direct contact with the air through porosive spaces and is therefore at atmospheric pressure. A perched aquifer is a layer of saturated soil above the main water table accumulated on top of a lens of low-permeability material. A confined aquifer is covered by a confining layer, where the water is in a confined space and under pressure higher than the atmospheric, Fetter (2001).

All three types of aquifers are found in the area of study, Colquehuanca Matias (2006).

According to the study of López Cortés (2006), the water extracted in the mine of Bolívar comes from a confined aquifer, with its recharged far away. This would mean that the groundwater basin does not completely coincide with the surface water basin. Further the conclusion of the study is that the ground water has a uniform hydraulic behaviour and that there are no connections between aquifers but that they all flow towards river Antequera.

4.5 Thermal waters

There are various geological formations that lead to the occurrence of natural springs. The mechanism could be a topographic low spot with soil surface below the water table or when water stored under pressure higher than the atmospheric can submerge through a crack, existing due to faults or fractures, Fetter (2001).

When the aquifer discharging water in the spring is situated deep underground the water is warm and usually contains dissolved minerals. Such springs are called thermal or hot springs. Faulting creates a geologic control favouring spring formation. An impermeable rock may be emplaced bordering an aquifer and force water to discharge as a fault spring, Fetter (2001). The thermal springs in Pazña and Urmiri are located in such geological faults. The thermal water has meteoric origin, and not magmatic, which can be concluded by the fact that the water only contain minerals also present in the rocks in the area, Salinas Revollo (2005).

5 Water demand and source of contamination

Water is necessary for all life. Making sure that adequate and reliable water supplies are available for agricultural activities and domestic use is a key to reduce poverty throughout the developing world. But practically all water use also leads to contamination, be it industrial domestic or agricultural.

5.1 Flow used in agriculture and live-stock farming

Information obtained from interviews and workshops show that the farmers in the area use neither pesticides nor herbicides. Little irrigation is used in the basins and further extension of the irrigation system does not seem to have negative consequences for the quality of the soil, Montaño (2002).

4 300 people live in the area under investigation, in 1 300 households. Most of the 117 (350/3) rural families are landowners with an average area of 15 ha, distributed in the agrarian reform. The vast majority of these families keep livestock whilst many miners live temporarily in the area and have mining as sole income. In the study by Montaño (2002) 31% of the population, downstream from Urmiri, are presumed to be dedicated to agriculture as well as live-stock farming. The number should be somewhat smaller for the whole study area since mining is predominating further upstream along river Pazña. The total number of live-stock is estimated to 4 900 (14*0.27*1300) with about 14 animals (conclusion from the workshop about livestock), including cows, sheep and llamas, owned by each family. The families keeping live-stock constitutes 27% of the total number of families. Every animal consume an estimated average of 20 litres of water per day which equals 35 900 m^3/year. Since the number of live-stock is relative to the cultivated area, the number is likely to increase with improved irrigation systems.

5.2 Flow used in households

Both surface and ground water are used for drinking water. At times, although knowing that the water is contaminated, the villagers have no option but to use it. Some of the villages in the river valleys have access to potable water which is pumped from deep wells or piped from upstream locations and in some cases treated with filters. Most people however fetch their water directly from the rivers or a shallow well without further treatment. There is no waste water treatment in the region but the waste water from Bolívar is collected in a septic tank where the water is separated from the solid residues and discarded into the river without treatment whilst the solid residues are collected once every month.

The water usage for household uses such as drinking, cooking, cleaning and laundry is estimated through interviews and observations. In developing countries the water consumption per person and day is 40 litres if there is access to tap water. The consumption drops to 15 l/(p,d) if the water source is 200 meters away, Caircross (1987). Given the scarcity of resources, the access to water and the lifestyle of the inhabitants, the average consumption was estimated to 25 litres per person and day. In Sweden every person use between 180 and 200 l/day. 25 l/(p,d) times 4 300 persons gives a total consumption of 107 m^3/ day and a yearly consumption of 39 200 m^3.

The following information about water systems, consumption and resources has been obtained through interviews with villagers and the mayor of the village, when possible.

5.2.1 Pazña

Pazña is actually situated west of the defined catchments area but is still taken into account in the work of this paper since it uses water transferred from the catchments and many families living in Pazña own land and livestock within the area. Pazña has approximately 1 300 inhabitants and access to potable water with 90% coverage. The water is piped from the uncontaminated river Urmiri and filtered. The pipe system is very much deteriorated and sometimes the villagers lack access to potable water for more than a month. The water used, is then fetched from a local well, a well in which the water quality was determined unfit for human, animal and agricultural use, in a study by Quino Lima (2006). The tap water costs Bs 2.50 (0.23 €) per month but the reason for the lack of maintenance of the pipe system is the insufficient economical resources.

5.2.2 Avicaya

In Avicaya live slightly more than 100 villagers. The water is transferred through pipes from a stream uphill with good quality water. The villagers have sufficient potable water all year around.

5.2.3 Totoral

According to the sub mayor, the village of Totoral has 488 families, which would mean around 1 500 inhabitants. After visiting the village his number was considered highly exaggerated. The number of inhabitants is likely to be no more than 500. Totoral has a precarious water situation. Historically, the inhabitants have gotten their water from deep wells but because of recent changes of the water table, the wells are dry from July to September. The situation is made more difficult by the fact that economic resources are inadequate for the maintenance of the existing equipment. Electric pumps are not in function and the only well currently working is the hand pumped one at the main plaza. Totoral consider the lack of water to be a consequence of the extraction of groundwater in the mine Bolívar further upstream and they have made several complaints to the mining company Sinchi Wayra. Sinchi Wayra executed, together with the university Tómas Frías in Potosí, a classification of the ground water in the area and found the ground water in Bolívar to have different origin than that in Totoral. During the months of drought the inhabitants of Totoral fetch water in cans from the village Avicaya. The water in the river is unusable because of contamination.

5.2.4 Bolívar

The village Bolívar is divided in two parts, the part owned by the mining company with around 1 000 miners and the actual village with 1 000 inhabitants. The houses in the mining camp have potable water that is extracted and treated by the mining company. The rest of the villagers transfer their potable water from the upstream river and there is no pre-treatment.

5.3 Flow used in mining activities

The contamination generated by mining activity, the extraction and processing of minerals, affects humans, flora and fauna. There are three main sources of the contamination: the water used in metallurgical processes contains heavy metals, dissolved sludge or reactants from the flotation and lixiviation, there are solid residues left in form of piles of sludge and it gives rise to the process called acid drainage, Ríos (2002).

Acid rock drainage occurs when sulphur rocks are exposed to water and oxygen. The exposure can have natural or anthropogenic cause. Piles of solid residues from mines are one source of acid rock drainage. When the drainage occurs in mines it is called acid mine drainage (AMD).

AMD occurs both in active sub-surface mines, where the excavations many times occur under the water-table and the water is constantly pumped out, as well as in abandoned mines where the water has flooded the mine. The acid drainage is the foremost environmental problem concerning the mining activity where the ore is a sulphide or is associated with pyrites. In abandoned mines, the drainage eventually stops when all rock surfaces have reacted, but this can take decades or even centuries, Sheoran & Sheoran (2006).

AMD is a complicated reaction consisting of metal sulphides (often pyrite) oxidation through chemical, electrochemical or bacterial reactions. As described in the study by Colquehuanca Matias (2006) the reaction can be presented through the general and simplified formula (2):

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O = 4\ Fe(OH)_3 \downarrow + 8\ H_2SO_4 \qquad (2)$$

Pyrite +Oxygen + Water = Iron(lll)hydroxide + Sulphuric acid

As can be understood from the reaction formula, iron, sulphates and acids are formed. The drainage can become extremely acid and values of pH as low as -3.6 has been registered, Nordstrom et al. (2000). The $Fe(OH)_{3(s)}$ gives the water a yellowish, at very high concentrations reddish, colour, see Figure 14. When waterways have high concentrations of iron hydroxide it can lead to the smothering of plant and animal life.

Figure 14. Stream, in Bolívar, with the characteristic colour of $Fe(OH)_3$, pH 3.1

Figure 15. Dam formed through dredging by ESTALSA, pH 3.07

It was observed while visiting the river valley of Antequera that many streams and ponds have the reddish colour typical for iron hydroxide and that there exists little vegetation along river banks and around water pools, see Figure 14 and 15. The pH was measured to be around 3 in main stream, puddles and ponds. Streams formed through recent precipitation have a pH of around 7. Groundwater wells and the main stream of river Pazña, downstream the confluence with river Urmiri, have a pH of around 6.3.

The map in Figure 16 is made in ArcView with information from López Cortés (2006) and own measurements. The samples were not taken regularly, nor were consideration taken to difference between rainy and dry season. The map should be considered as a simplified overview of the situation.

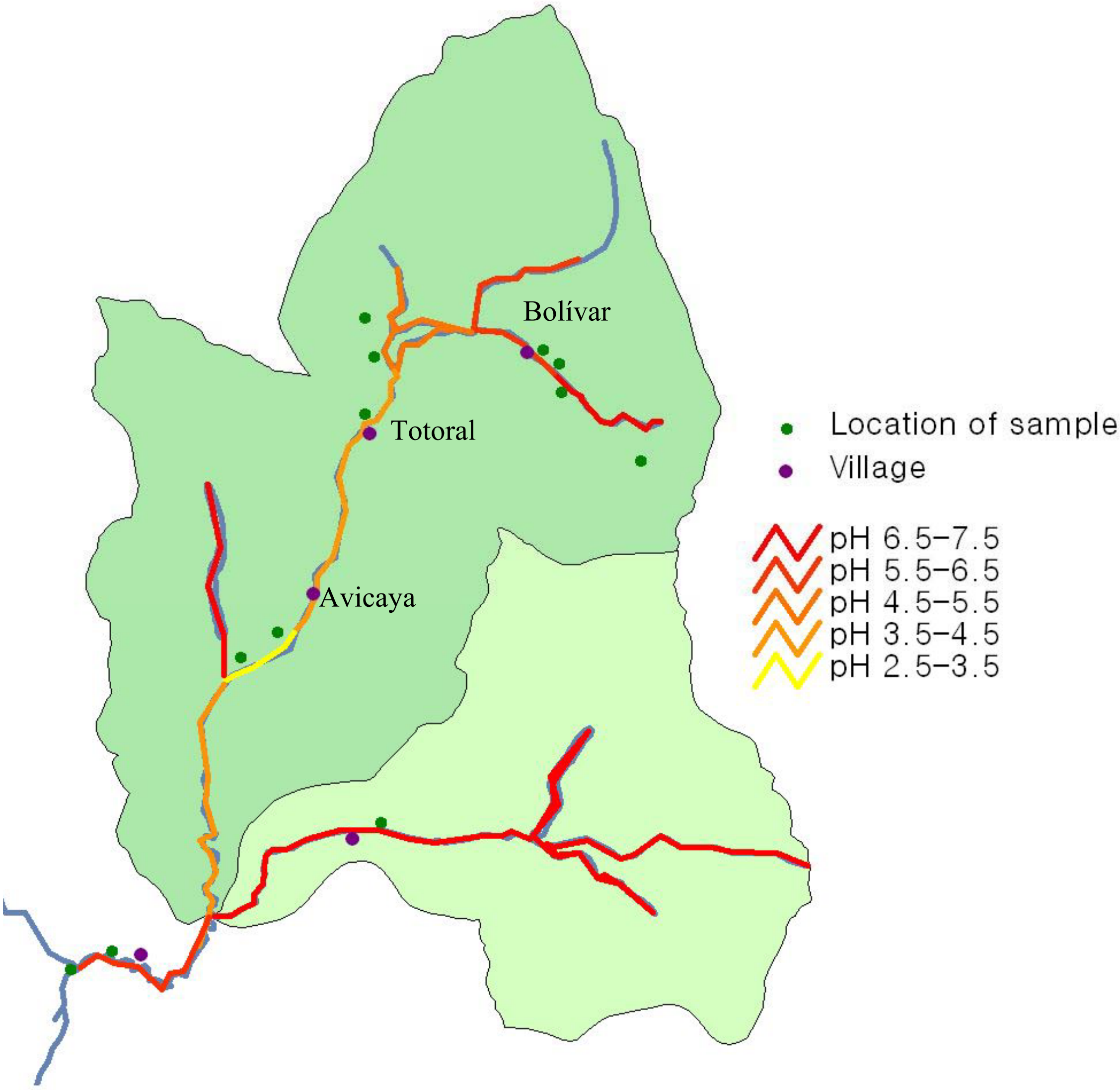

Figure 16. Values of pH in different parts of the waterway system

The upper part of the basin of Antequera, around Avicaya, Totoral and Bolívar, is full of evidence of mining activity. The hills are densely perforated, there are numerous piles of sludge and there are abandoned mining villages and equipment.

5.3.1 Mine in Bolívar

The ore deposits in Bolívar were discovered in 1810 and until 1890 only silver was exploited. In 1993 COMIBOL took over the mine exploiting silver, zinc and led. The mine has since then changed owner to the mining company Sinchi Wayra, Swiss owned and currently with 533 employees.

The mine in Bolívar is an underground mine far below the water table. The pumps pumping out groundwater from the mine are placed at -195 and -311 m. The water discharge from the mine varies from 95 l/s in the dry season to 115 l/s in the rainy season. Of the total average of 105 l/s, 2 l/s are pumped from -195 m to a water treatment plant, see Figure 17, where treated with aeration, pH neutralization with chalk, sedimentation in clarification basins and chloration. The potable water is then distributed to the employment facilities and the village.

The rest of the water is pumped to an evaporation lagoon where an average of 3 l/s is evaporated, 26 l/s is recirculated for use in the metallurgical processes and the remaining 90 l/s is treated before discarded into river Pampitas, a small tributary to river Antequera.

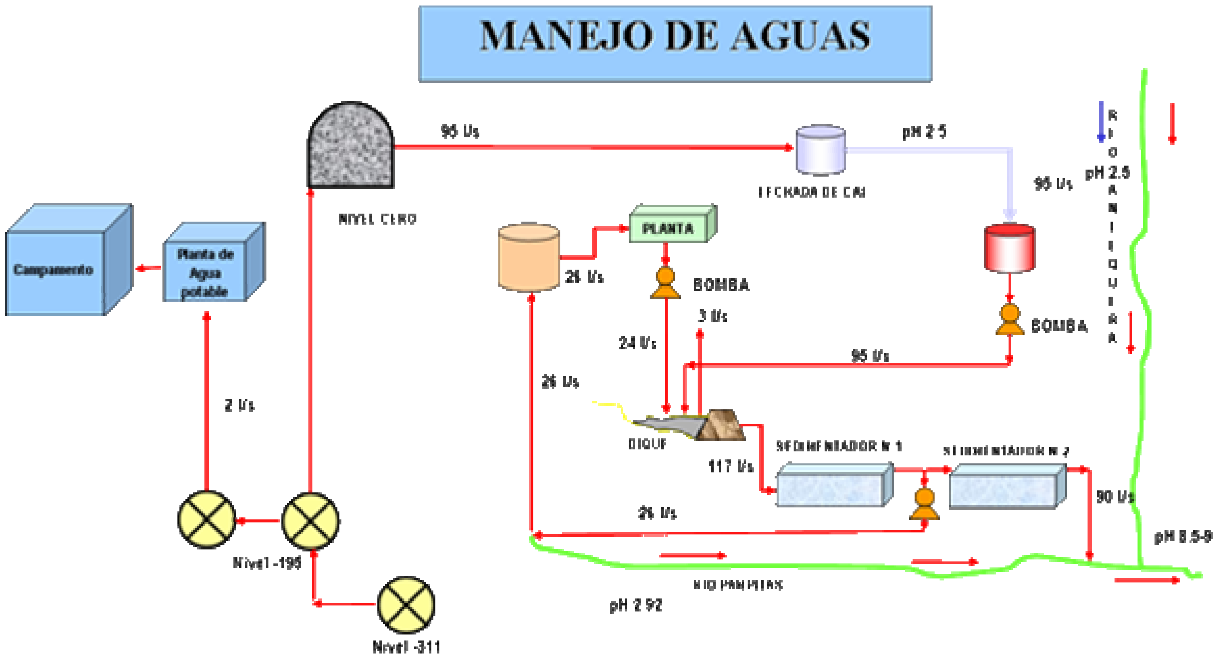

Figure 17. Water treatment at the mine Bolívar
Source: Sinchi Wayra

Due to the exploitation process the water from the mine contains high concentrations of heavy metals and suspended solids as well as being acid. Before discharged into the river the water is neutralized with chalk, lead through a sedimentation basin and filtered.

The water quality is monitored monthly whilst internal monitoring of the quality is on weekly basis. The quality of the water discharged into river Pampitas is within the limits stipulated in the environmental laws of Bolivia.

5.4 Thermal waters

5.4.1 Thermal waters in Pazña

The thermal waters are transferred through pipes into a bathing facility. The water is known to the people living in the area to have healing effects for rheumatism, arthritis as well as different skin diseases and healing broken bones. The water coming from the spring has a temperature of around 50 ºC. It is salt and smells of sulphur. The administrator explains that there are 7 different elements in the water including iodine. A momentary measurement shows the flow to be 12 l/s.

5.4.2 Thermal waters in Urmiri

People in the area, notably mining workers from Bolívar, come to the thermal waters in Urmiri for their healing effect. The properties of the water is said to be similar to those in Pazña but there is no smell of sulphur. At Sundays women come to wash clothes in the warm waters. The water in the spring has a temperature of around 70 ºC. A momentary measurement shows the discharge flow from the facilities to be 41 l/s.

5.5 Solid waste

There is no treatment of solid waste in the study area.

6 Background information about the contamination in the area

6.1 Previous quality studies of surface and groundwater

The contamination of soil and waterways in the area has been known for some time and several studies have been executed with diverse objectives. A comparison and combination of results is made difficult by the fact that Bolivia has not yet established a national standard for water contamination and different standards have been used to in order to complete each other. Below follows a summary of three interesting studies with the purpose of confirming the statement made earlier in this thesis, that the water is contaminated. For further details about standards and values obtained from the studies, see Appendix 1.

Quino Lima (2006) has studied the groundwater in Pazña. The samples were taken from a well located outside the village with a depth of 5-8 m. The water was found to have high concentrations of sulphates, iron and zinc which implicate an acid mine drainage and the H^+ can explain the relatively hard water in Pazña, see Table 6. Further, the level of salinity was found to be high, measured through conductivity. This salinity could have its origin in the thermal waters discharged in the river, as could the high concentration of total dissolved solids (TDS).

The conclusion of the study was that the groundwater extracted from the well in Pazña is not fit to be used for human consumption, animal consumption nor agriculture due to the low pH (6.1-6.2), the high values of conductivity and the hardness of the water. It can also be mentioned that the levels of chlorines and calcium are high and on the limit of acceptance.

In the study of López Cortés (2006) several analyses of both surface and ground water samples are presented, see maps in Appendix 1. It can easily be seen that the contamination of the surface water gets heavier further downstream, see Figure 18. The pH drops from 7.35 to 2.8, the conductivity increases from 0.22 to 2.46 mS/cm, the concentration of sulphates raises from 35 to 1 350 mg/l and the concentrations of heavy metals increases. In some surface water samples the iron levels are very high[2], see Table 6.

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[2] The unit was not specified in the study but presumed to be mg/l

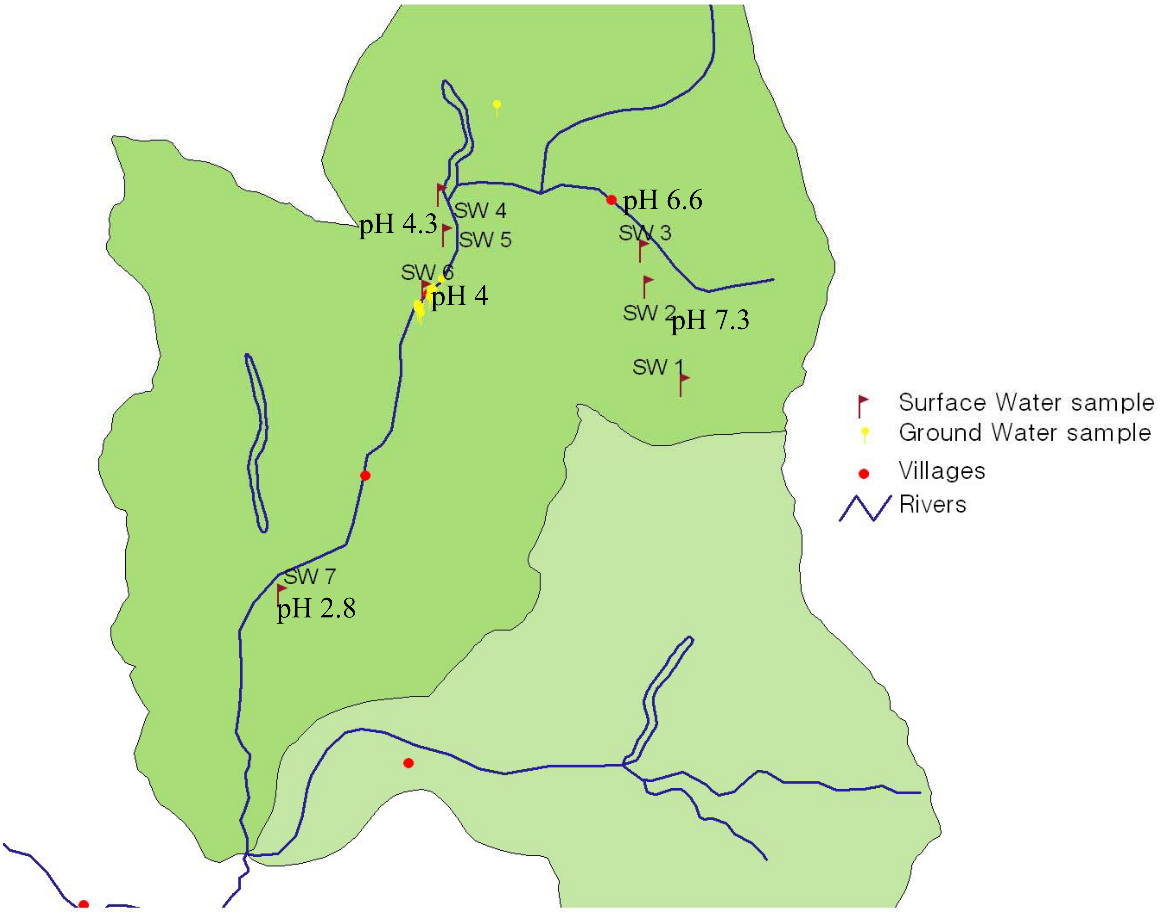

Figure 18. Location and pH values of surface water samples.
Source: López Córtes (2006)

The groundwater samples where taken from the area around Totoral and in the mine of Bolívar with the main objective of investigating whether the water at the two locations has the same origin, i.e. if the water use in the mine affects the hydrological conditions in Totoral. The main contamination of the groundwater in Totoral is found to be salt, with half of the wells having conductivity exceeding the limit for human consumption, and the hardness of the water which is on the limit for human consumption. The water extracted from the mine is acid, has a high conductivity and high levels of iron and sulphates. As explained, the enrichment of iron and sulphates is characteristics typical of water in contact with mineral structures and deposits.

The conclusion of the study is that the water in the mine comes from a confined aquifer with recharge far away and that the groundwater in Totoral comes from an open aquifer recharged by rainwater. Further López Cortés reports that because of the genesis, the flow and the physio- and hydro chemical properties, it can be concluded that the water in the mine has no relation with the groundwater in Totoral.

Table 6 is a synthesis of the results of Quino Lima (2006) and López Cortés (2006) studies. The studies use different norms for limits and the results are for the purpose of simplifying the comparison, here below compared to the limits set in the "Guidelines for Drinking-water Quality" by WHO (2006).

Table 6. Values of samples of constituents in ground and surface water. GW stands for groundwater and SW for surface water. No spec. means that there is no health-based guideline values proposed.

	pH	Conductivity (mS/cm)	TDS (mg/l)	Hardness (mg/l $CaCO_3$)	Iron (mg/l)	Arsenic (mg/l)	Zinc (mg/l)	Sulphates (mg/l)
WHO Limits	**6.5-9.5**	**No spec.**	**1 000**	**No spec.**	**2**	**0.01**	**3**	**500**
Lima, well	6.1-6.2	1.9-2.3	998-1170	632-681	0.16-0.17	0.0014	1.62-1.67	No value
Cortés, GW	7.3-7.9	0.2-1.7	328-1136	114-456	0-0.6	0-0.0018	0.05-0.36	33-375
Cortés, SW	2.8-7.3	0.2-2.5	629-1412	114-342	0-307	0.0001-0.013	0.06-0.314	35-1350

Source: Quino Lima (2006), López Cortés (2006), WHO (2006)

WHO (2006) acknowledges the importance of acceptability in appearance, taste and odour of drinking-water, explaining that aesthetically unacceptable water undermines the confidence of consumers and might lead to the use of less safe water sources. However, WHO (2006) has not established guideline values for constituents that have no direct link to adverse health impacts.

Though there is no health-based guideline value for hardness, the taste threshold for the calcium ion is recognised to be between 100-300 mg/l. Depending on pH and alkalinity of the water, 200 mg/l may cause scale deposits.

There is no guideline for iron in drinking-water proposed. Though the value 2 mg/l should not present a hazard to health, the taste and appearance usually will be affected below this level.

pH does not have a health-based guideline value since it usually has no direct impact on consumers, although it is one of the most important operational water quality parameters.

No health-based guideline has been proposed for sulphate. However, WHO (2002) recommends that health authorities should be notified if concentrations exceed 500 mg/l because of the sulphate's gastrointestinal effects. "It is generally considered that taste impairment is minimal at levels below 250 mg/l."[3]

No health–based guideline value is proposed for TDS, nevertheless, drinking-water is considered to be significantly unpleasant when TDS levels exceed 1000 mg/l.

In the classification of surface water in the department of Oruro, conducted by the consultancy company CACC, 2002, the water in the rivers Antequera, Urmiri and Pazña is analysed. It is concluded that the water in river Antequera is of class D, not suitable for any use with its source of contamination being the mining activity, Urmiri is of class B, partially suitable for irrigation and consumption after treatment with its source of contamination being human and finally Pazña of class D, not suitable for consumption but partially for irrigation. For further specification of the classification, see Appendix 1.

6.2 Effects of water contamination

Below is presented some known adverse effects on the health of humans and animals as well as plants, by constituents known to be of excessive amount in the water of the study area. Possible explanations to problems witnessed by livestock farmers, presented in chapter 2.6.3 "livestock", can be found here. Table 7 presents a summary of the effects.

Table 7. Description of the adverse effects of constituents present in the area of study
.

Constituent	Sulphates	Iron	Zinc	Hardness	Chlorines
Adverse effect	Gastrointestinal irritation	Toxic, damaging to heart and liver	Toxic to plants	Foul taste and scale deposits	Corrosive and damaging to plants

Source: WHO (2002)

Sulphates are not very toxic but have an unpleasant bitter taste, do not reduce the sensation of thirst and have a laxative effect. In excessive amounts sulphates have been observed to cause catharsis, dehydration and gastrointestinal irritation, WHO (2006).

Excessive ingestion of iron can be toxic and damage cellular components in the gastrointestinal tract. This can lead to high levels of iron in the blood with damages to most organs, particularly heart and liver, as effect.

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[3] WHO (2006), page 218.

Excessive amounts of zinc can be harmful and the free zinc ion is highly toxic to plants.

The hardness of the water is caused by the calcium and magnesium dissolved in the water. Several studies imply that there is a relation between hardness and cardiovascular diseases. The hardness also has an impact on the taste and the appearance of the water with scale deposits.

The main effect of a high level of chlorines is the corrosive effect it has on the pipe system leading the water to the consumer. The corrosivity in turn can lead to release of metals and to further elevation of the levels in the water. In plants the chlorines are absorbed by the roots and accumulated in the leaves when not evapotranspired. If levels exceed the tolerance of the plant, damage is done.

7 Future projects planned in the area

It has been planned by the prefecture of Oruro since 2002 to build a dam in river Urmiri, to be implemented sometime year 2008. The objectives are to give access to water for irrigation, to increment the area with agricultural production and to increase the production per ha but also to get an additional resource from fish in the dam. The usable volume is to be 1.8 Hm^3 (1.8 $*10^6$ m^3) and 181 families are to benefit from the project with an increase of the cultivatable area from 14.6 to 302.64 ha.

The water in river Urmiri is of good quality and several tests were made while the dam was designed. The thermal waters from the spring in Urmiri join the river further downstream and are therefore not collected in the dam. The levels of salts and sodium were found to be low to moderate and considered well enough for irrigation use, Montaño (2002).

This project will strongly improve the living conditions in the area. The village of Urmiri has been depopulated due to the lack of income sources, with landowners moving to larger villages or cities. The dam could change this and repopulate the area. An additional income could come from the extra milk and cheese produced, organized by a local merchant organisation, as has been the case in other areas with access to effective irrigation.

8 Analysis and conclusions

There are many conceivable ways of improving the hydrological and thereby life quality situation in the basins of Antequera and Urmiri. The one and overall important circumstance, always to be taken into account, always a hindrance, are the extremely limited economic resources.

8.1 Availability

The main problem with the water supply is the seasonal variation within the year as well as from year to year. Frequent draughts limit the agricultural production and there is currently no alternative than depending on the rain. The effect of El Niño sometimes destroys a year's complete harvest. Locally there is a lack of drinking water periodically. The village of Totoral experiences a difficult situation with several months of dry wells every year. Pazña does sometimes not have access to tap water due to the bad condition of the pipe system and lack of funding for reparation.

If more water was to be used for irrigation in the river valleys of Antequera and Urmiri, it could aggravate the situation of Lake Poopó. Already now not enough water reaches the lake but river Pazña contributes only with a 3 % of the inflow to the lake, Pillco & Bengtsson (2006).

Improvement of temporal variations in water supply can be done through storage such as dams. Another way is to improve the access to natural storages, aquifers, through drilling wells. There are also the possibility to render existing systems more effective, reduce leakage from pipes and irrigation canals, terrace plantations. In order for this to be attractive, the population and the farmers have to see a future profit from their investments of money, time and work. Today, people are leaving the area to seek optional income sources.

When trees are cut down in arid areas, the land, in many cases, dries out and becomes an inhospitable environment for new trees, especially in the case of overgrazing and erosion of top soil. There have been and are several small tree-planting projects in the region. Behind these efforts lies a commercial interest, but afforestation is also known to reduce pollution in streams and can be effective in managing dry land salinity, Zhang (2004). Afforestation also reduces soil erosion by retaining water for discharge during dry season, enhancing infiltration and evapotranspiration, Sun et al. (2006). Afforestation, in larger scales, could be of interest for the area, not only by the shelter and the restoration of biodiversity it provides, but also through carbon sequestration. Through the Clean Development Mechanism, an industrialized country under greenhouse gas reduction commitments, according to the Kyoto Protocol, could be interested to invest in the afforestation project.

The major concern to be considered regarding afforestation is the reduction in water yield. The reduction for an area with a PET of 1 300 mm/year and precipitation of 450 mm/year (in Pazña the corresponding values are 1 671 mm/year and 451 mm/year, A.L.T. (1996)) could be as much as 30 mm/year or up to 60 % of the water yield, Sun et al. (2006), but this is in a full grass to forest scenario in China. The water yield reduction is affected by conditions such as soil depth and climate. A study of the conditions of the area should be conducted. Another concern is the education and effort for local participation that needs to be initialized, in order for a project of this character to survive, seedlings have to be watered and well protected.

8.2 Demand

Water demand is an adaptable factor, people change their lifestyle and water demand according to the resources available. There is not a lack of water unless a demand for larger quantities has already been built up. However, there is a direct relationship between the abundance of water, population density, and quality of life.

Presently, the population in the study area often have higher demands of good quality water than what is accessible. Many of these demands could be fulfilled if water would be treated or if access would be made to optional sources or stored water. In some parts of the study area, such as Pazña, the limit is caused by contamination rendering the accessible water unusable for most purposes. In other parts, in particular Totoral, the main concern is variations of water supply over time.

Table 8 shows the quantifications, made in this paper, of the yearly volumes of surface water supply and water consumption.

Table 8. Yearly volumes (m^3) of river flow and water consumption in the area of study

Mean annual river flow	Minimum annual river flow	Flow consumed in households	Flow consumed by livestock	Flow extracted from the mine Bolívar
15 610 000	236 000	39 200	35 900	3 311 000

The numbers in Table 8 can not be compared without some further considerations. The flow computed by Pillco Zolá (2002) using the rainfall-runoff model Qbox does not account for consumption of water upstream. Therefore, this river flow values could be compared to the consumption. However, the flow consumed in households and by livestock is also to some degree groundwater that should not be included. Irrigation has not been considered since it is used only to a small degree in the area but should increase dramatically if a dam and irrigation canals would be constructed.

The water extracted in the mine Bolívar is groundwater which, to some extent gets evaporated but to the largest part is discharged in the river. This volume should not be taken into account while comparing surface flow and consumption. However, it is an interesting value, 14 times higher than the minimum annual river flow, especially considering that the mine Bolívar is just one of three major mines in the river valley of Antequera. This clearly shows to what point the mining activity must affect the hydrological situation in the area.

As shown in chapter 6.1 "Previous studies of surface and groundwater" the main stream in the river valley Antequera is contaminated from Bolívar and downstream. From a simple comparison between catchments areas river Urmiri should have a mean annual flow of 5 250 000 m^3 (15 610 000*(76/(76+150))) at the confluence with river Pazña. The analogous minimum annual river flow would be 79 362 m^3. This water is of good quality but not even enough for irrigation, human and livestock consumption in dry years, especially when considering the variation over time. Water can also be taken from small streams but they are dry most part of the year.

Considering variations over time, the good quality water is, at present, barely enough in years with mean values of precipitation. In dry years, there are not enough water supplies. This limits the consumption and thereby the standard of living, the population and the economic development of the area. Both for household uses and agriculture, an improvement of life quality and productivity must lead to larger demands of water.

8.3 Quality

The water is of good quality in most streams. When the water passes old piles of mining residue and sludge, it gets contaminated. The water in river Antequera is heavily contaminated downstream from Bolívar with a pH of 3 to 6 in the river water. This water is not to be used for anything without pre treatment but at times there is no option since no other water is available.

The contamination severely limits the possible uses of the water resources. High levels of zinc, chlorines and salts have negative effects on agriculture and can lead to the reduction of cultivable area. High values of sulphates and iron make livestock and people sick.

The contamination originates from the mining industry and the inhabitants want the mining companies to take their responsibility. The present mining industry is not entirely responsible for the contamination. Rather, it has accumulated during long time and former companies have left residue still influencing the situation. The situation is further complicated through the illegal mining activity. Many people have no option but to exploit mines illegally, leading to high personal risks and to absolute lack of environmental control. The international mining companies present in the area are, in many cases, held accountable for the problems, for want of someone responsible. These companies are the only ones controlling their discharge but they have also complete control and power over their district and employees.

The main objective should not be to further control international mining companies though a future goal should be to restrict the limits for discharge levels. The first measures to be taken should be to support, help and control the small mining industry, make sure there is no mine worked illegally and help small mines take care of and treat the extracted water, sludge and residue. Development of agriculture and stock-farming, a way to decrease the dependence of mining, would further improve the situation for the miners.

There exist ways of treating the already contaminated soil. Heavy metal contaminants can not be degraded but have to be either extracted from the soil or stabilised. Extraction techniques are expensive and not applicable in this case. Stabilising techniques change the physical form of heavy metals, reducing their mobility, based on the use of amendments and/or plants, Pérez-de-Mora et al. (2006). In Bolívar, Sinchi Wayra has started a project where they cover contaminated soil with lime, followed by a top-soil cover where trees and bushes are planted. Vegetation cover can prevent spreading through wind and reduce water pollution by interception of a considerable part of the precipitation. It increases pH in soil and decreases heavy metal solubility, Pérez-de-Mora et al. (2006).

The reclamation of the contaminated soil is possible but, 392 000 m^2 is a large area to recover and most probably considered too costly. It is also ineffective unless the continuous AMD does not stop.

A low cost alternative of removing heavy metals from water contamination from AMD are the construction of wetlands. Wetlands have low investment and operational costs and absorb and bind heavy metals, which slowly concentrate in sedimentary deposits to become part of the geological system, Sheoran & Sheoran (2006). A wetland can be difficult to construct in the area but river banks can be used for Totora growth. There have been trials in a nearby village, Poopó, to grow Totora for water treatment. The plant can grow in the hostile environment and is also appreciated for forage by livestock, see Figure 19. Investigations about the suitability of using Totora should be conducted. If heavy metals are absorbed by and accumulated in the plant, it might not be suitable for forage.

Figure 19. Cow grazing Totora in the river Antequera. The mine in Totoral is visible in the background, pH in water 5.1.

8.4 Conclusions

The total water resources in the study area would not have to be insufficient if the quality and the distribution over time and space could be improved and controlled.

First and most important of all, the hydrological situation in the area has to improve in order for it to survive. The severest problems are all connected to the water supply, both locally and regionally. If water quality and availability in the basins does not improve, leading to additional income sources, the area will depopulate, become entirely dependent on the mining industry and completely die out if or when the mineral deposits dry out. Regionally, it is important that Lake Poopó remains a lake. Otherwise, most likely, the area will turn into desert.

Secondly, the continuous contamination from the mining industry has to slow down and eventually stop. This is a long and complicated process but essential for agriculture and stock-farming to prosper. This is also fundamental for the survival of the ecosystem in Lake Poopó, being a terminal lake with accumulation of the contamination.

There are a number of solutions, both acute and long-term contributions to the improvement of the situation. The main impediment is the lack of economic resources, both because of the limited possibilities of implementation of and investment in projects, but also due to the preoccupation for the daily bread and lack of planning for the future. Another hindrance, leading to short-term and sometimes thoughtless or insufficient planning, is the low level of education hindering public participation and poor understanding of consequences.

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Appendix 1 - Water quality

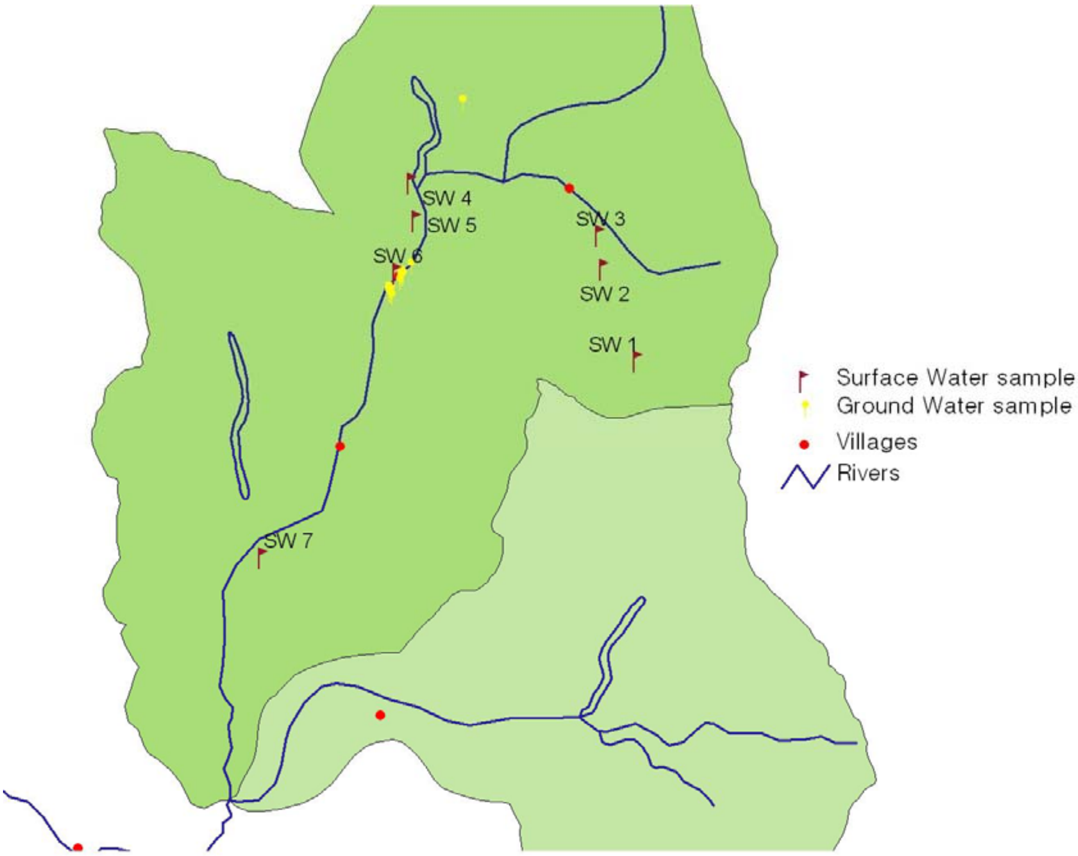
Place	pH	Conductivity (mS/cm)	TDS (mg/l)	Hardness (mg/l CaCO3)	Iron (µg/l)	Arsenic (µg/l)	Zinc (µg/l)	Sulphates (mg/l)
A	6,0 to 8,5		1000		300	50	200	300
B	6,0 to 9,0		1000		300	50	200	400
C	6,0 to 9,0		1500		1000	50	5000	400
D	6,0 to 9,0		1500		1000	100	5000	400
Lim agriculture*	min 5,5	1,5	500-1500	no info	5000	100-2000	5000	no info
Lim animals*	min 6,5	1,5	5000	no info	1000	200	5000	no info
Lim humans*	min 6,5	0,1-1,00	500-3500	450	300	50	5000	350
GW 1**	7,9	1,72	932	456,71	80	1,05	90	375
GW 2**	7,85	0,41	912	228,35	120	1,77	90	49
GW 3**	7,45	0,75	924	342,53	640	1,59	190	43
GW 4**	7,4	1,2	612	456,71	80	0,17	70	250
GW 5**	7,4	0,54	660	228,35	0,1	0,18	280	250
GW 6**	7,35	0,88	600	228,35	0,1	1,19	360	225
GW 7**	7,35	0,91	1036	114,18	0,1	1,14	90	72
GW 8**	7,32	0,4	1044	114,18	20	0,05	50	64
GW 9**	7,7	1,69	1068	342,53	0,1	0,0001	90	375
GW 10**	7,8	1,7	1136	456,71	10	0,0001	250	350
GW 11**	7,7	1,18	376	342,53	0,1	0,0001	220	225
GW 12**	7,5	0,19	328	114,35	60	0,0001	100	33
Pazña rainy	6,2	2,3	1170	681	173,2	1,4	1674	
Pazña dry	6,1	1,9	998	632,4	166	1,5	1615	
SW 1**	7,35	0,22	952	114,35	0,1	0,64	70	35
SW 2**	7,3	0,33	964	342,53	50	0,13	60	200
SW 3**	6,6	0,33	684	342,53	20	0,63	180	63
SW 4**	4,25	2,42	863	228,35	307 300	13,11	314	1250
SW 5**	4,3	2,43	848	114,35	197 050	10,43	228	1225
SW 6**	4	2,46	629	114,35	24 100	4,61	90	1350
SW 7**	2,8	2,38	1412	228,35	2 360	1,16	119	1125
M 1**	3,7	2,48	1152	342,53	710 570	11,07	205,1	1275
M 2**	5,75	0,45	968	228,35	56 270	2,83	22,71	325
M 3**	3,1	1,62	1072	228,35	216 350	5,29	102,3	800
M 4**	6,15	0,28	288	342,53	7 720	0,61	16,74	175

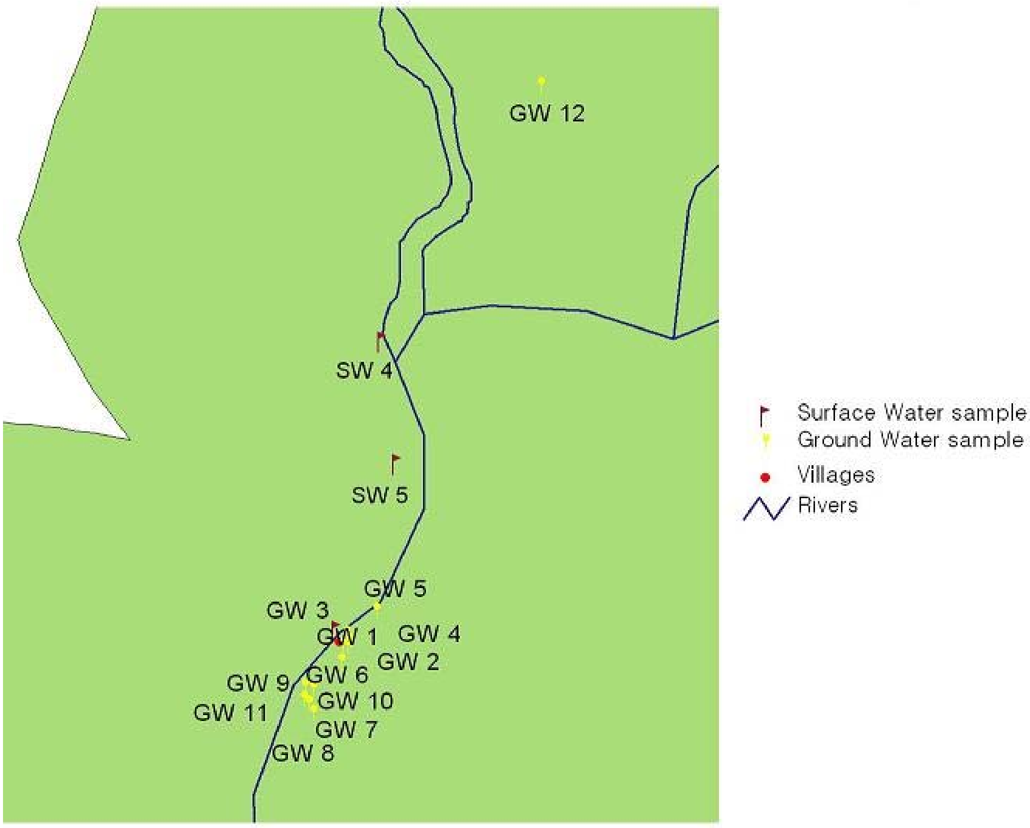
Source: López Cortés, (2006) and Quino Lima, (2006)

***** Quino Lima, (2006)

** Units are not specified, López Córtes (2006)

Location of surface and groundwater samples, López Cortés (2006)





Law 1333 - Normativa Boliviana

General water body classification; in relation to its aptitude for use, follows the subsequent orientation:

CLASS "A" natural water of maximum quality, fit as potable water for human consumption without previous treatment, or with a simple bacteriological disinfection in case of need, verified in laboratory.

CLASS "B" Water for general use, which for human consumption requires physical treatment and bacteriological disinfection.

CLASS "C" Water for general use, which for human consumption requires complete physical-chemical treatment and bacteriological disinfection.

CLASS "D" Water of minimum quality, which for human consumption, in case of extreme public need, requires an initial pre sedimentation process, since it might contain an elevated turbidity due to the suspended solids, followed by a complete physical-chemical treatment and special bacteriological disinfection against eggs and intestinal parasites.

		PERMISSIBLE LIMITS			
PARAMETER	**UNIT**	**CLASS A**	**CLASS B**	**CLASS C**	**CLASS D**
pH		6,0 a 8,5	6,0 a 9,0	6,0 a 9,0	6,0 a 9,0
Temperature	oC	+/-3oC de C receptor	+/-3oC de C receptor	+/-3oC de C receptor	+/-3oC de C receptor
Turbidity	NTU	< 10	< 50	< 100 < 2000	< 200 < 10000
Colour mg Pt/l	mg/l	< 10	< 50	<100	< 200
DBOs	mg/l	< 2	< 5	< 20	< 30
DQO	mg/l	< 5	< 10	< 40	< 80
Total Dissolved Solids	mg/l	1000	1000	1500	1500
Oils and Grease	mg/l	Absent	Absent	0,3	1
Nitrates	mg/l	20,0 c. NO3	30,0 c. NO3	50,0 c. NO3	50,0 c. NO3
Total nitrogen	mg/l	5 c. N	12 c. N	12 c. N	12 c. N
Total Phosphate	mg/l	0,4 c	0,5 c	1 c	1 c
Chlorines	mg/l	250c Cl	300c Cl	400c Cl	500c Cl
Sulphates	mg/l	300 c.SO4	400 c. SO4	400 c. SO4	400 c. SO4
Boro	mg/l	1,0 c. B	1,0 c. B	1,0 c. B	1,0 c. B

Sodium	mg/l	200	200	200	200
Calcium	mg/l	200	300	300	400
Manganese	mg/l	100 c. Mg.	100 c. Mg.	150 c. Mg.	150 c. Mg.
Arsenic	mg/l	0,05 c. As.	0,05 c. As.	0,05 c. As.	0,05 c. As.
Mercury	mg/l	0,001 Hg.	0,001 Hg.	0,001 Hg.	0,001 Hg.
Lead	mg/l	0,05 c. Pb	0,05 c. Pb	0,05 c. Pb	0,1 c. Pb
Cadmium	mg/l	0,005	0,005	0,005	0,005
Total Chromium	mg/l		0,6 c. Cr + 3	0,6 c. Cr + 3	1,1 c. Cr + 3
Hexavalent Chromium	mg/l	0,05 c. Cr. Total	0,05 c. Cr. + 6	0,05 c. Cr. + 6	0,05 c. Cr. + 6
Manganese	mg/l	0,5 c.Mn	1,0 c.Mn	1,0 c.Mn	1,0 c.Mn
Zinc	mg/l	0,2 c. Zn	0,2 c. Zn	5,0 c. Zn	5,0 c. Zn
Copper	mg/l	0,05 c. Cu	1,0 c. Cu	1,0 c. Cu	1,0 c. Cu
Selenium	mg/l	0,01 c. Se	0,01 c. Se	0,01 c. Se	0,05c. Se
Antimony	mg/l	0,01 c. Sb	0,01 c. Sb	0,01 c. Sb	0,01 c. Sb
Nickel	mg/l	0,05 c, Ni	0,05 c. Ni	0,5 c. Ni	0,5 c. Ni
Thermotolerant Coliforms	N/100 ml	< 50 and <5 in 80% of the samples	<1000 and <200 in 80% of the samples	<5000 and <1000 in 80% of the samples	<50000 and <5000 in 80% of the samples
Nitrates	mg/l	< 1,0 c.N	< 1,0 c.N	< 1,0 c.N	< 1,0 c.N
Cyanide	mg/l	0,002	0,1	0,2	0,2
Dissolved Oxygen		>80% sat	>70% sat	>60% sat	>50% sat

FAO – for use in agriculture and irrigation

PARAMETER	UNIT	PERMISSIBLE LIMITS
pH		6,5-8,4

		N LM S
Salinity (Electric Conductivity)	dS/m	<0,7 0,7-3,0 >3.0
Dissolved Solids	mg/l	0 - 2000
Nitrates	mg/l	0 -10
Amoniacal Nitrogen	mg/l	0 - 5
Total Phosphore	mg/l	0 - 2
Chlorines	me/l	0 - 30
Boron	mg/l	0 -2
Sodium	me/l	0 - 40
Calcium	me/l	0 - 20
Manganese	me/l	0 -5
Arsenic	mg/l	0.10
Lead	mg/l	5.00
Cadmium	mg/l	0.01
Total Chromium	mg/l	0.1
Hexavalent Chromium	mg/l	0.10
Iron	mg/l	5.00
Manganese	mg/l	0.20
Zinc	mg/l	2.00
Copper	mg/l	0.20
Nickel	mg/l	0.2
		N LM S
RAS		<3 3-9 >9
Thermotolerant Coliformes	No./ml	< 10000

N None

LM Light Moderate

S Severe

Appendix 2 - Workshops and form

Here follows a list of prioritized projects from the workshop about agriculture. These are the matters that the agriculturalists first want help to develop.

1. Irrigation
2. Commercialization so as to sell at higher price
3. Technical assistance
4. Training and improvement of capacity
5. Organisation of farmers
6. Micro enterprises

Here follows a list of prioritized projects from the workshop about livestock farming.

1. Access to clean water
2. Infrastructure such as roads, shelters and stables
3. Forestation
4. Forage industry
5. Technical assistance
6. Handicraft (from wool)

Here follows a list of prioritized projects from the workshop about fishing.

1. Prohibitions and control to stop fishing at certain periods and by non-fishermen
2. Dredging to make more fresh, uncontaminated water reach the lake
3. Infrastructure such as roads and shelters
4. Water contamination control
5. Repopulation of fish
6. Equipment

Cuestionario para uso de agua

Número de habitantes y familias:...

Tiene agua potable? Si No

Precio de agua potable:...

Fuente de agua (tipo y ubicación):...

....

Pre-tratamiento de agua potable:..

....

Caudal consumida:……………………………………………………………...........................

Cobertura de agua en %:…………………………………………………………….................

Tratamiento de aguas servidas:...

....

Problemas relacionados con el uso de agua:

- Salinidad
- Savor
- Color
- Otra contaminación
- Falta de agua
- Variaciones imprevisibles en oferta y demanda
- Precio
- Otros

Consecuencias de los problemas de agua:………………………………………………...........

....

Tratamiento de residuos solidos:………………………………………………………………...

....

Cambios que le gustaría realizar:………………………………………………………..............

....

Problema para realización:……………………………………………………………………