Rural Drinking Water in Illapel, Chile
—Investigation of Water Supply and Metal Content

Niklas Ekberg
Stina Åstrand

Arbetsgruppen för Tropisk Ekologi
Committee of Tropical Ecology
Uppsala University, Sweden

Minor Field Study 121
ISSN 1653-5634

June 2006 Uppsala

UPPSALA UNIVERSITET

Rural Drinking Water in Illapel, Chile
—Investigation of Water Supply and Metal Content

Niklas Ekberg
Stina Åstrand

Project work in aquatic and environmental engineering
Department of Earth Sciences, Air & Water Science
Uppsala University, June 2006
Supervisors: Roger Herbert, Wladimir Givovich Diaz

Key Words: Water quality, heavy metals, drinking water guidelines, Chile

Abstract

The Illapel area in Chile is rich in minerals and has been exploited by small scale miners to a large extent. There are many enrichment plants and mine waste deposits close to the Illapel River. The climate is dry and people in the rural areas do not have many choices in where they acquire their water. The majority does not have access to treated drinking water and no previous investigations of the water quality have been performed in these communities. The objectives of this Minor Field Study are to investigate the water sources of the rural population, to analyse water for heavy metal concentrations, and to examine if the mining industry has affected drinking water quality in the studied areas. A field investigation of the water supply and quality was conducted. Electrical conductivity and pH were measured and water samples were collected that were analysed with respect to metal and sulfur content using ICP-AES. The analyses of drinking water did not show much variation between locations. The mean pH value was 7.48 and the mean electrical conductivity was 688 µS/cm. The metal content was compared to various drinking water guidelines. At 20 out of 46 locations, one or more of the guideline values were exceeded for aluminium, arsenic, calcium, copper, iron, magnesium or lead but only two exceeded limits for “unsuitable” drinking water. No relation to mining has been shown, which could be explained by the custom to locate wells above enrichment plants and mine waste deposits.

Resumen

La comuna Illapel en Chile es un sector rico de minerales y ha sido explotado por la pequeña minería desde hace mucho tiempo. Hay abundantes plantas mineras y relaves ubicados cerca del Río Illapel. El clima es árido y las personas que viven en las zonas rurales no tienen muchas alternativas para conseguir agua. La mayoría de ellos no tienen acceso a agua potable y no existe investigaciones previos acerca de de la calidad del agua en estas localidades. Los objetivos de este proyecto fueron investigar las fuentes de agua de poblados rurales, analizar las concentraciones de metales pesados en el agua y examinar si la actividad minera ha afectado la calidad del agua que la gente toma en las zonas estudiadas. Una investigación del campo sobre el abastecimiento y calidad del agua fue realizada. Conductividad eléctrica y pH fueron medidos y muestras de agua fueron tomados y analizados con ICP-AES por el contenido de metales y azufre. Los análisis del agua para tomar no mostraban mucha diferencia entre los sitios. El promedio del pH es de 7.48 y el de conductividad eléctrica es de 688 µS/cm. El contenido de metales fue comparado con los estándares de calidad del agua potable. En 20 de 46 sitios uno o más de los límites para aluminio, arsénico, calcio, cobre, hierro, magnesio o plomo fueron sobrepasados pero solo dos muestras sobrepasaron límites de “no apta para consumo”. De acuerdo a los resultados obtenidos no existiría una relación entre la actividad minería y la calidad del agua. Quízas una explicación puede ser la costumbre de localizar los pozos por encima de las faenas y relaves.

Table of Contents

1. Introduction

According to UNICEF (2006) in the year 2002, 95 % of Chile's population was using improved drinking water sources. That accounted for 100 % of the urban and 59 % of the rural population. The proportion of the rural population that did not have access to treated drinking water (41%), was higher than in neighbouring countries such as Bolivia (32%) and Peru (34%). There are rural areas where the water quality has never been investigated. Regulations and control programs for water sanitation do not include these areas so there is no guarantee for the health of the people.

The Illapel municipality in the north of Chile has been pointed out as an area where there is a lack of water investigations. The zone is rich in minerals, and gold and copper mines are abundant. The Illapel River valley has been exploited by small scale miners to a very large extent and many of the enrichment plants and mine waste deposits are located close to the river (CONAMA, 2005). Wastewater from these plants and deposits is discharged to the river. Figure 1.1 shows the Illapel municipality with the Illapel River and its tributaries. Communities and the distribution of mines and enrichment plants can also be seen. People in the rural areas are poor and in many cases do not own the land they live on. Since the climate is very dry and droughts occur frequently the people do not have many choices in where they acquire their water.

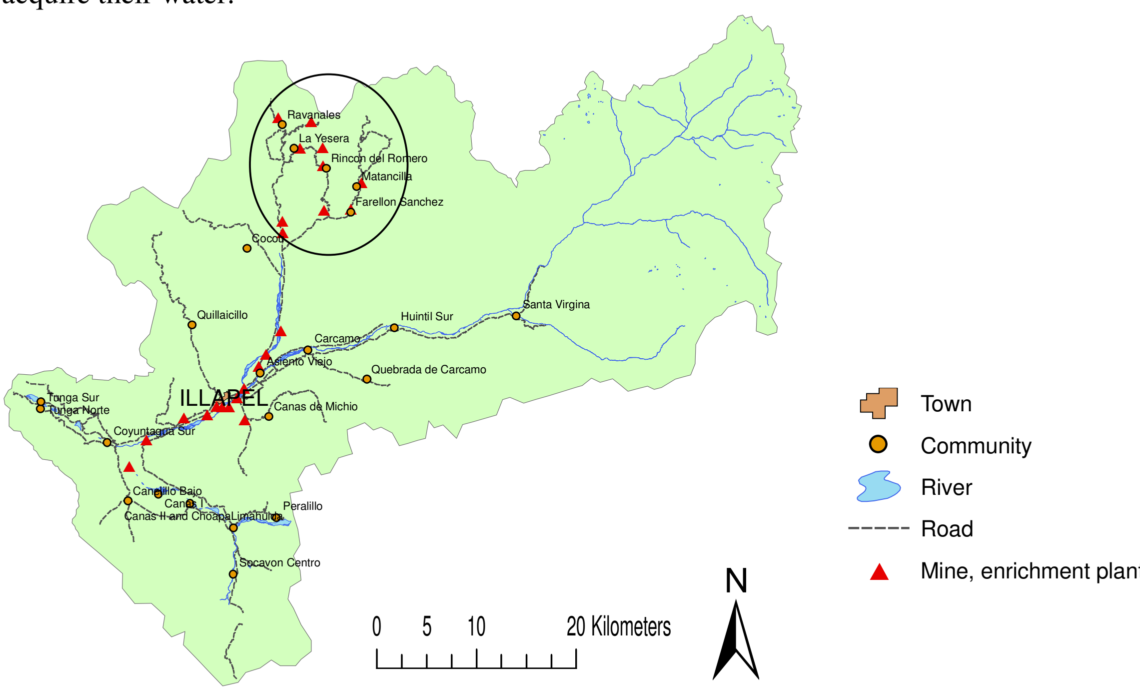

Figure 1.1. Illapel municipality, distribution of mines and mine waste deposits. Plan de Horno marked with a circle.

The importance of further studies of the Illapel River system has been pointed out in several reports. In a large study of the environmental impacts of small scale mining (Sánchez & Enríquez, 1996), funded by the International Bank for Reconstruction and Development, the Illapel river valley is indicated as an area where detailed studies need to be conducted to assess the environmental impact of the many small scale mines and the problems that are associated with them. This was confirmed by Braun (2000) in a report on global water management in the province and in an environmental survey of the water resources in the Choapa River made by SAG (2005).

There are many factors that may affect the water quality, for example bacteria, pesticides and nutrients from manure. However, because of the intense mining activity in the Illapel area, it was suspected that the water might be contaminated with heavy metals and this is therefore the focus of this study. The initiative for the study was taken by the applicants in cooperation with the Non Governmental Organisation, Aqua – Water for Humanity. Based on the scarce background information that was available, objectives and goals were drawn up and a field study was planned.

1.1 Objective and Goals

The objective of this Minor Field Study is to investigate drinking water in the rural areas of the Illapel municipality, with emphasis on water supply, heavy metal contamination and treatment techniques. Since there is little information on the water supply in this area a general overview of the situation has to be established in terms of where people acquire their water. The objectives of the field study are investigating the water sources of the rural population, analysing water for heavy metal concentrations, and examining if the mining industry has affected drinking water quality in the studied areas. The analyses of drinking water will be compared to drinking water guidelines. Based on the results of the investigation, suggestions for possible improvement of the water treatment will be made if necessary. Additionally WHO's, EU's, the Chilean and the Swedish drinking water guidelines for metals will be compared with each other.

2. Background

2.1 Heavy Metals

Because of the large amount of mining activity in the Illapel municipality, heavy metals were suspected to be found in the investigated drinking water. Metals with a density higher than $5g / cm^3$ are called heavy metals. They are elements and non-degradable and have always existed as natural components in the earth's crust. Many are essential for plants, animals and humans in small amounts, but at the same time many of them are harmful if they are ingested in too large amounts. One example is that high amounts of copper in drinking water are suspected to cause diarrhoea to small children (Occumed, 2006). Cadmium is easily taken up by plants, for example wheat, and may be transferred to the human body where it accumulates in the kidneys and may cause damage. Lead may cause injuries to the nervous system and long time exposure can cause anaemia. Iron, which is essential to almost all organisms, is toxic in excessive amounts because free radicals are formed in the body (Wikipedia, 2006). Some of the metals are even toxic in small doses and a few also bioaccumulate in living tissues (SEPA, 2006). These characteristics make it important to have proper knowledge of heavy metals and their behaviour in nature.

Metals are released to the environment from minerals and bedrock by chemical and physical weathering. Metals are stable elements and may occur in different forms, either as free ions or bound in organic or inorganic complexes. When occurring in water the pH-value of the water is the primary parameter which determines the chemical form of the metal, which might be as free ions, bound to soil particles or bound in complexes with for example CO_3^{2-}, OH^- or PO_4^{3-}. Metals are more soluble at low pH which means that a larger amount of the heavy metals are free ions, not bound to other compounds. Under normal or more neutreal pH, the metals are usually bound in some form and not that toxic as when occurring as free ions. Aluminium, which is the most common metal in the earths crust, is very reactive and usually appears bound to other elements or compounds. However when pH is below 5.5 the solubility of aluminium complexes increases drastically and more aluminium appear as free ions in the water. The mobility of cadmium, lead, copper, cobalt and manganese is also higher at lower pH. Arsenic, which is not a metal, but a semi metal, is a well-known poison and may cause serious effects. It is carcinogenic and chronic exposure may cause other health effects such as diabetes, liver injuries or tumours in skin, lung or kidney (Institute of Internal Medicine, 2006). Arsenic is more soluble at higher pH (SGU, 2006). The toxicity and bioavailability of metals are closely related to the chemical form in which they appear in. Often is the free metal ion the most toxic (Stenbäck & Östlund, 1999).

As described by Tarbuck & Lutgens, (1999), metals are generally very mobile under acidic conditions. Other factors that influence the metal form are temperature, redox potential, concentration of soluble oxygen and content of particles, humic substances and negative ions in the water (Olsberg, 2004). Temperature is a factor because the production and decomposition of biological material, is increased when temperature is high. This leads to more organic molecules and compounds that the metal ions may bind to and form complexes with and thus remove the metals from the more toxic ion form. Temperature also influences the concentration of dissolved oxygen in the water. The redox potential decides if the conditions in the water are reducing or oxidising. Under reduced conditions metal ions easily form complexes with for example sulphide ions. These complexes are often difficult to dissolve and tend to precipitate. Reducing conditions therefore tend to make metals less mobile and less bioavailabe.

2.2 Weathering

Physical and chemical weathering helps release the metals to the environment and thereby also in Illapel. Physical weathering occurs through different forms of mechanical influence, for example thermal expansion or freeze-thaw action. Physical weathering appears more as a fragmentation to smaller particles whereas chemical weathering implies a more or less complete dissolution where the composition of the mineral or bedrock is altered. Chemical weathering (dissolution, oxidation and hydrolysis) can also be described as when bedrock or minerals are broken down to smaller components and converted to new minerals or released to the environment (Tarbuck & Lutgens, 1999). Water is an important agent of dissolution, oxidation and hydrolysis. Most minerals are not soluble in pure water, but with the presence of a small amount of acid, the corrosive force of water increases.

A lowering of the pH means more free hydrogen ions in the water. These ions compete for binding sites with the metal ions. This means that more hydrogen ions are bound to particles, complexes and molecules when pH in the water is low. At the same time more of the bound metal ions are released because the binding places are limited, as they are out-competed by the hydrogen ions.

A lowering of the pH implies a higher concentration of free metal ions in the water. The opposite is also true; a higher pH results in an increased metal adsorption to mineral surfaces that lessen the amount of free metal ions in the water.

The pH-value of natural waters will be determined from the buffer capacity of the minerals in soil and bedrock and the alkalinity of the water. Alkalinity is a measure of a watercourse’s ability to neutralize addition of hydrogen ions without a lowering of pH. Minerals that have a buffering effect are called buffering minerals. Examples of these are the carbonate minerals calcite and dolomite and aluminosilicate minerals such as chlorite and olivine (Fröberg & Höglund, 2004). Calcite ($CaCO_3$) has an especially high weathering rate (Table 2.1) and will thus have a strong influence on pH buffering if it is present. The dissolution reaction of calcite (reaction 1) is as follows:

$$CaCO_3(s) + 2H^+ \leftrightarrow Ca^{2+} + CO_2(g) + H_2O \qquad (1)$$

The reaction uses hydrogen ions and acidity is consumed. Another buffering reaction is when the carbonate mineral dolomite ($MgCa(CO_3)_2$) is dissolved (reaction 2), releasing carbon dioxide:

$$MgCa(CO_3)_2(s) + 4H^+ \leftrightarrow Mg^{2+} + Ca^{2+} + 2CO_2(g) + 2H_2O \qquad (2)$$

This reaction also consumes acidity.

Oxidation, which is a part of chemical weathering, occurs when an element loses electrons during a reaction. One example is that iron objects rust when coming into contact with water and air, the same thing may happen to iron-rich minerals. The iron was oxidised because it lost electrons to oxygen. It is a slow process in dry climates, but the rate increases in more humid climates. Oxidation is an important process when decomposing iron rich minerals such as olivine, pyroxene and hornblende. Other important oxidation processes are when sulphide minerals decompose. Hydrolysis, which is the third part in chemical weathering, is more or less the reaction of any substance with water. Silicates, which are the most common mineral group, are primarily decomposed by hydrolysis. Minerals have different weathering rates (Table 2.1), depending on their composition. Ca-plagioclase feldspar is easily degraded by chemical weathering whereas quartz and muscovite are not easily degraded (Langmuir, 1997). The composition of the water, the composition of the minerals, and how fast the weathering of the minerals occurs will determine the final solution pH value and therefore the form with which the metal will occur.

Table 2.1. Examples of weathering rates for different minerals. Calcite and dolomite with high weathering rates and quartz with low. Log dissolution rates and corresponding theoretical mean lifetimes of a 1-mm- diameter cube of some silicate and carbonate minerals at pH = 5 and 25°C. n.a. = data not available (Drever & Clow, 1995; Langmuir, 1997).

Mineral	-log rate (mol/m^2s)	Lifetime (y)
Calcite	5.1[a]	$0.43*10^0$
Dolomite	6.32[a]	n.a.
Diopside	10.15	$6.8*10^3$
Muscovite	13.07	$2.6*10^6$
Kaolinite	13.28	$6.0*10^6$
Quartz	13.39	$2.4*10^7$

Sulphide minerals are major constituents in many metallic ores and pyrite (FeS_2) is the most common and widespread sulphide mineral (Tarbuck & Lutgens, 1999). When pyrite is oxidised due to chemical weathering, acid is generated in different reactions.

$$FeS_2(s) + \frac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{\ 2-} + 2H^+ \qquad (3)$$

The ferrous iron released may then be oxidised to ferric iron:

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O \qquad (4)$$

At low pH (less than 4), the ferric iron reacts with pyrite:

$$FeS_2(s) + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{\ 2-} + 16H^+ \qquad (5)$$

When pH is high the ferric iron forms ferric hydroxide which precipitates:

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3(s) + 3H^+ \qquad (6)$$

Reaction (3), (5) and (6) generate acid which may then, if not neutralized, dissolve other minerals and metal ores and release the constituents of the minerals and ores, such as arsenic and heavy metals, to the surrounding environment (Tarbuck & Lutgens, 1999).

Reactions (7) - (9) are examples of oxidation reactions for the sulphide minerals arsenopyrite, chalcopyrite and galena, respectively:

$$FeAsS(s) + 3\frac{1}{4}O_2 + 1\frac{1}{2}H_2O \rightarrow Fe^{2+} + HAsO_4^{\ 2-} + SO_4^{2-} + 2H^+ \qquad (7)$$

$$CuFeS_2(s) + 16Fe^{3+} + 8H_2O \rightarrow Cu^{2+} + 17Fe^{2+} + 2SO_4^{\ 2-} + 16H^+ \qquad (8)$$

$$PbS(s) + 2O_2 \rightarrow Pb^{2+} + SO_4^{\ 2-} \qquad (9)$$

Reaction (9) does not produce acid (Höglund & Herbert, 2004), but dissolve the sulphide mineral and release the metal.

3. Study Area

3.1 Illapel

The Illapel municipality is located in the north of Chile and is one of four municipalities in the province of Choapa in the fourth region, Coquimbo (Figure 3.1). The other municipalities are Los Vilos, Canela and Salamanca. The municipality has an area of 2 697 km^2 and a population of 31 607. The city of Illapel is situated on the bank of the Illapel river and has about 22 000 inhabitants. Out of the population, 30 % lives in rural areas, and there are about 50 smaller communities. A comparative summary of the population density and the proportion between urban and rural population is shown in Table 3.1 (Braun, 2000). Agriculture and commerce are important income sources in the urban zone, whereas the main occupation in the rural areas is goat-breeding and small-scale mining.

Table 3.1. Demographic facts for Chile, the Coquimbo region and the Illapel municipality. (Braun, 2000).

	Surface area (10^3 km^2)	Population (10^3 habitants)	Population density (habitants/km^2)	Urban population (10^3 habitants/ percentage)	Rural population (10^3 habitants/ percentage)
Chile	757	15018	19.8	12 822 / 85%	2 195 / 15%
Coquimbo region	41	570	14.0	419 / 73%	151 / 27%
Choapa province	10	85	8.4	50 / 59%	35 / 41%
Illapel municipality	3	32	11.7	22 / 70%	10 / 30%

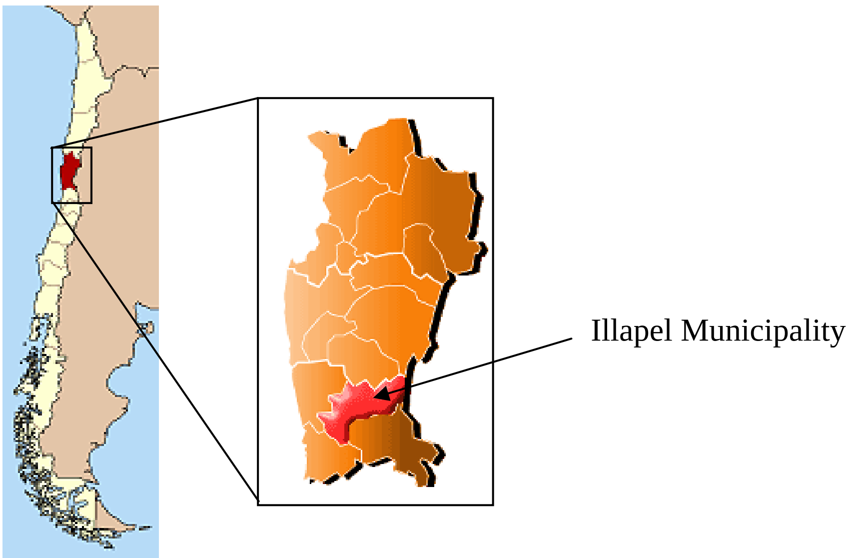

Figure 3.1. Chile, the Coquimbo region and the Illapel municipality.

The rural area called Plan de Horno (circled in Figure 1.1) has a history of excessive mining. Figure 1.1 shows the distribution of larger enrichment plants, mine waste deposits and villages in the area. It has also a large number of small-scale gold and copper mines where people work independently. In a study of land possession in the Illapel municipality, the occupation of people in the rural communities in Plan de Horno was investigated (Givovich & Krtizner, 2004). Figure 3.2 shows the distribution in the different communities and Figure 3.3 shows the total proportion of the occupations. In the area, 25% of the people are working full time or partly in the mining business and 72% are in occupations related to goat breeding.

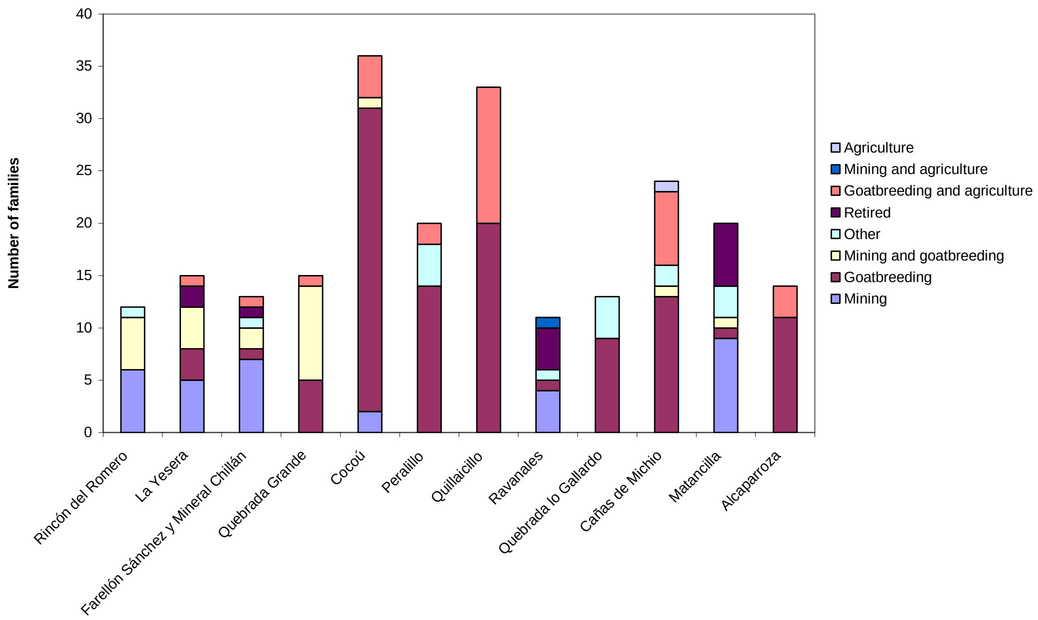

Figure 3.2. Distribution of occupations in different rural communities in the Illapel municipality. (Givovich & Krtizner, 2004).

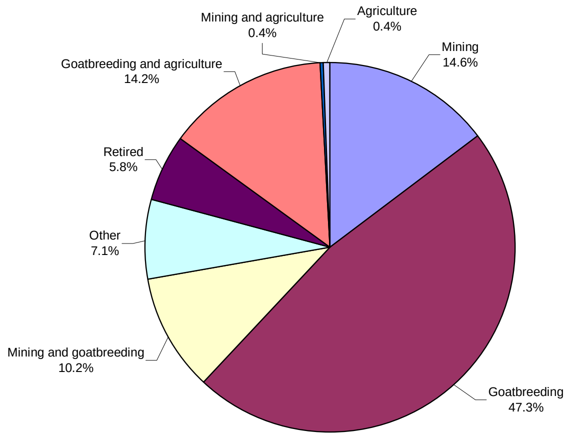

Figure 3.3. Proportions of different occupations for the people in the rural areas of the Illapel municipality. (Givovich & Krtizner, 2004).

3.2 Climate & Hydrology

The Coquimbo region stretches between the southern latitudes 29° 02’ and 32° 16’ and between the Pacific Ocean and the eastern longitude 69° 49’. It is part of the section of Chile traditionally called “Norte Chico” meaning the small north. According to SAG (2005) the Illapel area can be divided into two subclimate zones. At higher altitudes in the mountain range the climate is cold temperate with high precipitation, low temperatures and permanent snow. In the lower parts of the area the climate is semi-arid Mediterranean. This climate is characterised by high temperatures in the summer (November through April) and low temperatures and precipitation concentrated to the winter. The mean annual temperature is 13.9 °C, mean annual precipitation is 208 mm/year and annual potential evapotranspiration is 1350 mm/year (Givovich & Krtizner, 2004). The relative air humidity is low during the whole year and periods of drought occur frequently.

There are two larger rivers in the municipality, the Choapa and the Illapel River. The Illapel River originates in the Andes mountain range and has two larger branches, the Carén River and the Auco Stream. It joins the Choapa River 55 km from its origin (Givovich & Krtizner, 2004). The river system is shown in Figure 1.1. Water from the Illapel River is used for irrigation of fruit and vegetable cultivations and exploited in the mining industry. The peak flow in the Illapel River occurs in November and December as a product of melting snow higher up in the mountain range. Low flow is common in April, May and June but normally the river contains water at all times of the year except during extreme drought, so it is a perennial stream. The Auco Stream is an intermittent stream. It has a defined channel but flows only during wet periods initiated by rainfall or snowmelt. During dry periods, in summer, the bed seepage and evapotranspiration exceed the available water supply and it appears dry although there might be water flowing in the stream bed. In the river valleys that cross the hilly Illapel area, traces of many ephemeral streams are visible. These are small streams that carry water only during and immediately after periods of rainfall or snowmelt.

3.3 Bedrock

The geological structure of Chile is relatively new and very complex due to the different processes that were a part of the formation. In the Illapel area three main structural domains may be found. "Cordillera de la Costa" (Paleozoic units and Jurassic plutonic rocks), "Mediana Montaña" (Mesozoic units) and "Cordillera Principal" (predominant folds, reverse and thrust faults). The biggest mineral deposits may be found in the intrusive belts and the most important ones can be associated with the Illapel superunit (Cretaceous) (Rivano & Sepulveda, 1986). Igneous, metamorphic and sedimentary rocks are common in the area. Along the rivers in the Illapel region valleys recent sediments are dominating. The bedrock composition in the area varies from amphibole and pyroxene diorites to amphibole sienogranite through tonalites, granodiorites and monzonite.

Small scale gold and copper mines are abundant in the area because of the rich assets of minerals containing high amounts of copper and gold. The primary minerals carrying gold and copper in the area are sulphide minerals and can be found in arsenopyrite (FeAsS), chalcopyrite ($CuFeS_2$), and pyrite (FeS_2). Secondary minerals are oxidised sulphide minerals such as malachite ($Cu_2CO_3(OH)_2$) and atacamite ($Cu_2(OH)_3Cl$) (SRK, 1999). The distribution of metal deposits is concentrated in a series of thin strips going in north to south direction. These series have approximately the same direction as some regional faults. This indicates that in most cases the deposits are primary ones. Different non-metallic deposits are plentiful in the area and with varying composition, for example carbonates, gypsum ($CaSO_4 \times 2H_2O$), combarbalite and lapis lazuli (25 - 40% lazurite ($(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$) among others.

3.4 Soil

As described by Alvarez (1994) the formation of Chile's soils is affected by many factors. Chile has a very large longitudinal extension with different climate and nature conditions. The three main geomorphologic units in the country generate zones with different soils because of their varying composition. Chile is a very mountainous country and therefore the general tendency is that the soils have a slow development in their profiles and therefore most soils are young in their evolution. The volcanic activity in large parts of the Andes is an example of incorporation of new materials that regenerate the soils. Another example is the erosive activity generated by the large amounts of melt water from the mountains that sediment later in the valleys when the velocity of the water slows down. Since the soils are generally young they have not undergone much weathering. The soils in the river valleys are very much affected by the bedrock up in the mountains.

The most common soil type in the Illapel region is aridosols. They are typical in arid and semiarid climates. Their colour is typically light since there often is little vegetation that may add organic matter to the soil. The soil horizons are in many cases weakly developed. Common soil forming processes in these soils are calcification and salinization (University of Wisconsin, 2006). The soils in the Illapel region are suitable for growing maize, peanuts, wheat, potatoes, tobacco, grapes, avocados, tomatoes and flowers. Irrigation is needed for all type of cultivation. The soils in the river valleys are the most fertile.

3.5 Drinking Water in the Rural Areas

For rural communities in Chile there is a system called APR- Agua Potable Rural, which means rural drinking water, and is financed by the government. In general, the system consists of collection, treatment and distribution of the water. The water source can be superficial (lakes, rivers or creeks) or subterranean (drainage or a dug or drilled well). The water is collected in a central treatment plant, a house with a tank where treatment, filtration and chlorination, is performed, and then distributed to the users (Figure 3.4). Communities with a population between 150 and 3000 habitants and a density of at least fifteen houses / km^2 can take part in the program. In the Illapel municipality there are nine communities with APRs in function and also seventeen smaller similar systems financed by the municipality. In the rural areas of the Illapel municipality, 45% of the rural population lives in villages with an APR-program and within these villages 85 % have access to drinking water (Braun, 2000).

More than half (55%) of the rural population does not have access to APR. They live in remote rural areas that are sparsely populated and in general very arid. The most common way for people to aquire water is a system with shallow wells and hoses to bring water to the house. This is described more in detail in paragraph 5.2.2.

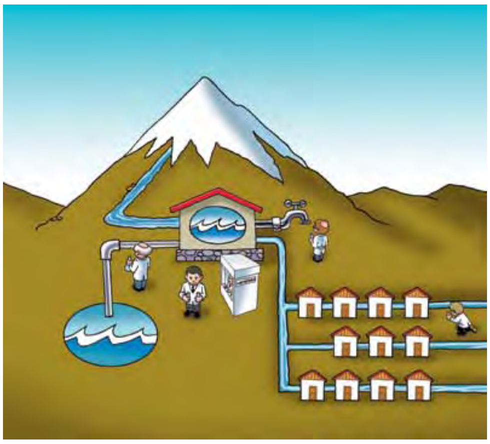

Figure 3.4. Illustration depicting APR, the system for rural drinking water, with collection, treatment and distribution. (Essbio, 2006)

3.6 Goat Cheese Production

Goat-farming is important in the Illapel area and cheese production from goat's milk is an important source of income for goat-farmers. According to Givovich and Krtizner (2004), there are about 40 000 goats in the Illapel municipality and the majority of the goat farmers have between 31 and 120 goats. They graze the lands surrounding the farms during the rainy season and move higher up into the mountains during the dry season. Livestock drink the same water as the people, and the water is also used to clean the equipment used in the cheese production. The cheese is then sold at local markets to people coming from other areas. Only 10 to 15 % of the produced cheese is controlled by the sanitary services. In 2003 a pilot project with objectives to improve the sanitation in the cheese production was tried out in the Illapel municipality. Small houses with an indoor sink and working space were constructed (Figure 3.5). A water tank tower was located outside in order to provide running water and to allow chlorination of the water in an effective way.

Figure 3.5. Small house for cheese production.

4. Material and Methods

4.1 Field Work

Due to the varying types of water supply the inventory and sampling was divided in four parts.

- APR – The rural central water treatment and supply plants spread out over the municipality.
- Plan de Horno – A rural area without access to a central water treatment plant that was chosen because of its history of intense mining and lack of previous water investigations.
- Cheese houses – Water used for goat cheese production.
- Stream water near possible contamination sources such as mines, enrichment plants and waste deposits.

The field work was conducted on nine different occasions between the 19^{th} of November and the 6^{th} of December 2005. In the villages with APR, samples were collected, both at the well, before treatment, and in a house in the distribution net. The houses where sampling was made were chosen based on accessibility. In Plan de Horno, the rural communities were dispersed. Sampling locations were chosen based on accessibility and so that the sampling points were spread over the area. The samples were taken, when possible, from the well. In other cases and for the cheese houses, samples were taken from the hose that was connected to the well. Depth, water level, origin of the water, type of tubing, how long the system had been in use and roughly how many people obtained their water there were documented for each well. The treatment method, if any, was also noted. In addition, samples were taken from surface water, streams, in the Auco river valley. At these locations the water flow was approximated using simple methods such as the small float and volumetric technique.

The sampling methods used were adopted from Ficklin and Mosier (1999). A rough survey of the surroundings was conducted at each location with emphasis on land use and possible sources for contamination such as mines, waste deposits, tailing dams and enrichment plants. A GPS was used to mark latitude, longitude and altitude at every location and weather conditions and air temperature were documented. The water was described in forms of colour, odour and turbidity. Electrical conductivity, which provides an indication of the total amount of ions in the water, pH, water temperature and the amount of total dissolved solids were measured in situ at each spot. Water samples were collected for further analyses.

Acid washed plastic bottles (20 ml) were used for the water samples. Three samples were taken at each spot: one was filtered through a sterile filter with 0.45 µm pores, which removes most particulate matter, and two were sampled without filtering. A 20 ml disposable syringe with needle was used for the hand filtering. To collect the unfiltered sample, the bulk sample container, a plastic cup, was shaken to mix any sediment. The bottles were rinsed two times with a few millimetres of the sample water, filtered or unfiltered, before filling and marked with site ID, date and type of sample. Pro analysi nitric acid (69 %) was added to the samples to obtain an acid concentration of 1% in order to prevent metals from precipitating. The samples were stored in room temperature. Facts for the equipment are specified in appendix I.

4.2 Analysis, ICP-AES

The water samples were analysed with respect to metal and sulphur content using ICP-AES at the Department of Geology and Geochemistry, Stockholm University. For each spot one of the unfiltered samples was analysed for metals in order to determine the levels of total metals, dissolved and suspended, in the water. The other samples were saved for security reasons and to enable double-checking the results. The filtered samples were not analysed since the unfiltered samples were considered to give a satisfactory picture of the water composition.

ICP-AES stands for Inductively Coupled Plasma Atomic Emission Spectrometry. The ICP-AES technique is a multielement method which means it may quantify many elements in a short time. The sample needs to be in liquid form to be analysed. The plasma uses argon gas and reaches a very high temperature, up to 10 000°C. At high temperatures different elements emit energy at specific wavelengths when excited electrons of the specific element return to ground state. The intensity of the emitted energy is measured and is proportional to the concentration of the element in the analysed sample (ODP, 2006).

5. Results

5.1 Comparison of Drinking Water Guidelines

Drinking water as defined by the European council directive is:

(a) all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers;

(b) all water used in any food-production used for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the responsible national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form.

The Swedish regulations regarding drinking water are based on the EU’s drinking water directive (DWD), European council directive 98/83/EC. In the forming of EU’s directive, the WHO’s guidelines were used as a starting point. Sweden is a part of the European Union and is, as a member, not allowed to have less stringent requirements. Member states are on the other hand allowed to have more stringent requirements, regulate more substances or set additional requirements that are relevant in their specific country. Sweden has limit values linked to an estimation of the water quality based on the expressions “suitable”, “suitable with a remark” and “unsuitable” for drinking. The limit values for “suitable with a remark” are based on health, aesthetic or technical grounds, for example unacceptable smell and taste or high amounts of microorganisms.

A comparison of the drinking water guidelines for the WHO, EU, Sweden and Chile was conducted (Table 5.1). The general trend is that the four guidelines do not differ much. The Swedish and the EU guidelines are very similar, but Chile has fewer limit values (no values for Al, B, Ni, Na or Sb). The limit values for As, Cd and Pb are higher in Chile than in EU, Sweden and the WHO. This means that higher concentrations of the substances are allowed in drinking water. In the cases of As and Pb, five times higher concentrations are allowed in Chile (0.05 mg/l compared to 0.01 mg/l) and for Cd double the concentration is allowed (0.01 mg/l compared to 0.005 mg/l). The limit value for Cu is lower in Chile (1 mg/l compared to 2 mg/l), but higher values may be accepted under special circumstances. Sweden has two limit values for copper, one unsuitable for drinking and one suitable with a remark. The only substances which have the same limit values in the WHO, EU, Sweden and Chile are Cr, Hg and Se. The WHO has less stringent requirements for Sb and Mn compared to EU and Sweden but more stringent requirements in the cases of B and Cd.

Table 5.1. Drinking water guidelines.

Element	Symbol	WHO[a] (mg/l)	EU[b] (mg/l)	Sweden[c] (mg/l)	Chile[d] (mg/l)
Aluminium	Al	(0.1-0.2)[3]	0.2	(0.1-0.2)[1]	
Antimony	Sb	0.02	0.005	0.005	
Arsenic	As	0.01	0.01	0.01	0.05
Barium	Ba	0.7			
Boron	B	0.5	1.0	1.0	
Cadmium	Cd	0.003	0.005	0.005	0.01
Calcium	Ca			(100)[1]	
Chromium	Cr	0.05	0.05	0.05	0.05
Copper	Cu	2.0	2.0	2.0/(0.2)[1]	1.0[2]
Iron	Fe		0.2	(0.2)[1]	0.3[2]
Lead	Pb	0.01	0.01	0.01	0.05
Magnesium	Mg			(30)[1]	30/125[4]
Manganese	Mn	0.4	0.05	(0.05)[1]	0.1[2]
Mercury	Hg	0.001	0.001	0.001	0.001
Molybdenum	Mo	0.07			
Nickel	Ni	0.02	0.02	0.02	
Selenium	Se	0.01	0.01	0.01	0.01
Sodium	Na		(200)	(100)[1]	
Uranium	U	0.015			
Zinc	Zn				5.0

[a] World Health Organisation (2004)
[b] European Union (1998)
[c] Swedish National Food Administration (2001)
[d] Ministero de Salud, Chile (1969)
[1] Threshold concentration, suitable with a remark
[2] The Chilean ministry of health may allow higher values of these substances
[3] No health-based guideline value but practical levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants
[4] Limit value for magnesium if content of sulphate is less than 200 mg/l, otherwise limit value is 30 mg/l

5.2 Water Supply

The following paragraphs present the results from the inventory of the water sources for the four different parts of the field study. Here, the factors, concerning water supply, that were investigated are summarized. Latitude, longitude, altitude, water temperature, pH, electrical conductivity, depth, water level, origin of the water, type of tubing, treatment method, how long the system had been in use, roughly how many people obtained their water there and comments for each location are specified in appendix II.

5.2.1 APR

In the APR-part of the study samples were taken from twelve systems spread all over the Illapel area. The communities with APR, Asiento Viejo, Cañas I, Cañas II, Carcamo, Choapa, Coyuntagua Sur, Huintil Sur, Limahuida, Peralillo, Santa Virginia, Socavon Centro, Tunga Norte and Tunga Sur, can be seen in Figure 1.1. The wells where constructed between 1979 and 2005 and had between 25 and 270 users (families). The depth of the wells varied between 6 and 60 meters and the water source was groundwater. Most of the wells were situated close to a river. The treatment consisted of chlorination in all twelve systems and in four systems also filtration through granular potassium permanganate, which is an oxidant and acts as a disinfectant. One chlorination system was currently not working. The water was distributed to the users through a system of PVC tubing. Figure 5.1 shows pictures from different parts of the APR system.

Figure 5.1 APR. a) Inside a treatment plant house, tanks for chlorination. b) Pump and tubing outside a treatment plant. c) Water sampling at a well. d) Tap outside a house.

5.2.2 Plan de Horno

In the study areas without an APR-system, people have dug shallow pits (0.3 m – 2 m) where vegetation suggested that there could be water near to the surface. The pit was preferably placed uphill from the house and hoses were used to bring the water to the house with gravity only. The wells were sometimes situated far from the house and therefore long plastic hoses were needed. In one location, water had been found when drilling for minerals and a pipe had been put in the drill hole that was 25 meters deep. In two locations the water for consumption was acquired from running water i.e. streams. Figure 5.2 shows some examples of the wells in Plan de Horno.

Samples were taken from seventeen water sources (figure 5.4 a) used by between one person and 20 families (a family is approximately four persons). The wells had been used between 10 and 35 years. Four wells were reinforced with rocks and concrete and three were covered with lids. At three wells, rough filters had been put at the end of the hoses to avoid leaves and other larger particles from plugging the hose. Four of the families added chlorine to the water before using it, but sampling was performed at the wells prior to treatment. Nine of the locations were in the altitude range of 500-1000 meters above sea level and eight locations higher than 1000 meters above sea level. Six families reported that the water supply shortens or runs out in late summer. In these cases, they have to move their hoses to other parts or bring water from neighbouring communities. There were a lot of traces of mining such as pits, ore piles, ore treatment plants and waste heaps in all of Plan de Horno. The sampled locations were however not placed downstream from any waste deposits.

Figure 5.2 Plan de Horno. a) Shallow well with lid. b) Drilled well with pipe and hoses. c) Well reinforced with concrete. d) Uncovered water hole.

5.2.3 Cheese Houses

Eight cheese houses were visited. Seven of these were located in remote rural areas and used the system with shallow wells and hoses. One house had access to APR. The farmers had between 40 and 300 goats. All but one farmer were producing cheese and two of them were not using the cheese house. The cheese was then sold locally or in central Illapel. Five of them chlorinated the water used in the cheese production. All of the farmers were consuming the same water that they used in the cheese production and the number of persons using the water from the wells varied between 3 and 20 persons. The wells had been in use from four to fifty years. One of the cheese houses was located at about 400 meters above sea level, five between 500 and 1000 and two higher than 1000 meters above sea level.

5.2.4 Streams

In the Auco Stream samples were collected from running surface water at nine locations starting in the tributary Alcaparrosa Stream (figure 5.3a) and finishing just before the inflow to the Illapel River (figure 5.3b). Electrical conductivity and pH were measured at six additional spots. The samples were taken at locations in the altitude range between 350 and 900 meters above sea level. The Auco Stream is an intermittent stream and in the period that this study was conducted it did not have a continuous surface flow. The channel was well defined so it has been assumed that the water along its course had the same source and was flowing underground in the river bed. The flow in the different streams was approximated to between 0.0004 m^3 / s for the highest located sampling spot and 0.09 m^3 / s just before the inflow to the Illapel River. Even though the flow measurements are very rough this indicates that the flow is increasing downstream. Figure 5.4 shows some of the streams where sampling was performed.

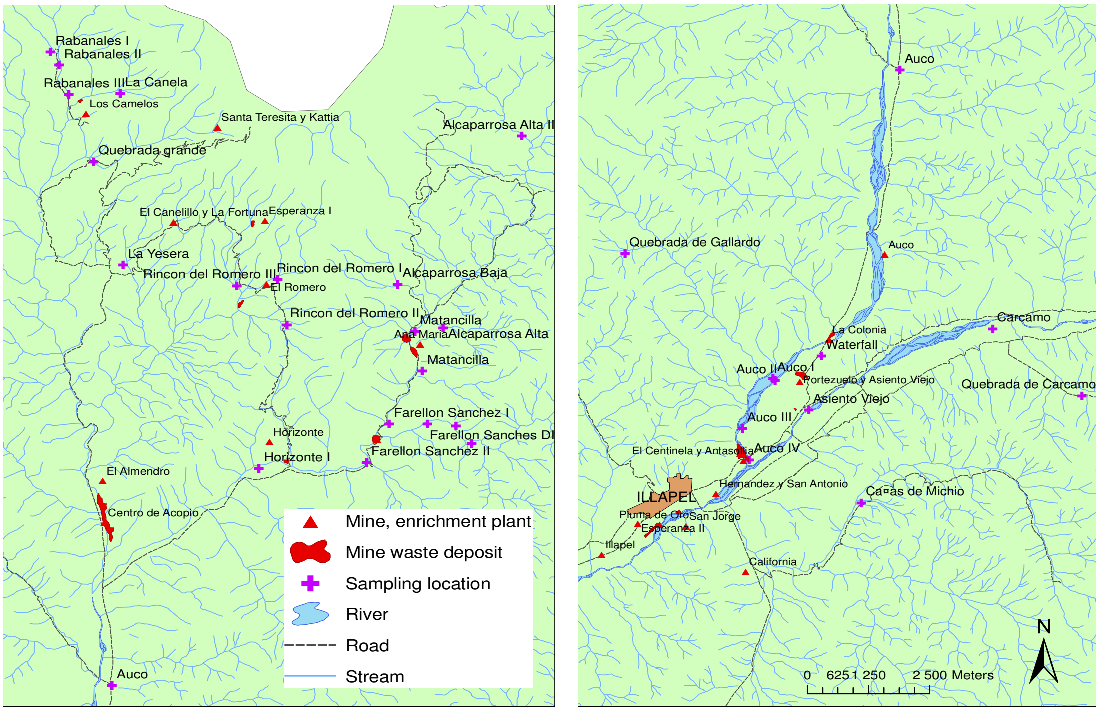

Figure 5.3. Sampling locations.
a) Plan de Horno *b) Auco Stream*

Figure 5.4 a) Stream close to mine waste deposit. b) Stream close to mine waste deposit. c) Mine waste deposit. d) Stream in the inner part of the valley.

5.3 Water Analyses

The following paragraphs present the in situ measurements of pH and electrical conductivity and the results of the water analyses. A detailed list of the measured parameters and elements are shown in appendix III. The amount of total dissolved solids, TDS, are presented in the appendix but not discussed.

pH & EC

The in situ measured pH-values varied between 5.3 and 8.5 with a total mean of 7.48 and a median of 7.39. For the different parts of the study, means and medians are plotted with the standard deviations (samples not normally distributed) in Figure 5.5. The highest mean pH was measured in stream water which also has the largest variation and contains both the maximum and the minimum value. The water from the APR-wells has the lowest mean. It can be noted that the mean pH measured for houses in APR-systems is slightly higher than the one measured at the wells before treatment. Figure 5.6 presents the in situ measured electrical conductivity. The EC varied between 121 µS/cm and 2212 µS/cm with a total mean of 688 µS/cm and a median of 604 µS/cm. The stream water and the water in Plan de Horno had the highest mean EC. The lowest mean EC was measured in the APR-wells. The maximum EC-value was measured in a stream in Plan de Horno, where the water is used for household purposes. The mean water temperature was 23 ºC.

Within the four parts, APR, Plan de Horno, Cheese and Stream, of the survey, the water came from three different sources. Water was derived from groundwater for all the APR-wells and one community in Plan de Horno, water was obtained from shallower groundwater in pits from the majority of the locations in Plan de Horno and the cheese houses, and surface water was the water source for all the streams and two locations in Plan de Horno. With this distribution, the mean pH was the highest for surface water and lowest for groundwater. Stream water also had the highest mean electrical conductivity and groundwater the lowest.

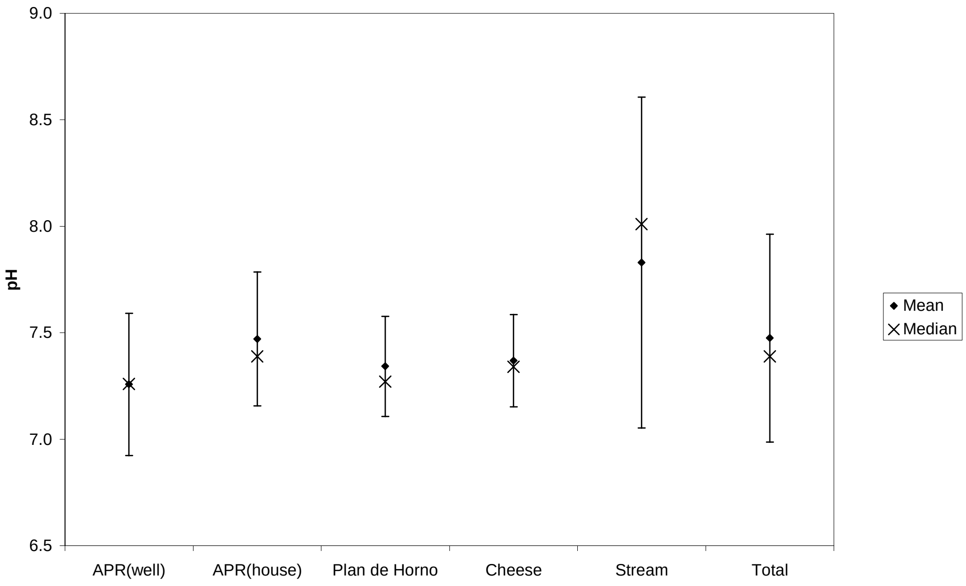

Figure 5.5. Mean, median and standard deviation for pH measured in situ in the Illapel municipality, Chile, between the 19th of November and 6th of December 2006.

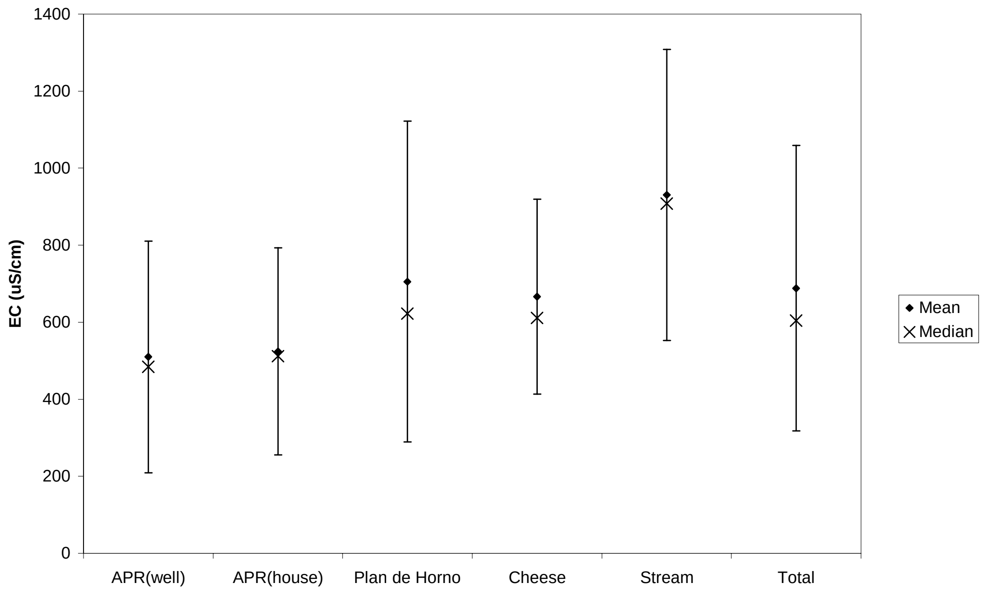

Figure 5.6. Mean, median and standard deviation for electrical conductivity measured in situ in the Illapel municipality, Chile, between the 19th of November and 6th of December 2006.

Metals

The water samples were analysed with respect to metal and sulfur content using ICP-AES at the Department of Geology and Geochemistry, Stockholm University. The content of total metals, dissolved and suspended, in the water were analysed for 46 unfiltered samples. For the APR-systems where samples had been taken both from the well, before treatment, and from a house in the distribution net, only the samples from the houses were analysed. The results and detection limits for the 32 analysed metals in all samples are shown in appendix III. Figures 5.7 and 5.8 present a summary of the means, medians and standard deviations for the analysed metals (samples are not normally distributed). Out of the 32 analysed metals, 28 have been detected in at least one sample. The figure also shows the metals that were not detected (circled). When calculating the mean, median and standard deviation a few outliers, circled in the appendix III, have been removed. Points that had values more than a hundred times larger then the rest were considered outliers. Cu, Fe Sr, Zn, Ca and S have the largest variations. Where there is no variation, the element was only detected in one sample.

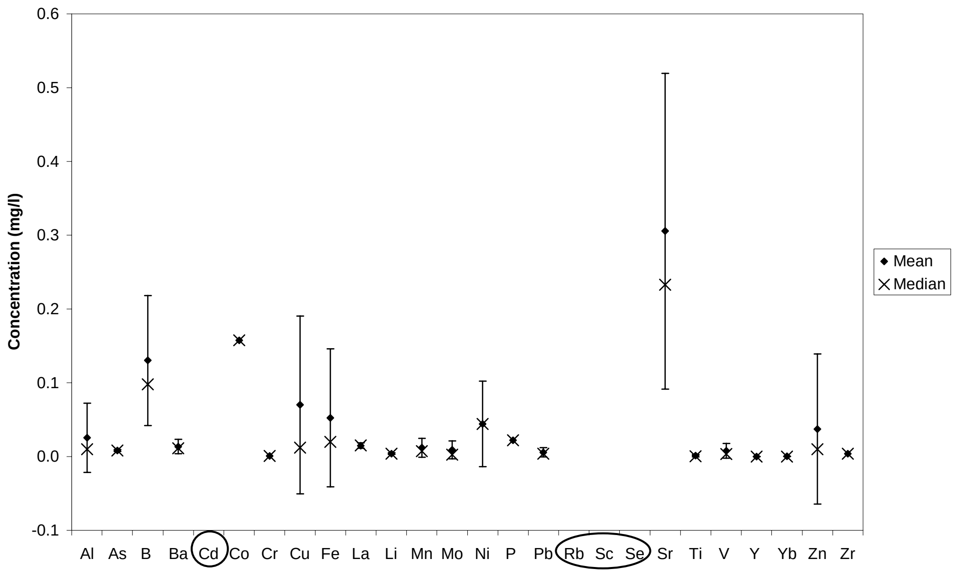

Figure 5.7. Means, medians and standard deviations for total metals and some other elements analysed with ICP-AES in water samples taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile. Circled elements were not detected in any sample.

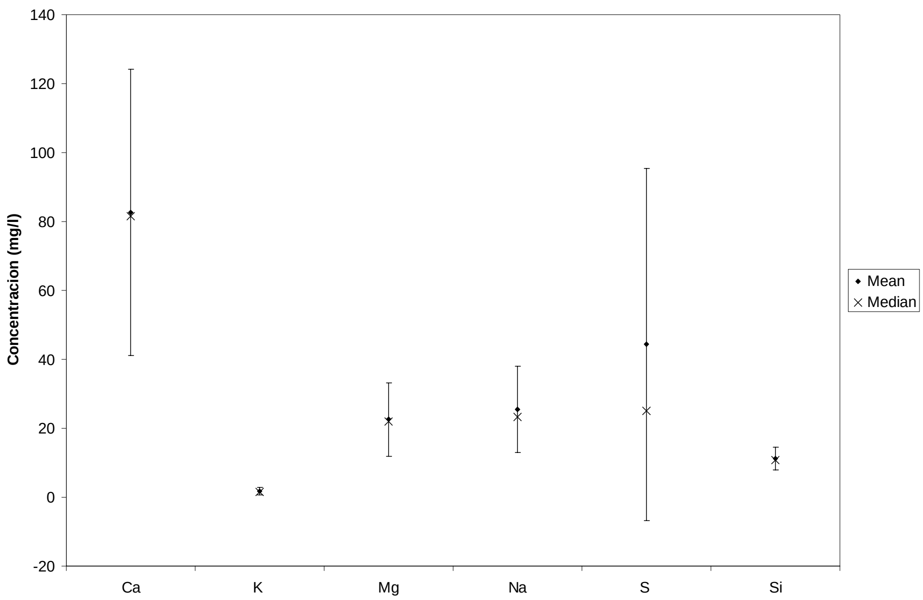

Figure 5.8. Means, medians and standard deviations for total metals and sulphur analysed with ICP-AES in water samples taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

The mean metal concentrations were compared for water of different origin, groundwater, pit or stream, in Figure 5.9 and 5.10. The stream water has the highest mean for 18 out of 28 samples. Pit water had higher mean than groundwater for 16 out of 25 elements.

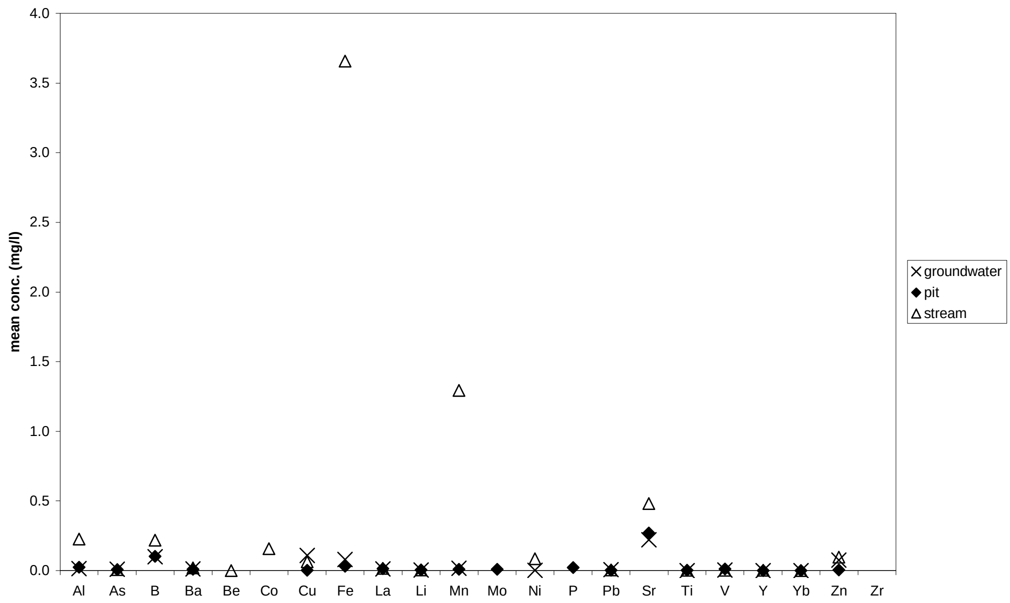

Figure 5.9. Comparision of mean values for total metals and some other elements in water of different origin. Samples were taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

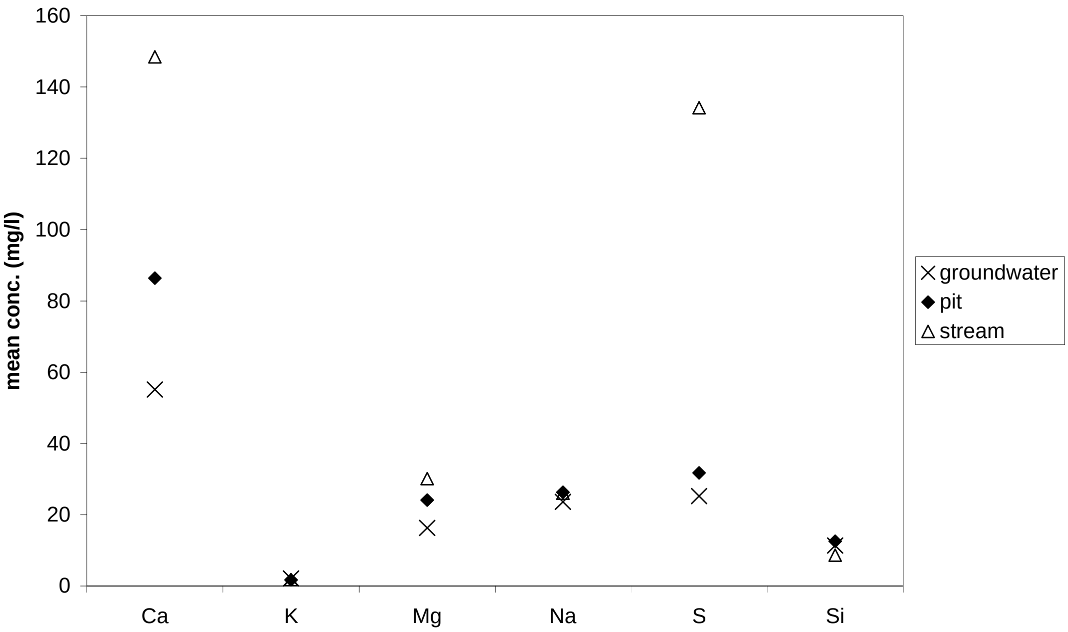

Figure 5.10. Comparision of mean values for total metals and sulphur in water of different origin. Samples were taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

The metal content of the analysed samples was compared with the drinking water guidelines that are shown in Table 5.1. Using the strictest of the four limits for all elements, 20 of the samples had values that exceeded one or more limits. These are shown in Table 5.2. For Ca, Cu and Mg, the exceeded limit is classified as “suitable with a remark”. Four samples have values that exceed limits for “unsuitable” water. Out of these, only the water at Santa Virginia and Quebrada Grande was used as drinking water. In Santa Virginia, which is the sampling location furthest upstream the Illapel River, the European Union's limit values for Fe and Pb were exceeded. In Quebrada Grande, which is situated in Plan de Horno (figure 5.4a), the Chilean limit value for Fe was exceeded. The sample from Auco II, which is situated close to to the inflow of Auco stream to Illapel River (figure 5.4b), the limit values for Al, Fe, Mn and Ni were exceeded. For Fe and Mn, at this location, the limit values were exceeded 200 respectively 300 times. It may be noted that for mercury (Hg), which was not detected in any sample, the detection limit (0.0045 mg/l) was above the guideline limit (0.001 mg/l).

Table 5.2. Samples for which total metals exceed one or more guideline limits.

Location	Category	Site ID	Al	As	Ca	Cu	Fe	Mg	Mn	Ni	Pb
Limahuida	APR	7	0.010		101	0.0707	0.04	33	0.0096	0.003	
Cañas II, Choapa	APR	9	0.008		87	0.4554	0.02	34			0.004
Santa Virgina	APR	21	0.078		25	0.1151	0.21	5	0.0008		0.021
Canelillo	cheese	50	0.007		59		0.01	35			
Cañas de Michio	cheese	57	0.011		128		0.01	37			
Quebrada grande	plan de horno	30	0.046	0.0099	143		0.55	14	0.0267		
La Yesera	plan de horno	31	0.009	0.0083	153		0.01	14			
Rincon del Romero III	plan de horno	34	0.010		157	0.0022	0.01	34			
Alcaparrosa Alta	plan de horno	35	0.123		105	0.0006	0.14	23	0.0459		
Alcaparrosa Baja	plan de horno	36	0.023		101		0.03	24	0.0043		
Alcaparrosa Alta II	plan de horno	37	0.017		500		0.04	63	0.0403		
Farellon Sanches III	plan de horno	42	0.038		113	0.0028	0.04	24	0.0038		
Auco I	stream	2	0.009		135	0.0012	0.02	26	0.0058		
Auco II	stream	3	2.036		167	0.4259	39.66	51	14.1117	0.09	0.005
Matancilla	stream	39	0.009	0.0065	172		0.02	42	0.0125		
Farellon Sanchez I	stream	43	0.008		138		0.02	30	0.0059		
Horizonte I	stream	45	0.012		112	0.0066	0.02	30	0.0036		
Waterfall	stream	46	0.296		15	0.0035	0.29	3	0.0126		
Auco III	stream	48	0.012		136	0.0004	0.05	27	0.0122		
		Limit (mg/l)	0,1 0.2	0.01	100	0.2	0.2	30	0.05	0.02	0.01
		Detection limit (µg/l)	0.6790	5.20	0.16	0.3410	0.803	0.1	0.1160	2.49	2.050

= suitable with a remark
= unsuitable

A ternary diagram is a way to present chemical data and to compare and identify trends and relationships between samples from different locations. The ternary diagram shows the concentration of the most common cations (Ca, Mg & Na + K) in a triangular diagram. The key function is to visualise clustering of data points to indicate samples that have similar composition. It may be used as a quick test to see if water samples at different locations have the same chemical characteristics and come from the same source or not and it reveals useful properties for large sample groups (Groundwater Chemistry Software, 2006). Ternary diagrams have been plotted for different selections of the data according to figure 5.11-5.13.

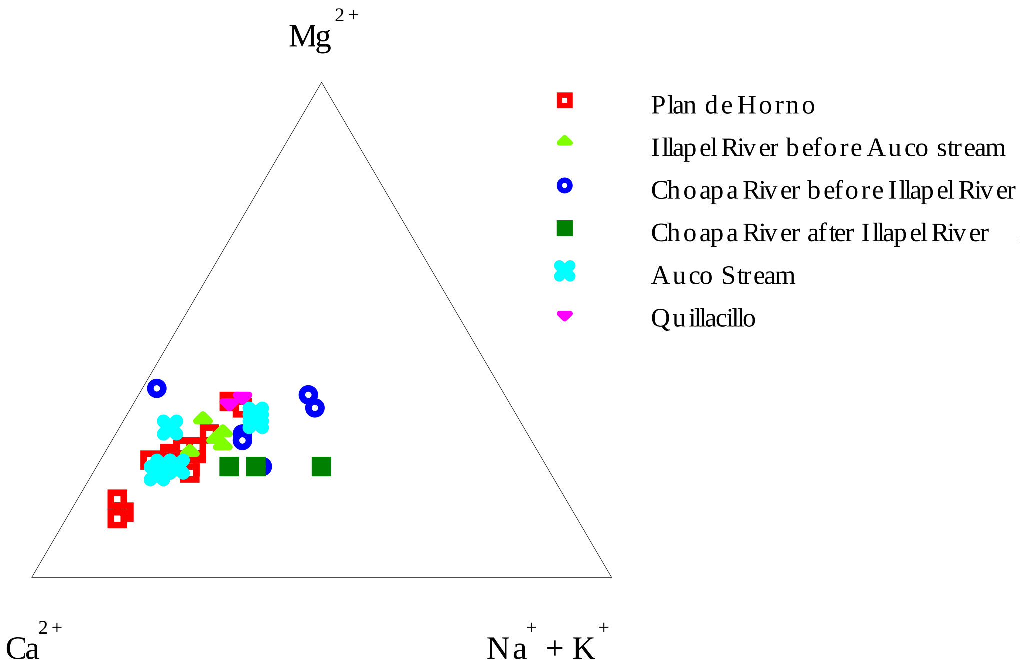

Figure 5.11. Ternary diagram, relative concentration of the most common cations (Ca, Mg & Na + K) of all water samples taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

Figure 5.11 shows all samples divided into suitable groups and plotted depending on location. The variation between the different groups was not large. Most samples had more or less the same composition. In the Quillacillo group, se figure 1.1 for location of Quacillo, the results were almost identical for all the samples. The samples in the group Choapa River before Illapel River had the most varying results.

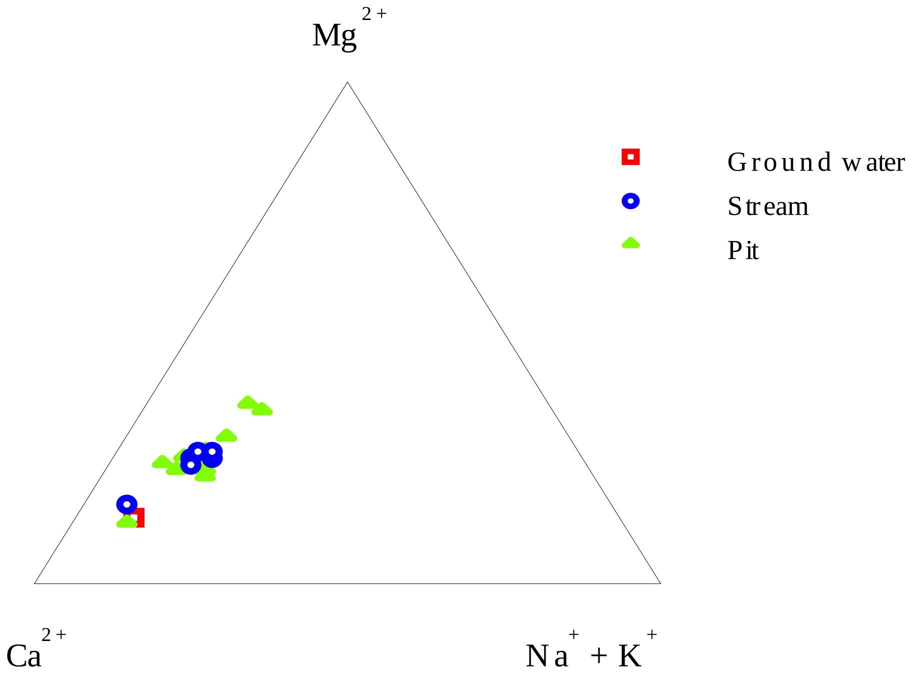

Figure 5.12. Ternary diagram, relative concentration of the most common cations (Ca, Mg & Na + K) of water samples taken between the 19th of November and 6th of December 2006 in Plan de Horno, Illapel municipality, Chile.

In figure 5.12 samples taken in Plan de Horno were plotted depending on origin of water, from a shallow pit, groundwater or from a stream.

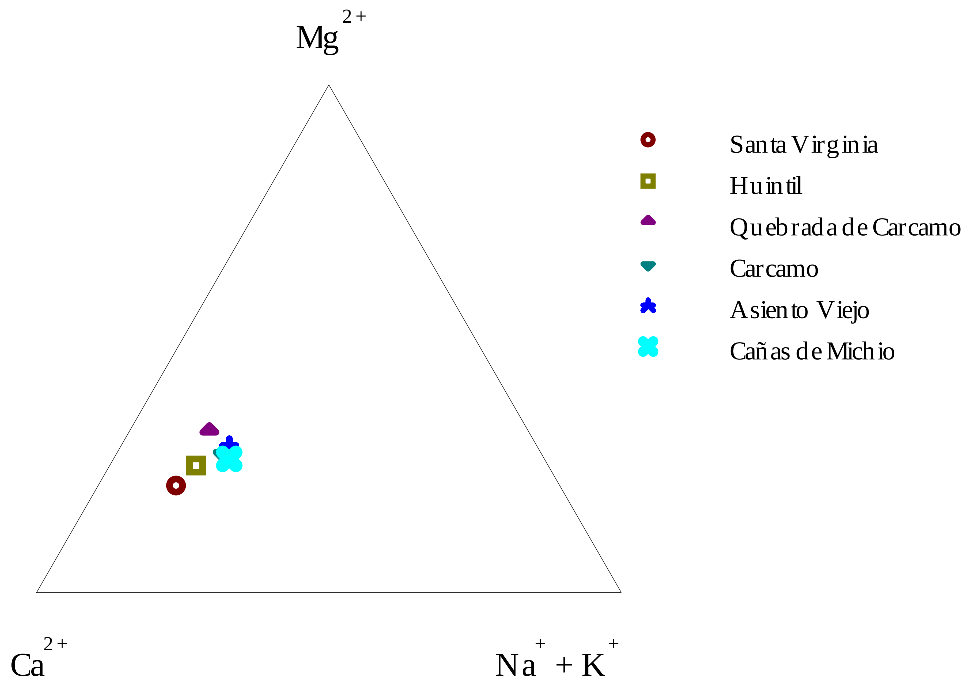

Figure 5.13. Ternary diagram, relative concentration of the most common cations (Ca, Mg & Na + K) of water samples taken between the 19th of November and 6th of December 2006 in the upper part of the Illapel River, Illapel municipality, Chile.

In figure 5.13, samples from the upper part of the Illapel River were plotted to see if there existed any differences in water composition. A slight relationship can be seen between relative calcium content and location. The sample taken furthest upstream (Santa Virginia) shows the highest relative calcium content. For sample locations see figure 1.1. Huintil, which is the next sample location downstream of Santa Virginia, has the second highest relative calcium content. Next location downstream is Quebrada de Carcamo and has the third highest. The relative calcium content for Carcamo, Asiento Viejo and Cañas de Michio are the same, but lower than the other tree locations.

To analyse the data further a few common geochemical relations were studied. Figure 5.14 shows the relation between electrical conductivity and sulphur. Where the sulphur concentration (that is correspondent to the concentration of sulphate anions) is high, there is a linear correlation with electrical conductivity (EC) and hence the content of metal ions (cations). When the concentration of sulphate is low, bicarbonate (not measured) is normally the dominating anion, but in this case it might also be chloride ions since the samples from APR have been chlorinated. The plotted data set suggest that the water has a different composition for low S. In figure 5.15, the relation between Ca and Sr has been plotted. They are two similar metals of roughly the same size that normally, as in this plot, show a linear correlation (Selinus, 2005).

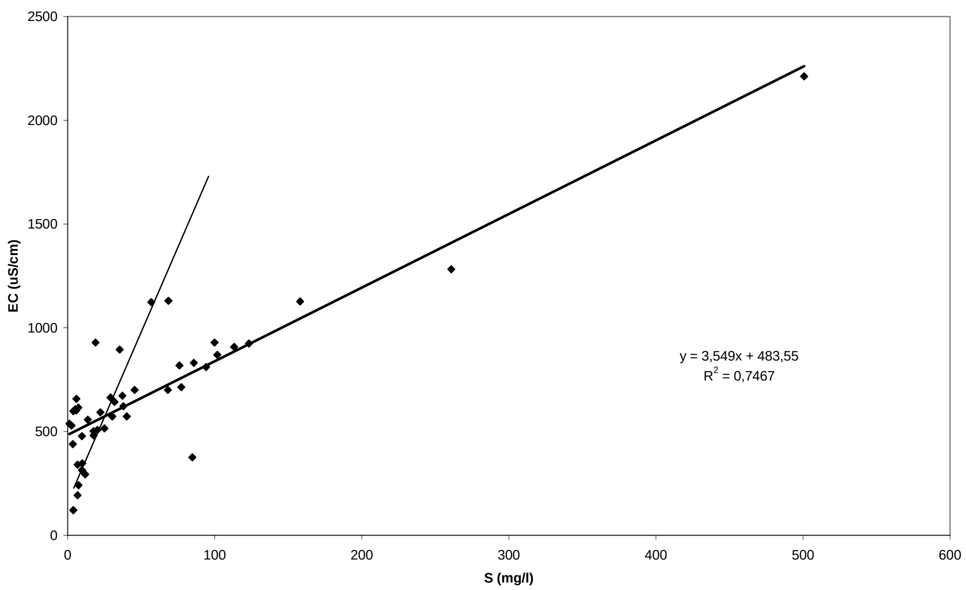

Figure 5.14. The relation between electrical conductivity and sulphur in water samples taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

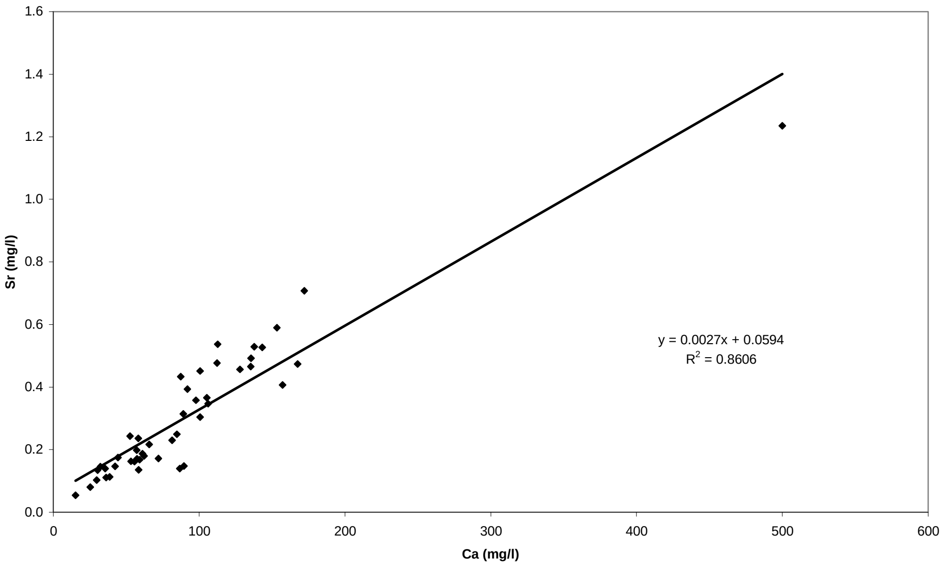

Figure 5.15. The relation between calcium and strontium in water samples taken between the 19th of November and 6th of December 2006 in the Illapel municipality, Chile.

6. Discussion and Concluding Remarks

Water Supply

In Chile, water issues are handled by many different authorities and institutes. Determining who is responsible for what, and where certain information can be found, is difficult even in a small municipality like Illapel. Due to this complex situation, this study has the four somewhat incoherent parts (APR, Plan de Horno, Cheese and Stream) and it makes the water situation in the rural areas more difficult to summarize.

It seems that the APR-system is working well. The parts of the population that have access to APR have a secure water supply all year round and quality controls are done regularly by the local health authorities. Nevertheless some of the visited treatment plants had or had had problems with the chlorination. It might be a concern that many of them were located close to rivers and that river water may infiltrate to the groundwater. The APR wells are tested regularly by the health authorities, but since it was not possible to get access to this data, testing these wells was still an important part in the study.

In Plan de Horno, the water supply is a big concern for the majority of the people. Although only six out of seventeen visited families reported that water shortages are common, the majority of the people are constantly occupied in obtaining water, economize with the limited resource, and prioritise between household requirements, livestock and irrigation. The system with wells located uphill from the house seems to be working satisfactorily. Constructing some kind of structure to maintain the water and covering the pit with a lid to avoid evaporation and contamination are probably good investments. To aquire the plastic hoses is a large cost and it is a problem because they are easily damaged by the hot sun. If the ground allows it, it is advisable to bury or cover the hoses with soil. In the study, two families used stream water as drinking water. This water may not have had any soil filtration and is much more exposed to contamination from rainfall, surface runoff and other external factors.

The cheese-producing goat farmers were, as mentioned in paragraph 5.2.4, using the same system as the people in Plan de Horno and have similar problems. The project to improve sanitation seemed to have worked in some cases although the majority had complaints and problems about the construction of the cheese house and two were not using the house.

The samples taken from stream water along the Auco stream and it tributaries were hard to analyse since they were taken at such different locations and there was no continuous surface flow the whole way. Too few samples were also taken; they may only be used as indicators of specific locations. This water was not used as drinking water directly, but animals drink it and the Auco stream ends up in the River Illapel just upstream of the city of Illapel.

Water Analyses

The mean pH of the water was relatively high. This is probably caused by the geology in the area. The pH levels are suitable for drinking water. Stream water had the highest mean, the highest and the lowest value and the largest variation, a lot larger then the other groups. This is probably due to flow variations with different proportions of water from varying depth. The other sample groups, APR, Plan de Horno and Cheese had their mean pH values around 7.4 which are suitable for drinking. The pH was slightly higher in the houses in the APR-systems then directly at the well, and this has not been clarified. It might have something to do with the chlorination treatment. These differences in pH between the groups are related to the origin of the water. Surface water has the highest mean pH and groundwater the lowest. The EC values showed the same pattern as the pH except that the EC did not differ much between APR-wells and houses. EC was highest in stream water and lowest in groundwater. A simple explanation to this might be the high evaporation that affects the surface water more and might concentrate the ions.

The mean concentration of metals was also higher in stream water then in pit and groundwater for the majority of the elements. One explanation to this might be the evaporation but it is also probable that it has to do with the sampling location and depth. Comparing groundwater to pit water, pit water (mainly from Plan de Horno) had the higher mean for the majority of the elements.

The suspected high levels of metals were not found. In the water used for household purposes, only two samples exceeded drinking water guidelines for “unsuitable” drinking water. The elements for which the limits were exceeded were Fe in Quebrada Grande, the drilled hole in Plan de Horno, and Fe and Pb in Santa Virginia, an APR-system constructed in 2005. Fe is not believed to be dangerous to humans in normal amounts, but a dose of 3000 mg is counted as a deadly dose for a two year old child. Pb on the other hand may cause damage to the nervous system or other health effects. Children and unborne children are especially at risk for long-term exposure which may lead to reduced intellectual capacity. For Hg, the detection limit was above the guideline limit so even though Hg was not detected in any sample it may have had levels above the guideline limit.

Based on the ternary diagrams, there is not much difference in the major cation composition in the study area. The geological structures in the area are varied which contributes to the differences in the water composition. In figure 5.11 a relation between relative calcium content and location may be seen, probably because of differences in the bedrock.

General

Since water investigations in general are both expensive and time consuming, a project with the time frame and budget of this current study can only be an indication of the situation. In this case the study indicated that there are no large problems with heavy metals in drinking water in the investigated wells. No relation between metal content and mining has been shown. In Plan de Horno, where the mining activity is visible in all parts of the area, this could maybe be explained by the location of the wells. By placing them uphill from enrichment plants and waste desposits, possible leakage or surface runoff does not affect the quality of the water at the sampled locations. In case of the stream water, it is very probable that the situation is different in the rainy period. Generally, the metal concentration would be lower when there is a higher flow, as the concentrations are diluted. But with surface runoff from deposits, which occurs when it rains, metals might be washed along and make the concentrations higher. Waste deposits show apparent traces of surface runoff and since they are located so close to the rivers and streams this is an obvious threat. The streams that have melt water as their main water source had their peak flow during the period of this study, but water levels in pits for household use was declining.

Other risks that were not covered in this study are, as mentioned earlier, the metals for which the detection limits of the ICP-AES were above the drinking water guidelines, such as Hg. F (fluorine) which at high levels can damage teeth and bones were not investigated. For the water sources that are not controlled by the local health authorities, there is also a need of investigations concerning nutrients, pesticides and bacteria. Further studies are therefore recommended, covering a larger area, over a longer period of time and not only analysing the metal content in the water, especially in the areas where no previous studies have been conducted. At present, this is a very good time for mining because of the high metal prices. This might lead to new or reopened old mines and a generally larger mining activity in the area sinc it is profitable at the moment.

Compared to Sweden, EU and the WHO, the limit drinking water guideline in Chile is a bit less stringent. Chile is not a relatively rich country and for the government to lower the threshold concentration from the criteria today would imply that companies would have to invest in new equipment to lower their emissions. This would cost money and would be hard for the government to get approval for this by the people. Environmental issues do not have a high agenda in Chile and the people rather see that money go to other, in their opinion, more important issues. Mining is a very large industry in Chile and gives lots of money to the government and this probably negatively influences the will to lower the threshold concentration for certain metals.

7. Acknowledgements

This project has been a great experience and we are very grateful that we were given the opportunity to carry out this MFS in Illapel, Chile. Therefore we would like to thank certain people and institutions that have helped us along the way.

The main financial means for this study was issued by the Swedish International Development Agency (SIDA) through the committee of Tropical Ecology (ATE) at Uppsala University.

Our partner in Chile, NGO- AQUA was helpful during our stay in Chile. Special thanks to Jack Stern, the director and most of all to our supervisor, Wladimir Givovich Diaz, who came up with the idea for the project, welcomed us very warmly to Chile and was very helpful in setting us up with useful contacts in the Illapel municipality.

We are also deeply grateful to our supervisor in Sweden, Roger Herbert, at the Department of Earth Sciences, Air and Water Sciences, at Uppsala University, for helping us throughout the project work from defining the project to finalising the report.

We would also like to express our gratitude to:

> Fransisco Meza at INIA (Instituto de Investigaciones Agropecuarias) for help and advices and loan of equipment.
>
> Victor Larraguibel from Servicio País for friendship, good advices, support and guiding in the Illapel municipality.
>
> Nancy Sanhueza at CIPMA, Chile, for help in search of background information
>
> Claudio Lara at Prodemu, Illapel.
>
> Agapito Santander for the loan of books, Illapel.
>
> Karina Reyes, Yovana Vega and Andrea Gaete for being really wonderful flatmates and for lending us bicycles and accompanying us on field trips.
>
> Alejandro Mardones for helping us navigate the difficult roads and finding the places where we wanted to go and also for his friendly attitude and large knowledge of the area and its inhabitants.
>
> Laila and Loik for letting us use their apartment in Santiago and becoming very good friends.
>
> Anna, Hanna and Lisa for welcoming us to Santiago, supporting and understanding us and sharing good times, cooking fancy dinners, in Santiago and on Eastern Island.

Finally, big thanks to the persons we visited in the rural areas of the Illapel municipality for showing us hospitality and helping us realise this project.

8. References

Alvarez M.R, 1994. *Perfil Ambiental de Chile*. Comisión Nacional del Medio Ambiente. Primera edición. pp 27, 34.

Braun E, 2000. *Gestion globale de l'eau dans la province du Choapa.* Ecole Nacional du Génie Rural, des Eaux et des Forêts.

Drever J.I, Clow D.W, 1995: *Weatherin grates in cathments.* White A.F & Brantley S.L (eds). *Chemical weathering rates of silicatemineral.* Rev. Mineral, 31. Washington (D.C): Mineral.Sos. Am., 463-483.

European Union, Council Directive 98/83/EC, 1998-11-01.

Ficklin W, Mosier E, 1999. *Field methods for sampling and analysis of environmental samples for unstable and selected constituents*. The Environmental Geochemistry of mineral deposits, Reviews in economic Geology, Volume 6A. Society of Economic Geologists, Littleton, Co. pp 249-263.

Fröberg G, Höglund L.O, 2004. *MiMi Light*. En populärvetenskaplig sammanfattning av MiMi-programmets forskning kring efterbehandling av gruvavfall. MiMi Print, Luleå. pp 30-31 and 52.

Höglund L.O, Herbert R.B (Eds.), 2004. *MiMi – Performance Assessment Main Report.* MiMi print, Luleå.

Givovich W, Krtizner L, 2004. *Situatión de la tenencia de la tierra en la comuna de Illapel, IV región.* 3-46.

Langmuir, D, 1997. *Aqueous environmental geochemistry*. Prentice-Hall, Inc, New Jersey, pp 233 and 371.

Ministero de Salud, Chile, Reglamento de los servicios de agua, destinados al consume humano, DTO. N° 735 de 1969-12-19.

Olsberg E, 2004. *Metal transport in landfill leacate*. An investigation of the landfill of Albäck, Trelleborg. Department of Water Resource Engineering, University of Lund. pp 19-31.

Rivano S.G, Sepulveda P.H, 1986. *Hoja Illapel*. Servicio Nacional de geologia y mineria, carta geologico Chile, No. 69.

SAG, 2005, Servicio Agricola y Ganadero, Gobierno de Chile. *Monitoreo ambiental de los recursos hídricos de río choapa- IV región*. pp 9-18.

Sánchez JM, Enríquez SM, 1996. *Impacto Ambiental de la Pequeña Minería en Chile.* Document for the International Bank for Reconstruction and Development, Project: "Environmental Study of Artisanal, Small and Medium mining in Bolivia, Chile and Perú".

SRK, Steffen, Robertsson & Kirsten, 1999. *Estudio socioeconómico y técnico pequeña minería, comuna de Illapel, IV region*. pp III.

Stenbäck J, Östlund P, 1999. *Nya metaller och metalloider i sammhället, rapport B 1332*. Stockholm.

Swedish National Food Administration, Livsmedelverkets föreskrifter om dricksvatten, SLVFS 2001:30.

Selinus O (ed), 2005. *Essentials of Medical Geologi, Impacts of the Natural Environment on Public Health.* Elsevier Inc, Academic Press.

Tarbuck E, Lutgens F, 1999. *Earth*. An introduction to physical geology. Prentice Hall, int, New Jersey. pp 124-129, 552-560.

World Health Organisation, Guidelines for Drinking-water Quality, Vol. 1: 3rd Ed, 2004.
ISBN 92 4 154638 7, NLM Classification: WA 675.

Internet References

CONAMA (Comisión Nacional del Medio Ambiente), 2005. *Desarollo de un Patron de Análisis Ambiental de la Pequeña Minería*. Subterrra Ingenieros Limitada, http://www.conama.cl, 2005-05-05

Essbio,
http://www.essbio.cl/educacion/el_agua_potable.asp, 2006-06-07

Groundwater Chemistry Software,
http://www.ssgintl.com/aquachem_details/aquachem_details.html, 2006-03-05

Institute of Internal Medicine, Karolinska Institutet,
http://www.imm.ki.se/riskweb/bedomningar/arsenik.html, 2006-05-17

Occumed,
http://www.occmed.uu.se/metal/, 2006-06-11

ODP (Ocean Drilling Program), Inductive Coupled Plasma Atomic Emission Spectrophotometer (ICP-AES),
http://www-odp.tamu.edu/publications/tnotes/tn29/technot2.htm, 2006-02-24

SGU (Swedish Geological Survey),
http://www.sgu.se/sgu/sv/geologi_samhalle/vad_geologi/geokemi/Markgeokemi.html, 2006-05-20

SEPA (Swedish Environmental Protection Agency),
www.naturvardsverket.se, 2006-03-10

University of Wisconsin,
http://www.uwsp.edu/geo/faculty/ritter/glossary/a_d/aridisol.html, 2006-04-15

UNICEF,
www.unicef.org/infobycountry/chile_statistics.html, 2006-05-08

Wikipedia, Encyclopedia,
http://en.wikipedia.org/wiki/, 2006-03-10

9. Appendices

Appendix I: Equipment Specifications

Electrical Conductivity meter: HI 98311 EC/TDS/Temp tester from Hanna Instruments

Range: 0 to 3999 µS/cm EC, 0 to 2000 ppm TDS, 0.0 to 60.0 °C
Resolution:1 µS/cm EC, 1 ppm TDS, 0.1 °C
Accuracy: (at 20°C) ±2% Full Scale EC & TDS, ±0.5 °C
Typical EMC Deviation: ±2% Full Scale EC & TDS, ±1 °C
Calibration: Automatic 1 point at 1413 µS/cm
Conversion Factor: 0,5
Temperature Compensation Coefficient: BETA (ß) = 1,9
Environment: 0 to 50°C ; R.H. 100%
Battery Type / Life: 4 x 1.5V / 100 hours
Dimensions: 163 x 40 x 26 mm
Weight 85 g

Conductivity calibration solution used: 1413µS/cm

pH meter: HI 98128 from Hanna Instruments

±0,01 pH at 25º C / 77º F
Range: -2.00 to 16.00 pH; 0.0 to 60.0 °C
Resolution: 0.01 pH; 0.1°C
Accuracy: ±0.05 pH; ±0.5°C
pH Calibration: automatic at 1 or 2 points with 2 sets of memorized buffers
Temperature Compensation: automatic
Battery Type / Life: 4 x 1.5V with BEPS / approx. 300 hours of continuous use
Environment: -5 to 50°C (23 to 122°F); RH max 100%
Dimensions: 163 x 40 x 26 mm
Weight: 100 g

pH buffer solutions used: pH 4,01 and pH 7,01

www.hannainst.com

Appendix II: Water Supply

APR

Location	Site ID	Category	Date	Long	Lat	Water Temperature (°C)	pH	EC (µS/cm)	TDS (ppm)	Depth (m)	Water Level (m)	Construction Year	Users (branches)	Treatment	Tubing
Limahuida	7	house	2005-11-22			22.0	7.62	895	448						
Socavon Centro	5	house	2005-11-22			21.5	7.05	573	285						
Carcamo	23	house	2005-11-23	300.351E	6.501.845N	22.0	7.15	314	157						
Asiento Viejo	25	house	2005-11-23			21.2	7.30	481	239						
Santa Virgina	21	house	2005-11-23			16.9	8.01	193	96						
Cañas II and Choapa	9	house	2005-11-22			24.8	7.36	1124	557						
Cañas I	10	house	2005-11-22	288.002E	6.488.862N	24.1	7.71	515	255	50			270	Chlorination	1000 m galvanised steal. then PVC
Huintil Sur	19	house	2005-11-23			20.9	7.10	241	121						
Tunga sur	12	house	2005-11-22			21.8	7.37	557	314						
Coyuntagua Sur	13	house	2005-11-22			26.6	7.63	593	294						
Peralillo	16	house	2005-11-23			20.5	7.41	508	255						
Tunga Norte	15	house	2005-11-22	275.763E	6.498.512N	22.4	7.94	294	146				(20)	Chlorination	
Peralillo	17	well	2005-11-23	300.321E	6.486.406N	17.9	7.33	513	256	30	20	1996	77	Filter + permanganat + Chlorination	Galvanised steal pipe. PVC in net. copper for some households
Huintil Sur	18	well	2005-11-23	312.626E	6.506.207N	18.0	7.48	233	116	60(18)		1999	86	Filter + permanganat + Chlorination	Galvanised steal pipe. PVC in net.
Coyuntagua Sur	14	well	2005-11-22	282.670E	6.494.253N	22.5	7.54	567	283	6		2003	25	Non working chlorination	PVC
Santa Virgina	20	well	2005-11-23	325.347E	6.507.448N	16.5	7.89	177	88	18	14	2005	90-92	Chlorination	63m galvanised steal. 300m PVC
Tunga Sur	11	well	2005-11-22	275.705E	6.497.754N	21.7	7.17	301	149	16	16	1998	91	Chlorination	PVC with galvanised joints.
Carcamo	22	well	2005-11-23	303.607E	6.503.891N	18.3	7.00	299	148	33	29	1979	198	Chlorination	Galvanised steal pipe. rocali. PVC
Cañas II och Choapa	8	well	2005-11-22	291.313E	6.487.890N	21.6	7.28	1124	559	21		1998		Filter + permanganat + chlorination	Galvanised steal pipe. PVC in net.
Asiento Viejo	24	well	2005-11-23	298.625E	6.501.499N	18.9	6.92	456	229	7	2	2000	105 (+100 new)	Chlorination	PVC. rocali
Limahuida	6	well	2005-11-22	295.848E	6.485.348N	20.4	7.24	904	450	9	6		77	Chlorination	
Socavon Centro	4	well	2005-11-22	295.803E	6.480.524N	19.3	6.73	525	264	7.9	6	1990-1991	150	Filter + permanganat + chlorination	PVC with galvanised joints.
				Total	Min	16.5	6.7	177	88						
					Max	26.6	8.0	1124	559						
					Mean	20.9	7.4	518	260						
					Median	21.3	7.3	511	255						
					Stdev	2.5	0.3	277	138						

House	Min	16.9	7.1	193	96
	Max	26.6	8.0	1124	557
	Average	22.0	7.5	524	264
	Median	21.9	7.4	512	255
	Stdev	2.4	0.3	269	134
Well	Min	16.5	6.7	177	88
	Max	22.5	7.9	1124	559
	Average	19.5	7.3	510	254
	Median	19.1	7.3	485	243
	Stdev	2.0	0.3	301	150

Plan de Horno

Location	Site ID	Date	Long	Lat	Altitude (m.a.s.l)	Water Temperature (°C)	pH	EC (µS/cm)	TDS (ppm)	Depth (m)	Start year	Users	Treatment	Tubing	Description
Matancilla	38	2005-12-01	309.156E	6.520.713N	820	28.1	7.27	700	347		1998-2000	22 families		Hose	System with central tank that is filled upp from a hose higher up in the hills and distributed to the villagers. Mine pits in the slope below. ore on the ground.
Rabanales I	26	2005-11-30	299.500E	6.530.061N		19.7	7.11	538	268	1		6 persons	Lid	Hose	Digged well. pit in a slope. dry surroundings. Water fills up slowly. runs out occasionaly. Clear water. no smell. No previous analysis. Gold. copper and quarts in the area.
Rabanales II	27	2005-11-30	299.728E	6.529.680N	1264	19.4	7.12	529	262	1		6 persons	Lid. chlorinates	Carries the water in bottles	Pit. Stones on the bottom. Shortage of water in the end of summer. one bucket a day.
Rabanales III (school)	28	2005-11-30	299.978E	6.528.813N	1168	29.5	7.24	622	310		1985	15 pupils	Chlorinates	Hose	Sample taken from hose by the school house. appr 700m from source. Lack of water in summer. No previous analysis.
La Canela	29	2005-11-30	301.308E	6.528.849N	1303	18.5	7.28	573	286			11 persons	Rough filter on the hose to avoid litter.	Hose	Uphill from the school in Rabanales. Pits with hoses. Below deserted enrichment plant and waste deposit.
Quebrada grande	30	2005-11-30	300.619E	6.526.850N	1042	23.3	7.36	376	159	25	1995	20 families		Hose	Grw. Drilling made by mining company looking for ores. Pipe put in. has water all year round. Red percipitations on stones and hoses. reddish algae. Clear water. no smell.
La Yesera	31	2005-11-30	301.391E	6.523.822N	908	29.2	7.53	811	406		>10 ar	12-13 families + school	The tank is cleaned with chloro.	Hose	Central tank for the community that collects water from different sources. No previous analysis.
Rincon del Romero I	32	2005-11-30	305.401E	6.523.398N	1053	21.5	7.26	478	240			7 families	Litter filters on the hoses	Hose	Small pit in stream channel (currrently no running water). this year very dry. Dries up during the day and fills up very slowly at night. Animals have acces to the well.
Rincon del Romero II	33	2005-11-30	305.646E	6.522.062N	1064	22.2	7.43	598	299	1	1970	3 families	the pit is partly covered with lid	Hose	Small concrete pond. Fills up slowly but never dries out. Clear water.
Rincon del Romero III	34	2005-11-30	304.336E	6.523.207N	990	22.2	7.24	924	463			7 families+ 9 pupils		Hose	Shallow well. partly enforced with concrete. in a small ravine below the school in RdR. 6 pumps for the different families. Never dried out.
Alcaparrosa Alta	35	2005-12-01	309.704E	6.521.979N	873	17.7	7.23	673	333	0.3	1975	2 persons	Chlorinates	Hose	Pit enforced with concrete. Not much water this year. No previous analysis. Small coper mines in the valley. close to the pit.
Alcaparrosa Baja	36	2005-12-01	308.517E	6.523.255N	926	18.2	7.15	643	320		1975	4-6 persons	Chlorinates	Hose	Pit with gravel bottom. small stone weir to keep the water. Water all year. has never dried out. Dusty surface film but clear water. Produces goat cheese in small scale.
Alcaparrosa Alta II	37	2005-12-01	311.748E	6.527.599N	1008	23.9	7.41	2212	1096			5 families		Hose	Small stream with little flow. Brown particles accumulated in the stream bed. Salt precipitations on the rocks. Dries out in summer.
Farellon Sanches I	40	2005-12-01	309.297E	6.519.154N	817	25.1	8.06	340	193			10 persons mon-fri		Hose	Stream of meltwater from the mountains. Hoses put in a small natural pond upstream from the village. above an abandoned mine with a small waste deposit.
Farellon Sanches II	41	2005-12-01	310.442E	6.518.588N	876	27.4	7.09	502	256		1983	1 person		Hose	Pit uphill from the house. sample taken from the hose. Less water in summer.
Farellon Sanches III	42	2005-12-01	310.036E	6.519.109N	873	15.7	7.54	818	408			7 persons		Hose	Pit uphill from the house. sample taken from the hose. Water all year round.
Auco	55	2005-12-06	301.096E	6.511.485N	532	27.8	7.51	658	329			6 persons		Hose	Pit further up in the mountains. sample taken from the hose. Never dries out.

				Min	532	15.7	7.09	340	159				
				Max	1303	29.5	8.06	2212	1096				
				Mean	970	22.9	7.34	706	351				
				Median	958	22.2	7.27	622	310				
				Stdev	188	4.4	0.23	417	206				

Cheese

Location	Site ID	Date	Long	Lat	Altitude (m.a.s.l)	Water Temperature (°C)	pH	EC (µS/cm)	TDS (ppm)	Start year	Users	Treatment	Description
Canelillo	50	2005-12-06	284,670E	6,487,58N	396	28.2	7.20	929	462		6 families, 18-20 persons	Lid	Pit enforced with cement.Water all year round. 80 goats. Produce cheese every day that is sold on location. Were using the house but not the tank for cheese production.
Quillacillo I	51	2005-12-06	287,036E	6,515,369N	835	28.0	7.36	616	308	2001	9 persons	Chlorinates	Pit.180 goats. Uses the house.
Quillacillo II	52	2005-12-06	289,520E	6,516,777N	1022	24.5	7.32	439	219	1990	3 persons	Chlorinates	Small enforced pit. Visible particles in the water. 300 goats. Were not using the house for cheese production.
Cocou I	53	2005-12-06	292,840E	6,517,502N	1033	34.5	7.57	606	302	1975	6 persons	Chlorinates	Pit. Visible particles in the water.50 goats. Were not using the house for cheese production.
Cocou II	54	2005-12-06	292,542E	6,516,364N	714	39.7	7.73	602	302				Pit. Nobody was home so sample was taken from a leaking hose.
Quebrada de Gallardo	56	2005-12-06	293,655E	6,506,096N	713	33.6	7.50	664	335		8 persons	Chlorinates	Pit. Mines in the slope. Were using the house and the tank for cheese production.
Cañas de Michio	57	2005-12-06	300,048E	6,498,780N	540	31.9	7.15	1130	568	1955	5 persons	Chloro for cheese production	Pit. 70 goats. Transports the cheese to Illapel. Were using the house for cheese production since two years.
Quebrada de Carcamo	58	2005-12-06	306,026E	6,501,915N	619	29.5	7.12	347	173	1999			APR. 40 goats but no cheese production. Copper mine in the area.
				Min	396	24.5	7.12	347	173				
				Max	1033	39.7	7.73	1130	568				
				Mean	734	31.2	7.37	667	334				
				Median	714	30.7	7.34	611	305				
				Stdev	223	4.7	0.22	253	127				

Stream

Location	Site ID	Date	Long	Lat	Air Temperature(°C)	Water Temperature (°C)	pH	EC (µS/cm)	TDS (ppm)	Altitude (m.a.s.l)	Flow (m^3/s)	Description
Auco I	2	2005-11-20	297.656E	6.502.428N	22.0	24.0	7.82	831	416	384	0.059	Stream. green plants in the streambed. Yellow-brown algae growing on plants and stones.Clear water with fry.
Auco II	3	2005-11-20	297.720E	6.502.370N	22.0	28.9	5.34	1282	641	386	0.0036	Stream 30 m downstream eduction/efflux area. Deposition above eduction/efflux area. Stony stream bed. some reed grass and mud. Thick layer of rosty (orange brown-red) precipitations covering bottom and rocks. Salt precipitations. Particles in the water.
Matancilla	39	2005-12-01	308.967E	6.521.871N	23.6	27.8	7.66	1127	566	836	0.00036	Upstream the Ana Maria deposit. Stony. some algae. Yellowish material accumuleted on the stream bed. Clear water.
Farellon Sanchez I	43	2005-12-03	308.296E	6.519.160N	18.0	17.9	7.20	908	455	765		Slow stream above the destroyed weir.Yellow algae. some salt precipitations.Clear water. water plants. fry and frogs.
Farellon Sanchez II	44	2005-12-03	307.709E	6.518.028N	23.0	24.6	8.34	700	344	734	0.054	Downstream the Farellon Sanchez deposit. Stony stream bed. water plants. some yellow algae. Clear water.
Horizonte I	45	2005-12-03	304.914E	6.517.849N	24.9	29.1	8.47	870	435	665	0.0095	Small digged ditch below houses and cultivations. Some brown algae.
Vattenfall	46	2005-12-04	298.972E	6.503.084N	14.8	14.0	7.63	121	60	397	0.0006	Waterfall from stream in a rocky mountain. Salt precipitations in the ponds below the fall. Particles in the water.
Auco III	48	2005-12-04	296.834E	6.500.953N	23.4	24.1	8.29	929	465	362	0.03	Confluence of Auco I and Auco II that had passes through irrigation ditches before the the concrete pipe from which the sample was taken. Clear water.
Auco IV	49	2005-12-04	297.019E	6.500.041N	26.2	24.4	8.01	714	359	357	0.092	Just before confluence with the Illapel River. Below the Centinela deposit and another deposit (name??). Digged ditch bordered by grass. bushes and trees.
Almendro I		2005-12-04	300.453E	6.517.908N	15.7	16.5	7.64	1636	819	610		Almost still water. no continuous surface flow. Some grass in and beside the channel. Clear water. some salt precipitations.
Almendro II		2005-12-04	300.874E	6.516.193N	17.2	19.4	8.34	1579	791	585		5 m from the base of the Almendro deposit. Stony stream bed with yellow-brown covering. Running water appears and is infiltrated.
Estero Alcaparrosa		2005-12-01	310.283E	6.523.335N	23.0	28.0	8.27	945	460	896		Stream that crossed the road going from alcaparossa alta-baja.
Auco I+II		2005-12-04	297.509E	6.502.322N	23.3	24.5	7.94	933	467	395		Just below confluence of Auco I and II.
Horizonte II		2005-12-03	305.744E	6.517.876N	21.6	27.2	8.29	828	413	680		Below the railway bridge before crossing the road. A lot of green algae.
Farellon Sanchez III		2005-12-03	308.147E	6.518.742N	20.8	22.2	8.21	554	275	760		Stream with meltwater from the mountains that flow past a number of deposits. Crosses the road in F S.
				Min	14.8	14.0	5.34	121	60	357		
				Max	26.2	29.1	8.47	1636	819	896		
				Mean	21.3	23.5	7.83	930	464	587		
				Median	22.0	24.4	8.01	908	455	610		
				Stdev	3.4	4.7	0.78	378	190	192		

Appendix III: Metal Analysis

Location	Origin	Category	Site ID	Al	As	B	Ba	Ca	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn	Mo	Na	Ni	P	Pb	S	Si	Sr	Ti	V	Y	Yb	Zn	Zr
			Atomic weight	26.98	74.92	10.81	137.33	40.08	58.93	52.00	63.55	55.85	39.10	138.91	6.94	24.31	54.94	95.94	22.99	58.69	30.97	207.20	32.07	28.09	87.62	47.87	50.94	88.91	173.04	65.39	91.22
			Detection limit (ppb)	0.68	5.20	1.25	0.47	0.16	0.95	0.48	0.34	0.80	0.84	0.97	1.78	0.06	0.12	1.89	0.21	2.49	15.87	2.05	35.75	5.12	0.01	0.12	1.12	0.13	0.09	1.12	0.34
			Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Socavon Centro	grw	APR	5	0.007		0.14	0.032	58			0.0439	0.08	1.5	0.014	0.003	20	0.0117		29				30	14	0.2	0.0005	0.006		0.0001	0.043	
Limahuida	grw	APR	7	0.010		0.17	0.031	101			0.0707	0.04	2.3	0.016	0.007	33	0.0096		52	0.003			35	14	0.5	0.0005	0.002		0.0002	0.028	
Cañas II and Choapa	grw	APR	9	0.008		0.14	0.032	87			0.4554	0.02	3.0	0.015	0.005	34						0.004	57	12	0.4	0.0006	0.004		0.0002	0.025	
Cañas I	grw	APR	10	0.010		0.12	0.017	53			0.0564	0.02	3.1	0.013	0.005	14			34				25	9	0.2	0.0007	0.003			0.539	
Tunga Sur	grw	APR	12	0.007		0.10	0.010	30			0.0121	0.10	4.0	0.010	0.003	8			18				14	8	0.1	0.0006	0.003			0.057	
Coyuntagua Sur	grw	APR	13	0.010		0.12	0.009	44			0.1254	0.01	2.4	0.012	0.004	15			49			0.006	22	10	0.2	0.0006	0.007			0.031	
Tunga Norte	grw	APR	15	0.007		0.09	0.009	32			0.0310	0.02	1.7	0.011	0.005	8			15				12	8	0.1	0.0005	0.003			0.025	
Peralillo	grw	APR	16	0.007		0.12	0.003	36			0.0151	0.01	0.8	0.011		24	0.0378		33				20	18	0.1	0.0006	0.030		0.0001	0.023	
Huintil Sur	grw	APR	19	0.004		0.05	0.004	30			0.1167	0.01	1.6	0.010		8			8				7	9	0.1	0.0006	0.004			0.037	
Santa Virgina	grw	APR	21	0.078		0.03	0.001	25		0.0007	0.1151	0.21	3.7	0.009		5	0.0008		6			0.021	7	7	0.1	0.0024	0.001	0.0001		0.129	
Carcamo	grw	APR	23	0.007		0.07	0.004	36			0.1746	0.02	0.7	0.010		11			13			0.004	10	11	0.1	0.0007	0.006			0.014	
Asiento Viejo	grw	APR	25	0.006		0.08	0.016	57			0.1898	0.01	0.4	0.014		19			20				18	14	0.2	0.0004	0.005		0.0001	0.009	
Canelillo	pit	cheese	50	0.007		0.08	0.002	59				0.01	1.0	0.016	0.003	35			60				19	14	0.2	0.0005	0.017		0.0001	0.002	
Quillacillo I	pit	cheese	51	0.057		0.07	0.017	61				0.08	4.5	0.014	0.005	28	0.0009		24				7	19	0.2	0.0075	0.042		0.0001		
Quillacillo II	pit	cheese	52	0.011		0.08	0.016	42				0.03	0.4	0.010	0.003	21	0.0070		18				4	19	0.1	0.0012	0.028	0.0001			
Cocou I	pit	cheese	53	0.023		0.06	0.006	58				0.03	0.6	0.014	0.005	27	0.0073		22				5	18	0.1	0.0019	0.039	0.0001	0.0001		
Cocou II	pit	cheese	54	0.013		0.07	0.003	56				0.02	0.6	0.013	0.003	24	0.0137	0.002	25		0.02		6	13	0.2	0.0009	0.016	0.0001	0.0001		
Quebrada de Gallardo	pit	cheese	56	0.009		0.06	0.021	58			0.0004	0.01	0.8	0.012	0.004	26	0.0002	0.023	30			0.002	29	11	0.2	0.0007	0.009		0.0001		
Cañas de Michio	pit	cheese	57	0.011		0.15	0.012	128				0.01	1.2	0.016	0.004	37			56				68	13	0.5	0.0006	0.009		0.0002	0.003	
Quebrada de Carcamo	grw	cheese	58	0.006		0.09	0.005	39			0.0288	0.01	1.6	0.012		14			11			0.002	10	12	0.1	0.0005	0.002		0.0001	0.019	
Rabanales I	pit	plan de horno	26	0.030		0.04	0.003	90				0.04	2.8	0.015		19	0.0031		16				1	8	0.1	0.0005	0.001	0.0002	0.0002		
Rabanales II	pit	plan de horno	27	0.016		0.03	0.009	87			0.0005	0.06	1.1	0.015		18	0.0249		16				3	9	0.1	0.0006		0.0002	0.0002		
Rabanales III	pit	plan de horno	28	0.009		0.02		82				0.01	1.5	0.016		22			20				38	13	0.2	0.0004	0.003		0.0002		
La Canela	pit	plan de horno	29	0.017		0.02		85			0.0010	0.03	1.6	0.016		22	0.0018		20				40	13	0.2	0.0008	0.002		0.0002	0.002	
Quebrada grande	grw	plan de horno	30	0.046	0.0099	0.09	0.010	143				0.55	0.8	0.019	0.004	14	0.0267		19				85	14	0.5	0.0012			0.0002		
La Yesera	pit	plan de horno	31	0.009	0.0083	0.09	0.004	153				0.01	3.0	0.018	0.005	14			17				94	13	0.6	0.0004	0.002	0.0002	0.0003		
Rincon del Romero I	pit	plan de horno	32	0.044		0.05	0.007	62			0.0012	0.05	1.4	0.015		20	0.0005		19				10	11	0.2	0.0019	0.007		0.0001	0.014	
Rincon del Romero II	pit	plan de horno	33	0.013	0.0084	0.10	0.005	89				0.01	1.9	0.015		20			25				4	14	0.3	0.0004	0.017		0.0002	0.008	
Rincon del Romero III	pit	plan de horno	34	0.010		0.03	0.020	157			0.0022	0.01	0.6	0.017	0.004	34			21				123	11	0.4	0.0004	0.002	0.0002	0.0003	0.011	
Alcaparrosa Alta	pit	plan de horno	35	0.123		0.30	0.010	105			0.0006	0.14	0.3	0.017	0.003	23	0.0459		28				37	11	0.4	0.0034	0.004	0.0001	0.0002	0.003	
Alcaparrosa Baja	pit	plan de horno	36	0.023		0.09	0.020	101				0.03	1.9	0.016		24	0.0043		20				32	10	0.3	0.0010	0.002	0.0002	0.0002	0.002	
Alcaparrosa Alta II	stream	plan de horno	37	0.017		0.19	0.023	500				0.04	1.6	0.019		63	0.0403		47				501	7	1.2		0.001	0.0002	0.0009		
Matancilla	pit	plan de horno	38	0.010		0.21	0.019	92				0.01	1.9	0.016	0.004	24			28				46	10	0.4	0.0005	0.005	0.0002	0.0002		
Farellon Sanches DI	stream	plan de horno	40	0.010		0.25	0.016	53				0.02	3.4	0.014		14	0.0118		15				7	11	0.2	0.0006	0.006		0.0001		
Farellon Sanches DII	pit	plan de horno	41	0.006		0.26	0.002	72				0.03	0.6	0.015	0.002	18			18			0.002	18	9	0.2	0.0005	0.004		0.0001		
Farellon Sanches DIII	pit	plan de horno	42	0.038		0.23	0.005	113			0.0028	0.04	1.7	0.015	0.003	24	0.0038		32				76	11	0.5	0.0010	0.004		0.0002	0.003	
Auco	pit	plan de horno	55	0.012		0.10	0.012	66				0.01	1.6	0.015	0.004	28		0.002	35				6	12	0.2	0.0006	0.014	0.0002	0.0001		
Auco I	stream	stream	2	0.009		0.17	0.022	135			0.0012	0.02	2.4	0.018		26	0.0058		26				86	9	0.5	0.0006	0.002	0.0002	0.0002	0.007	

Auco II	stream	stream	3	2.036		0.20	0.014	167	0.16		0.4259	39.66	2.3	0.027	0.007	51	14.1117		25	0.09		0.005	261	10	0.5	0.0003		0.0154	0.0012	0.668	0.004
Matancilla	stream	stream	39	0.009	0.0065	0.39	0.041	172				0.02	3.3	0.021	0.004	42	0.0125		38				158	11	0.7	0.0004	0.002	0.0001	0.0003		
Farellon Sanchez I	stream	stream	43	0.008		0.25	0.017	138				0.02	2.6	0.020	0.003	30	0.0059		30				113	8	0.5	0.0007	0.003	0.0002	0.0002	0.001	
Farellon Sanchez II	stream	stream	44	0.009		0.29	0.023	98			0.0057	0.01	1.9	0.014	0.003	26	0.0005		23				68	9	0.4	0.0009	0.003	0.0001	0.0002	0.001	
Horizonte I	stream	stream	45	0.012		0.31	0.031	112			0.0066	0.02	2.0	0.016	0.003	30	0.0036		33				102	9	0.5	0.0008	0.003		0.0002		
Waterfall	stream	stream	46	0.296		0.04	0.004	15			0.0035	0.29	3.9	0.007		3	0.0126		3				4	6	0.1	0.0070	0.002	0.0002		0.002	
Auco III	stream	stream	48	0.012		0.19	0.011	136			0.0004	0.05	1.6	0.018	0.003	27	0.0122		27				100	9	0.5	0.0008			0.0002	0.002	
Auco IV	stream	stream	49	0.058		0.14	0.019	106			0.0052	0.08	1.0	0.018		20	0.0170		19				77	7	0.3	0.0019	0.001	0.0001	0.0002	0.002	
			Min	0.004	0.0065	0.02	0.001	15	0.16	0.0007	0.0004	0.01	0.3	0.007	0.002	3	0.0002	0.002	3	0.003	0.02	0.002	1	6	0.1	0.0003	0.001	0.0001	0.0001	0.001	0.004
			Max	2.036	0.0099	0.39	0.041	500	0.16	0.0007	0.4554	39.66	4.5	0.027	0.007	63	14.1117	0.023	60	0.085	0.02	0.021	501	19	1.2	0.0075	0.042	0.0154	0.0012	0.668	0.004
			Mean	0.069				92				0.91					0.5155						54					0.0009		0.059	
			Median	0.010				83				0.02					0.0085						27					0.0002		0.011	
			Stdev	0.300				74				5.84					2.6646						84					0.0034		0.154	
			Average (without outlier)	0.025	0.0083	0.13	0.013	83	0.16	0.0007	0.0701	0.05	1.8	0.015	0.004	23.2	0.0119	0.009	25	0.044	0.02	0.006	44	11	0.3	0.0011	0.008	0.00016	0.0002	0.037	0.004
			Median (without outlier)	0.010	0.0083	0.10	0.011	82	0.16	0.0007	0.0121	0.02	1.6	0.015	0.004	22.5	0.0073	0.002	23	0.044	0.02	0.004	25	11	0.2	0.0006	0.004	0.00015	0.0002	0.010	0.004
			Stdev	0.047	0.0014	0.09	0.010	42			0.1205	0.09	1.1	0.004	0.001	11.3	0.0127	0.012	13	0.058		0.006	51	3	0.2	0.0015	0.010	0.00002	0.0002	0.102	

= limit guideline exceeded

= outlier

Detection limits for the elements that were not detected in any sample:

Cd: 0.89 µg/l
Se: 14.03 µg/l
Rb: 11.25 µg/l
Sc: 0.17 µg/l