A WATER QUALITY ASSESSMENT OF THE RIO KATARI RIVER AND ITS PRINCIPLE TRIBUTARIES, BOLIVIA

BY

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B.S. Earth and Environmental Science (Geology Option)
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Professional Project

Submitted in Partial Fulfillment of the
Requirements for the Degree of

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The University of New Mexico
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ABSTRACT OF THESIS

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ABSTRACT

The Altiplano region of Bolivia located between Lake Titicaca and La Paz is one of the fastest growing regions in the world. Demands for safe drinking water, sewage treatment and cleaner industrial and agriculture methods are not being met and are adversely affecting surface and groundwater sources. Detrimental water quality often leads to water borne illnesses that can be fatal, especially in young children, the elderly and immune compromised individuals.

This paper describes a project that was conducted to determine the impact of El Alto and surrounding communities on the water quality of the Rio Katari and its principal tributaries. Water samples were collected and analyzed in January and June 2009 to determine the seasonal changes and the spatial variability in the Rio Katari, Rio Seco and Rio Pallina. Results indicate that the waters of the Rio Seco and Rio Pallina are greatly impacted by anthropogenic activities from the cities of El Alto and Viacha. The Rio Katari is impacted by agricultural uses and the discharge of the Rio Pallina. At all sampling locations during both sampling events fecal coliform exceeded Safe Drinking Water Act (SDWA) Minimum Concentration Limit (MCL). In addition to fecal coliform nitrate-N exceeded its SDWA MCL and World Health Organization (WHO) recommended limit at one location and neared the SDWA MCL and WHO recommended limit at other locations. Toluene exceeded its SDWA MCL and WHO recommended limit at

multiple locations, and sulfate exceeded its SDWA MCL at two locations.

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1.0 INTRODUCTION

1.1 Problem Statement

The Altiplano region of Bolivia, located between Lake Titicaca and La Paz (study region) (Figure 1 and 2) is one of the fastest growing regions in the world (Arbona and Kohl, 2004). As the population of this region has increased, so have the stresses on the water sources and water and wastewater systems. Currently, there are limited facilities in the area to properly collect and treat municipal wastewater prior to discharge. It is estimated that between 35% and 54% of the population of the municipality of El Alto have access to the El Alto wastewater treatment facility (WWTP). This estimation is based on a portion of El Alto, not the entire municipality, thus it is an over-estimation of coverage (Inter-American Development Bank, 1998). The remaining waste, from the population of El Alto that is not connected and from the municipality of Viacha (which lacks a wastewater treatment facility) is thought to be discharged directly to surface water or to onsite latrines (Komives, 1999). Other contributors to surface water contamination in the region include impacts from erosion, industrial discharges, and urban storm water (Field visit, 2009).

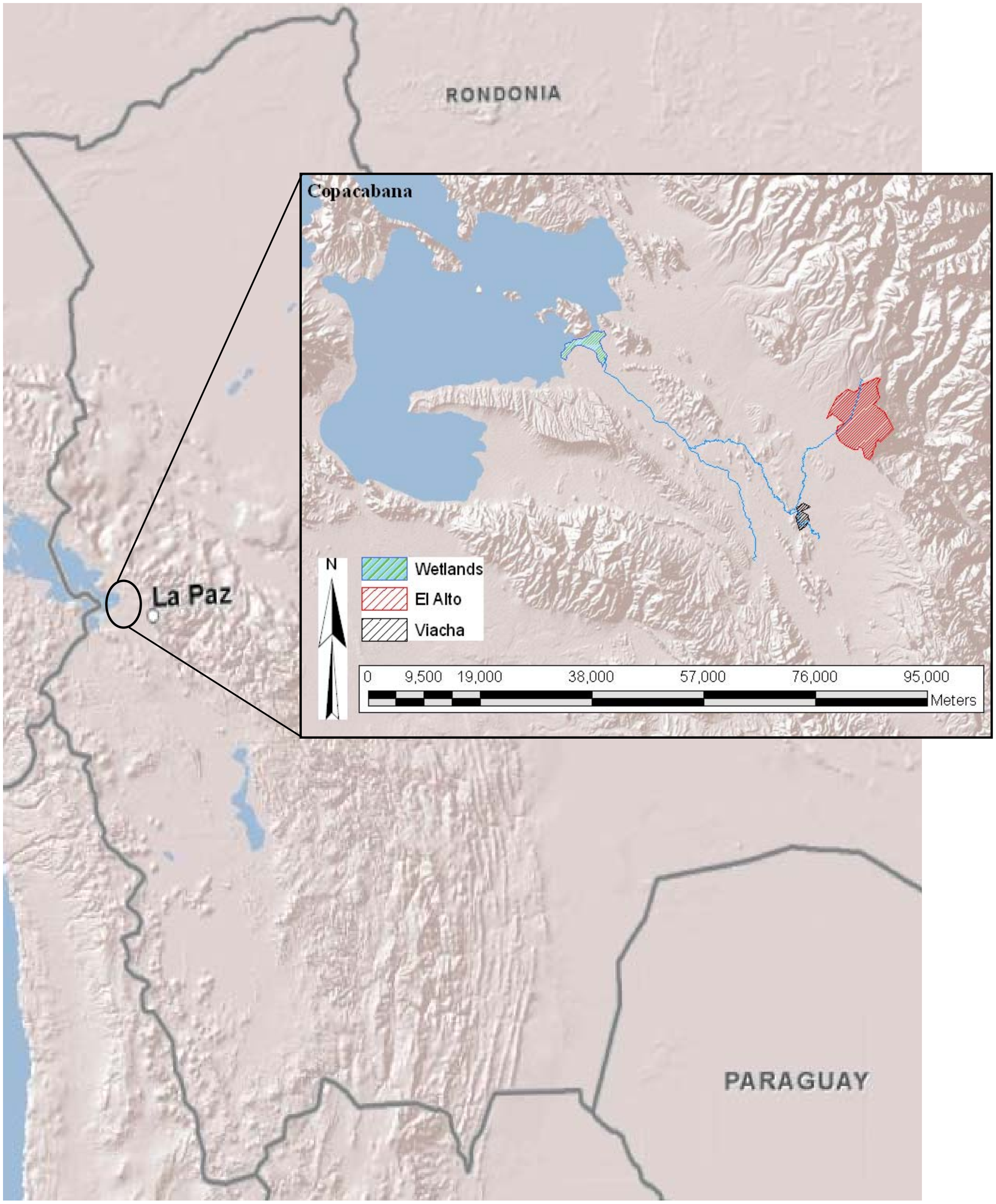

Figure 1: Location of Bolivia with study site circled and blown up.

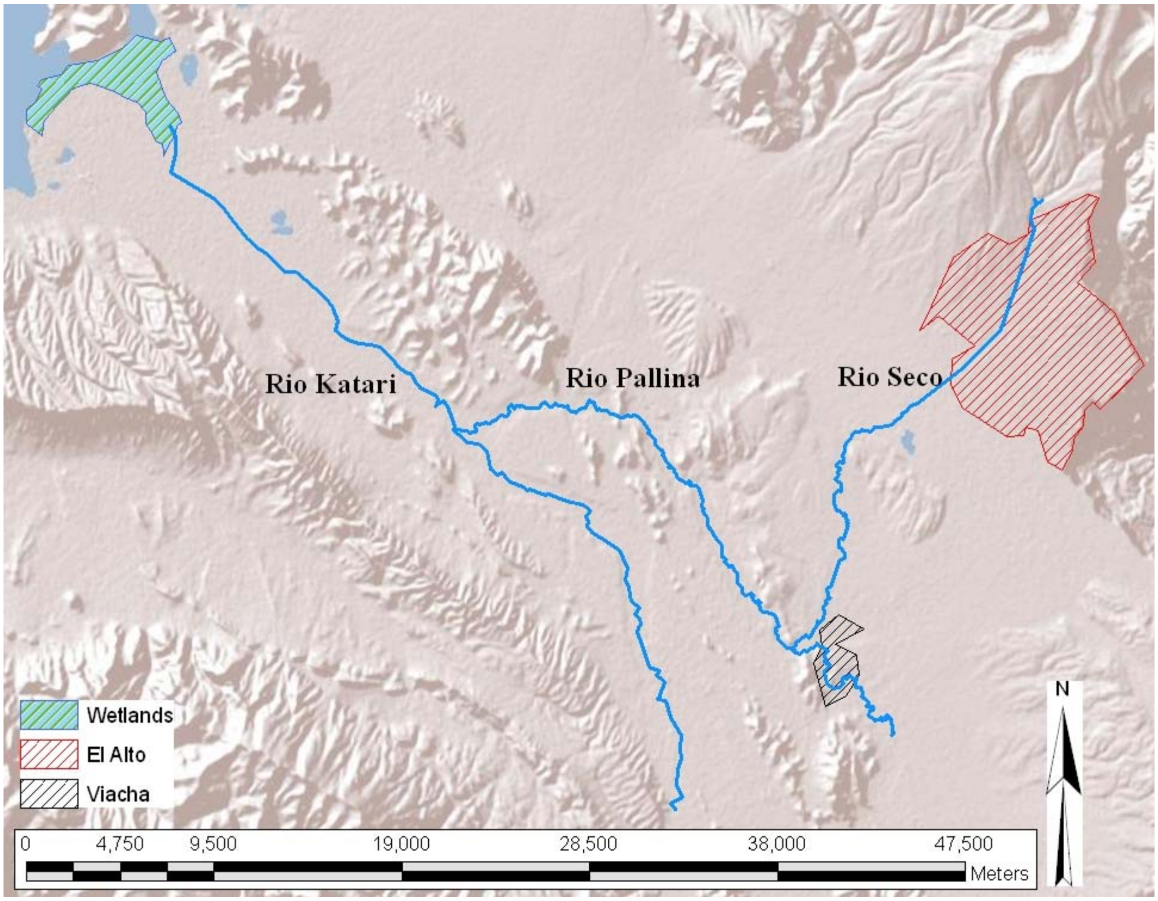

Figure 2: Study site showing the location of the Rio Katari, Rio Seco and Rio Pallina and the municipalities of El Alto and Viacha.

Three rivers flow through the study region; the Rio Katari, Rio Seco and Rio Pallina. Because of rapid growth, a lack of environmental protection, lack of facilities to properly treat wastewater, urban contaminants and other types of waste the three rivers are being adversely impacted. The Rio Seco flows through El Alto, where treated and untreated sewage and other contaminants are discharged into it. The Rio Seco discharges into the Rio Pallina approximately 20.8 km downstream of El Alto and 2 km downstream of Viacha. The Rio Pallina flows through Viacha, where untreated sewage and contaminants are discharged into it (Field visit, 2009) and flows into the Rio Katari approximately 18 km downstream of Viacha. The Rio Katari flows through rural areas and discharges into Lake Titicaca. Figure 3 provides three photos taken in the study region, showing some of the types of contamination in the region.

Figure 3. Three common types of contamination in the study region. The picture on the left is raw sewage and waste from a nearby slaughter house/tannery entering the Rio Pallina. The middle picture is an oil change business where the waste oil/fluids are being discharged into the Rio Seco. The picture on the right is the Viacha cement plant that increases sediment levels in the river and air.

In the study region there are two large municipalities; El Alto and Viacha (Figure 2). As mentioned above El Alto has a wastewater collection and treatment system servicing up to 54% of the population, while Viacha has no wastewater treatment system (WEFTA, 2008). In addition to El Alto and Viacha there are small villages and single family houses spread out in the region between the two cities and Lake Titicaca.

Human exposure to and consumption of the impaired water in the study region can result in waterborne illnesses. Waterborne illnesses cause gastro-intestinal symptoms such as diarrhea and abdominal cramps. According to the World Health Organization (WHO), 17% of the deaths in children worldwide under five are caused by diarrheal diseases (World Health Organization, October 2008). Ingesting excessive fecal coliform may lead to bloody diarrhea, diarrhea and abdominal cramps. Children under five and the elderly can also contract hemolytic uremic in which red blood cells are destroyed and the kidneys fail. Elevated nitrogen concentrations in the water may cause methemoglobinemia (blue baby syndrome) in young children and in infants. Methemoglobinemia impairs the oxygen carrying capacity of the blood. In adults elevated nitrogen may cause diuresis, an increase in starchy deposits and hemorrhaging of the spleen. Many of the volatile organic carbons found in gasoline and industrial waste are carcinogenic and may cause an increase in cancer related illnesses (Center for Disease Control and Prevention, October 2008). Consumption of impaired water in El Alto has led to the outbreak of acute Fascioliasis (Bjorland, et. Al., 1995) and Cryptosporidium (Esteban, et. Al, 1998). Figure 4 is a photo of women washing laundry in the Rio Seco, it is unknown if they also consume the water.

Figure 4. Women washing laundry in the Rio Seco, El Alto, during field work. Human consumption of the water was not observed, however water borne pathogens and contaminants can also enter the human body through open wounds and the eyes and nose.

1.2 Study Objectives

The objective of this project was to investigate the impacts of urban development on the water quality of the Rio Katari, Rio Seco and Rio Pallina. The three rivers flow through varying forms of land use so to the extent feasible, a determination as to how each of the three rivers are being impacted and what they are being impacted by was also completed.

The specific objects were to:

- Determine water quality characteristics of the three rivers during two sampling events that occurred in the dry season and wet season.
- Identify critical areas of contamination
- Make recommendations for future work

2.0 BACKGROUND

2.1 Project Site and Description

2.1.1 El Alto-City Profile

The region in the Altiplano in Bolivia located between Lake Titicaca and La Paz is one of the fastest growing regions in the world. The reason for the rapid growth of the area can be attributed to the geography of the region and natural and economic events (Arbona and Kohl, 2004). El Alto is located adjacent to the Bolivian capitol city of La Paz, which is located in a steep canyon with limited room for growth. In the early 1900's industries that needed a lot of space built their facilities in El Alto. Industries included a railroad, oil refinery and an airport (Arbona and Kohl, 2004). In the 1950's as workers in rural areas were set free from estates in which they worked they migrated to El Alto. A drought between 1982 and 1983 brought tens of thousands of farmers to El Alto. Another population boom occurred in 1985 as state mines closed, many of those who lost jobs migrated to El Alto. As a result of these events, El Alto has experienced an average growth rate of about 8.2% per year and estimates project the population to approach 1 million people by 2010 (Arbona and Kohl, 2004). In 1988 El Alto became incorporated; however the high poverty rate makes it difficult to tax citizens to support needed infrastructure (Arbona and Kohl, 2004).

2.1.2 Viacha-City Profile

Viacha is located approximately 12 kilometers southwest of El Alto. In 2001 the population of Viacha was 29,108 (Instituto Natcional de Estadistica, 2009). Viacha is a relatively wealthy city due to industry. Industry in Viacha includes a cement plant, and a bottling plant for Bolivia's largest brewery. Many textile, brick and tile factories are spread out between El Alto and Viacha along the road known as Camino de Viacha. The industries are taxed; however those who benefit financially from the different industries tend to relocate to La Paz bringing their wealth with them (Faguet, 2003).

2.1.3 Water and Wastewater System of El Alto-La Paz

In 1966 SAMAPA (Servicio Autonomo Municipal de Agua Potable y Alcantarillado) was established in La Paz to supply drinking water and sewer services to La Paz and its suburbs (Komives, 1999). When El Alto became incorporated in 1988 SAMAPA extended its service to cover both municipalities. The national government announced a plan in the 1990's to place national supervision over water and sanitation services offered by municipalities. The National Regulations for Water and Sanitation Service in Urban Areas founded in 1992 declared that the only acceptable long-term management of water and wastewater would be to offer all services in individual homes, thus public bathrooms and delivered potable water would be unacceptable. In 1997 another regulation was passed to appoint a Superintendencia de Aguas (Superintendent of Water), who would be responsible in giving permission to municipalities to extend water and wastewater services. In 1997 the Superintendent of Water gave Aguas del Illimani, a private company and subsidiary of Lyonnaise des Eaux, a 30-year contract to take over SAMAPA and supply water and wastewater services to El Alto and La Paz (Komives, 1999),

Aguas del Illimani signed a contract with specific targets for expansion of water and wastewater connections. In the contract Aguas del Illimani was obligated to bring wastewater coverage in La Paz up to 82% and in El Alto up to 41%. The contract also required Aguas del Illimani to bring water connections up to 84% in La Paz and 71% in

El Alto by 2001 (Inter-American Development Bank, 1998). Contract requirements were not met and in 2006 the contract with Aguas de Illimani was dissolved due to a popular movement that opposed privatization of water and wastewater services (Jacobs, 2007). The water and wastewater systems are now managed by a Minister of Water and strategic planning is in place to extend water and wastewater coverage (bolivia.gov, 2009).

2.1.4 Environmental Laws and Regulations Protecting the Waters of Bolivia

On April 27, 1992 the Ministry of Sustainable Development and the Environment of Bolivia published the "Reglamento de la Ley Nº 1333 del Medio Ambiente, Reglamento en Materia de Contaminacion Hidrica." A copy of the law can be found in Appendix E. This environmental law was promulgated for the prevention and control of water pollution. The law is divided into sections as follows:

- Title I – Classification of the four types of water (Articles 1-7)
- Title II – Institutional Framework (Articles 8-12)
- Title III – Technical and Administrative Procedures (Articles 13-29)
- Title IV – Monitoring, Evaluation, Prevention, Protection and Conservation of Water Quality (Articles 30-70)
- Title V – Legal Violations (Article 71)
- Title VI – Transitory Disposition (Articles 72-74)

Currently the situation in the study area is such that the law is not being abided by or enforced. Title III primarily addresses wastewater effluent; it is unknown if the El Alto WWTP is following these laws, or if any industries in the area are, but based on observations it is unlikely. Title 4, Article's 41, 43, 44, 46, 50, 51, 53 and 63 are all being violated: Article 41 addresses the spills of hydrocarbons; Article 43 addresses the entry of mining water to surface waters; Article 44 addresses the entry of large volumes of untreated/treated effluent into surface waters; Article 46 addresses the discharge of effluent from leach fields; Article 50 addresses the pre-treatment of industrial effluent;

Article 51 addresses the protection of wetlands; Article 53 addresses corrective action by the ministry for impaired waters and Article 69 addresses the maintenance of international waters.

2.1.5 Environmental Management of Lake Titicaca

In 1955 Peru and Bolivia signed a formal agreement to manage and study the Lake Titicaca watershed (Rieckermann, et. Al., 2006). This agreement was formalized in 1986, and the European Union was asked to help develop a framework for the management of the Lake Titicaca watershed. Consulting and engineering firms from Europe carried out multiple studies, which resulted in a "Binational General Master Plan for the Development of the Integrated Region of Lake Titicaca." The master plan has a time-frame of 20 years and was evaluated by Rieckermann, Daebel, Ronteltap and Bernauer in a research article titled *Assessing the performance of International Water Management at Lake Titicaca*. What the article found that information is limited, management objectives are vague and the environmental problem is larger than what was anticipated. The authors also found widespread poverty impedes environmental awareness, and due to the lake straddling the border of two third-world countries, the plan is not realistic.

2.2 Climate and River Network

2.2.1 Climate

The height of the wet season in the study area is in January when the area receives about 130 mm of rainfall during the month (Table 1). Given the localized nature of the thunderstorms, one portion of the watershed may experience heavy precipitation while other areas remain dry. The height of the dry season is in June, when the region receives about 4mm of precipitation during the month (gaisma.com, 2009). During the dry season flow in the rivers is highly augmented by treated and raw domestic and industrial waste from El Alto and Viacha.

Table 1. Average Monthly Precipitation												
Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Precipitation (mm/month)	130	104	75	33	13	4	6	16	34	34	51	99

Data acquired from Gaisma

2.2.2 River Network

The Rio Katari flows through the Altiplano and discharges into either a wetland (when water levels in Lake Titicaca are low) or into the Cohana Bay of Lake Titicaca (when water levels are high) (Figure 1). The slope of the Rio Katari is approximately 0.07%. The river profile for the Rio Katari can be seen in Figure 32, Appendix C. The wetlands are utilized for farming and transportation. Along the Rio Katari there are scattered farms. The density of farms increases as the river nears Lake Titicaca. There are many ephemeral tributaries that flow into the Rio Katari, but only two perennial tributaries; the Rio Seco and Rio Pallina. The headwaters of the Rio Seco originate north-east of the Rio Katari, which flows through the city of El Alto and into the Rio Pallina. The Rio Seco has a slope of about 0.9%. The river profile for the Rio Seco can be seen in Figure 33, Appendix C. The headwaters of the Rio Pallina are east of the Rio Katari, and the rivers flows through the city of Viacha and into the Rio Katari. The slope of the Rio Pallina is approximately 0.03%. The river profile for the Rio Pallina can be seen in Figure 34, Appendix C.

2.3 Geology of the Site

The Project Site is located in the region of the Andes known as the Altiplano, between Lake Titicaca and La Paz. The Altiplano is an intra-arc basin located between the eastern and western cordilleras of the Andes (Smith and Landis, 1995). The basin began to form about 16.4 million years ago and contains fill of up to 10 kilometers in thickness (Smith and Landis, 1995). The basin fill consists of primarily of clastic sediments derived from streams and shallow lakes; in addition there are sandstones, mudstones and reworked volcanic material present (Allmendinger, et. al., 1997).

2.4 Previous Work

In 2002 Octavio Maquera Nina and John Wilson Loza Callisaya, two students of the Engineering Department at the Universidad Mayor de San Andres (UMSA) completed a study titled "Evaluacio de la Calidad de las Aguas del Curso de Agua "Rio Seco" de la Ciudad de El Alto" as part of their degree requirement. The general objectives of this report were to evaluate the stream quality of the portion of the Rio Seco that flows through El Alto, determine the chemical, physical and microbiological characteristics of the River and determine uses of the river and quantify contamination in the river. The specific objectives were to categorize water quality, evaluate the river's impact on the ecosystem, establish the level of impairment, evaluate the applicability of environmental law, determine possible uses for the river and provide El Alto with a study of the water quality.

The study found 13 facilities/industries located along the margins of the Rio Seco including; milk and soda factory, two tanneries, a sawmill, a PVC factory, two laundry and dry cleaning facilities, two public bathrooms, the El Alto-La Paz international airport and a mechanic. In addition to the 13 identified facilities/industries there are undocumented facilities/industries along the Rio Seco, which include slaughter houses, tanneries, car washes and sand and gravel mining activities. The documented and undocumented facilities/industries do not have treatment, and it is presumed they discharge into the Rio Seco. Downstream of El Alto livestock impacts include sheep and pigs.

The results of this study indicated that the Rio Seco is impacted by domestic sewage, garbage, discharges from documented and undocumented facilities/industries and downstream of El Alto by livestock (sheep and pigs). The study found the highest impact is from the slaughter houses and tanneries. During dry months contamination accumulates due to the lack of precipitation and runoff from glaciers. The direct impact to human health has not been quantified, but the study speculates that those who live on the margin of the Rio Seco and utilize the water may suffer from diarrhea, parasites and dysentery. Furthermore animals that consume the water may become ill and when they are consumed, those illnesses may spread outside the margins of the Rio Seco.

As documented in the study, a large part of the problem is related to the fact that El Alto has no strategic or integrated plans to help address improvements to infrastructure, manage growth or educate people about the environmental consequences associated with the quality of the river. The study recommended the implementation of programs to improve environmental awareness, especially for those who live near the Rio Seco. The recommendations include a public authority to develop/adopt environmental standards, instantiating a campaign to improve the water quality, control stormwater runoff from entering the river, improve open channels to improve oxygenation of the Rio

Seco and provide solid waste management. The study also recommends further monitoring, examination of solid waste impact on water quality and placement of new industries in a consolidated area where post treatment can occur prior to discharge to the Rio Seco. Further recommendations include the implementation of treatment for slaughter houses and tanneries and examination of appropriate technologies for treatment of waste from households. Future work the study identified includes quantification of population and population distribution, mapping topography, quantifying discharges, improving hydrologic data available and consolidating work that has been completed.

In November 2006 volunteers from the non-profit group Water Engineers for the Americas (WEFTA) visited the Lake Titicaca region of Bolivia and were alerted to water quality issues at Lake Titicaca and its tributaries (Personal Interview with Peter Fant, President of WEFTA, 2008). During various other visits to Bolivia, WEFTA volunteers photo documented additional examples of significant water contamination, such as leaking wastewater transmission lines, leachate from landfills entering surface water, agricultural waste directly discharged to surface water, and slaughter-house waste being discharged into the surface water.

Tierramerica is an online newsletter published by the United Nations Environment Program (UNEP), United Nations Development Program (UNDP) and the World Bank (Tierraamerica, 2008). The newsletter focuses on informing people of environmental and development issues. In the June 2, 2008 issue, Bernarda Claure contributed a piece titled “Titicaca Truths Revealed” highlighting the issues associated with developing surface water monitoring programs at Lake Titicaca and its affiliated tributaries. This article also highlighted the problem that although many private, public and academic institutions have investigated contamination at Lake Titicaca and its tributaries, the information collection efforts have not been standardized, sustained or continuous. What is known is that untreated sewage, industrial and agriculture discharges have a very large impact on water quality in the region. Due to the lack of consolidated data the full impact is unknown (Tierraamerica, 2009).

The compromised water quality impacts the environment, social welfare and health of the people who depend on the Rio Katari its tributaries and Lake Titicaca. Those who are most impacted are the ones who do not have access to safe drinking water, or a shallow well that is hydrologically connected to the contaminated rivers, those that are downstream of the contamination, and anyone who needs to utilize the rivers and/or Lake Titicaca. Based on this information there is a need for a continuation of the investigation of water quality impacts in the region, as well as the need for recommendations to curb the problems.

3.0 METHODOLOGY

3.1 Introduction

The objectives of this project were to analyze the quality of the Rio Katari and its principal tributaries; Rio Seco and Rio Pallina. Due to rapid growth, a lack of facilities to manage waste and no strategic planning, the Rio Katari, Rio Seco and Rio Pallina are being contaminated. Locations that would best represent water quality prior to contamination and areas that would best show where contamination was coming from were selected for sampling. Analysis was done for parameters that would help determine the chemistry of the water, as well as the types of contamination impacting the area. For this project sample analysis was performed by the Universidad Mayor de San Andres Facultad Ingenieria Carrera de Ingenieria Civil Laboratorio (UMSA Lab), and by Hall Environmental Analytical Laboratory (Hall). The UMSA Lab was selected because of its proximity to the field area and Hall was chosen for their capabilities in analyzing volatile organic carbons (VOCs).

3.2 Sample Site Selection and Sampling Frequency

The Rio Seco, Rio Katari and Rio Pallina were surveyed to determine where the location of headwaters and discharge points are located, as well as determine land use along the rivers. Sample sites were chosen in order to determine water quality upstream from development, degree of water quality degradation along the length of the river, and to determine areas of greatest impact. In addition, intermittent points along the Rio Seco and Rio Pallina were sampled to determine the impact El Alto and Viacha have on the rivers.

January and June were selected as the sampling months in order to determine seasonal water quality in the region. In January 2009 (the wet season), 13 sampling sites were selected. Five sampling sites were located on the Rio Seco, four sites on the Rio Pallina, two sites on the Rio Katari and one site in a ditch that flows between El Alto and Viacha. Additionally, one sample was inadvertently taken at a river that was thought to be the Rio Katari near Lake Titicaca, but was not. In June 2009 (the dry season) the same sites were selected, except for the incorrect river, and two additional samples from the Rio Katari were taken. Figure 5 shows the sampling locations for the January and June 2009 sampling events.

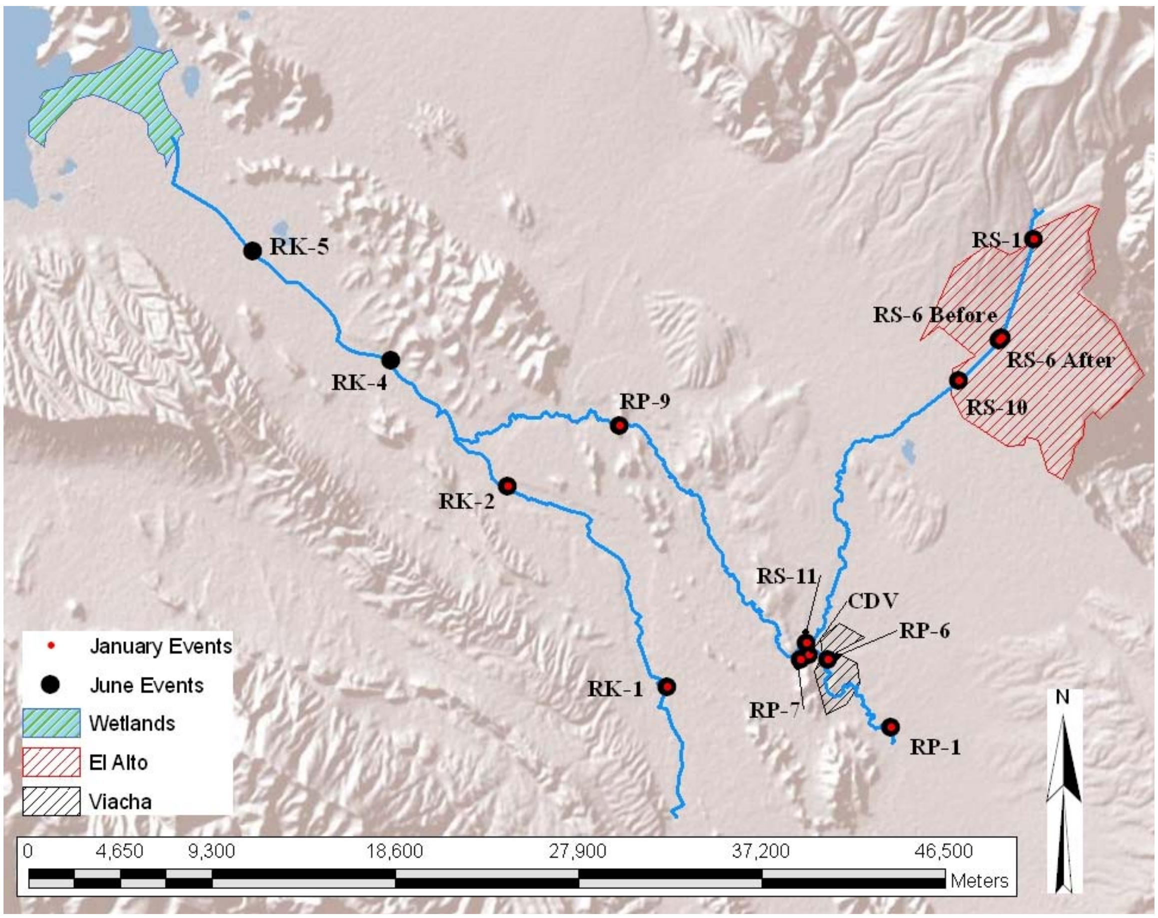

Figure 5. January and June 2009 sampling event and sample locations.

The selected sites and their description are as follows:

RS-1 is located at the headwaters of the Rio Seco, which is at the northern edge of El Alto. In January a ditch, lined with trash, from a cluster of nearby houses discharged into the river. Between the January and June sampling events the trash lined ditch was replaced with a plastic pipe. In January there was flow in the river upstream of the above mentioned discharge point. The water upstream of the discharge point was sampled, however in June there was no base flow and the water sample was collected from the discharge water that came from the nearby housing cluster. During both sampling events the water downstream of the discharge was grey and had a slight wastewater odor. During both sampling events the river was used for watering livestock, excavation of rocks and dirt, and as a dumping ground for trash. In addition during both sampling events children and adults were seen in the river. Figure 6 shows sample location RS-1 during the January and June 2009 sampling events.

Figure 6. Photo on left shows RS-1 during January 2009 when there was water in the river. The photo on the right shows RS-1 during June, when the only water in the river was from raw sewage being discharged into the river.

RS-6 wet season and dry season sampling sites are located in the Rio Seco in El Alto. In this reach the Rio Seco is confined to a cement channel with a rocky bottom. Between the two sampling points is a large ditch from the downtown portion of El Alto that enters the river (Ceja). At both sampling location the water had a slight wastewater odor and at RS-6 After the water contained blood. At these sampling points there were dead animals and trash in the water course. During both sampling events people were observed in the river utilizing the water for cleaning clothing, vehicles and recreational use (children playing in the water, adults and children walking in the water). Figure 7 is two photos of the sampling sites taken in January and June 2009.

Figure 7. RS-6 Before and RS-6 After sampling locations. The photo on the left shows the site in January 2009, during this sampling event the river was discolored because of animal slaughter waste being dumped into the river. RS-6 before was taken upstream of the canal on the right hand side of the photo, and RS-6 after was taken downstream of the canal after the two waters had mixed.

RS-10 is located in the Rio Seco. During the January 2009 sampling event this sampling point coincided with the end of development in El Alto. In January 2009 there was extensive foaming observed in the water and there was a slight wastewater odor. During June 2009 the river was dark grey and had a very strong wastewater odor. During both sampling events the river was used for livestock watering and recreational uses. In June 2009 new development at this point was observed, this consisted of installing a pipe (use uncertain) from the new houses to the river, as well as mining gravel from the river. Due to the removal of the gravel the course of the river had also shifted dramatically. Figure 8 is photos of sample site RS-10 during the January and June 2009 sampling events.


Figure 8. The photo on the left is RS-10 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event. Between the two sampling events water level in the river had decreased greatly. They were also developing more adjacent to the site and the course of the river had been moved and gravel was being excavated at the sampling site.

RS-11 is located in the Rio Seco, downstream of the WWTP and upstream of where the Rio Seco discharges into the Rio Pallina. During both events water was clear, with a slight wastewater odor and extensive foaming was observed in the water. Vegetation consisting of duckweed and algae was observed at this sampling point. Figure 9 is photos of RS-11 taken in January and June 2009.

Figure 9. The left photo is from RS- 11 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event.

RP-1 is located at the headwaters of the Rio Pallina and upstream of Viacha. The water was clear and contained no odor. Upstream of this point is a small community, it is unknown if the community discharges wastewater into the dry bed portion of the Rio Pallina. Figure 10 is photos from the January and June 2009 sampling events.

Figure 10. Photo on right is RP-1 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event. Flow was very low during both events.

RP-6 is located in the Rio Pallina, downstream of Viacha. The water was dark grey and had a very strong wastewater odor. During both events garbage and dead animals were observed in the water. During both sampling events children were seen playing in the river. Figure 11 is photos from the January and June 2009 sampling events.

Figure 11. The photo on the right is RP-6 during the January 2009 sampling event, and the photo on the left is from the June 2009 sampling event. During both events people were using the river for recreation purposes, and the sewage odor was very strong.

RP-7 is located in the Rio Pallina, upstream of the confluence with the Rio Seco. The Viacha cement plant is located adjacent to this sampling point. During both sampling events no discharge points from the cement plant were observed entering the river. The water was clear with a very slight wastewater odor. Vegetation consisting of duckweed and algae was present in the river. Along this region the air quality was compromised due to the cement plant, and suspended sediment was present in the river. Figure 12 is photos taken at RP-7 during the January and June 2009 sampling events.


Figure 12. Photo on the left is RP-7 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event. In January there was more sediment in the river.

RP-9 is the in the Rio Pallina down stream of its confluence with the Rio Seco and upstream of where it discharges into the Rio Katari. The water was slightly turbid with a slight wastewater odor. Figure 13 is photos from the January and June 2009 sampling events.


Figure 13. Photo on the left is RP-9 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event.

RK-1 is located at the headwaters of the Rio Katari. During the January 2009 sampling event the river was very turbid, in June 2009 the water was clear and some algae was growing on and around rocks. Adjacent to the sample point is agriculture fields and red windblown sands. Figure 14 is photos from the January and June 2009 sampling events.

Figure 14. The photo on the left RK-1 during the January 2009 sampling event and the photo on the right is from the June 2009 sampling event. The water level had decreased between the two events as well as the amount of suspended sediments. In June precipitates could be seen on the gravel along the bank of the river.

RK-2 is in the Rio Katari and is upstream of the confluence with the Rio Pallina. During January 2009 sampling event the river was very turbid, during the June 2009 sampling event the water was clear. Adjacent to the sampling point is agriculture fields and red windblown sands. Figure 15 is photos from the January and June 2009 sampling event.

Figure 15. The photo on the left is RK-2 during the January 2009 sampling event, and the photo on the right is from the June 2009 sampling event. The amount of flow and suspended sediment decreased between the two events. In June 2009 there was precipitates present on the bank of the river and algae in the river.

RK-4 is in the Rio Katari downstream of its confluence with the Rio Pallina. This point was only sampled during the June 2009 event. Water was clear with no odor; algae growth was observed in the river along the sides and attached to rocks and other objects in the river. Adjacent to the sampling point is an agriculture field and a single family home, no impact from the family was observed during sampling. Figure 16 is a photo from the June 2009 sampling event.

Figure 16. Photo of RK-4 during the June 2009 sampling event. The bottom of the river had lots of algae growth.

RK-5 is located in the Rio Katari, and was only sampled during the June 2009 event. The water was clear with no odor and algae was present in the water. Adjacent to the site is a foot bridge, agriculture fields, red windblown sand and an adobe wall (possibly from Tiwanaku raised bed agriculture). Figure 17 is a photo of RK-5 during the

June 2009 sampling event.

Figure 17. Photo of RK-5 during the June 2009 sampling event.

3.3 Sample Collection Procedure and Analytical Procedure

Water samples were collected with field assistance from Suma Jayma (non-profit in Bolivia), Maryknoll lay Missionaries (January 2009 event) and Engineers in Action (June 2009 sampling event). Clean sample bottles were provided by the UMSA Lab, and rinsed with sample water prior to the collection of the water sample. The water sample was collected between the bank and middle of the river, depending on the height of the river bank. Samples were then placed in a cooler and brought to the UMSA lab on a daily basis for sample preservation and analysis. Prior to sampling, photos of the site were taken, Global Positioning System (GPS) coordinates, date, time and color and odor of water were recorded in a field notebook in addition to any other site observations that were pertinent in determining the basic chemistry of the water and contaminants. Water temperature, pH and conductivity were measured in the field using a multi-meter and recorded in the field book. Prior to field work the multi-meter was calibrated with a buffer solution and rinsed with clean water between samples. During the June 2009 sampling event the multi-meter broke in the field and UMSA lab measured temperature, pH and conductivity of the samples upon delivery of the samples to the lab. Table 1 lists the constituents measured and the analytical methods used.

Samples were also collected for VOC's, preserved with HCL, placed on ice and brought back to the United States for analysis by Hall Environmental Analytical Laboratory (Hall). Table 1 is a table of the ASTM standards that the UMSA lab and Hall used for analysis of the water samples.

Table 2. Water Quality Analysis Methodology			
Type of Analysis	Method Number	Method Name	Reference
Temperature	SMWW 2550	pH and Conductivity meter	SMEWW, 2005
pH	SMWW 4500-H^+ B	pH and Conductivity meter	SMEWW, 2005
Conductivity	SMWW 2510	pH and Conductivity meter	SMEWW, 2005
Calcium	SMWW 3500-Ca B	EDTA Titrimetric Method	SMEWW, 2005
Magnesium	SMWW 3500-Mg B	Atomic Absorption Spectrometric Method	SMEWW, 2005
Sodium	SMWW 3111 B	Direct Air-Acetylene Flame Method	SMEWW, 2005
Potassium	SMWW 3111 B	Direct Air-Acetylene Flame Method	SMEWW, 2005
Alkalinity	SMWW 2320 B	Titration Method	SMEWW, 2005
Chloride	SMWW 4500-Cl^- E	Automated Ferricyanide Method	SMEWW, 2005
Sulfate	SMWW 4500-$SO4^{2-}$ E	Turbidimetric Method	SMEWW, 2005
Nitrate	SMWW 4500-$NO3^-$ E	Cadmium Reduction Method	SMEWW, 2005
TKN	4500 N_{org} C 4500-NH3 B	Micro-Semi kjeldahl Method and preliminatry Distillation	SMEWW, 2005
Total Phosphorus	SMWW 4500-P B	Digestion/Colurimetry	SMEWW, 2005
Fecal Coliforms	SMWW 9222 D	Membrante Filtration	SMEWW, 2005
Chemical Oxygen Demand	SM 5220 B	Open Reflux Method	SMEWW, 2005
Volatile Organic Carbon	EPA 8260	Gas Chromatography/ Mass Spectrometry	EPA, 2009

SMWW/SMEWW-Standard Methods for the Examination of Water and Wastewater
EPA-Environmental Protection Agency

3.4 Discharge Measurements

Estimates of flow volume were done in areas where flow could be estimated without having to contact the water, or where flow over a weir could be estimated. Flow estimates were utilized to estimate contaminant loading. During the January 2009 sampling event six sites were estimated. Five of the sites were located at a sampling site, and one measurement was taken upstream of a sampling site. In June only four estimates were taken due to sites no longer being accessible.

The velocity-area method was utilized in determining the discharge. This was done by finding a location with uniform width, with little to no flow disruptions in the stream and a constant velocity. The stream profile was measured by measuring the depth of water approximately every foot across the stream channel. Velocity along the river was then estimated by measuring a length along the river and calculating the time it took for a partially filled bottle to travel the distance, this was done multiple times to improve the estimate. Because the velocity profile varies between the surface and bottom of the stream the measured velocity is multiplied by a correction factor of 0.66 (USBR, 2001). Discharge was calculated by multiplying the cross sectional area by the corrected velocity.

Mass flow is the total amount of mass per time of a particular constituent flowing past a given location in the river. This calculation is done by multiplying the discharge (liters per second) by the concentration of the constituent of concern (mg/l), this calculation yields mg/s. Mass flows are used to determine the input of constituents in the river and their transport along the river. They are also useful in quantifying the transformations of reactive constituents such as nitrogen species and coliform bacteria.

4.0 RESULTS AND DISCUSSION

4.1 Background

Samples were collected from the Rio Katari, Rio Seco and Rio Pallina in January and June 2009. In the field, pH, temperature and conductivity were measured with a calibrated multimeter. Samples were collected in the field and analyzed for cations, anions, nitrate, Total Kjeldahl nitrogen (TKN), total phosphorus, fecal coliform and chemical oxygen demand (COD) at the UMSA lab. After evaluation of the first set of samples TKN and COD were added to the sampling list for analysis during the June 2009 sampling event. The results are compared to USEPA Safe Drinking Water Act (SDWA) Maximum Concentration Level (MCL) and World Health Organization (WHO) recommended drinking water concentrations. SDWA MCLs and WHO recommended concentrations were chosen for comparison because drinking water standards for Bolivia could not be located. Additionally the river is source of drinking water. WHO's recommended list is not as extensive as the one compiled by SDWA, thus both SDWA and WHO's recommended limits were chosen for comparison. Constituent which were detected above either the SDWA MCL or WHO level are noted in Table 5 in red and bold and Table 2, 3 and 4 in Appendix B.

4.2 Discharge Measurements

In January and June discharge measurement were taken where site conditions made it allowed. In many areas the river is channelized and access to it is limited. Other areas were deemed as too much of a health related risk to enter due to the presence of large quantities of blood, dead animals and raw sewage. Figure 18 is a bar graph of discharge measurements collected in the field area. Although no precipitation occurred in the region during the June 2009 sampling event, discharge increased at some locations relative to the January 2009 sampling event. Increase of discharge occurred downstream of the WWTP, thus the increase is probably due to an increase in effluent discharge from the WWTP.

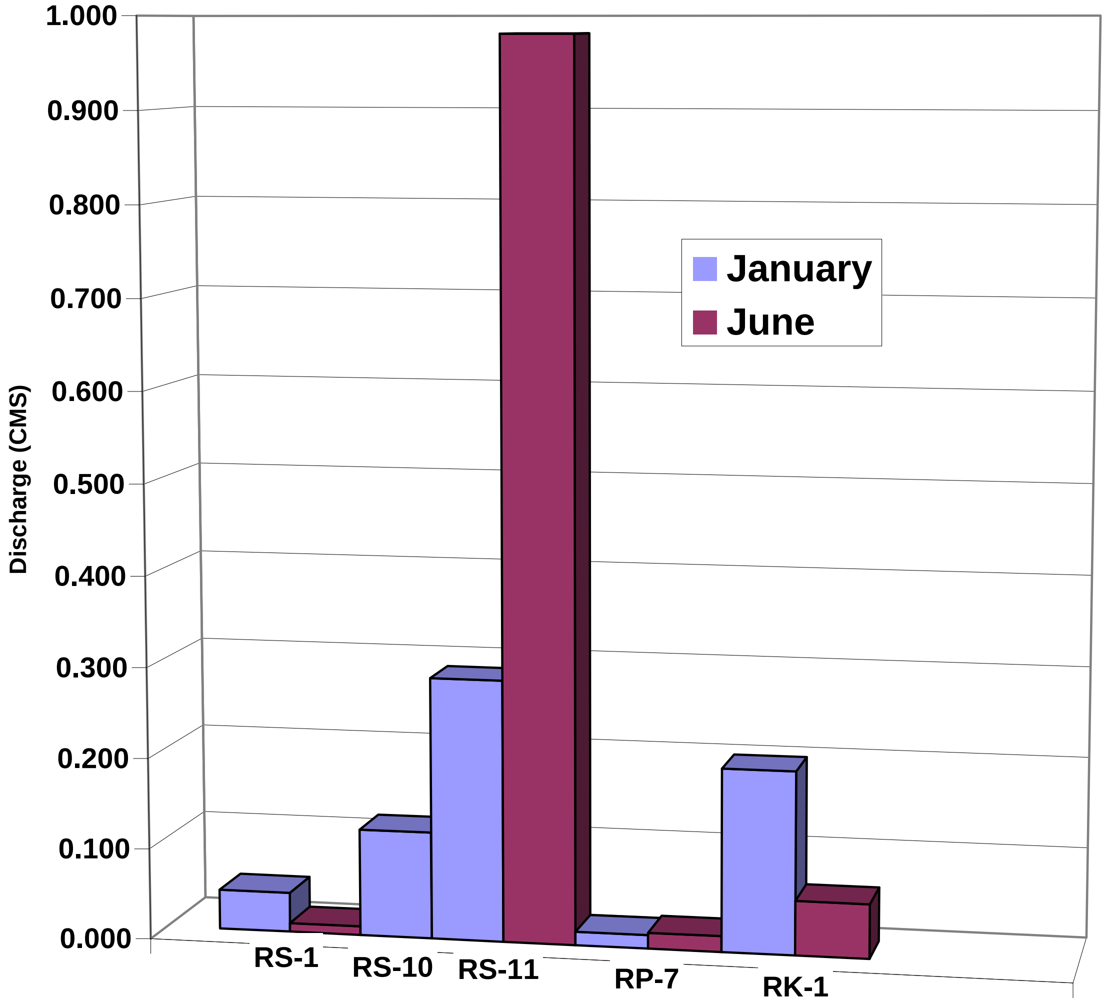

Figure 18. Bar graph of discharges calculated during the January and June 2009 sampling events. A discharge estimate was not available for RS-10 during the June sampling event

4.3 Water Chemistry

Samples were collected and analyzed for pH, temperature, conductivity, cations and anions to help determine changes in water chemistry due to anthropogenic impacts.

Table 1 in Appendix B is field measurements; Table 2 in Appendix B is the cation and anion analytical results. Figures 1-10 in Appendix C are graphs showing the spatial distribution of field measurements and cation/anion concentrations for the Rio Katari and Rio Pallina for the January and June 2009 sampling events. Figures 16-25 in Appendix C are graphs of the spatial distribution of field measurements and cation/anion concentrations for the Rio Seco and Rio Pallina for the January and June 2009 sampling events. Table 3 shows results of the ion balance completed for all sample sites for both sampling events. Full results and calculations can be seen in Appendix D. The ion balance indicates eight of the 26 samples have a difference in excess of 10%. This difference is likely associated with laboratory analytical error. Table 4 shows the ion mass loading calculations done for sites with calculated or estimated discharges.

Table 3. Table Cation/Anion Balance Results		
Sample ID	**Sample Date**	**% Balance**
RS-1	1/27/2013	1.21
RS-1	6/23/2013	18.75
RS-6 Before	1/27/2013	0.45
RS-6 Before	6/23/2013	1.65
Large open channel from Ceja region of El Alto flows into the Rio Seco between these points		
RS-6 After	1/27/2012	7.70
RS-6 After	6/23/2013	16.10
RS-10	1/27/2013	0.62
RS-10	6/23/2013	12.50
Effluent from El Alto WWTP flows into Rio Seco between these points		
RS-11	1/28/2013	16.68
RS-11	6/25/2013	14.27
CDV	1/28/2013	11.40
CDV	6/25/2013	5.13
RP-1	1/28/2013	3.64
RP-1	6/25/2013	2.60
RP-6	1/28/2013	3.23
RP-6	6/25/2013	16.25
RP-7	1/28/2013	6.20
RP-7	6/25/2013	4.43
Rio Seco and Camino de Viacha ditch flow into Rio Pallina between these points		
RP-9	1/28/2013	0.76
RP-9	6/24/2013	3.70
RK-1	1/28/2013	7.78
RK-1	6/25/2013	5.64
RK-2	1/28/2013	10.15
RK-2	6/24/2013	12.91
Rio Pallina flows into Rio Katari between these points		
RK-4	NS	
RK-4	6/24/2013	10.04
RK-5	NS	
RK-5	6/24/2013	6.69

Table 4. Cation and Anion Mass Loading									
Sample ID	Sample Date	Conductivity (μs/d)	Calcium (kg/d)	Magnesium (kg/d)	Sodium (kg/d)	Potassium (kg/d)	Alkalinity (kg/d)	Chloride (kg/d)	Sulfate (kg/d)
RS-1	1/26/2009	4.68E+08	34.54	10.94	20.23	11.99	22.48	7.53	147.58
RS-1	6/22/2009	1.17E+09	46.21	12.01	79.07	48.92	403.58	84.40	116.92
RS-10	1/26/2009	1.03E+10	508.92	98.74	1,178.33	288.49	1,970.66	1,380.68	1,043.23
RS-11	1/27/2009	3.06E+10	1,096.82	362.70	3,134.47	910.49	8,458.09	3,331.00	1,857.79
RS-11	6/24/2009	1.31E+11	4,078.16	1,442.19	10,174.21	4,408.82	40,357.68	13,773.33	4,814.94
CDV	1/27/2009	9.13E+08	15.95	65.72	84.29	22.01	304.39	59.52	74.69
RP-7	1/27/2009	7.34E+08	36.63	17.28	82.76	23.61	182.79	50.16	103.00
RP-7	6/24/2009	1.45E+09	63.41	16.48	141.64	52.74	436.98	109.21	128.77
RP-9*	1/27/2009	2.85E+10	1,195.54	364.78	2,968.21	869.70	7,693.29	2,993.57	1,986.89
RP-9*	6/23/2009	1.27E+11	4,576.29	1,488.89	11,588.02	4,222.32	38,794.55	13,637.06	5,056.85
RK-1	1/27/2009	2.07E+10	127.19	20.06	195.48	12.44	159.94	2,846.42	282.43
RK-1	6/24/2009	6.45E+09	480.27	82.43	687.32	40.70	651.15	845.98	1,123.77
RK-4*	6/24/2009	1.29E+11	4,693.44	1,548.42	11,446.47	4,226.66	38,649.01	14,107.13	6,033.17

*Flows for RP-9 and RK-4 were not measured in the field, mass loading for these two sampling sites were calculated based on mass loadings and discharge of upstream sampling points

4.2.1 Rio Katari

The region along the Rio Katari is more rural then that around the Rio Seco and Rio Pallina. Along the reach there are single family homes and land use consists of primarily agricultural practices (livestock grazing and food production fields). Figure 19 is stiff diagrams for RK-1, RK-2 and RP-9 for the January 2009 sampling event, Figure 20 is stiff diagrams for RK-1, RK-2, RK-4, RK-5 and RP-9 for the June 2009 sampling event. Figure 21 is a trilinear diagram for the Rio Katari for both sampling events, and Figure 22 is a graph showing the spatial distribution of conductivity in the Rio Katari and Rio Pallina for both sampling events. Figures 4-10 in Appendix C show the spatial distribution of cations and anions in the Rio Katari and Rio Pallina, for both sampling events.

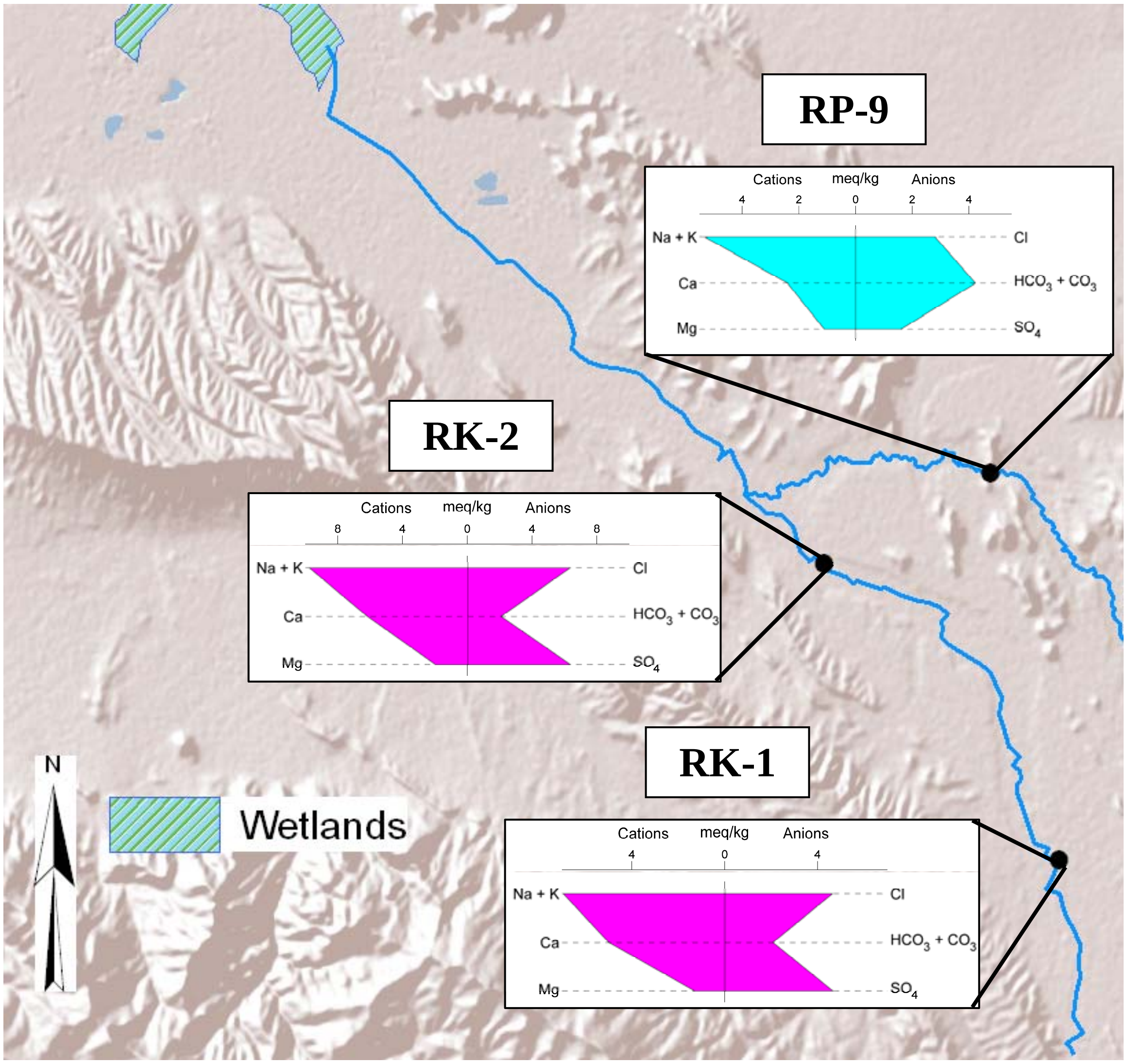

Figure 19. Stiff diagrams for the RK-1, RK-2 and RP-9 January 2009 sampling event.

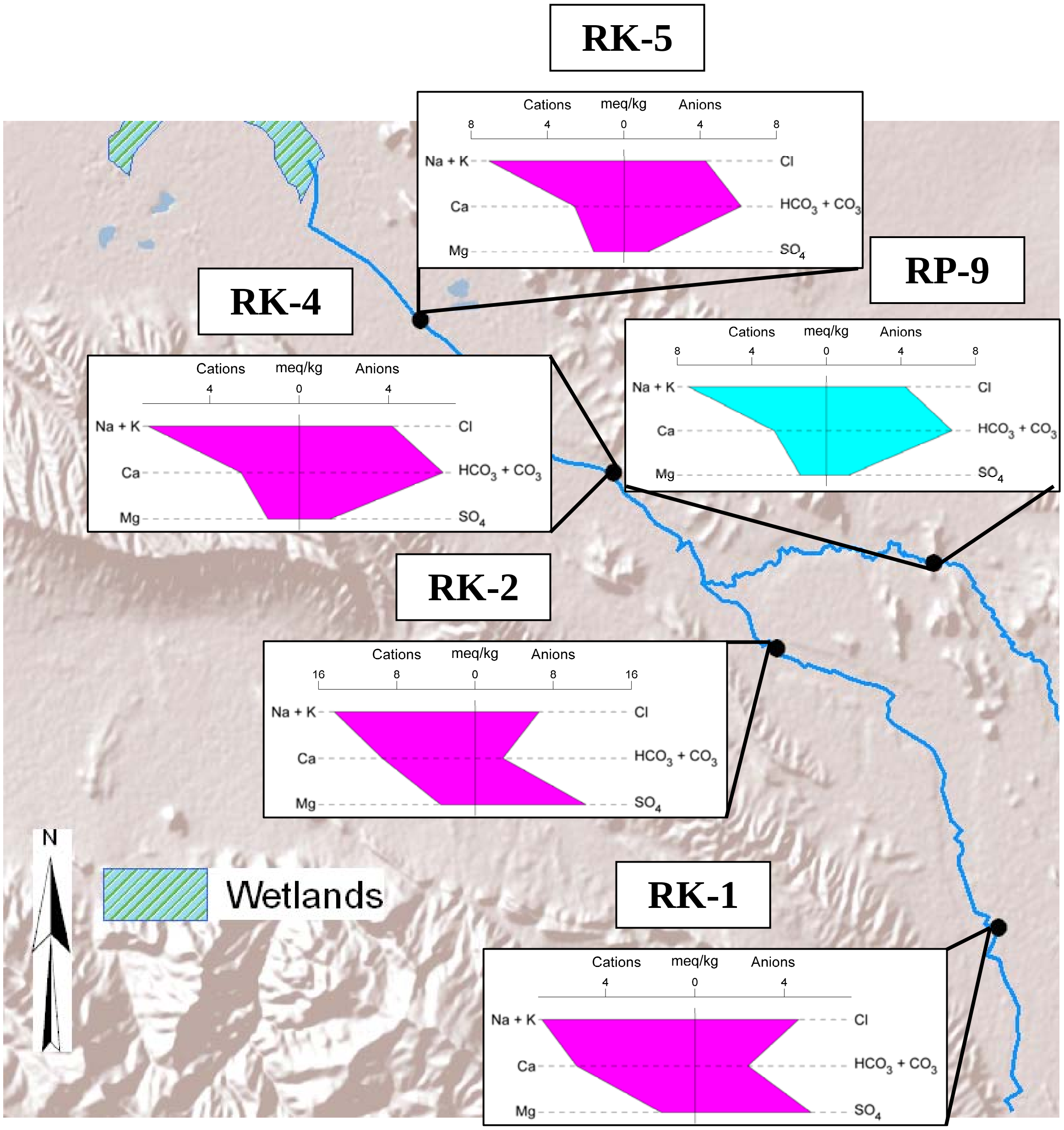

Figure 20. Stiff diagrams for the RK-1, RK-2, RK-4 and RK-5 and RP-9 June 2009 sampling event.

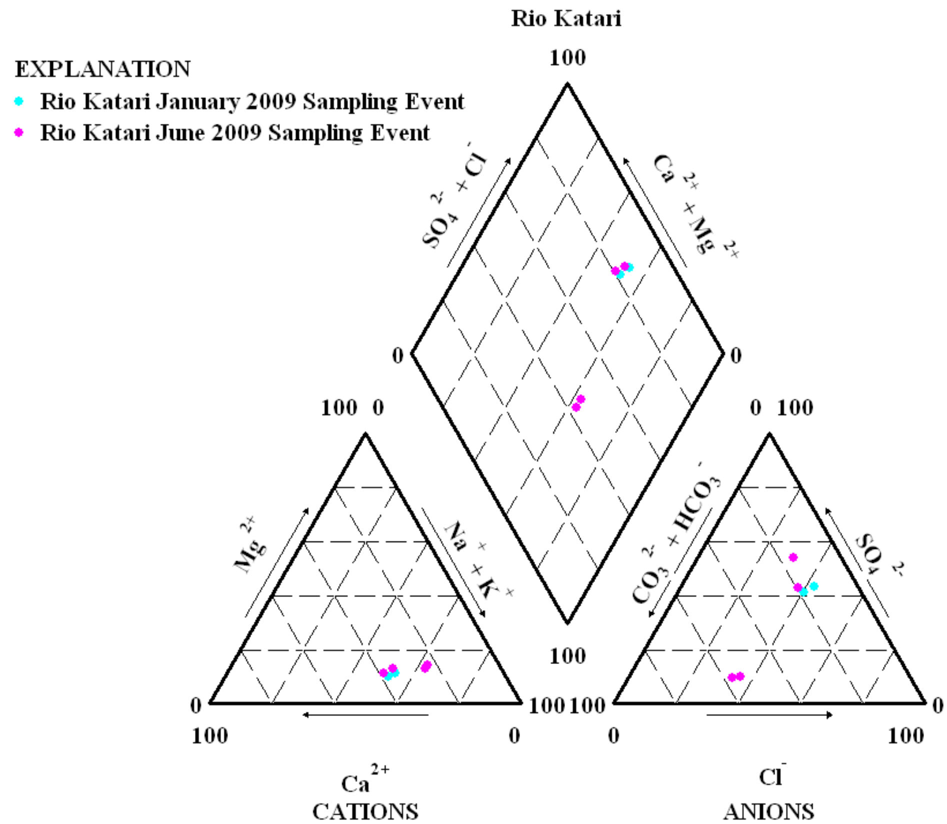

Figure 21. Rio Katari trilinear diagram

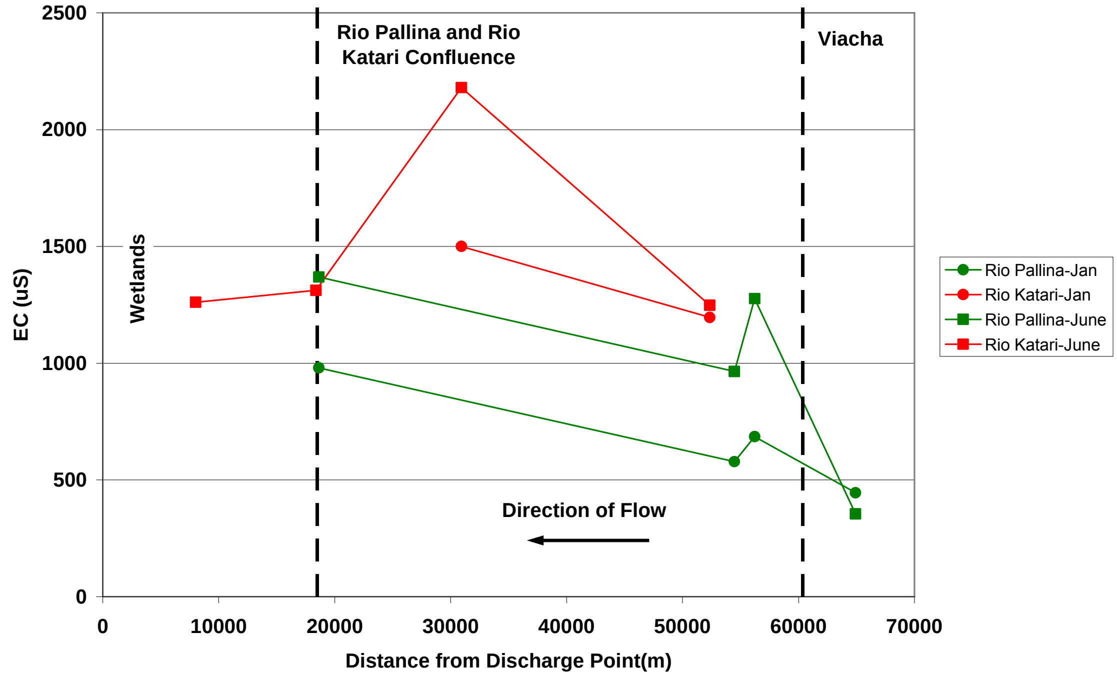

Figure 22. Spatial distribution of conductivity in the Rio Katari and Rio Pallina

In January 2009 conductivity, calcium, magnesium, sodium, potassium, alkalinity, chloride and sulfate increased between RK-1 and RK-2 (Figure 19). During the sampling event there was a lot of suspended sediment in the river, which may have resulted in the concentration increase, from surface water and sediment interactions. Groundwater might also be upwelling in the region, which also may introduce cations and anions.

In June 2009 concentrations of conductivity, calcium, magnesium, sodium, potassium, alkalinity, chloride and sulfate increased (Figure 20). During this sampling event some suspended sediment was noted in the river, but not as much as the January 2009 sampling event. The increase of cations and anions may be from surface water/sediment interactions, groundwater/sediment interactions, surface water/ground water interaction or evaporates along the water course being dissolved.

The January 2009 and June 2009 sampling events show the same trend with respect to which cations/anions increase (Figures 19, 20, 21 and 22). Sample analysis results for RK-1 during the January and June sampling events varied slightly. However during the June sampling event the following constituents increased between 19% and 79% in RK-2 relative to the January RK-2 sampling event; conductivity (45%), calcium (53%), magnesium (74%), sodium (46%), potassium (70%), alkalinity (19%) and sulfate (79%). The large variation in the RK-2 variance can be attributed to precipitation diluting the surface water in January and the small change in RK-1 can be attributed to the water source for the headwaters remaining constant between the two events.

Between RK-2 and RK-4 the Rio Pallina flows into the Rio Katari. All cations/anions approach the cation/anion concentration values present at sampling site RP-9. The change of cations/anion concentration can be attributed to the flow in the Rio Pallina being much greater then the flow in the Rio Katari (Figure 20 and 22).

Between RK-4 and RK-5 concentrations of cations and anions stay relatively constant, as there are no new discharges into the river. Mass loading was calculated for RK-1, and estimated for RK-4 and RP-9 for the June 2009 sampling event. Mass loading results indicate that the Rio Pallina discharges large quantities of cations/anions into the Rio Katari (Table 4).

4.2.2 Rio Seco

RS-1 was taken at two different locations during the January and June 2009 sampling events. In January the river had flow so the sample was taken prior to any contamination flowing into the river. In June there was no flow in the river, therefore the sample was taken immediately below a pipe that carries wastewater from nearby houses.

Because of the different sampling locations these two points can not be compared. Results of the analysis of cations/anions and field measurements at RS-1 can be seen in Table 2 in Appendix B. Figure 23 is stiff diagrams for RS-1, RS-6 Before, RS-6 After, RS-10 and RS-11 for the January 2009 sampling event, Figure 24 is stiff diagrams for RS-1, RS-6 Before, RS-6 After, RS-10 and RS-11 for the June 2009 sampling event. Figure 25 is a trilinear diagram for the Rio Seco for both sampling events, and Figure 26 is a graph showing the spatial distribution of conductivity in the Rio Seco and Rio Pallina for both sampling events. Figures 19-25 in Appendix C show the spatial distribution of cations and anions in the Rio Seco and Rio Pallina for both sampling events.

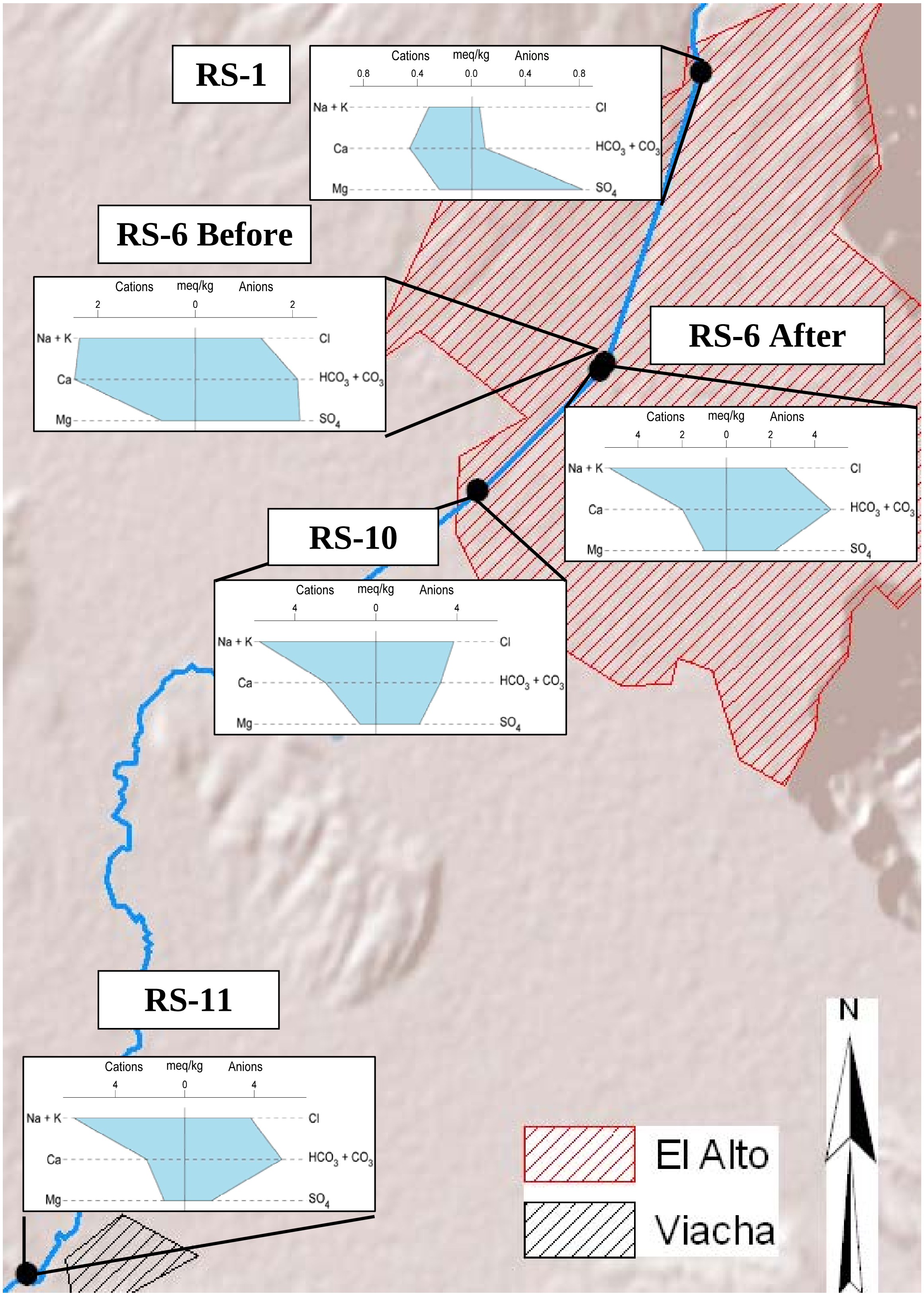

Figure 23. Stiff diagrams for the Rio Seco January 2009 sampling event.

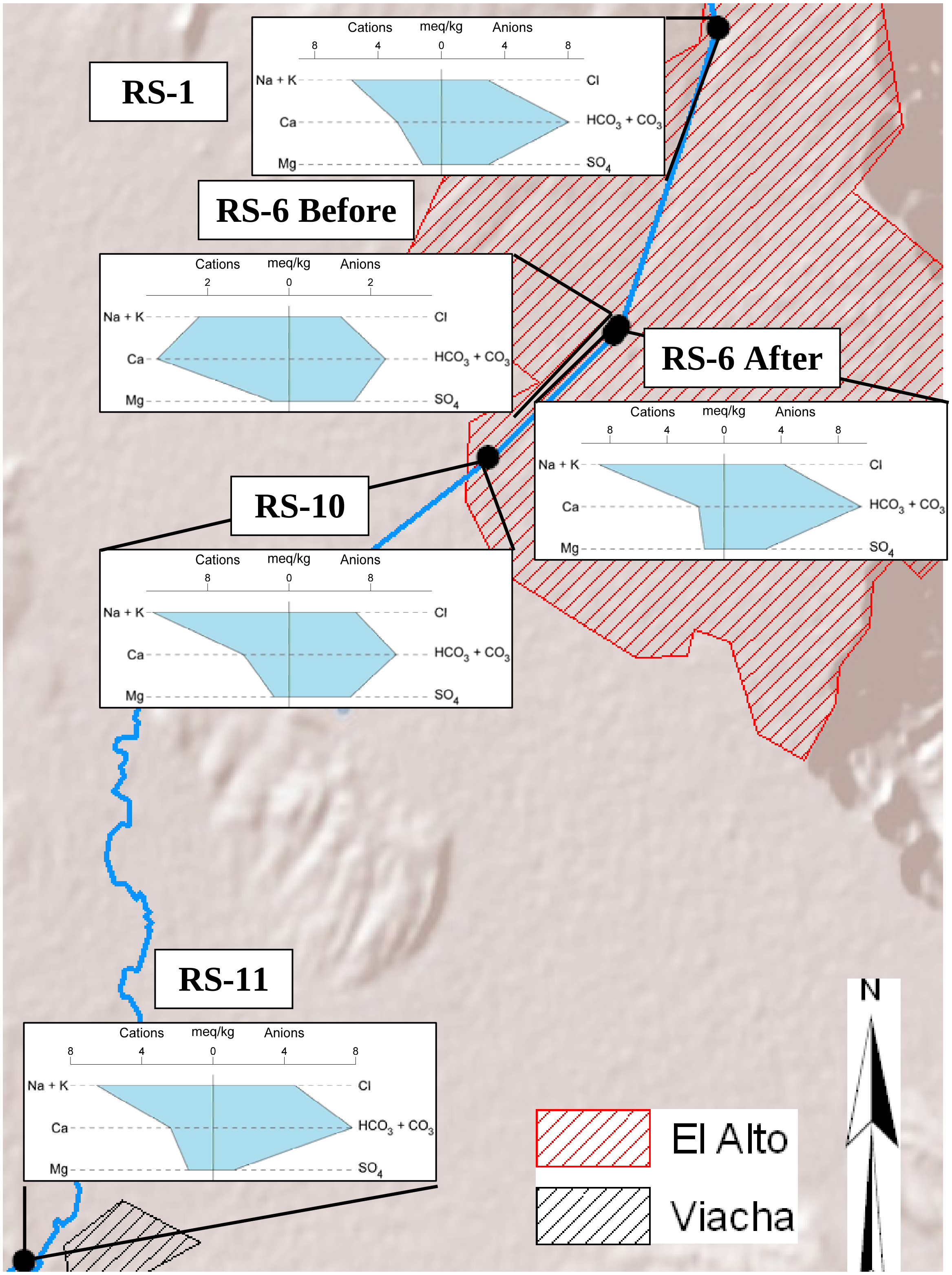

Figure 24. Stiff diagrams for the Rio Seco June 2009 sampling event.

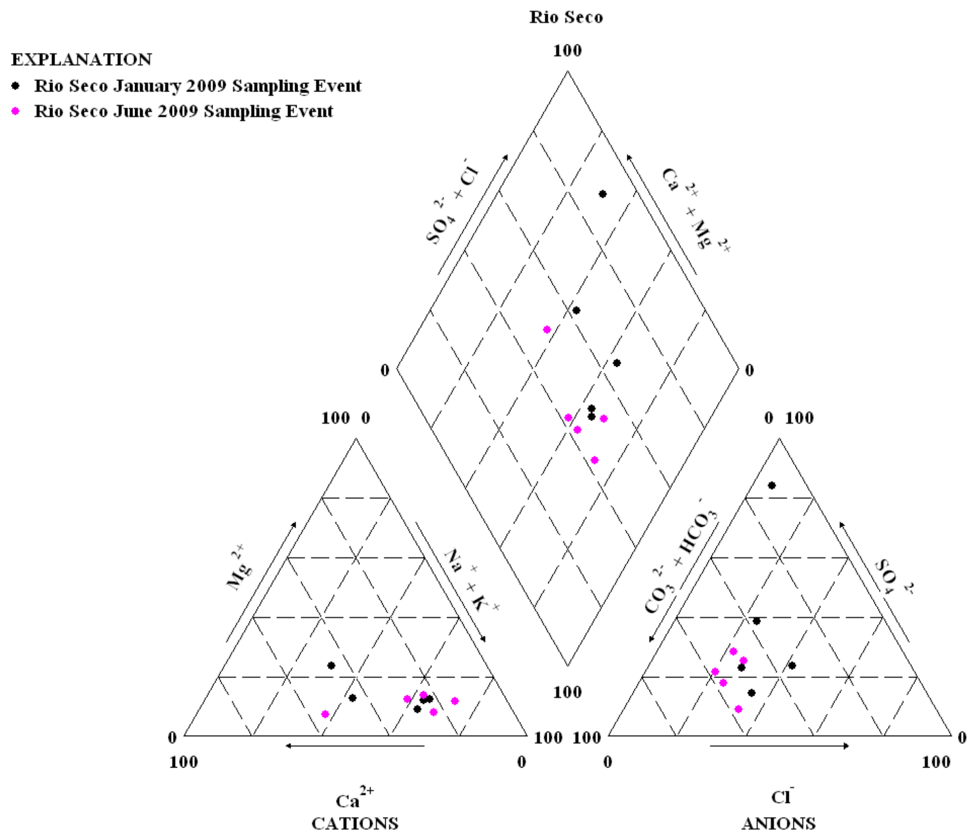

Figure 25. Rio Seco trilinear diagram

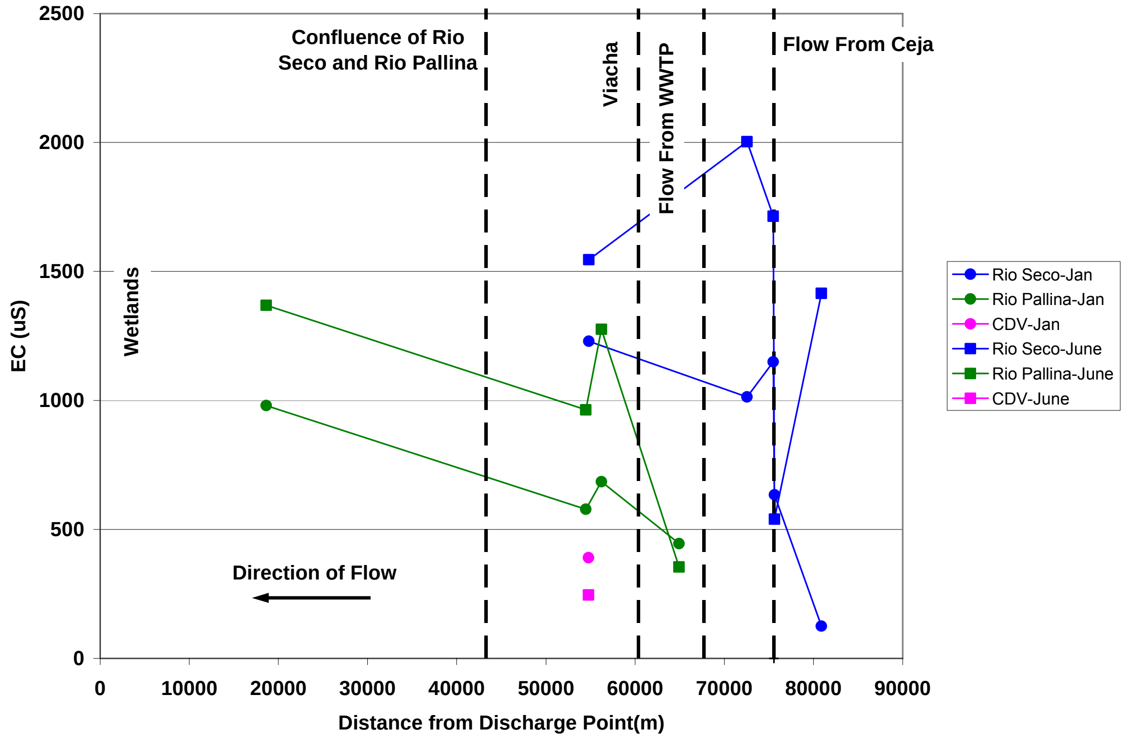

Figure 26. Spatial distribution of conductivity in the Rio Seco and Rio Pallina

<u>RS-6 Before to RS-6 After</u>

In January and June 2009 conductivity and concentrations of magnesium, potassium, sodium, alkalinity, chloride and sulfate increased. Calcium decreased during both events. The increase in most concentrations is due to a large input between the two points. In January increases in cations/anions between RS-6 Before and RS-6 After are as follows: conductivity (81%), magnesium (43%), sodium (133%), potassium (92%), alkalinity (125%), chloride (97%) and sulfate (0.3%). In June increases in cations/anions between RS-6 Before and RS-6 After are as follows: conductivity (217%), magnesium (233%), sodium (260%), potassium (527%), alkalinity (305%), chloride (229%) and sulfate (83%). The large difference in the increase of constituents between the two points is seasonally influenced, as there is no precipitation in June. Calcium concentrations probably decreased because of dilution (Figures 23, 24, 25 and 26).

RS-6 After to RS-10

In January and June 2009 concentrations of calcium, sodium and chloride increased and potassium decreased. In January 2009 magnesium, alkalinity and sulfate decreased, whereas in June 2009 they increased. These differences can be attributed to precipitation in January diluting the concentrations, whereas in June there is no precipitation, thus no dilution (Figures 23, 24, 25 and 26).

RS-10 to RS-11

In January and June 2009 concentrations of calcium, chloride and sulfate decreased. In January 2009 concentrations of magnesium, sodium, potassium and alkalinity increased, while in June 2009 these concentrations decreased. Between these two sampling points is the El Alto WWTP. Effluent from the WWTP in June dilutes concentrations in the river, whereas in January concentrations of cations/anions in the river upstream of the WWTP are below the concentrations of the effluent the effluent acts as a source (Figures 23, 24, 25 and 26). Mass loading calculated between RS-10 and RS-11 for the January 2009 sampling event show an increase of conductivity, calcium, sodium, potassium, alkalinity, chloride and sulfate loads (Table 4). This increase indicates the WWTP is a point source pollutant for cations and anions.

4.2.3 Rio Pallina

In general, waters from the Rio Pallina do not tend to vary much seasonally or spatially. Unlike the Rio Seco, the Rio Pallina has less non-point source and point source pollution. Figure 27 is stiff diagrams for RP-1, RP-6, RP-7, RP-9, RS-11 and CDV for the January 2009 sampling event, Figure 28 is stiff diagrams for RP-1, RP-6, RP-7, RP-9, RS-11 and CDV for the June 2009 sampling event. Figure 29 is a trilinear diagram for the Rio Pallina for both sampling events, and Figures 22 and 26 are graphs showing the spatial distribution of conductivity in the Rio Katari and Rio Pallina and the Rio Seco and Rio Pallina for both sampling events. Figures 4-10 in Appendix C show the spatial distribution of the Rio Katari and Rio Pallina for both sampling events and Figures 19-25 in Appendix C show the spatial distribution of the Rio Katari and Rio Pallina for both sampling events

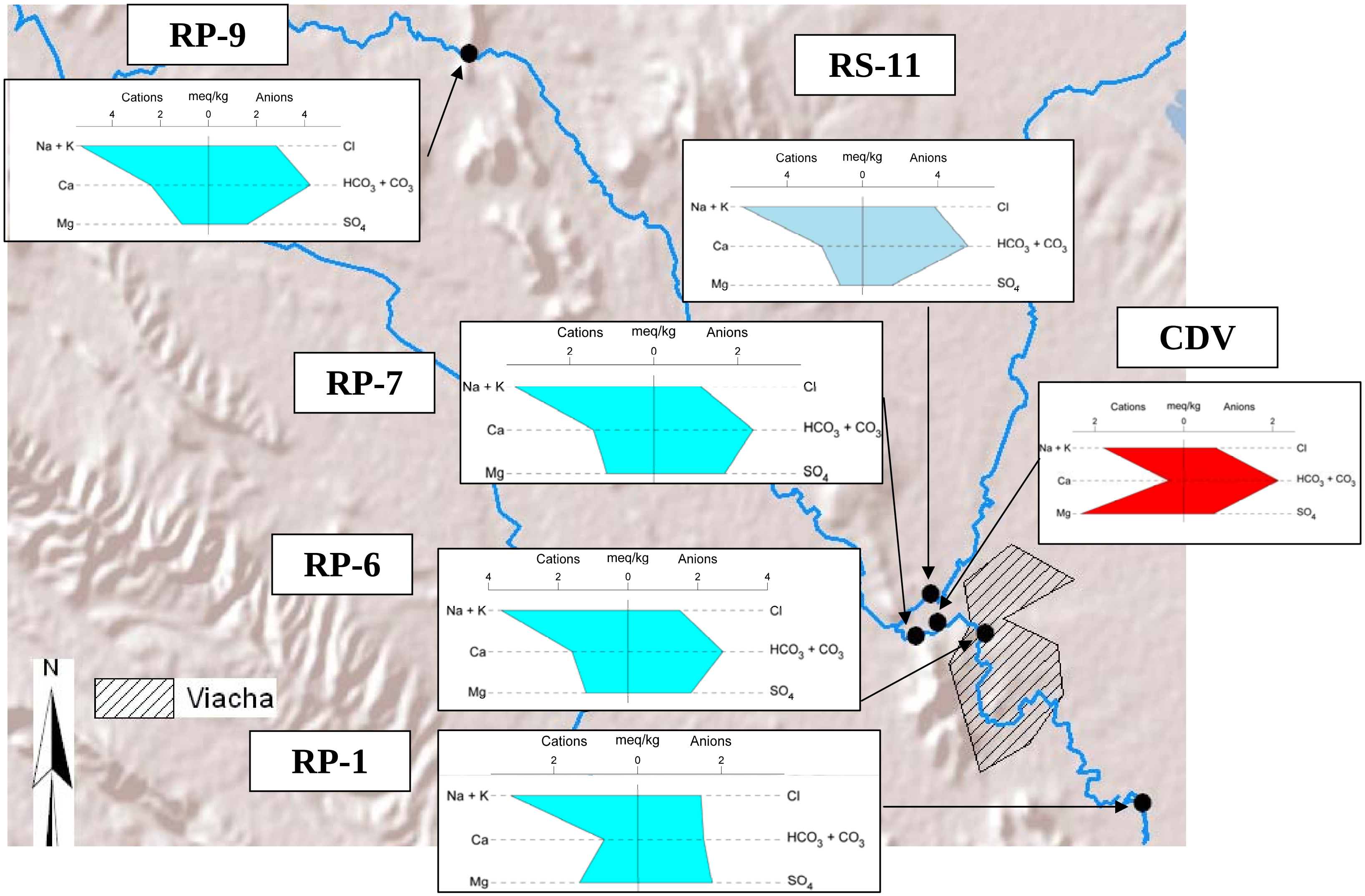

Figure 27. Stiff diagrams for the Rio Pallina, RS-11 and CDV January 2009 sampling event.

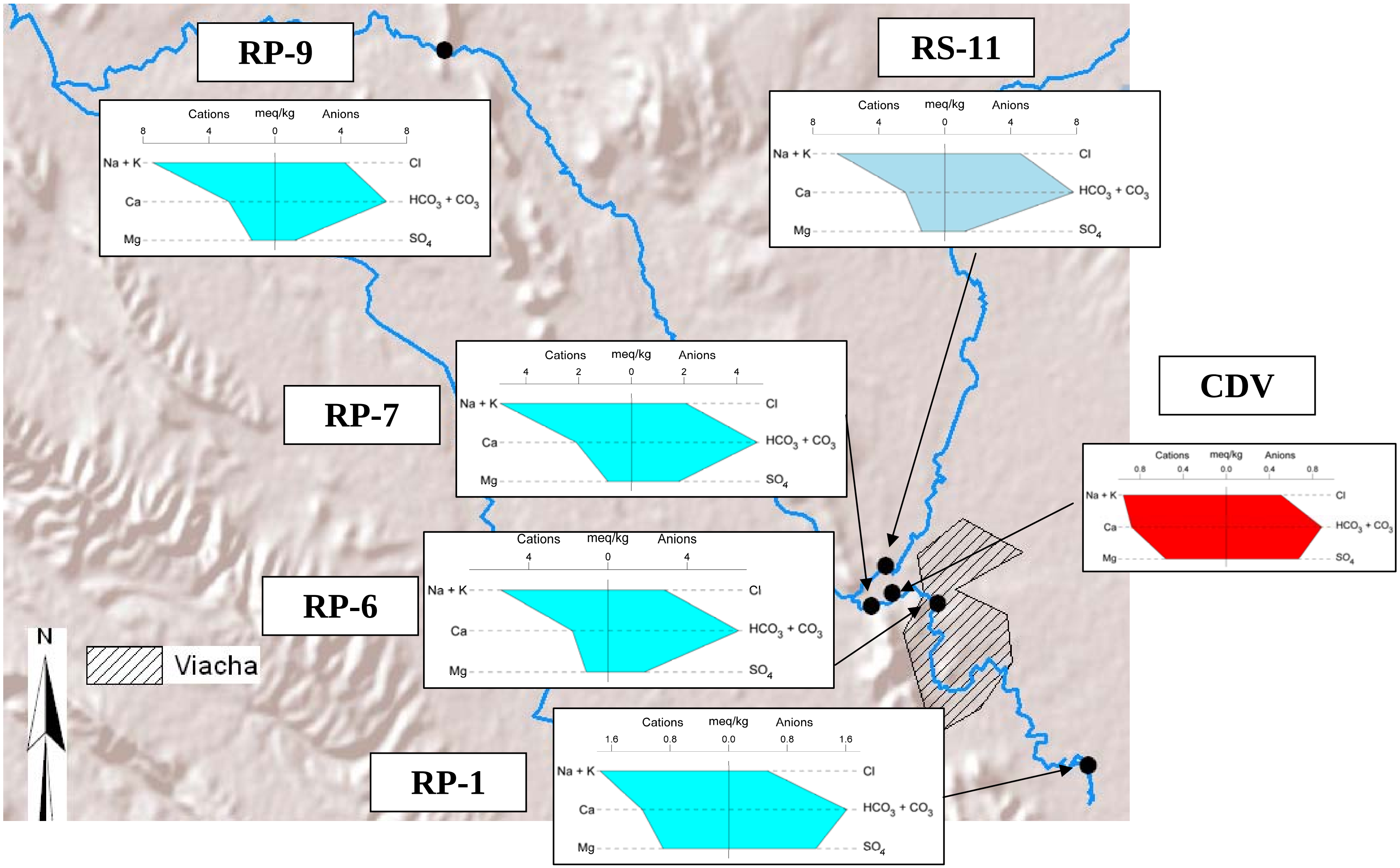

Figure 28. Stiff diagrams for the Rio Pallina, RS-11 and CDV June 2009 sampling event.

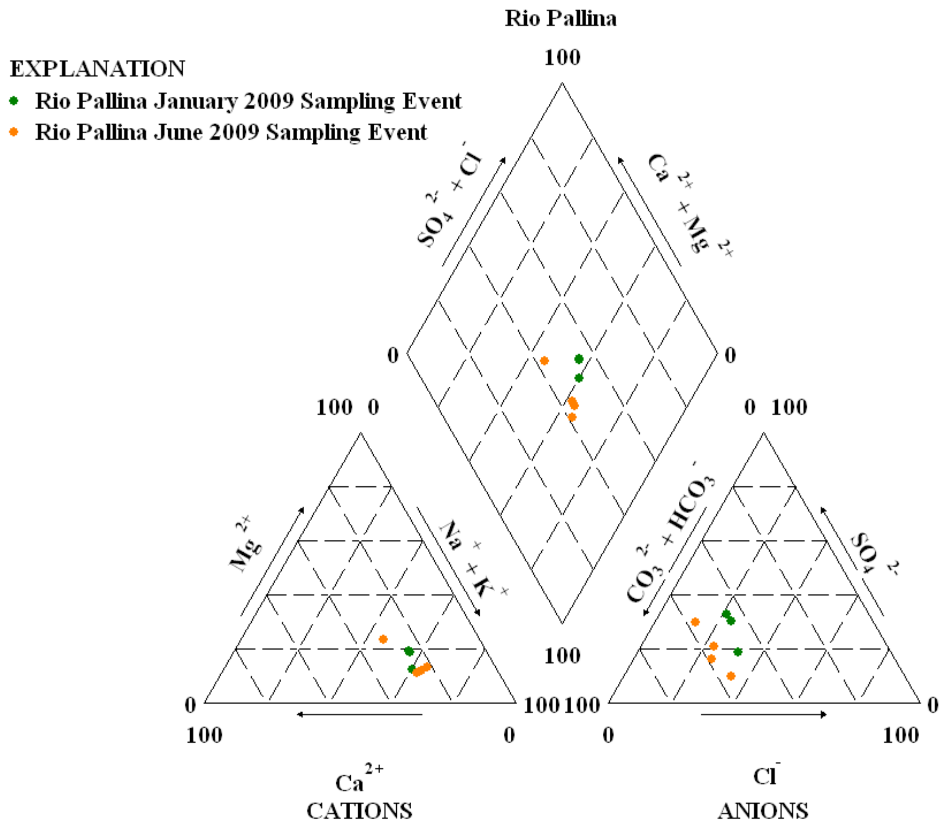

Figure 29. Trilinear diagram of the Rio Pallina

<u>RP-1 to RP-6</u>

January and June 2009 concentrations of calcium, potassium, sodium, alkalinity, chloride and sulfate increased between RP-1 and RP-6. In January and June 2009 magnesium decreased (Figures 22, 26, 27, 28 and 29). The increase can be attributed to land practices between the two points. Between these two points is Viacha, which lacks any wastewater collection or treatment system and discharges many pollutants into the river. Viacha also utilizes groundwater, which may contain dissolved concentrations of the cations/anions, thus increase the amount in the surface water. In January constituents increased between RP-1 and RP-6 by the following: calcium (100%), sodium (20.3%), potassium (17.6%), alkalinity (72.9%), and sulfate (2%). In June constituents increased between RP-1 and RP-6 by the following: calcium (52.6%), sodium (191%), potassium (282%), alkalinity (310%), and sulfate (54%). The variability of the increase of constituents during the two sampling events can be attributed to seasonal changes and changes in discharges.

RP-6 to RP-7

In January and June 2009 with the exception of calcium in June 2009 all concentrations of cations/anions decreased. In January the decrease can be attributed to dilution from precipitation. In June the decrease of cations and anions may be from unseen irrigation practices (Figures 22, 26, 27, 28 and 29). The percent change between the cations and anions at the two sampling points during the two events does not vary much.

RP-7 to RP-9

In January and June 2009 concentrations of calcium, potassium, sodium, alkalinity and chloride increased. In January 2009 concentrations of magnesium and sulfate decreased, whereas in June 2009 they increased. Between these two points the Rio Seco flows into the Rio Pallina, during both sampling events the concentrations of cations/anions in the Rio Pallina approach those in the last sampling point of the Rio Seco. During field work the flow in the Rio Seco was greater than the Rio Pallina, therefore the concentration trends of the Rio Seco tends to dominate the ion composition (Figures 22, 26, 27, 28 and 29). This can also be seen in mass loading (Table 4) in which the loads of conductivity, cations and anions increase.

4.4 Water Contamination

Samples were collected and analyzed for nitrates, fecal coliform, total phosphorus, TKN, COD and VOC's to determine the anthropogenic impact. Table 5 is the sampling results for nitrates, fecal coliform, total phosphorus, TKN and COD at all sampling locations during both sampling events and Table 6 is mass loading results for the above mentioned constituents, calculated where flows were measured. Table 4 in Appendix B is the VOC sampling results. Figures 11-15 in Appendix C are graphs showing the spatial distribution of nitrate-N, fecal coliform, total phosphorus, TKN and COD concentrations in the Rio Katari and Rio Pallina for the January and June 2009 sampling events. Figures 26-30 in Appendix C are graphs showing the spatial distribution of nitrate-N, fecal coliform, total phosphorus, TKN and COD concentrations in the Rio Seco and Rio Pallina for the January and June 2009 sampling events. Where applicable on the spatial distribution graphs exceedances of the MCL was noted. Table 7 is a table of TKN and COD ratios from a literature review for raw effluent from hog slaughter house waste and high concentrate wastewater compared to the June 2009 sampling results from the site. Figure 31 in Appendix C is TKN vs. COD for the Rio Katari, Rio Seco and Rio Pallina.

Table 5. Contaminant Concentration Results

Sample ID	Sample Date	Nitrate (mg/l)	Nitrate-N (mg/l)	TKN (mg/l)	Total Phosphorus (mg/l)	Fecal Coliform (CFU/l)	Chemical Oxygen Demand
RS-1	1/26/2009	1.09	0.25	NA	ND	**2.00E+03**	NA
RS-1	6/22/2009	17.9	4.05	119	11.6	**5.00E+06**	782
RS-6 Before	1/26/2009	1.16	0.26	NA	0.53	**1.50E+04**	NA
RS-6 Before	6/22/2009	3.15	0.71	10.5	1.47	**4.20E+03**	46.0
Large open channel from Ceja region of El Alto flows into the Rio Seco between these points							
RS-6 After	1/26/2008	11.8	2.66	NA	11.9	**3.00E+07**	NA
RS-6 After	6/22/2009	43.2	9.77	204	36.1	**2.70E+07**	2,600
RS-10	1/26/2009	2.02	0.46	NA	2.26	**1.10E+06**	NA
RS-10	6/22/2009	55.8	**12.6**	214	21.2	**1.20E+06**	1,920
Effluent from El Alto WWTP flows into Rio Seco between these points							
RS-11	1/27/2009	2.83	0.64	NA	ND	**5.00E+03**	NA
RS-11	6/24/2009	14.1	3.18	83.3	14.8	**2.10E+04**	204
CDV	1/27/2009	2.07	0.47	NA	ND	**4.00E+03**	NA
CDV	6/24/2009	5.95	1.34	4.20	1.29	**2.00E+03**	ND
RP-1	1/27/2009	1.02	0.23	NA	ND	**6.10E+01**	NA
RP-1	6/24/2009	2.86	0.65	0.70	ND	**5.00E+02**	ND
RP-6	1/27/2009	1.48	0.33	NA	0.08	**5.30E+06**	NA
RP-6	6/24/2009	14.3	3.22	37.8	20.6	**3.10E+06**	562
RP-7	1/27/2009	1.31	0.30	NA	ND	**9.80E+04**	NA
RP-7	6/24/2009	9.08	2.05	45.5	10.1	**6.60E+05**	98.0
Rio Seco and Camino de Viacha ditch flow into Rio Pallina between these points							
RP-9	1/27/2009	2.12	0.48	NA	3.82	**4.60E+03**	NA
RP-9	6/23/2009	10.6	2.39	64.4	11.8	**4.30E+04**	102
RK-1	1/27/2009	0.58	0.13	NA	ND	**1.20E+03**	NA
RK-1	6/24/2009	1.97	0.45	2.10	1.47	**9.90E+01**	ND
RK-2	1/27/2009	1.07	0.24	NA	ND	**7.00E+02**	NA
RK-2	6/23/2009	3.30	0.75	10.5	1.31	**4.00E+02**	ND
Rio Pallina flows into Rio Katari between these points							
RK-4	NS	NS	NS	NS	NS	NS	NS
RK-4	6/23/2009	7.66	1.73	53.9	10.59	**5.60E+01**	148
RK-5	NS	NS	NS	NS	NS	NS	NS
RK-5	6/23/2009	7.84	1.77	49.0	11.8	**8.50E+03**	70.0
SDWA MCL (mg/l)		None	10	None	None	Presence/ absence	None
WHO (mg/l)		None	11.3	None	None	None	None

ND-Non Detect
NS-Not Sampled
NA-Not Analyzed
Red and bold indicates the sample is above SDWA MCLs and/or WHO values

Table 5. Contaminant Mass Loading							
Sample ID	Sample Date	Nitrate (kg/d)	Nitrate-N (kg/d)	TKN (kg/d)	Total Phosphorus (kg/d)	Total Coliforms (CFU/d)	Chemical Oxygen Demand (kg/d)
RS-1	1/26/2009	4.08	0.92			7.49E+09	
RS-1	6/22/2009	14.77	3.34	98.01	9.55	4.12E+12	644.08
RS-10	1/26/2009	20.52	4.64		22.96	1.12E+13	
RS-11	1/27/2009	70.40	15.91			1.24E+11	
RS-11	6/24/2009	1194.62	269.98	7062.59	1250.58	1.78E+12	17296.15
CDV	1/27/2009	4.85	1.10			9365.76	
RP-7	1/27/2009	1.66	0.38			1.24E+11	
RP-7	6/24/2009	13.68	3.09	68.56	15.17	9.94E+05	1709.12
RP-9*	1/27/2009	63.75	14.41		99.88	1.20E+05	
RP-9*	6/23/2009	1076.59	243.31	6441.26	1158.45	3.84E+06	105431.78
RK-1	1/27/2009	10.06	2.27			2.08E+10	
RK-1	6/24/2009	10.18	2.30	10.85	7.60	5.12E+07	
RK-4*	6/24/2009	959.53	216.85	6035.84	1120.95	5.12E+03	15416.09

*Flows for RP-9 and RK-4 were not measured in the field, mass loading for these two sampling sites were calculated based on mass loadings and discharge of upstream sampling points

Table 7. TKN:COD				
Sample Name	COD (mg/l)	TKN (mg/l)	COD:TKN	Source
1	2941	174	16.90	Masse, 2000
2	3589	271	13.24	Masse, 2000
3	4976	372	13.38	Masse, 2000
4	2333	90	25.92	Masse, 2000
6	3417	158	21.63	Masse, 2000
High Strength Wastewater	800	70	11.43	Metcalf & Eddy 2003
RS-1	782	119	6.57	Analysis from June 2009 sampling
RS-6 Before	46	10.5	4.38	Analysis from June 2009 sampling
RS-6 After	2600	204	12.75	Analysis from June 2009 sampling
RS-10	1920	214	8.97	Analysis from June 2009 sampling
RS-11	204	83.3	2.45	Analysis from June 2009 sampling
RP-6	562	37.8	14.87	Analysis from June 2009 sampling
RP-7	98	45.5	2.15	Analysis from June 2009 sampling
RP-9	102	64.4	1.58	Analysis from June 2009 sampling
RK-4	148	53.9	2.75	Analysis from June 2009 sampling
RK-5	70	49	1.43	Analysis from June 2009 sampling

4.3.1 Rio Katari

In January and June 2009 fecal coliform is present in all samples. Upstream of the Rio Katari's confluence with the Rio Pallina the source of fecal coliform in the river is probably from a mixture of agriculture and households (Figure 30). RK-4, the sample taken downstream of the confluence with the Rio Pallina has increased concentrations of TKN (Figure 31), nitrate-N (Figure 32), total phosphorus (Figure 13 Appendix C) and COD (Figure 33), however fecal coliform decreases. Between RK-4 and RK-5 nitrate-N, TKN and total phosphorus changes slightly and COD decreases by 50%. The decrease then increase in fecal coliform may be from the limited of amounts of nutrients available for the fecal coliform, thus the dying of colonies. The increase of fecal coliform is probably from a new source of contamination that was unseen during field work

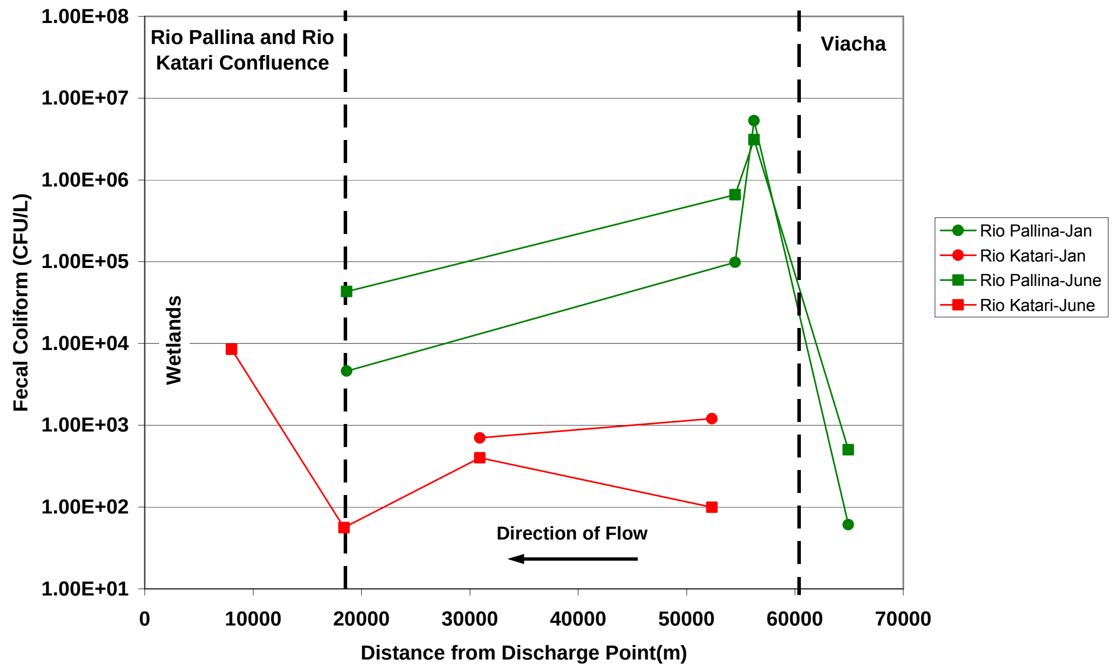

Figure 30. Spatial distribution of fecal coliform concentrations in the Rio Katari and Rio Pallina.

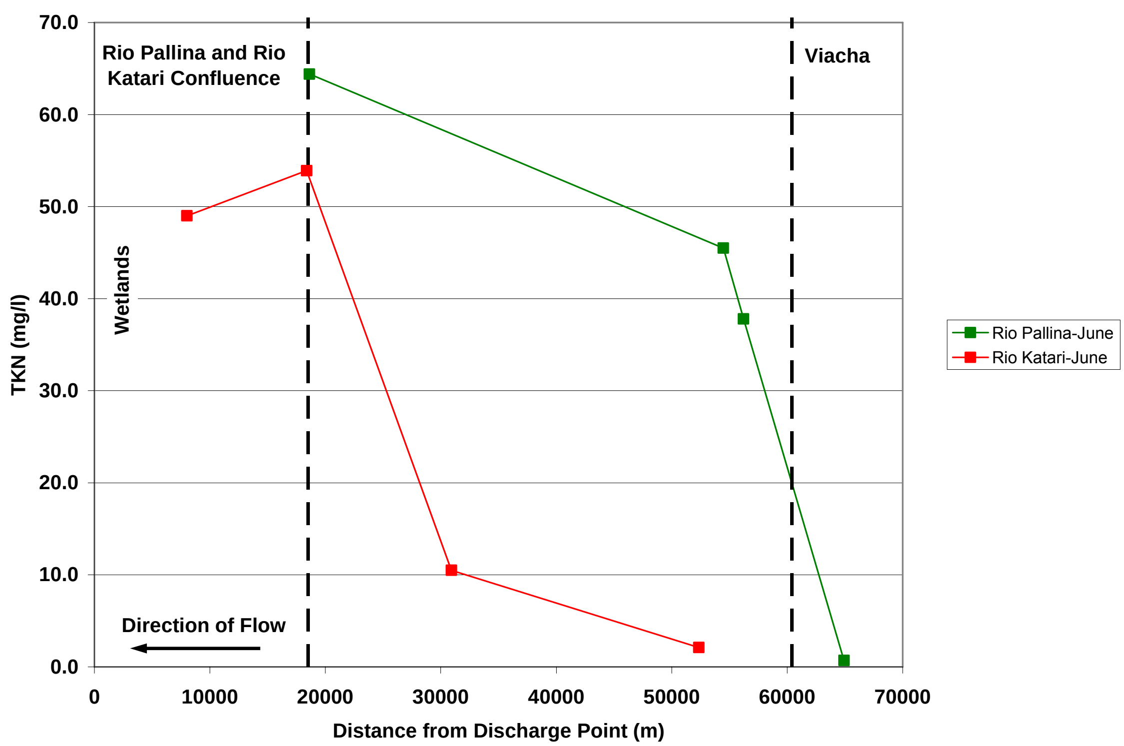

Figure 31. Spatial distribution of TKN concentrations in the Rio Katari and Rio Pallina.

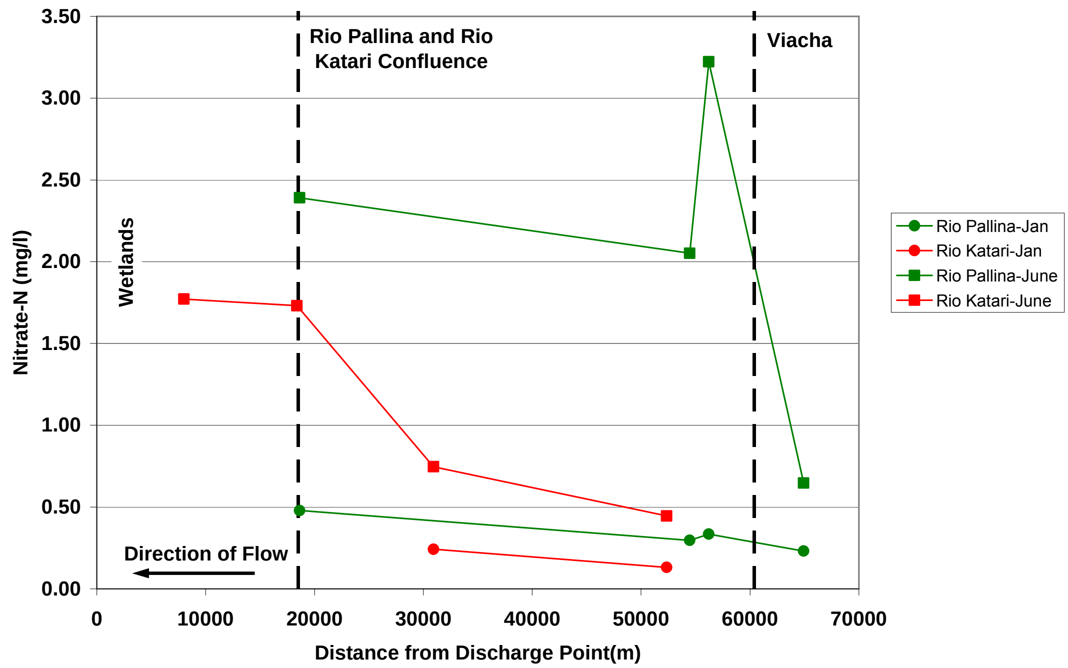

Figure 32. Spatial distribution of nitrate-N concentrations in the Rio Katari and Rio Pallina.

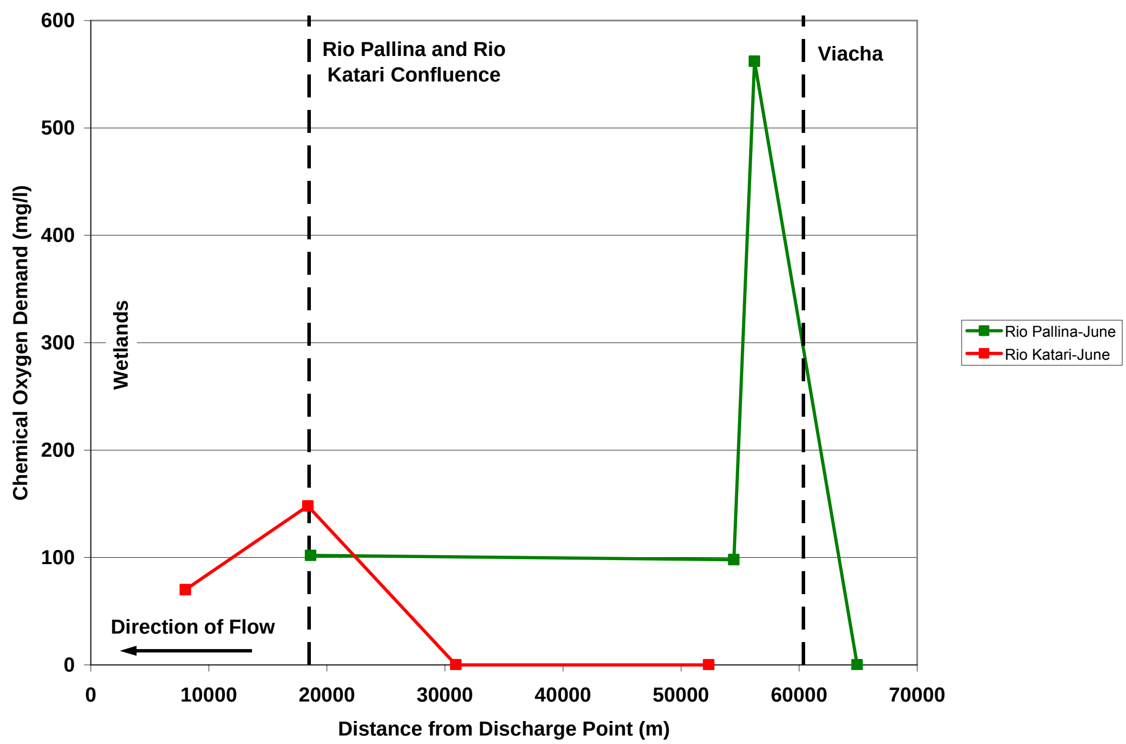

Figure 33. Spatial distribution of COD concentrations in the Rio Katari and Rio Pallina.

4.3.2 Rio Seco

The largest source of municipal contaminants enters the Rio Seco between RS-6 Before and RS-6 After. The pollution comes from an arroyo that flows through the Ceja and discharges into the Rio Seco. The pollution in the arroyo is from residences, slaughter houses, tanneries, textile factories, laundry facilities, dry cleaning facilities, public bathrooms and automotive repair shops that discharge into the arroyo. Between these two points during both events concentrations of fecal coliform (Figure 34), TKN (Figure 35), nitrate-N (Figure 36), COD (Figure 37) and total phosphorus (Figure 28 Appendix C) increased. The high concentration of TKN and COD relative to the low concentration of nitrate-N indicates anoxic conditions, which is suppressing nitrification of TKN. In order to determine the cause of the anoxic conditions COD and TKN were plotted on a graph (Figure 31 Appendix C). Results of the graph and R^2 calculated values indicate a positive relationship between COD and TKN. However, because so much dilution is happening in the system nitrification is not seen.

To determine the source of TKN, TKN and COD concentrations from untreated hog slaughter house effluent (Masse, 2000) and high concentration wastewater effluent (Metcalf and Eddy, 2003) values were compared to the Rio Seco concentrations (Table 7). COD:TKN ratio in the slaughter house waste ranged between 13 and 25, and the COD: TKN ratio in the high concentration wastewater effluent was 11.43. The COD:TKN ratio in RS-6 After was 12.75 and in RS-10 it was 8.97, indicating the source could be either. However given the nature of the site it is most likely a combination of wastewater effluent and slaughter house effluent.

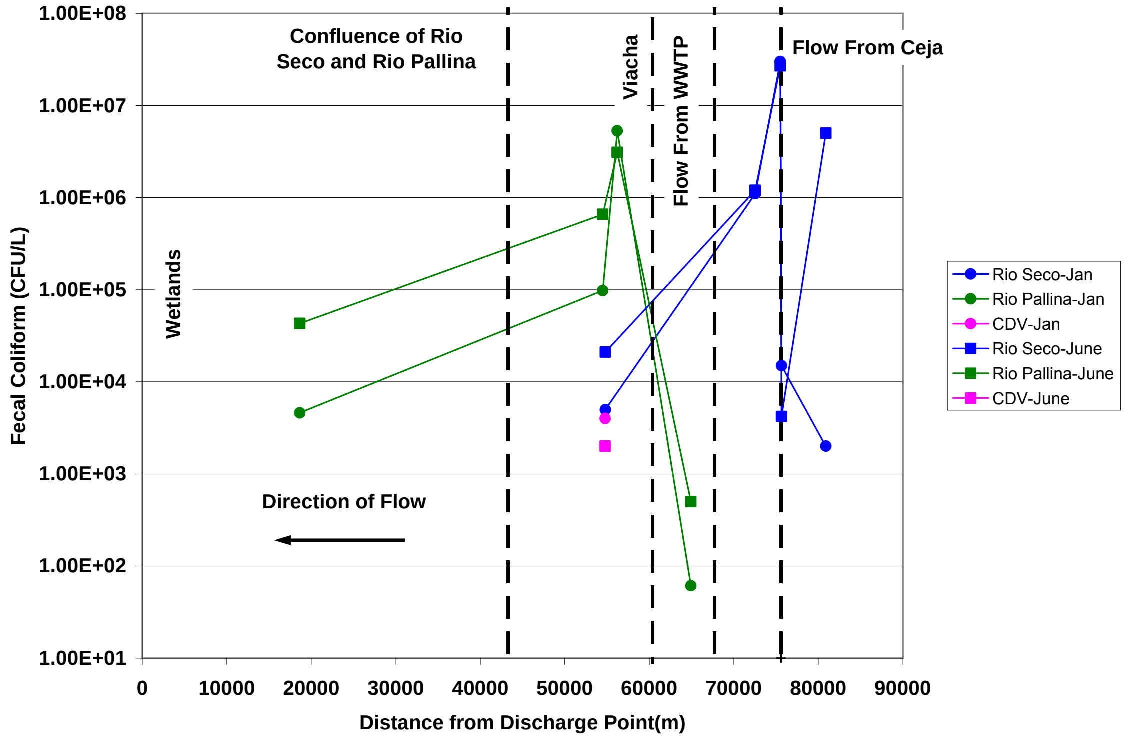

Figure 34. Spatial distribution of fecal coliform concentrations in the Rio Seco and Rio Pallina.

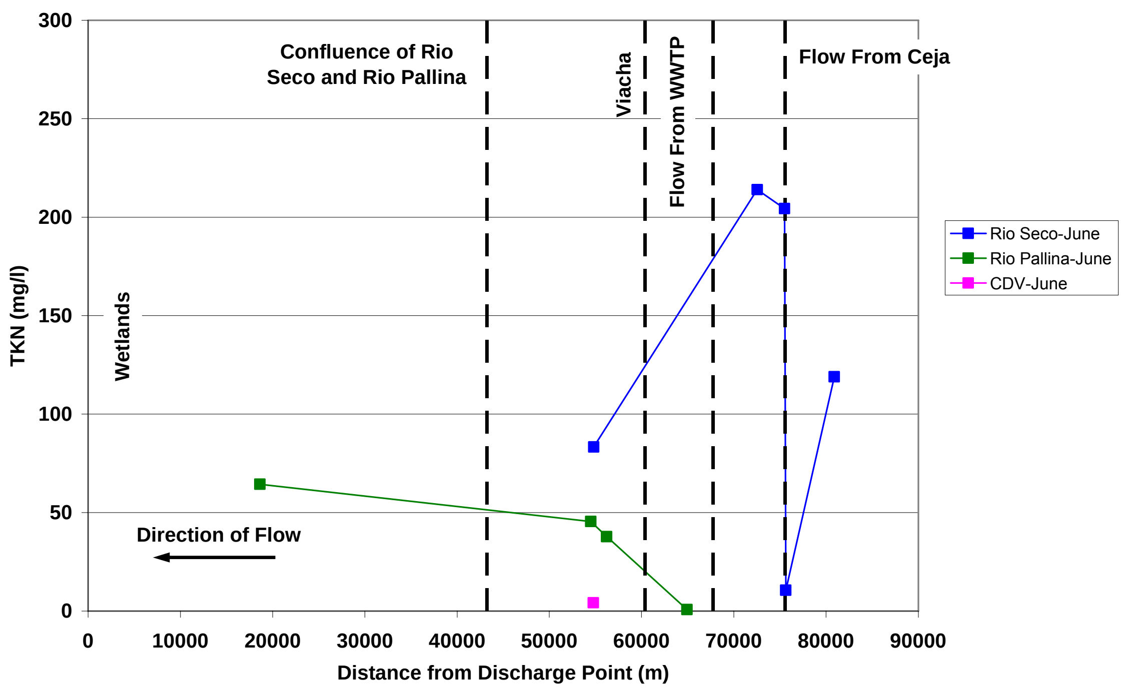

Figure 35. Spatial distribution of TKN concentrations in the Rio Seco and Rio Pallina.

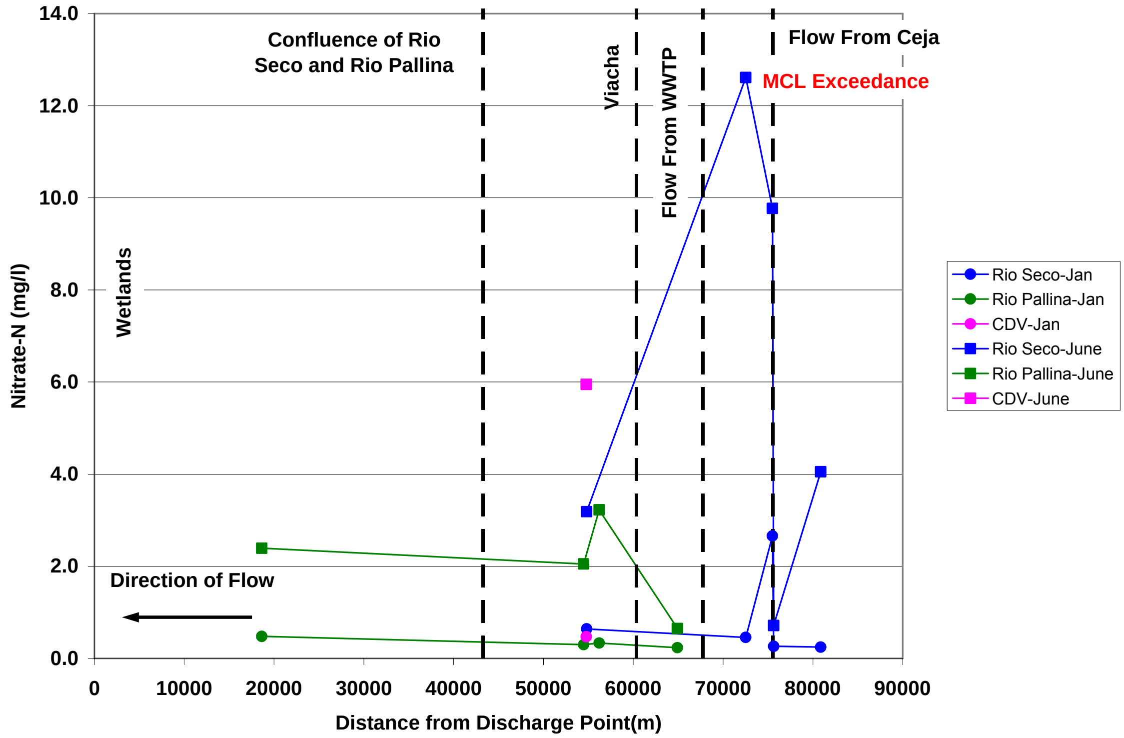

Figure 36. Spatial distribution of nitrate-N concentrations in the Rio Seco and Rio Pallina.

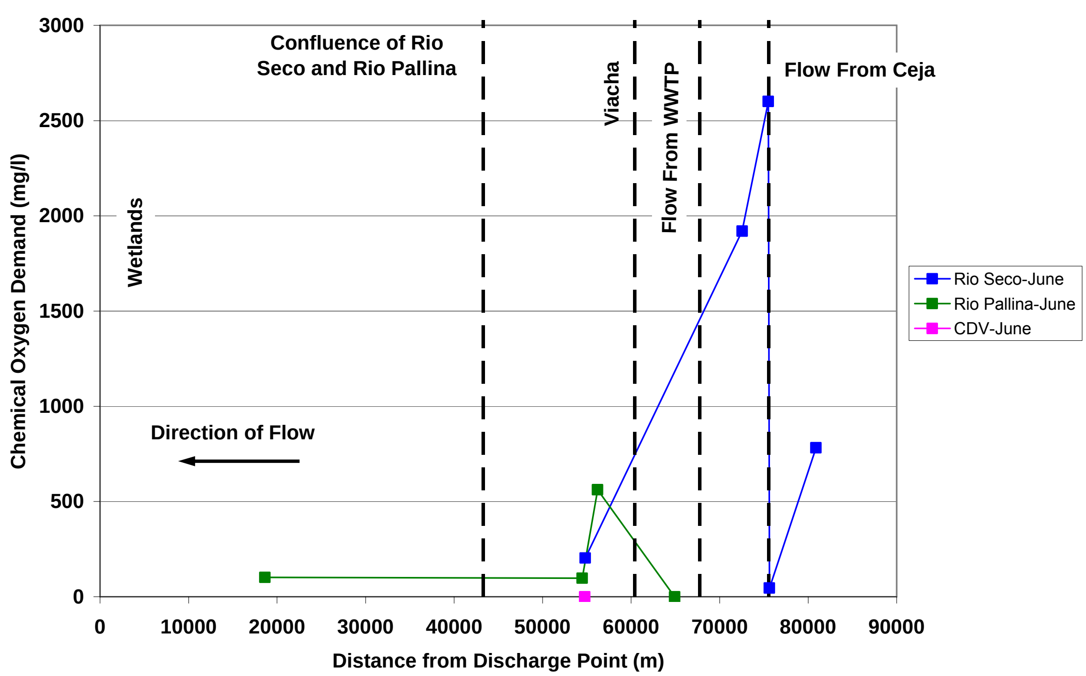

Figure 37. Spatial distribution of COD concentrations in the Rio Seco and Rio Pallina.

In January 2009 between RS-10 and RS-11 concentrations of fecal coliform and nitrate-N decreased. In June 2009 between RS-10 and RS-11 concentrations of fecal coliforms, TKN, nitrate-N and COD decreased. The decrease of TKN, nitrate-N and COD indicates dilution of all three constituents is occurring from the WWTP effluent. However, mass loading calculations (Table 5 Appendix B) shows an increase in the nitrate load between RS-10 and RS-11. The increase of nitrate is probably from a combination of WWTP loading and the nitrification of TKN.

4.3.3 Rio Pallina

In the Rio Pallina the main sources of pollution come from Viacha and the Rio Seco. Fecal coliform concentrations increase at the sampling point just downstream of Viacha during both sampling events, and then decrease (Figures 30 and 34). TKN (Figures 31 and 35), nitrate-N (Figures 32 and 36) and COD (Figure 33 and 37) all increase at the sampling point adjacent to Viacha, then decrease. However upon the confluence with the Rio Seco the concentrations of fecal coliform, TKN, nitrate-N and COD all approach the concentrations of the RS-11 sampling site.

COD:TKN rations at RP-6 immediately downstream of Viacha was 14.87, which falls in the range of COD:TKN ratios of slaughter house effluent. Although the ratio was high there is a large amount of untreated wastewater in the Rio Pallina, so the source of TKN is probably from a combination of untreated wastewater and slaughter house waste. COD and TKN values were plotted (Figure 31 Appendix C), however the R^2 value is very small, showing no relationship between the two, indicating another source may also be responsible for anoxic conditions.

4.3.4 Volatile Organic Carbon

Toluene, acetone, 2-butenon, carbon disulfide and 4-isopropyltoluene were detected at various points in all three rivers (Table 4 Appendix B). Possible sources for these constituents are laundry facilities, dry cleaning facilities, plastic manufacturing factory and mechanical workshops. Toluene has a SDWA MCL of 0.001 micrograms per liter (μg/l) and a WHO recommendation of 0.0007 μg/l. In January 2009 the SDWA MCL and WHO recommendation was exceeded at RS-10, RS-11, RP-6, RP-7 and RP-9. In June 2009 the SDWA MCL and WHO recommendation was exceeded at RS-1, RS-6 After, RS-10, RS-11, RP-6, RP-7 and RP-9. None of the other VOC detected have a SDWA MCL or WHO recommendation; however studies have shown many of the above mentioned constituents may have adverse health effects.

5.0 CONCLUSTIONS AND SUGGESTIONS FOR FUTURE WORK

The water quality of the Rio Katari, Rio Seco and Rio Pallina has been impacted by human use and negligence. Prior to its confluence with the Rio Pallina fecal coliform is present in the Rio Katari. During field work few houses were seen along the Rio Katari, however there are animals that graze along the river. A possible source of the fecal coliform in the Rio Katari may be a combination of the few households in the region and the animals that graze along the river. In the Rio Seco and Rio Pallina land use and water quality analysis indicates the impacts to the water quality are anthropogenic in nature. Mass flow calculations done for the January 2009 sampling event show an increase of loading of cations and anions between a factor of 1.7 and 4 and an increase of nitrate-N by a factor of 3.4 as a result of the WWTP effluent. The largest input of cations, anions and contaminant load to the Rio Pallina is the Rio Seco, and as a result the largest input of cations/anions and contamination to the Rio Katari is the Rio Pallina

In El Alto contamination comes from factories (bottling plant, milk factory and plastics), slaughter houses, leather tanneries, laundry and dry cleaning facilities, mechanical workshops, car repair and maintenance waste and public and private bathrooms. The effect is decreased levels of oxygen and increased levels of cations/anions, sulfate, nitrate-N, total phosphorus, TKN, total coliform, toluene, acetone, carbon disulfide and 4-isopropyltoluene all of which are detected in the water. Rainfall and effluent from the El Alto WWTP dilutes some of the constituents, but this is a seasonal and a temporary reduction. Downstream these constituents can accumulate in soils and vegetation, and through vegetative consumption and leaching may be reintroduced into the system.

The city of Viacha lacks a wastewater collection system and treatment plant, and during both field visits various types of discharges were observed entering the river. Discharges that were identified included raw domestic wastewater and discharge from a slaughter house and leather tannery. Total phosphorus, toluene, acetone, carbon disulfide and 4-isopropyltoluene detected in the Rio Pallina indicate that laundry/dry cleaning facilities and mechanical workshops are also present.

Land use along the Rio Katari is comprised of sparse single family houses, and agricultural practices (livestock and food production). The dominant indicator of contamination is fecal coliform, which is most likely from livestock. Downstream of the Rio Katari's confluence with the Rio Pallina anthropogenic contaminant concentrations increase.

Although direct consumption of the river water was not observed by people, animals were observed consuming the water, and through living in close proximity and consuming animal derived products people can become ill. Concentrations of fecal coliform were detected above SDWA MCL's at all sampling sites during January and June 2009. Nitrate-N exceeded its SDWA MCL and WHO recommendation in RS-10 in June and neared these levels at other sites. Toluene was detected at many of the sample sites above SDWA MCL's and WHO recommended standards. Sulfate exceeded SDWA MCL's at two locations. The consumption of fecal coliform, nitrate-N, toluene and sulfate may have adverse health affects and the consumption of these constituents may lead to death.

This study occurred during two different seasons and only one sample at each location was taken during each event. Because of this the analysis only provides a snapshot that represents that moment of time. Samples were taken during Monday, Tuesday and Wednesday during the day, so effects from households might be dampened as people are at work during these times. On weekends discharge from industrial areas might decrease because they're shut down during weekends, and flow from the wastewater treatment plant may increase. However the data collected does provide a general idea of the water quality in the three rivers as well as land use practices.

In order to quantify the water quality seasonally and daily much work needs to be done. A higher sampling frequency during both seasonal events and throughout the week could better help quantify what water quality looks like through out the day as well as the week. The effects of isolated precipitation events and stormwater runoff could be better quantified by an increased sampling frequency. Gauging discharge in the river would provide a tool to calculate contaminant loading volumes. Samples from the drinking water systems in El Alto and Viacha, as well as a sample from the El Alto WWTP would help determine what portion of the constituents are anthropogenic.

A land use survey needs to be done to determine the location and nature of industries as well as what they are manufacturing, how much they are manufacturing, what is being discharged and concentrations of discharge. Upon the survey a sampling list that is designed for the region to determine the effect of contamination would better help determine effects. Due to financial constraints this study did not look at metals.

Nina and Callisaya (2002) made recommendations in order to better quantify the quality of the water in the Rio Seco and to control pollution. They recommend quantifying population distribution, discharge, hydrological data and compiling data, these recommendations should also apply to the Rio Katari and Rio Pallina. In addition to better monitoring, El Alto needs to connect 100% of the population to the El Alto WWTP, restrict growth, require industrial pre-treatment and stop dumping and discharges into the Rio Seco, Viacha needs to build a wastewater treatment facility as well as restrict dumping and discharging into the Rio Pallina. The responsible parties for carrying out these tasks are uncertain. Currently monitoring work is done by non-profits and UMSA. There is no compilation of data and studies become redundant. Non-profits don't have the means nor the financial resources to build wastewater treatment facilities and wastewater collection systems for tens of thousands of people. The government of Bolivia needs to enforce and implement environmental laws, monitoring plans and build and expand treatment facilities to help improve the water quality of the Rio Katari and its tributaries.